Full Report: 381 pages

Expert Investigation Related to Cocoa and Chocolate Products:

Final Report

Submitted to:

As You Sow and the Settling Defendants

Submitted by:

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Note: All authors contributed equally to the development of this report. The authors' names are listed alphabetically. Bios for the authors appear after this report's table of contents.

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Bios for Expert Committee Members

Tim Ahn

Sr. Manager Food Safety
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Tim Ahn is a Senior Manager Food Safety with Lloyd's Register. With over 35 years experience in the chocolate and confectionery industry, Tim has global experience in chocolate and cocoa processing, cacao post-harvest handling, and chocolate ingredient food safety. Tim worked for Mars, Incorporated for 27 years where as the Global Director of Chocolate Quality & Food Safety, he was responsible for food safety, quality assurance, regulatory compliance, and technical services for the Mars global chocolate business. In this role, Tim visited and assessed the farm to port cocoa supply chain in Brazil, Indonesia, Ghana, and Cote d'Ivoire. Tim has a B.S in Chemical Engineering from the University of Delaware and is an IRCA certified Food Safety Management Systems assessor.

Rufus L. Chaney

Worked as Senior Research Agronomist with USDA-Agricultural Research Service for 47 years (Beltsville, MD), retiring in Oct., 2016; Elevated to Senior Scientific Research Service. Presently a consultant [Chaney Environmental: Risk Assessment and Remediation]; 10910 Dresden Drive, Beltsville, MD 20705. 301-937-1413; Cell=301-395-4852. rufuschaney@verizon.net. Education: B.S. (Chemistry) Heidelberg University, 1964; Ph.D. (Biochemistry) Purdue University, 1969. Research focus: 1) Identification of improved genotypes and agronomic management practices to reduce phytoavailability in order to reduce Cd and Pb concentration or Cd or Pb bioavailability in selected crops; 2) Assessment of potential soil heavy metal (Cd, Pb) risks to food-chains or environment, including urban gardens, and identification of management/regulatory methods to prevent/remediate these risks; 3) Assessment of potential risks from trace elements and xenobiotics in diverse soil amendments; 4) Development of metal hyperaccumulator plant species, and soil and plant management practices to phytomine elements from contaminated (Cd) or mineralized soils (Ni+Co); 5) Identified causes of iron deficiency chlorosis in soybean and other crops and mechanism of Fe uptake by crops other than grasses. Elected Fellow of the Soil Science Society of America and the American Society of Agronomy, 1992. Elected Fellow of the American Association for the Advancement of Science, 2001; USDA Presidential Rank Meritorious Senior Professional Award, 2003. Since beginning his career in 1969, Dr. Chaney has 511 published papers (357 Peer Reviewed) and 320 published abstracts on these topics. His H-Index=105 (March, 2022). He was elected to the Agricultural Research Service "Science Hall of Fame" in 2013.

Michael DiBartolomeis

Michael J. DiBartolomeis, PhD, DABT has over 38 years of professional experience practicing in the fields of environmental and occupational health. Dr. DiBartolomeis earned his doctorate degree in toxicology from the University of Wisconsin (Madison) with a minor in biochemistry, has been continuously certified by the American Board of Toxicology since 1988, and has presented original research and scientific assessments in 300 publications. Dr. DiBartolomeis retired from the California Department of Public in August 2017 after nearly 30 years of managing the California Environmental Contaminant Biomonitoring Program and the Exposure Assessment Section, the Occupational Lead Poisoning Prevention Program, the California Safe Cosmetics Program, and the Pesticide and Food Toxicology Program (Cal/EPA), among other roles. Dr. DiBartolomeis has extensive experience in all phases of the implementation and application of California's Proposition 65. He has prepared technical documents and provided subject matter expertise to the Scientific Advisory Panels and the Attorney General, assisted in the development of Safe Harbor Levels, evaluated chemical exposures from Proposition 65 listed chemicals in consumer products, and assisted in providing solutions to reformulation or exposure reductions in cases where Proposition 65 violations were upheld. Dr. DiBartolomeis declares that he has no financial conflict of interest and derives no personal benefit from his actions or decisions made in his capacity as a member of the Expert Committee while conducting this work.

Gideon Ramtahal

Gideon Ramtahal is a highly motivated Research Scientist at The University of the West Indies, St. Augustine, Trinidad and Tobago. Having attained a Ph.D. in Analytical Chemistry in 2012, he has been devoted to improving agricultural and environmental quality with a great emphasis on heavy metal contamination. He has been actively involved in research projects locally, regionally and internationally to understand and develop strategic approaches to manage cadmium levels in cocoa beans. As part of that, he has contributed to the development of soil amelioration approaches to mitigate cadmium accumulation into the cocoa tree and continues to explore other mitigation methods. He has co-authored a number of publications in peer-reviewed journals as well as participated at many international conferences.

List of Abbreviations

AYS	As You Sow
Cd	cadmium
MADL	Maximum Allowable Dose Levels
Pb	lead
SDs	Settling Defendants

1.0 Executive Summary

Since March 2018, a committee of four experts (the Expert Committee) has been investigating and reporting on the predominant sources of cadmium (Cd) and lead (Pb) in chocolate products and recommending feasible measures that may be taken to meaningfully reduce Cd and Pb levels in these products. The Expert Committee was charged with preparing the following reports:

- A Root Cause Report that identifies the sources of Cd and Pb in chocolate products. This report considered all phases of chocolate production, from farm to factory, and considered both natural and anthropogenic sources of Cd and Pb. This report was initially submitted on March 27, 2020.

- A Reductions Recommendation Report that identifies feasible means for reducing Cd and Pb levels in chocolate products over the nearer and longer term. These reduction strategies considered better agricultural practices, better business practices, and better manufacturing practices. This report was initially submitted on April 12, 2021.

- A Warning Triggers Report that includes analyses, comments, and recommendations from each individual Expert Committee member on potential Proposition 65 warning levels for Cd and Pb in chocolate products. This report was initially submitted on November 15, 2021.

- A Final Report (i.e., this report) that compiles the Expert Committee's findings and recommendations.

Per discussion with representatives of As You Sow and the Settling Defendants, this final report was to be framed around a compilation of the three earlier reports and 2-page "affirmative conclusions" prepared by the four Experts. Except for the 2-page reports authored by each of the Experts, this final report was prepared by the Project Manager and largely represents a compilation of information in the Experts' first three reports. The contents of this final report are organized as follows:

Section	Contents
2	Background information on the project and the process followed to prepare reports
3	The four Experts' individual affirmative conclusions on the overall project
4	Compilation of executive summaries from the first three reports
5	Alphabetical list of publications cited in the first three reports
Attachment 1	Root Cause Report
Attachment 2	Reductions Recommendations Report
Attachment 3	Warning Triggers Report

The versions of the three reports included in the attachments include some revisions made since the reports were originally submitted. For each of these reports, the attachments include a cover sheet that lists the revisions that were made.

On April 14, 2022, the four Experts will participate in individual presentation sessions with As You Sow and the Settling Defendants to discuss their findings and recommendations. After the presentations, the Project Manager will submit a final inventory of references considered and contacts made by individual Experts.

2.0 Background and Process for Completing Reports

In 1986, California voters passed Proposition 65, also known as the Safe Drinking Water and Toxic Enforcement Act of 1986. Proposition 65 has many requirements; one of which requires businesses to provide warnings on products that lead to toxic chemical exposures above "Safe Harbor" levels set by the California Office of Environmental Health Hazard Assessment. These requirements apply to a wide range of products, including food items.

Initially, between 2014 and 2017, As You Sow (AYS), a non-profit corporation in California, tested various chocolate products for the presence of cadmium (Cd) and lead (Pb). This testing revealed that numerous chocolate products had elevated Cd or Pb concentrations that, combined with typical serving sizes, indicated the potential for Cd and Pb exposures greater than the Proposition 65 Maximum Allowable Dose Levels (MADLs).

AYS subsequently issued Notices of Violation to several companies that manufacture, distribute, or sell chocolate products in California or precursors to those products (e.g., cocoa beans). The Notices indicated that the chocolate products with elevated Cd or Pb concentrations require warnings under California law. Rather than enter into prolonged and costly litigation on the matter, multiple companies entered into a Consent Judgment with AYS to investigate and address the sources of Cd and Pb in chocolate products. The companies that entered into this Consent Judgment are referred to as the Settling Defendants (SDs).

2.1 Formation of the Expert Committee

The Consent Judgment has many stipulations and requirements, one of which is the formation of an Expert Committee to complete the project scope (see Section 1.2). As stipulated by the Consent Judgment, AYS appointed one Expert Committee member; the SDs appointed another; and AYS and the SDs jointly agreed upon and appointed the remaining two. The names of the four Expert Committee members appear on the title page of this report and a short biographical sketch is included for each member after the title page.

AYS and the SDs also mutually identified and jointly appointed a Project Manager, who provided administrative and logistical support to the Expert Committee, facilitated discussions during Expert Committee meetings, ensured that the Expert Committee completed its work according to the budget and schedule, and provided word processing and editorial support for this report. Mr. John Wilhelmi of Eastern Research Group, Inc. (ERG) served as the Project Manager.

The Expert Committee members and the Project Manager performed their work under "consulting and confidentiality agreements" with AYS and the SDs, as joint contracting parties. The agreements required Expert Committee members to treat as strictly confidential and not disclose any non-public information provided by the SDs. The Expert Committee abided by these requirements. They considered all information received, including non-public information. The individual reports (see Attachments 1-3) are based on the information that Expert Committee members obtained and reviewed. However, the individual reports do not present confidential information.

2.2 The Expert Committee's Scope

The Consent Judgment specifies the Expert Committee's scope of work. It requires the Expert Committee to investigate and report on predominant sources of Cd and Pb in chocolate products and recommend feasible measures that may be taken, if any, to meaningfully reduce the Cd and Pb concentrations. The scope directed the experts to prepare four reports; three "technical" reports and this final report. The Executive Summary describes what the first three reports addressed and indicates when they were first submitted to AYS and the SDs. Current versions of those three reports are included in Attachments 1-3.

On January 19, 2022, the Project Manager participated in a conference call with representatives of AYS and the SDs to confirm the scope of the final report (i.e., this report). During that call, AYS and the SDs confirmed that the final report should primarily consist of a compilation of the three technical reports. One or both parties also requested that the final report describe the process followed to complete the reports and include a list of references cited across the technical reports. The final report has been structured to include this requested content.

2.3 Lines of Evidence Considered by the Expert Committee

The Expert Committee considered multiple lines of evidence when completing their three technical reports. These include:

- **Sampling data.** Cd and Pb sampling results weighed heavily in the Expert Committee's Root Cause analysis. The Experts considered analytical data from multiple media, such as cocoa beans, farm soils, process streams at cocoa bean processing and chocolate manufacturing facilities, and ingredients added in manufacturing processes. The Experts closely scrutinized all sampling data to assess whether they are of a known and high quality. The sampling data presented in the Root Cause Report largely originated from three sources. First, the Experts considered a large volume of sampling data provided by the SDs. Given the amount and importance of these sampling results, the Root Cause Report has a section dedicated entirely to reviewing the SDs' data. Second, the Experts considered sampling data reported in the peer-reviewed literature. Third, the Experts conducted their own sampling of beans and soils in Ecuador to fill data gaps and to confirm their preliminary findings.

The Expert Committee conducted two sampling studies during the Reductions Recommendations phase of the project. Their "Bean Cleaning and Winnowing Study" measured concentrations of Cd and Pb in numerous process streams at a cocoa bean processing facility; and their "Bean Abrasion Study" examined the degree to which a moderately abrasive technique removes Pb bound to the outer shell of cocoa beans. More information on these studies, including their measurement results, are presented in Appendixes C and D of the Reductions Recommendations report (see Attachment 2).

For the Warning Triggers Report, the Experts reviewed chocolate product sampling data provided by AYS and the SDs. This included the original SD data set shared with the Experts before the Root Cause Report was prepared and the complete AYS product sampling data set shared with the Experts prior to completing the Warning Triggers report.

- **Publications.** The Expert Committee considered insights and findings from scientific publications, largely relying on peer-reviewed literature. The Experts also reviewed graduate theses and unrefereed sources, as appropriate. By the end of the project, the Expert Committee compiled an inventory of more than 400 scientific publications, many of which were cited in the first three reports. Section 4 of this report has an alphabetized list of publications cited in the three technical reports. At the end of this project, the Project Manager will provide AYS and the SDs a complete inventory of documents that individual Experts compiled for this project.

- **Consultation with subject matter experts.** To inform their analyses across the three technical reports, Experts contacted outside subject matter experts. The Experts made these contacts individually and were required to inform the Project Manager of all contacts made. To date, the Experts have reported more than 250 such contacts. After the Experts deliver their final presentation, the Project Manager will submit to AYS and the SDs a final list of contacts reported by the Experts.

- **Direct observations.** The Expert Committee also considered their own observations from two field trips completed during the Root Cause Phase, both of which were attended by all four Experts. The first field trip included tours of three U.S. industrial facilities that either processed cocoa beans or manufactured chocolate products. The second field trip was of supply chain activity in Ecuador. That trip included visits to cocoa farms, bean collection facilities where drying and fermenting occurred, and bean exporter facilities where pre-export bean cleaning and packaging occurred. (Note: One Expert visited a chocolate liquor production facility as part of conducting the "Bean Cleaning and Winnowing Study," described above.) No additional field trips or experiments were conducted by the Expert Committee after the submission of the Reductions Recommendations Report.

- **Professional judgment.** The Expert Committee members bring decades of experience in relevant scientific disciplines. Their professional judgment also factored into all three technical reports, particularly for issues having limited or no information available from other lines of evidence.

2.4 Process for Completing Reports

The three technical reports were completed in similar fashion. The Experts shared initial ideas during a series of meetings, primarily conference calls and videoconferences. Based on the discussions, the Project Manager distributed an initial report outline with writing assignments for the Experts. The Project Manager wrote the background section of every report, and the Experts drafted all technical content. Once a draft report was available, additional meetings were held to discuss the need for revisions. Each technical report went through at least four sets of revisions by the Experts. For all three technical reports, the Experts authorized the Project Manager to submit the final version to AYS and the SDs, with no dissenting opinions.

As noted previously, Experts have identified errors and requested other corrections in the technical reports after the final versions were submitted. The Project Manager incorporated all requested revisions, which are reflected in the versions included in this report as Attachments 1-3. In those attachments, a cover sheet lists the revisions that have been made since the reports were previously submitted.

This final report was prepared differently. Given that AYS and the SDs requested that this report primarily be a compilation of the technical reports, the Project Manager assembled the report and wrote the executive summary and background sections. The Experts individually prepared all text in Section 3. As with the technical reports, the Experts authorized the Project Manager to submit this final report to AYS and the SDs, with no dissenting opinions.

3.0 Experts' Individual Affirmative Conclusions

AYS and the SDs requested that this final report include "affirmative conclusions" from each Expert. The Project Manager confirmed details of this request. The Experts were asked to prepare up to 2 pages of text that present their main findings, framed around the three project phases (Root Cause, Reductions Recommendations, and Trigger Levels). The affirmative conclusions were prepared individually and were not discussed among the entire Expert Committee.

The individual affirmative conclusions appear on the following eight pages, exactly as submitted by the Experts, except for minor formatting changes for consistency. The conclusions are shown in alphabetical order of the Experts' last names.

3.1 Conclusion Statement – Timothy Ahn

Cadmium (Cd)

Cocoa bean processing and chocolate manufacturing operations are not the source of Cd in chocolate products. Controls are in place to avoid the introduction of Cd through processing water, production equipment, product packaging, and environmental dust. Non-cocoa based ingredients that are used in typical chocolate formulations are not a significant source of Cd. The significant source of Cd in chocolate products is chocolate liquor. Chocolate liquor is produced from milled cocoa nibs, which are the deshelled portion of a cocoa bean. The most significant source of Cd in cocoa beans occurs pre-harvest.

Soil is the source of Cd in cocoa beans, which occurs through direct uptake of phytoavailable Cd by the cocoa tree during the pre-harvest stage. The origin of Cd in these cocoa-growing soils is a mixture of natural and anthropogenic sources, is highly variable, and is country- and farm-specific. Cacao grown in the Latin American and Caribbean regions have significantly higher Cd concentrations than cacao grown in other parts of the world, most notably West Africa. Many studies report that anthropogenic sources of Cd are of greater concern than the natural sources in areas where historical industrial or current industrial activities have resulted in elevated levels of soil Cd. The concentration of cacao Cd is a function of total soil Cd and bioavailable soil Cd. Bioavailable soil Cd is influenced by soil physiochemical properties that include soil pH, organic material content, and zinc concentration.

The only feasible reduction strategy for Cd in cocoa and chocolate products is to blend high Cd content cocoa beans with beans with lower Cd content to ensure that products do not exceed product warning triggers. Reduction strategies targeted to reduce the uptake of Cd by cacao trees are not currently feasible for companies that process cocoa beans or make chocolate to employ in their operations in the near term to reduce Cd levels in their products. This includes application of soil amendments to adjust soil physiochemical properties and cacao tree breeding and grafting techniques. Soil amendment recommendations have not been demonstrated to be effective at scale and it has not defined how they would be implemented across a large area if they were found to be effective at scale.

The cocoa market consists of two categories of products based on the type of cocoa beans used: “fine flavor” and “bulk or common.” Fine flavor cocoa beans are used in premium chocolate products for their distinctive taste and color. While fine flavor cocoa beans account for approximately 10 to 15% of world exports, Latin America and the Caribbean region accounts for approximately 90% of their production. The Consent Judgment does not differentiate between bulk and fine flavor cacao products.

While blending is an effective strategy to feasibly achieve Consent Judgment product warning triggers for bulk or common cacao products, it is not an effective strategy for fine flavor cacao products. Bulk or common cacao products can be formulated to use less of a high Cd region and more of a low Cd region. For fine flavor cacao products, at the current trigger levels, approximately 60% of the chocolate liquor from the Latin America and the Caribbean region exceeds the trigger. At the drop-down trigger levels, this will increase to approximately 70%. This will make it difficult to use blending as a reduction strategy. For fine flavor cacao products, there are no currently identified feasible reduction strategies that would enable the implementation of the drop-down triggers stated in Section 6.2.2 of the Consent Judgment.

Lead (Pb)

Cocoa bean processing and chocolate manufacturing operations are not the source of Pb in chocolate products. Controls are in place to avoid the introduction of Pb through processing water, production equipment, product packaging, and environmental dust. Non-cocoa based ingredients that are used in typical chocolate formulations are not a significant source of Pb. The significant source of Pb in chocolate products is chocolate liquor. Chocolate liquor is produced from milled cocoa nibs, which are the deshelled portion of a cocoa bean.

Scientific literature reports Pb concentrations in cocoa nibs and shells less than 3 ppb from cocoa beans sampled directly from the pod. This confirms that the source of Pb in cocoa beans occurs during post-harvest handling of wet cocoa beans, not through uptake by the cocoa tree. During the post-harvest handling of wet cocoa beans, beans contact soil through direct contact with the ground or exposed surfaces (roadsides, concrete patio, drying tables, plastic tarps, plastic bags, containers). Wet cocoa beans also contact soil through the deposition of airborne soil (dust) during outdoor drying. The source of post-harvest Pb in cocoa beans is a result of the following mechanisms.

- Foreign material included loosely within bulk cocoa beans.
- Encasement of soil particles on the wet and sticky cocoa bean shell during outdoor drying.
- Chemical adsorption of Pb by the wet and acidic cocoa bean shell during contact with soil.

The transfer of Pb from cocoa beans to nibs, and the subsequent chocolate liquor produced from nibs, occurs during the shell removal process. The bean cleaning and winnowing study conducted as part of this investigation found that the nib obtains approximately 70% of its Pb concentration through contact with Pb containing material (i.e., shell, soil, light and fine material) during bean breaking. Nib Pb concentration cannot be fully accounted by the Pb concentration of shell remaining in the nib after winnowing. Fine material removed during bean cleaning via aspiration and sieving was found to have a Pb concentration approximately 10 times higher than that of the shell. This suggests that a significant source of Pb is enriched fine shell material, most likely resulting from Pb adsorption by the wet cocoa bean shell during post-harvest handling. This was proposed as a likely mechanism in a study published by Manton (J. Agric. Food Chem. 2010, 58, 713–721).

A review of SD data for chocolate liquor, which is the ingredient that determines Pb concentration in chocolate products, suggests that the following Pb Product Warning Triggers can be feasibly achieved through the establishment and verification of bean cleaning and winnowing manufacturing practices.

- For products up to a 65% cacao content: 0.060 ppm
- For products greater than 65% cacao content and up to a 95% cacao content: 0.090 ppm
- For products greater than 95% cacao content: 0.180 ppm

The industry should develop and deploy Good Manufacturing Practices related to Pb control at bean cleaning and winnowing. These would include requirements for process control, preventive maintenance and record keeping. Compliance with practices should be subject to independent verification at each cocoa bean processing facility.

The industry should communicate to farmers the value of implementing Better Agricultural Practices related to reducing wet cocoa bean contact with soil during fermentation and drying. Drying wet beans in direct contact with the ground, road surfaces, and concrete patios should be discontinued as a farmer controllable Pb reduction activity.

3.2 Conclusion Statement – Rufus Chaney

Affirmative Conclusions – Pb: Research by Manton (2010) showed unequivocally that Pb in cocoa nibs above ~3 ng Pb/g (ppb) is contamination post-harvest. Careful separation of shells and nibs in a clean-room confirmed this low nib Pb for beans with as high as 2900 ng Pb/g (ppb). Our evaluation of the literature and available data clearly supports this natural level of Pb in all cocoa nibs at harvest. The higher levels of bean Pb are a result of fine soil particles adhering to the shells during fermentation and sun drying of beans on soil. With uncontaminated soils, beans can gain 100 ng Pb/g; if soil is rich in Pb, higher bean Pb levels can occur. Our field samples confirmed this understanding. And our chocolate factory experiment showed how "bean Pb" migrated with the broken shells and fine particles removed during cleaning, breaking and separation of nibs. But some of these fine soil particles were mobilized to the nibs. Some present bean processing/cleaning technologies are able to remove most of the Pb that arrived with the beans. Avoiding excessive Pb in chocolate products is attainable.

After our last report I conceived a tool to address the soil contamination problem. There are no Pb-specific rapid analysis methods (e.g., X-Ray Fluorescence; house paint Pb stains) that are sensitive enough to detect the soil-Pb contaminated beans. So a quick test of beans for soil-derived Fe could obtain the information needed. Releasing Fe^{3+} in/on the soil particles as Fe^{2+} could allow use a highly sensitive and specific color test for Fe^{2+} using Ferrozine. A simple, safe, very low cost color test could identify high soil contamination of beans and allow rejection of that load of beans.

Affirmative Conclusions – Cd: In contrast with Pb, the Cd in cocoa beans is accumulated by the cocoa roots and transported to beans by natural processes. *Theobroma cacao* is a tree grown in perennial orchards where it is difficult to incorporate soil amendments (e.g., limestone, biochar, compost, zinc) into the cocoa root zone to reduce Cd uptake without damaging the roots significantly. Field studies have shown that most fine feeder roots of cocoa are in the 0-15 cm topsoil.

Excessive nib Cd levels occur due to several main factors: 1) *Theobroma cacao* is a natural Cd accumulating plant species compared to others grown on the same soils; 2) topsoil Cd increases from deposition of litter and harvest debris on the soil surface; 3) Because cocoa roots remain in the topsoil, tillage to incorporate soil amendments harms the trees; 4) Most cocoa soils in South America and the Caribbean (LAC) are strongly acidic with pH as low as 4.5, so low that soil Cd is highly phytoavailable; 5) Some cocoa soils were historically Cd contaminated by mining wastes (minor part of land in cocoa production); and 6) some cocoa soils are naturally Cd enriched from parent rocks (e.g., marine shale) which makes these have high Cd:Zn ratios and thus have very high Cd phytoavailability. In these soils, beans can reach 10 mg Cd/kg rather than the 0.8 mg Cd/kg limit usually enforced on bean imports in the EU. One location in Colombia has 27 mg Cd/kg topsoil, 100-fold background levels. Other areas with high Cd:Zn problem soils growing cocoa were identified in at least Ecuador, Honduras, Peru and Trinidad & Tobago.

Cocoa plants absorb Cd into roots on a ZIP-family Zn transporter, not on the NRAMP5 transporter used by rice. Zn^{2+} in soil solution strongly inhibits Cd^{2+} uptake; thus higher Zn^{2+} in soil can reduce Cd in cocoa beans. The Cd:Zn ratio in the soil solution strongly affects Cd accumulation in cocoa trees and beans. Unfortunately, surface applied $ZnSO_4$ does not rapidly leach into the rooting zone soil, and foliar Zn sprays are ineffective in reducing Cd in beans. Surface applied ZnEDTA as a Zn fertilizer could leach Zn into the rooting depth soil. But ZnEDTA costs much more than $ZnSO_4$.

Several potential **genetic solutions** to the cocoa Cd problem have been studied, but absolute proof at the gene level has not been reported. As noted above, Zn transporters should be the focus for reducing Cd in cocoa beans.

Methods to assure lower Cd levels in cocoa beans include **soil management** and **genetic changes**. If very low Cd accumulating genotypes, or very low Cd translocating genotypes of existing cocoa genotypes were found, they could be used to breed low Cd commercial cultivars using traditional breeding. It must be recognized that cocoa breeding is a slow process because beans are not produced for about 5 years after seedlings are planted in the field. If the key genes affecting Cd in cocoa shoots/beans were defined, genetic probes could much more rapidly test for "Cd accumulation potential" in breeding programs; only those plantlets with effective Cd-lowering genes would be retained in breeding.

Several fundamental genetic solutions have been found to limit Cd uptake and translocation by other plant species. In the case of rice (which uses NRAMP5 for uptake of Mn and Cd), radiation mutants were grown in a Cd+Zn-contaminated rice paddy and grain of each plant analyzed. Three mutant plants with **very low grain Cd** were found (out of thousands) and the gene (NRAMP5) discovered. This gene codes for the main Mn^{2+} uptake transporter of rice. Null (inactivated) NRAMP5 has not caused problems in rice Mn uptake/yield because rice in grown in flooded soils where dissolved Mn^{2+} is high.

Another gene (HMA3) was found in rice and other species which can pump root-absorbed Cd into root cell vacuoles. If that gene is "over-expressed", it stops nearly all Cd translocation to the shoots. Higher Cd cultivars of several crops were found to have weak or defective HMA3 genes (soybean, durum wheat, Pakchoi). Different research groups have tested several "promoters of gene expression" which can greatly increase the expression of HMA3 and very effectively reduce Cd in plant shoots and grain. Some studies used the new CRISPR/Cas9 genetic modification system to make changes in the promoter and demonstrated very low Cd in rice shoots and other species studied.

Most cocoa trees in the field are grafted plants, using scions (above ground part of the plants) which have the needed quality, yield and disease resistance properties, on sturdy disease resistant rootstocks. In Japan, eggplant is commonly greenhouse-grown using grafting of the desired quality eggplant scion on a rootstock of the same genus but which transfers a much smaller fraction of the Cd to the shoots, thereby reducing Cd in fruits. Finding low Cd translocating natural cocoa rootstocks has not yet been reported. So making a low Cd cocoa rootstock may be the fastest solution. Even this "fastest" solution would take many years for replacement of existing trees in cocoa farms. Thus, making a genetic change (e.g., over-expression of HMA3) in the rootstock genotype used in usual commercial cocoa trees could solve Cd issues for most soils – more quickly than other genetic approaches.

The phytoavailability of soil Cd is most strongly affected by a few soil properties: plant available Cd and Zn levels; soil pH; and soil Cd sorption strength (organic matter and hydrous oxides of Mn and Fe). Because of the shallow rooting of cocoa in the field, it is difficult to mix the rooted topsoil with soil amendments to rapidly reduce soil Cd phytoavailability to cocoa. Surface application of limestone or organic matter had little effect on bean Cd. Ramtahal et al. (2022) used a pump device to inject a slurry of hydrated lime or biochar into the topsoil of field-grown cocoa trees, and found a significant reduction in leaf Cd compared to surface application of these amendments; bean Cd results have not been reported to date. Because Cd is absorbed on the Zn uptake transporter of cocoa, $ZnSO_4$ should be included with the hydrated lime and biochar if they are injected or surface applied because these amendments reduce the phytoavailability of soil Zn.

One more issue of Cd in cocoa bean markets should be considered: Most in the chocolate industry obtain certified analysis of "whole bean" levels of Cd and Pb prior to purchase decisions. But the shell of cocoa beans is significantly higher in Cd than the nibs. There is also genetic variation in the Nib-Cd/Shell-Cd ratio. Thus, beans with lower nib-Cd levels may be rejected by purchasers based on irrelevant whole bean Cd measurements. And genetic variation in shell-Cd/nib-Cd ratios may interact with variation in soils and crop management, making purchase of low Cd nibs even more complex.

3.3 Conclusion Statement – Michael DiBartolomeis

Summary. In a consensus opinion summarizing a three-year evaluation by the four-member Expert Committee, 15 strategies to reduce cadmium (Cd) and/or lead (Pb) contamination in chocolate products were rated as "high confidence feasibility." Most could be implemented within a range from less than one year to five years. By combining strategies, Pb and Cd contamination reductions of 50 percent or more could be attained. I propose, as feasible, health protective Proposition 65 warning trigger levels of 15, 20, and 40 ppb for Pb and 120, 175, and 400 ppb for Cd, depending on percent cacao content. These warning triggers are attainable for the majority of chocolate products available to California consumers.

Findings. Pb contamination in chocolate products originates from environmental contamination of the wet, sticky cocoa bean shells during post-harvest processing and not from the uptake of Pb in the nib. Five high confidence feasibility Pb reduction strategies identified by the experts include changes to certain agricultural, manufacturing, or business practices (e.g., protecting wet beans from soil and dust during drying, fermenting, and transport), and each could provide from 10 to greater than 25 percent (%) reduction in Pb levels in chocolate. Cd is accumulated in the cocoa nib from the uptake of Cd from contaminated soil into the cacao plant, with a smaller amount from environmental contamination of Cd associated with the shell. Cd reduction strategies include five agricultural and manufacturing strategies each projected to provide a greater than 25% reduction in Cd levels in chocolate products, and two business strategies, each which could reduce Cd levels in chocolate products from 10% to greater than 25%. Four genetic-based agricultural strategies were also rated high confidence feasibility for Cd reduction, but the experts were less sure of the reduction magnitude potential for these. Blending chocolate liquor or beans is the most cost-effective way to reduce Cd levels by 25 to 50% or more until additional measures can be established. Implementing combinations of these high confidence feasibility strategies could effectively reduce Pb and Cd in chocolates by 50% or greater.

Sampling and analytical market-based data collected by As You Sow (AYS) for Pb and Cd in nearly 600 chocolate products were the only California-specific data available to the experts to calculate the range of Pb and Cd concentrations to which California consumers could be exposed. Sampling and testing data of chocolate ingredients submitted by the Initial Settling Defendants proved to be of limited value for assessing Proposition 65 (Prop 65) warning triggers due to technical flaws in testing and reporting, lack of traceability, and lack of California specificity. AYS product test data fall into groups based on cacao content defined in the Consent Judgment: 40% in Group 1 (up to and including 65% cacao), 48% in Group 2 (more than 65% up to 95% cacao), and 12% in Group 3 (more than 95% cacao). There are also two subcategories of chocolate products sold as "premium" or "specialty" based on the origin of the cocoa beans (i.e., single origin) and the growing methods (i.e., certified organic). Specialty products represent about 22% of all chocolate products analyzed by AYS whereas the others are categorized as "bulk" products.

The intent of Prop 65 is to protect people from exposure to chemicals in consumer products that cause cancer, birth defects, or other reproductive harm. The Consent Judgement currently proposes Prop 65 warning trigger levels for Pb (Group 1: 100 and 65 ppb, Group 2: 150 and 100 ppb, Group 3: 225 and 200 ppb) and Cd (Group 1: 400 and 320 ppb, Group 2: 450 and 400 ppb, Group 3: 960 and 800 ppb), which are not health-based. According to the AYS market-based test data, all products are already greater than 95% compliant with the current Consent Judgment triggers for Pb and greater than 81% compliant with the current Consent Judgment triggers for Cd under *status quo* conditions. However, the charge to the Expert Committee was to evaluate strategies that could feasibly reduce Pb and Cd in chocolate products below existing, *status quo* levels and to revise the current Consent Judgement triggers downward where feasible. Under existing *status quo* conditions chocolate products are 90% compliant with Pb maximum allowable levels of 30, 50, and 100 ppb, and 80 to 90% compliant with Cd maximum levels of 190, 350, and 600 ppb for Groups 1, 2, and 3, respectively. Therefore, I conclude that limits for Pb and Cd contaminant levels in chocolate products below the current Consent Judgement triggers *must* be proposed by the experts.

Using the Prop 65 MADLs and available consumption data, I calculated the most public health protective Prop 65 warning triggers for Pb to be 14, 14, and 40 ppb for Groups 1, 2, and 3, respectively. Under *status quo* conditions, 20 to 56% of the chocolate products are already compliant with these health-based warning triggers for Pb. For these MADL-based warning triggers to be met for at least 90% of chocolate products, reductions of 56 to 73% in Pb would be required, depending on cacao content. For Cd, the most public health protective warning triggers are 111, 111, and 325 ppb for Groups 1, 2, and 3, respectively. Under *status quo* conditions, chocolate products are already 25 to 69% compliant with these MADL-based triggers. For the MADL-based triggers to be met for at least 90% of chocolate products, reductions of 49 to 73% Cd in chocolate would be required, depending on cacao content. Although I believe that these levels of Pb and Cd reduction are feasible assuming universal and effective implementation of the high confident feasibility reduction strategies, I propose alternative warning triggers that would be protective of health but even more feasible to attain.

Based on my analyses described in detail in the Phase 3 Report, I propose as feasible Prop 65 drop down warning triggers for Pb of 15 ppb for chocolate products in Group 1, 20 ppb in Group 2, and 40 ppb in Group 3. Under *status quo* conditions, chocolate products are already 35 to 57% compliant with these proposed Pb triggers. At least a 50% reduction in Pb levels can be feasibly achieved in chocolates by implementing high confidence feasibility Pb reduction strategies. With a 50% reduction, greater than 75% of all products would be compliant with my proposed Prop 65 Pb triggers. It is conceivable that more than 95% of chocolate products available in California could meet these warning trigger with a feasible 60 to 75% Pb reduction efficiency after fully implementing the reduction strategies. I base my feasibility analysis for Pb in part on the fact that over 27% of the AYS tested products were at or below 10 ppb under *status quo* conditions, which means that in areas where environmental Pb contamination is relatively low and/or post-harvesting processes are clean, Pb levels will be negligible in chocolate. For Cd, I propose Prop 65 drop down trigger levels of 120 ppb for chocolate products in Group 1, 175 ppb in Group 2, and 400 ppb in Group 3. Without any further effort to implement additional Cd reduction strategies, all products are 57 to 73% compliant with these triggers. With a 50% reduction in Cd from the implementation of high confidence feasible Cd reduction strategies, more than 80% of all AYS tested products would be compliant with my triggers. Therefore, my proposed Pb and Cd Prop 65 warning triggers are both protective of public health and feasibly attainable for the majority of chocolate products.

The AYS test data for specialty chocolate indicates the business decision to use single origin and/or organic beans significantly raises the risk for increased Cd concentrations compared to bulk products, whereas specialty chocolates do not appear to contain significantly elevated levels of Pb contamination. With the implementation of high confidence feasibility Cd reduction strategies, nearly 100% of the bulk chocolate products comply with the Prop 65 warning triggers I propose here. Compliance with these Cd triggers is also feasible for specialty products. Products in the combined specialty groups are 25 to 34% compliant under *status quo* conditions, however implementing high confidence feasibility Cd remedial strategies with 50% reduction could raise the compliance rate to 70% or higher, depending on cacao content.

Recommendations: Manufacturers should routinely test their products for both Pb and Cd as part of a routine surveillance plan to identify patterns of contamination in chocolate products and to assist in determining specific sources of contamination for further remediation. An independent third-party laboratory should continue to test chocolate products in California for Pb and Cd levels to build on the existing databases and to track changes in contamination levels as remediation measures are implemented. California-specific sales and consumption data for chocolate products in Cacao Groups 1, 2, and 3 should be compiled and compared to the AYS testing data in terms of representation of products in these groups. In the future, as more analytical data on chocolate products are collected, the compliance percentages and proposed Prop 65 warning trigger levels can be adjusted if necessary.

3.4 Conclusion Statement – Gideon Ramtahal

Affirmative Conclusion- Lead (Pb)- Gideon Ramtahal

Based on our work done in the Root Cause Phase, it is clear that the predominant source of Pb contamination in chocolate products occurs primarily during the post-harvest phase of the cocoa supply chain, however the way in which beans are cleaned and processed at chocolate manufacturing facilities also plays a significant role. At the post-harvest phase which includes transportation, fermentation and drying processes, the shells or outer coating of freshly harvested cocoa beans can become exposed to soil and dust particles resulting in their Pb contamination. The level of bean contamination will more than likely be site-specific and will depend on each country's unique post-harvest practices and their environmental conditions. Anecdotal evidence that we gathered from our field trip to the cocoa supply chain activity of Ecuador as well as research findings in the literature supports this conclusion. It is something that I would have also observed in Trinidad from experiments conducted. Additionally, the Expert Committee identified and determined that the bean cleaning and shell removal processes at chocolate manufacturing facilities can also significantly influence the Pb concentrations in chocolate products. The study that we conducted at a major North American cocoa processing plant demonstrated that cocoa nibs which typically has negligible Pb before being exposed can become contaminated during this phase when soil and dust particles adhered to the shells of the cocoa beans and other waste materials become loose and are redistributed.

Having identified these two primary areas of cocoa bean Pb contamination and by extension chocolate products, the Expert Committee evaluated a number of strategies to reduce Pb with a number of them showing great potential. For contamination at the post-harvest stage, the Pb better agricultural practices (Pb-BAPs) can be implemented to prevent or minimize Pb contamination of wet beans during on-farm transport, fermentation and drying, and transportation to processors and buyers. Though these post-harvest practices may vary from country to country and even within country, I do believe that these Pb-BAP strategies hold the key to limiting the source of Pb contamination in chocolates and other cocoa products. However, I think further research needs to be done to ascertain their efficacy in affected countries particularly as each country's capacity to implement them will differ depending on available resources. With respect to the manufacturing facilities, the Expert Committee's highly ranked better manufacturing practices could result in demonstrable Pb reductions in chocolate products at the bean cleaning and winnowing phase as per the findings from our investigation. These strategies will need to be optimized across the chocolate manufacturing industry as operational bean cleaning and winnowing practices may differ.

In terms of the current and proposed Pb triggers specified from the Consent Judgment, majority of the sample data provided by AYS and SDs could meet them. However, in my opinion there is significant value in taking a closer look at the cocoa powder origin data because if there are Pb levels of concern, it will provide us with a measure of traceability needed to pinpoint, evaluate and utilize Pb-BAPs and better manufacturing practices for reduction of Pb levels in cocoa beans. The country of origin cocoa powder Pb data provided by the SDs showed that 25% of the countries may have the potential to exceed the proposed trigger limit of 0.200 ppm (for covered products with greater than 95% cocoa content) with a Pb concentration value of 0.180 ppm. As discussed above, there may be an element of difficulty to use Pb-BAPS effectively across and even within affected countries until a proper assessment could be done on their post-harvest practices and their available resources. In light of this, I utilized the 0.180 ppm to determine feasible Pb drop-down levels because to me based on the data presented, it represents a realistic snapshot of where affected countries are with respect to Pb contamination of their beans and what could be expected in the different categories of products.

Affirmative Conclusion- Cadmium (Cd)- Gideon Ramtahal

It is evident from our findings in the Root Cause Phase, that compared to all other phases of chocolate production, from farm to factory investigated, the pre-harvest phase is the predominant contributor to Cd contamination of cocoa beans and by extension chocolates and other cocoa products.

A great deal of research conducted over recent years across a number of Latin American and Caribbean countries have shown that the level of Cd in cocoa-growing soils and the Cd levels found in the tissues of the cocoa tree are significantly correlated. This pre-harvest relationship identifies the soil as a primary source of Cd and demonstrates the main route by which Cd accumulates into cocoa beans. Though the Cd level of cocoa-growing soils is key to understanding this issue of Cd accumulation in cocoa beans, there are number of other soil factors that should be considered to determine the cause of the problem and the steps required to mitigate it. From my experience and from reviewing other research conducted, the source of Cd in the soil as well as other soil physiochemical properties including pH, OM and Zn are some soil factors which can significantly influence the Cd uptake in cocoa beans. It must be noted that these factors may differ across cocoa farms and thus soil amelioration strategies to reduce Cd uptake into cocoa beans will be farm-specific.

In our Reductions Recommendations Phase, the Expert Committee evaluated and identified a number of short-term and long-term Cd better agricultural practices (Cd-BAPs) with great potential to reduce Cd levels in cocoa beans at the pre-harvest stage. Some of these strategies are based on the amelioration of influential soil factors as mentioned above, whereas others may take a genetic or bean rejection approach. However, before these Cd-BAPs could be recommended, it is important that an affected country follows an evidence-based approach to address the issue. This will involve first strategically mapping all of their cocoa-growing areas and determining farms/regions with problematic Cd levels. A diagnostic study should then be conducted to determine which factor(s) are contributing to Cd uptake in those identified affected farms/regions. Based on the information gathered, the relevant farm/region-specific Cd-BAPs could then be utilized to reduce cocoa bean Cd levels. To date, a number of countries within the LAC regions have already embarked on studies to gather the necessary evidence from their primary cocoa-growing areas for subsequent management of their Cd issue and is still ongoing. I do believe however, that if these Cd-BAPs are not capable of providing a short-term solution, the post-harvest better manufacturing practice of blending beans or liquor could be utilized to produce beans as well as chocolates and other cocoa products that could meet the food safety regulatory limits for Cd.

It was also apparent from the data provided by the AYS and the SDs, that majority of the samples could meet the current and proposed Cd triggers, however, beans from the LAC region and their potential niche market products containing higher cocoa solids may encounter difficulty. Although there are efforts being made to manage the Cd issue in the LAC region, these trigger limits could affect their fine or flavour cocoa exports for which they are known for and the livelihoods of many farmers who depend on it. Thus, until there is significant progress in the management of the Cd issue in cocoa in this region, I believe that the original Cd warning triggers for each respective category of covered products should not be modified particularly for the chocolate products with higher cacao content (>65%).

4.0 Executive Summaries from the Experts' Three Technical Reports

This section presents a compilation of main findings presented in the executive summaries from the Experts' three technical reports. The following text was extracted from the individual reports' executive summaries, which are also included in this report in Attachments 1, 2, and 3.

4.1 Key Findings from the Root Cause Report

Note: The following text is quoted verbatim from the executive summary of the Root Cause Report. References to section numbers in the following text pertain to the sections shown in Attachment 1 of this report.

The Experts organized their conclusions around the following topics related to the chocolate product supply chain. For purposes of this report, "pre-harvest" pertains to the state of cocoa beans before pods are removed from cocoa trees; "harvest" refers to the process by which ripe pods are removed from trunks and branches of cocoa trees with their subsequent opening to extract wet beans; and "post-harvest" refers to activities that take place with extracted wet cocoa beans after harvest, from farm to port.

- **Conclusion regarding usability of SD testing data (Section 3).** The SDs provided the Expert Committee a large dataset of Cd and Pb testing of various materials. These data were not accompanied by important supporting documentation, such as descriptions of sampling and analytical methods, detection limits, and data quality narratives. The Expert Committee agreed to use the SD testing data in its Root Cause Phase analysis and acknowledge the data limitations when doing so.

- **"Pre-harvest" conclusion for Cd (Section 4.1).** Soil is one of the major sources of Cd in cocoa beans, which occurs through direct uptake of phytoavailable Cd by the cocoa tree during the pre-harvest stage. The Expert Committee therefore considers Cd in soils as a "common source" for the Root Cause Phase. The origin of Cd in these cocoa-growing soils is a mixture of natural and anthropogenic sources, is highly variable, and is country- and farm-specific. Many studies (mostly in Latin America and the Caribbean) report that anthropogenic sources of Cd are of greater concern than the natural sources in areas where historical industrial or current industrial activities have resulted in elevated levels of soil Cd. On the other hand, data and evidence are still needed to fully understand why pre-harvest cocoa beans from the African region have lower Cd. Additionally, though the source of soil Cd is needed to help understand and possibly mitigate Cd uptake, soil physiochemical properties (e.g., soil pH, clay and/or organic material content, zinc levels) and the cocoa tree's genetics are also very important interactive factors.

- **"Pre-harvest" conclusion for Pb (Section 4.2).** Only two publications (Rankin et al., 2005; Manton, 2010) used clean room preparation, appropriately low limits of quantification, and clean preparation techniques to separate nibs from shells to measure Pb concentrations directly from cocoa pods on trees. These publications report pre-harvest concentrations of Pb in cocoa nibs and shells less than 3 ppb dry weight. Thus, nearly all Pb in commercial cocoa beans is from post-harvest contamination.

- **"Harvest" conclusion for Cd and Pb (Section 5).** Though there may be the potential for Cd or Pb contamination of cocoa beans at the harvest stage, the Expert Committee believes that compared to other stages, this is most likely not a source of contamination. The Expert Committee does not recommend further study to evaluate this issue.

- **"Post-harvest" conclusion for Cd (Sections 6.1 to 6.4).** The Expert Committee finds that the most significant source of Cd in cocoa beans occurs pre-harvest. While post-harvest activities might slightly change the Cd concentrations, these changes are believed to be minimal in comparison to pre-harvest contributions.

- **"Post-harvest" conclusion for Pb (Section 6.5).** Based on information in the scientific literature regarding sources of Pb in cocoa products and observations made during a tour of a cocoa growing region, the Expert Committee finds that the most significant source of Pb in cocoa beans occurs "post-harvest." This includes fermentation and drying of harvested beans both on-farm and off-farm. Scientific literature demonstrates that cocoa beans on the tree contain very low concentrations of Pb (less than 3 ppb dry weight). Cocoa beans have been demonstrated in commercial markets as high as >1,000 ppb dry weight. Pb in cocoa beans has not accumulated by uptake from soils in which the cocoa tree roots are growing and translocated into the nib. The most likely source of "post-harvest" Pb contamination is believed to be from the outdoor fermentation and drying of beans. Fermentation has been observed to occur in bags, covered piles, and wooden boxes exposed to exterior elements. Outdoor drying has been observed being performed along roadsides, on concrete patios, on drying tables, on plastic tarps, and in direct contact with the ground. Soil and dust containing Pb from anthropogenic sources is believed to come into contact with the cocoa bean shell and serve as the primary source of Pb to the cocoa bean.

- **Manufacturing environment conclusion for Cd and Pb (Section 7).** Cocoa bean processing and chocolate manufacturing operations are not a likely source of Cd or Pb in chocolate products. Regulatory inspections and food safety certification audits assure that controls are in place to avoid the introduction of Cd or Pb through processing water, production equipment, product packaging, and environmental dust. Non-cocoa based ingredients that are used in typical chocolate formulations are not a likely source of Cd or Pb beyond that already in raw material shipments of cocoa beans. While not an additional source of Cd or Pb into chocolate products, bean cleaning and shell removal processes play a key role in the redistribution of Cd or Pb containing particles from cocoa bean shells and waste material to nibs. These processes are not specifically controlled to manage Cd or Pb levels in nibs.

4.2 Key Findings from the Reductions Recommendations Report

Note: The following text is quoted verbatim from the executive summary of the Reductions Recommendations Report. References to section numbers in the following text pertain to the sections shown in Attachment 2 of this report.

The Expert Committee identified 30 potential Cd and Pb reduction strategies from the available literature (e.g., CAOBISCO/ECA/FCC, 2015; CODEX, 2020; Meter et al., 2019) and from its own deliberations. Nearly every strategy evaluated would directly or indirectly reduce Cd or Pb concentrations and therefore would result in a public (consumer) health benefit due to measurable reductions of Cd and/or Pb in consumable chocolate products. Furthermore, the Expert Committee agreed that each strategy would be proposed as alternatives to providing warning labels or notification as required under Proposition 65; therefore Proposition 65 warning requirements were not included in the strategy list.

The 30 proposed strategies were grouped according to whether the primary reduction measure was for Cd, Pb, or both, targeting three areas key for chocolate production: agricultural practices, manufacturing practices, and business practices. Because the majority of the available research and data on heavy metal contamination in chocolate products is for Cd, the number of known potential Cd reduction strategies outweighs those available for Pb, particularly for agricultural practices. Strategies to limit Pb in cocoa beans are based on the Expert Committee's finding in the Root Cause Report that Pb on beans comes from environmental sources of dust and soil that contaminate the wet shell. During manufacturing, most of the contaminating Pb goes into the waste stream and is discarded. However, during the bean breaking process, some of the originally shell- bound Pb is redistributed to nibs as fines, which raises the Pb levels in chocolate products. Although the concentration of Pb in the nibs of freshly harvested cocoa beans ranges from 1-5 ppb, Pb concentrations in chocolate products can be 100 ppb or higher due to this manufacturing process. Therefore, the Expert Committee generally agrees the avoidance of soil and dust contact during fermentation and drying could be the most effective means to prevent Pb contamination.

Sections 4 through 6 of this report include descriptive summaries of each strategy. Individual reduction strategies are intended for specific chocolate industry stakeholders. Agricultural practices are intended for exporters and local traders (purchasing decisions); farmers (planting decisions, genetics, soil amendment practices, and post-harvest handling practices); governmental agencies and non-governmental organizations (NGOs) (supporting farmers through extension outreach); and universities and research organizations (plant breeding research). Manufacturing practices are intended for chocolate and cocoa manufacturers. Business practices are intended for manufacturers (certification schemes); governmental agencies and NGOs (local education and training); and exporters and local traders (cocoa bean testing).

Using the available scientific evidence for Cd and Pb reduction measures in the scientific literature and personal experience and professional judgement, the Expert Committee applied both qualitative and quantitative ratings in evaluating feasibility and in deriving a stratified confidence ranking of each strategy. Additionally, the Experts conducted two studies to inform their analyses:

- A Bean Cleaning and Winnowing Study (see Appendix C) was performed at a major North America cocoa processing plant operated by one of the largest companies in the industry. The study investigated the impact of the bean cleaning and shell removal processes on Cd and Pb concentration. The mechanical cleaning process, which is typical of the industry, was able to reduce cocoa bean mean Pb concentration by 58 percent, from 95.2 ppb to 39.7 ppb. When compared to wet cleaning beans with water and detergent, there was no significant difference between the reduction obtained by mechanical cleaning versus wet cleaning. With regards to winnowing, the study concluded that nib Pb concentration is a function of particle size. Nib Pb concentration increases as nib particle size decreases. Smaller nib particles have a higher surface area to volume ratio, which provides for more contact area with Pb containing material (i.e., shell, soil, light, and fine material) during bean breaking and winnowing. The study concluded that approximately 70 percent of nib Pb concentration is a result of contact during bean breaking and winnowing.

- A Bean Abrasion Study (see Appendix D) to further explore results of the Bean Cleaning and Winnowing Study, which found that fine particles separated during winnowing carried a large proportion of bean Pb. The Bean Abrasion Study tested whether bean-to-bean abrasion could release these Pb-rich particles as a Pb-reducing treatment. Several "shaking" methods were used with 200 g of dry beans in 500 mL polyethylene bottles: roller, side-to-side, and vigorous hand shaking just short of breaking beans. Because little or no fine particles (< 2 mm) were released by any of these shaking methods, only a small amount of broken shell, the Experts concluded that the fine particles were not easily released, or were generated during or after the heating step before breaking and winnowing at cocoa bean processing facilities.

The Expert Committee's approach for reviewing each strategy involved several iterations of discussion and scoring around eleven questions developed to address Cd and Pb reduction potentials, timeframes for implementation, six feasibility factors (public health impact, environmental impact, social impact, economic impact, technological considerations, and scalability), and the Expert Committee's overall confidence that the strategy would result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products.

Because the definition of feasibility in the Consent Agreement lacks specific detail, the Expert Committee developed its own interpretations of the six feasibility factors, with some additional but limited guidance from the AYS and the SDs. Specifically, the Expert Committee agreed that all the feasibility factors would be evaluated based on whether the implementation of the strategy would provide a potential benefit, detriment, or be case-neutral. For the public health feasibility factor, the Expert Committee evaluated whether the strategy would unintentionally introduce a public or occupational health risk during implementation. Likewise, for environmental and social impacts, the Expert Committee evaluated whether the implementation of the strategy would introduce an unintended impact on the environment or society or even a potential benefit. Economic impacts were considered only in terms of potential monetary costs to the industry, growers, or consumers; no other economic factors were considered by the Expert Committee. (Note: None of the Expert Committee members is trained or educated in the field of economics and credentialed economists were not consulted during the Committee's deliberations.) With respect to scalability and the availability of underlying technology, the Expert Committee agreed to evaluate each strategy based on the strength of evidence that the technology and means to implement the strategy exist across the universe of cocoa production, or a portion thereof, and that the strategy (e.g., the available or proposed new technology) would be effective for cocoa applications.

The Expert Committee used the rating scheme in Appendix A to score strategies. Quantitative scoring for each strategy and for each feasibility question was conducted three times by individual Expert Committee members over the course of developing this report with the third scoring being the final results (Appendix B). The compiled results of the scoring were mathematically analyzed by determining the percent of maximum score (percent of maximum points available) for each factor and for the confidence rating. A total score was calculated as was a separate score for confidence. The scoring was blinded in the final evaluation so that the scores submitted by individual members are not identifiable.

To group the scoring results into a meaningful presentation, the Expert Committee agreed to categorize each strategy according to whether the confidence score was "High," "Medium," or "Low." Based on the range of confidence scores (from 0 to 94 percent), the High grouping represents the top third, the Medium grouping represent the middle third, and the third grouping includes the bottom third. This same approach could also have been presented for the total feasibility scores, however the Expert Committee agreed that the confidence score is a more meaningful summary of the scoring results than the feasibility rankings. It should be noted that the three-tiered grouping of total scores for each strategy for the most part follows that of the confidence scores, with only three strategies falling on the borderline between the High and Medium groupings. The Expert Committee reached a consensus on the final groupings of these strategies.

The Expert Committee realized that reaching a consensus on each individual feasibility score would not be possible given the project timeline, data and information limitations, and the variation among the backgrounds, experiences, and perspectives of the Expert Committee members. To compensate for this, the discussion section of each strategy description summary (see Sections 4 through 6) provides a narrative describing the results of the feasibility ranking. These discussions acknowledge variations in the Experts' scoring and include individual comments on the uncertainties of the available information. The purpose of this discussion is to provide a transparent descriptive (qualitative) record of the Expert Committee's feasibility scoring to complement the quantitative scoring results.

The results of the final confidence scores are presented in Table 1 listed from the highest to the lowest relative ranking. Although the strategies presented in Table 1 are listed in a linear manner, the three categories of strategy approaches (better agricultural, manufacturing, and business practices) should be considered as a matrix or a menu of options for the following reasons:

1. The three categories represent different approaches to achieving Cd and Pb reductions and are therefore meant to be considered as complementary and in some cases supportive of the other strategies.
2. Some strategies offer a direct approach to reducing Cd and/or Pb, while other strategies offer an indirect approach. Therefore, selecting a strategy based only on direct reduction potential would not consider the other "foundational" strategies that would be required to ensure peak effectiveness of those direct strategies.
3. Reduced scalability and/or local resource availability might limit the application of some of these strategies in growing regions or manufacturing facilities.
4. Temporal considerations (e.g., time to implementation) need to be considered along with the feasibility and confidence scoring. Strategies that can be implemented in 1 to 5 years might offer a short-term solution but over the long-term might not be sustainable. Some strategies would likely take more than 5 years to implement but offer a more sustainable solution.
5. Further research and data will be required to refine the implementation potential for several strategies and allotting funding for research in a matrix plan will be more effective than considering each strategy as an individual option.

Table 2 presents the results of the Expert Committee's scoring in a matrix format to facilitate the development of a more holistic implementation plan.

Table 1. Reduction Strategies Listed in Order from Highest to Lowest Confidence Score

Strategy Title (Report Section Number Shown in Parentheses)
Strategies with "High" Confidence Scores
Better Agricultural Practices (Cd): Exporters to Stop Purchasing Beans from Regions with High Cd Phytoavailability (4.1.1)
Better Agricultural Practices (Cd): Farmers to Stop Planting New Orchards in Regions with High Cd Phytoavailability (4.1.2)
Better Agricultural Practices (Cd): Use Soil Amendments to Increase Soil pH (4.1.3)
Better Agricultural Practices (Pb): Prevent Pb Contamination of Beans during Fermenting and Drying (4.4.1.1)
Better Manufacturing Practices (Cd): Blend Beans or Liquor as a Cd Control Measure (5.1.1)
Better Agricultural Practices (Cd): Use Scion Grafts to Reduce Cd Uptake from Soils (4.1.5.1)
Better Agricultural Practices (Cd): Develop and Plant Rootstocks That Accumulate Less Cd from Soils (4.1.5.2)
Better Agricultural Practices (Cd): Use Zinc Sulfate Soil Amendments to Reduce Cd Uptake from Soils (4.1.4)
Better Agricultural Practices (Pb): Prevent Pb Contamination of Whole Wet Beans during Transport (4.4.1.2)
Better Manufacturing Practices (Pb): Establish Bean Cleaning/Winnowing QA Practices for Pb Contamination (5.1.2)
Better Business Practices: Incorporate Better Agricultural Practices into Cocoa Sustainability/Certification Programs (6.1.1)
Better Business Practices: Provide Education/Training at the Local Level to Implement Reduction Strategies (6.1.2)
Better Agricultural Practices (Cd): Use Self-Rooted Cocoa to Reduce Cd Uptake from Soils (4.1.5.3)
Better Agricultural Practices (Cd): Use Molecular Breeding Techniques to Identify Genotypes That Accumulate Less Cd (4.1.5.4)
Better Business Practices: Test Surfaces of Cocoa Beans for Pb Contamination at Point of Purchase (6.1.3)
Strategies with "Medium" Confidence Scores
Better Business Practices: Offer Incentives to and Provide Funding for Local Growers (6.2.1)
Better Manufacturing Practices: Develop and Use New Mechanical Techniques to Clean Beans (5.2.1)
Better Business Practices: Certify Management Systems to GFSI Schemes (6.2.2)
Better Agricultural Practices (Pb): Test Painted Surfaces for Pb (4.4.2.1)
Better Agricultural Practices: Test Water from Irrigation Sources and Use Alternate Water Sources, if Needed (4.2.1)
Strategies with "Low" Confidence Scores
Better Agricultural Practices (Cd): Use Amendments Recommended by CODEX But Not Included in Other Strategies (4.3.1)
Better Agricultural Practices (Cd): Use Zinc Sulfate Foliar Sprays to Reduce Cd Levels in Cocoa Beans (4.3.3)
Better Agricultural Practices (Cd): Phytoextract Cd from Soils Using Hyperaccumulators (4.3.5)
Better Agricultural Practices (Cd): Use Mineral Soil Amendments (4.3.2)
Better Agricultural Practices (Cd): Use Fertilizers Rich in Certain Elements (4.3.6)
Better Agricultural Practices (Cd): Adopt Agroforestry or Monoculture Techniques (4.3.7)
Better Agricultural Practices (Cd): Use Foliar Sprays Rich in Iron and Manganese (4.3.4)
Better Agricultural Practices (Cd): Manage Fermentation Practices to Reduce Cd in Beans (4.4.1.1)
Better Manufacturing Practices: Use Chemical Washing Techniques to Clean Beans (5.3.1)
Better Agricultural Practices (Cd): Use Microbial Inoculation Techniques (4.3.9)

Table 2. Reduction Strategies Grouped by Chocolate Production Sector and Confidence Scores

Better Agricultural Practices That Apply to…		Better Manufacturing Practices	Better Business Practices
…Cd	…Pb		
Exporters to Stop Purchasing Beans from Regions with High Cd Phytoavailability	Prevent Pb Contamination of Beans during Fermenting and Drying	Blend Beans or Liquor as Cd Control Measure	Incorporate Better Agricultural Practices into Cocoa Sustainability and Certification Programs
Farmers to Stop Planting New Orchards in Regions with High Cd Phytoavailability	Prevent Pb Contamination of Whole Wet Beans during Transport	Establish Bean Cleaning and Winnowing QA Practices for Pb Contamination	Provide Education and Training at the Local Level to Implement Reduction Strategies
Use Soil Amendments to Increase Soil pH	Test Painted Surfaces for Pb	Develop and Use New Mechanical Techniques to Clean Beans	Test Surfaces of Cocoa Beans for Pb Contamination at Point of Purchase
Use Scion Grafts to Reduce Cd Uptake from Soils		Use Chemical Washing Techniques to Clean Beans	Offer Incentives to and Provide Funding for Local Growers
Develop and Plant Rootstocks That Accumulate Less Cd from Soils			Certify Management Systems to GFSI Schemes
Use Zinc Sulfate Soil Amendments to Reduce Cd Uptake from Soils			
Use Self-Rooted Cocoa to Reduce Cd Uptake from Soils			
Use Molecular Breeding Techniques to Identify Genotypes That Accumulate Less Cd			
Test Water from Irrigation Sources and Use Alternate Water Sources, if Needed			
Use Amendments Recommended by CODEX But Not Included in Other Strategies			
Use Zinc Sulfate Foliar Sprays to Reduce Cd Levels in Cocoa Beans			
Phytoextract Cd from Soils Using Hyperaccumulators			
Use Mineral Soil Amendments			
Use Fertilizers Rich in Certain Elements			
Adopt Agroforestry or Monoculture Techniques			
Use Foliar Sprays Rich in Iron and Manganese			
Manage Fermentation Practices to Reduce Cd in Beans			
Use Microbial Inoculation Techniques			

Note: Green shaded cells are strategies with "High" confidence scores; blue shaded cells are strategies with "Medium" confidence scores; and orange shaded cells are strategies with "Low" confidence scores.

4.3 Key Findings from the Warning Triggers Report

Note: The following text is quoted verbatim from the executive summary of the Warning Triggers Report. References to section numbers in the following text pertain to the sections shown in Attachment 3 of this report. The only change made to the following text was to the table numbering.

In this third report, the Expert Committee was charged with recommending whether and when concentrations of lead (Pb) and cadmium (Cd) in chocolate products shall be modified from "drop-down" Proposition 65 trigger levels included in the Consent Judgment. The Experts were instructed to base their findings on the lowest Pb and Cd levels that can be feasibly achieved, considering the Pb and Cd reduction strategies identified and evaluated in Phase Two of this project. Feasible, as defined in the Consent Judgment, means "capable of being accomplished in a successful manner within a reasonable period of time, taking into account public health, and economic, environmental, social, and technological factors." Evaluations of 30 potential Cd and Pb reduction strategies using these criteria were developed and reported in the Phase Two report. The Experts based their assessments on their Phase One and Phase Two findings, sampling data provided by As You Sow (AYS) and the Settling Defendants (SDs), a review of relevant scientific literature, consultation with subject matter experts, and their professional judgment.

During a series of videoconferences, the Experts discussed feasible drop-down levels for Pb and Cd. While the Experts agreed on certain findings, described below, consensus was not reached on the lowest Pb and Cd drop-down levels (concentrations) that industry can feasibly achieve for chocolate products sold in California. The Experts agreed that, even with further discussion, they would not be able to converge on the same concentrations for drop-down levels. In short, they "agreed to disagree" on the lowest Pb and Cd concentrations that can be feasibly achieved.

As a result, the Expert Committee agreed that this Phase Three report would present each Expert's individual assessment of the lowest drop-down levels that can be feasibly achieved, and each Expert was charged with proposing drop-down levels and justifying how they were derived. Sections 3 and 4 of this report present the Experts' individual assessments and derivations of Pb and Cd drop-down levels, respectively. A summary of their findings follows:

- **Pb drop-down levels.** Table 3 summarizes the Experts' findings on Pb Proposition 65 drop-down (i.e., trigger) levels. Consensus was reached that it is feasible for the industry to meet all drop-down levels referenced in Section 6.2.1 of the Consent Judgement. However, there is no consensus as to what conditions (e.g., implementation of new Pb reduction strategies versus no new actions) are required to meet these drop down levels. In addition, consensus was reached that further reductions in Pb to lower drop-down levels are feasible. However, there is no consensus as to the lower level of reduction that can be feasibly achieved. The entries in Table 3 show the range of Pb drop-down levels that the Experts recommended.

- **Cd drop-down levels.** Table 4 summarizes the Experts' findings on Cd Proposition 65 drop-down levels. There is no consensus as to whether it is feasible for the industry to meet the current limits, the proposed drop-down limits, or further reductions.

The Experts' conclusions are based on the information available to the Expert Committee as of September 1, 2021.

Table 3. Experts' Findings Regarding Pb Drop-Down Levels

Chocolate Products with up to 65% Cacao Content (Section 6.2.1.a*)			
Expert	**Can the Following Pb Drop-Down Levels be Feasibly Achieved?**		
	0.100 ppm	**0.065 ppm**	**<0.065 ppm****
Tim Ahn	Yes	Yes	Yes (0.060 ppm)
Rufus Chaney	Yes	Yes	Yes (0.050 ppm)
Michael DiBartolomeis	Yes	Yes	Yes (0.015 ppm)
Gideon Ramtahal	Yes	Yes	Yes (0.060 ppm)
Chocolate Products with Greater Than 65% and up to 95% Cacao Content (Section 6.2.1.b*)			
Expert	**Can the Following Pb Drop-Down Levels be Feasibly Achieved?**		
	0.150 ppm	**0.100 ppm**	**<0.100 ppm****
Tim Ahn	Yes	Yes	Yes (0.090 ppm)
Rufus Chaney	Yes	Yes	Yes (0.075 ppm)
Michael DiBartolomeis	Yes	Yes	Yes (0.020 ppm)
Gideon Ramtahal	Yes	Yes	Yes (0.090 ppm)
Chocolate Products with Greater Than 95% Cacao Content (Section 6.2.1.c*)			
Expert	**Can the Following Pb Drop-Down Levels be Feasibly Achieved?**		
	0.225 ppm	**0.200 ppm**	**<0.200 ppm****
Tim Ahn	Yes	Yes	Yes (0.180 ppm)
Rufus Chaney	Yes	Yes	Yes (0.100 ppm)
Michael DiBartolomeis	Yes	Yes	Yes (0.040 ppm)
Gideon Ramtahal	Yes	Yes	Yes (0.180 ppm)

* These section numbers refer to text in the Consent Judgment.
** Concentrations in the final column are the lowest Pb drop-down levels that the Experts identified as being feasibly achievable.

Table 4. Experts' Findings Regarding Cd Drop-Down Levels

Chocolate Products with up to 65% Cacao Content (Section 6.2.2.a*)			
Expert	Can the Following Cd Drop-Down Levels be Feasibly Achieved?		
	0.400 ppm	0.320 ppm	<0.320 ppm**
Tim Ahn	No	No	No
Rufus Chaney	Yes	No	No
Michael DiBartolomeis	Yes	Yes	Yes (0.120 ppm)
Gideon Ramtahal	Yes	No	No
Chocolate Products with Greater Than 65% and up to 95% Cacao Content (Section 6.2.2.b*)			
Expert	**Can the Following Cd Drop-Down Levels be Feasibly Achieved?**		
	0.450 ppm	**0.400 ppm**	**<0.400 ppm****
Tim Ahn	No	No	No
Rufus Chaney	Yes	No	No
Michael DiBartolomeis	Yes	Yes	Yes (0.175 ppm)
Gideon Ramtahal	Yes	No	No
Chocolate Products with Greater Than 95% Cacao Content (Section 6.2.2.c*)			
Expert	**Can the Following Cd Drop-Down Levels be Feasibly Achieved?**		
	0.960 ppm	**0.800 ppm**	**<0.800 ppm****
Tim Ahn	No	No	No
Rufus Chaney	Yes	Yes	No
Michael DiBartolomeis	Yes	Yes	Yes (0.400 ppm)
Gideon Ramtahal	Yes	No	No

* These section numbers refer to text in the Consent Judgment.

** Concentrations in the final column are the lowest Cd drop-down levels that the Experts identified as being Feasibly achievable.

5.0 References Cited in the Three Technical Reports

This section lists the references that were cited in the three technical reports. The first list below is for documents cited in any of the three reports. The second list below is for international agricultural training programs and links to selected documents that were cited in the Reductions Recommendations Report. The third list below is personal communications that appeared in the technical reports. (Note: Each technical report has its own list of references. All three reference lists were compiled and alphabetized to create the following lists.)

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International Agricultural Training Programs and Documents Links

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Ecuador: https://www.we.org/en-CA/we-stories/global-development/cacao-farm-ecuador-rainforest-agricultural-training.

Rainforest Alliance (New York): https://www.rainforest-alliance.org/sites/default/files/2017-04/toward-sustainable-cocoa-sector.pdf.

Feed the Future (Florida): https://www.agrilinks.org/sites/default/files/resource/files/MEAS%20CS%20Ecuador%20-%20Cacao%20-%20What%20Does%20It%20Mean%20to%20be%20Socially%20Responsible%20-%20Blare%20and%20Useche%20-%20July%202014.pdf.

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Attachment 1: Root Cause Report

Version 1 of the Experts' Root Cause Report was submitted to AYS and the SDs on March 27, 2020.

When preparing the Phase 3 report, the Experts noted an error in the Venezuela entries in Table 3a of the Root Cause Report. An additional error was identified and corrected for the Ecuador entries in the same table. Those errors have been corrected, and the Root Cause Report in this attachment is referred to as Version 2 and is dated March 2022. Additionally, a citation in the final paragraph of Section 4.1.1.1 was replaced with two other citations, and the list of citations in the report was updated accordingly. All headers in the report were changed from "Version 1.0" to "Version 2.0."

Clarifications were included in the text in the following paragraphs:

- The "Nutrients" paragraph in Section 4.1.1.1.
- A citation was added to Section 4.1.2.1 and to the reference list.
- A sentence was added to the end of the first bulleted item in Section 4.2.1.
- A clarification was included in the first bulleted item in Section 6.3.

Two other passages in the Root Cause Report were revised to explain the difference between the report versions: (1) the final paragraph in Section 2.1 was revised and (2) the final paragraph in Section 2.3 was revised. These revisions did not alter the content of the Expert Committee's findings.

Expert Investigation Related to Cocoa and Chocolate Products:

Root Cause Phase Report

Submitted to:

As You Sow and the Settling Defendants

Submitted by:

Timothy Ahn, Lloyd's Register

Rufus Chaney, PhD, Chaney Environmental: Risk Assessment and Reduction

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Note: All authors contributed equally to the development of this report. The authors' names are listed alphabetically.

March 2022

CONTENTS

List of Abbreviations

ASV	anodic stripping voltammetry
AYS	As You Sow
Cd	cadmium
CFSAN	Center for Food Safety and Nutrition
ERG	Eastern Research Group, Inc.
FAAS	flame atomic absorption spectroscopy
FDA	U.S. Food and Drug Administration
GFAAS	graphite furnace atomic absorption spectroscopy
GFSI	Global Food Safety Initiative
GMP	good manufacturing practice
ICP-AES	inductively coupled plasma atomic emission spectrometry
ICP-MS	inductively coupled plasma mass spectrometry
ID-TI-MS	isotope dilution thermal ionization mass spectrometry
IQR	interquartile range
LOD	limit of detection
LOQ	limit of quantification
MADL	Maximum Allowable Dose Level
OECD	Organization for Economic Cooperation and Development
OEHHA	Office of Environmental Health Hazard Assessment
Pb	lead
Q1, Q2, Q3	quartiles of a data distribution
QA/QC	quality assurance and quality control
SDs	settling defendants
SME	Subject Matter Expert
SOP	standard operating procedure
TI-MS	thermal ionization mass spectrometry
USDA	U.S. Department of Agriculture

1. Executive Summary

In 1986, California voters passed Proposition 65, also known as the Safe Drinking Water and Toxic Enforcement Act of 1986. Proposition 65 has many requirements; one of which requires businesses to provide warnings on products that lead to toxic chemical exposures above levels set by the California Office of Environmental Health Hazard Assessment (OEHHA). These requirements apply to a wide range of products, including food items.

Between 2014 and 2017, As You Sow (AYS), a non-profit corporation in California, tested various chocolate products for the presence of cadmium (Cd) and lead (Pb). This testing revealed that numerous chocolate products had elevated Cd or Pb concentrations that, combined with typical serving sizes, indicated the potential for Cd and Pb exposures greater than the Proposition 65 Maximum Allowable Dose Levels (MADLs).

AYS subsequently issued Notices of Violation to several companies that manufacture, distribute, or sell chocolate products in California or precursors to those products (e.g., cocoa beans). The Notices indicated that the chocolate products with elevated Cd or Pb concentrations require warnings under California law. Rather than enter into prolonged and costly litigation on the matter, multiple companies entered into a Consent Judgment with AYS to investigate and address the sources of Cd and Pb in chocolate products. The companies that entered into this Consent Judgment are referred to as the Settling Defendants (SDs).

The Consent Judgment has many stipulations and requirements, one of which is the formation of an Expert Committee tasked with investigating and reporting on predominant sources of Cd and Pb in chocolate products and recommending feasible measures that may be taken, if any, to meaningfully reduce the Cd and Pb concentrations. The Expert Committee's scope of work directs the experts to prepare four reports. This document is the Expert Committee's Root Cause Phase report, which presents the Expert Committee's assessment of the sources of Cd and Pb in chocolate products. The Experts were charged with considering all phases of chocolate production, from farm to factory; and they evaluated both natural and anthropogenic sources.

Section 2 of this report describes the process by which the Expert Committee reached its findings and developed this report. As Section 2 explains, the Experts organized their conclusions around the following topics related to the chocolate product supply chain. For purposes of this report, "pre-harvest" pertains to the state of cocoa beans before pods are removed from cocoa trees; "harvest" refers to the process by which ripe pods are removed from trunks and branches of cocoa trees with their subsequent opening to extract wet beans; and "post-harvest" refers to activities that take place with extracted wet cocoa beans after harvest, from farm to port.

- **Conclusion regarding usability of SD testing data (Section 3).** The SDs provided the Expert Committee a large dataset of Cd and Pb testing of various materials. These data were not accompanied by important supporting documentation, such as descriptions of sampling and analytical methods, detection limits, and data quality narratives. The Expert Committee agreed to use the SD testing data in its Root Cause Phase analysis and acknowledge the data limitations when doing so.

- **"Pre-harvest" conclusion for Cd (Section 4.1).** Soil is one of the major sources of Cd in cocoa beans, which occurs through direct uptake of phytoavailable Cd by the cocoa tree during the pre-harvest stage. The Expert Committee therefore considers Cd in soils as a "common source" for the Root Cause Phase. The origin of Cd in these cocoa-growing soils is a mixture of natural and anthropogenic sources, is highly variable, and is country- and farm-specific. Many studies (mostly in Latin America and the Caribbean) report that anthropogenic sources of Cd are of greater concern than the natural sources in areas where historical industrial or current industrial activities have resulted in elevated levels of soil Cd. On the other hand, data and evidence are still needed to fully understand why pre-harvest cocoa beans from the African region have lower Cd. Additionally, though the source of soil Cd is needed to help understand and possibly mitigate Cd uptake, soil physiochemical properties (e.g., soil pH, clay and/or organic material content, zinc levels) and the cocoa tree's genetics are also very important interactive factors.

- **"Pre-harvest" conclusion for Pb (Section 4.2).** Only two publications (Rankin et al., 2005; Manton, 2010) used clean room preparation, appropriately low limits of quantification, and clean preparation techniques to separate nibs from shells to measure Pb concentrations directly from cocoa pods on trees.

These publications report pre-harvest concentrations of Pb in cocoa nibs and shells less than 3 ppb dry weight. Thus, nearly all Pb in commercial cocoa beans is from post-harvest contamination.

- **“Harvest” conclusion for Cd and Pb (Section 5).** Though there may be the potential for Cd or Pb contamination of cocoa beans at the harvest stage, the Expert Committee believes that compared to other stages, this is most likely not a source of contamination. The Expert Committee does not recommend further study to evaluate this issue.

- **“Post-harvest” conclusion for Cd (Sections 6.1 to 6.4).** The Expert Committee finds that the most significant source of Cd in cocoa beans occurs pre-harvest. While post-harvest activities might slightly change the Cd concentrations, these changes are believed to be minimal in comparison to pre-harvest contributions.

- **“Post-harvest” conclusion for Pb (Section 6.5).** Based on information in the scientific literature regarding sources of Pb in cocoa products and observations made during a tour of a cocoa growing region, the Expert Committee finds that the most significant source of Pb in cocoa beans occurs “post- harvest.” This includes fermentation and drying of harvested beans both on-farm and off-farm. Scientific literature demonstrates that cocoa beans on the tree contain very low concentrations of Pb (less than 3 ppb dry weight). Cocoa beans have been demonstrated in commercial markets as high as >1,000 ppb dry weight. Pb in cocoa beans has not accumulated by uptake from soils in which the cocoa tree roots are growing and translocated into the nib. The most likely source of “post-harvest” Pb contamination is believed to be from the outdoor fermentation and drying of beans. Fermentation has been observed to occur in bags, covered piles, and wooden boxes exposed to exterior elements. Outdoor drying has been observed being performed along roadsides, on concrete patios, on drying tables, on plastic tarps, and in direct contact with the ground. Soil and dust containing Pb from anthropogenic sources is believed to come into contact with the cocoa bean shell and serve as the primary source of Pb to the cocoa bean.

- **Manufacturing environment conclusion for Cd and Pb (Section 7).** Cocoa bean processing and chocolate manufacturing operations are not a likely source of Cd or Pb in chocolate products. Regulatory inspections and food safety certification audits assure that controls are in place to avoid the introduction of Cd or Pb through processing water, production equipment, product packaging, and environmental dust. Non-cocoa based ingredients that are used in typical chocolate formulations are not a likely source of Cd or Pb beyond that already in raw material shipments of cocoa beans. While not an additional source of Cd or Pb into chocolate products, bean cleaning and shell removal processes play a key role in the redistribution of Cd or Pb containing particles from cocoa bean shells and waste material to nibs. These processes are not specifically controlled to manage Cd or Pb levels in nibs.

The aforementioned conclusions are based on the information available to the Expert Committee as of February 15, 2020.

2. Background

This section presents background information on the Expert Committee and describes how the Experts developed the Root Cause Phase report. This section does not present the Experts' technical findings. Those are included in this report's Executive Summary and discussed in Sections 3 through 7.

2.1 Formation and Operation of the Expert Committee

As noted previously, the initiating event for this project was discovery of Cd and Pb in chocolate products purchased in California at levels that triggered Notices of Violation under the state's Proposition 65. The party that discovered these contamination levels (AYS) and several companies in the chocolate industry (the SDs) entered into the Consent Judgment that formed the Expert Committee and directed the Experts to prepare this report.

As stipulated by the Consent Judgment, AYS appointed one Expert Committee member; the SDs appointed another; and AYS and the SDs jointly agreed upon and appointed the remaining two. The names and affiliations of the four Expert Committee members appear on the title page of this report. AYS and the SDs also mutually identified and jointly appointed a Project Manager, who provided administrative and logistical support to the Expert Committee, facilitated discussions during Expert Committee meetings, ensured that the Expert Committee completed its work according to the budget and schedule, and provided word processing and editorial support for this report. Mr. John Wilhelmi of Eastern Research Group, Inc. (ERG) served as the Project Manager.

The Expert Committee members and the Project Manager performed their work under "consulting and confidentiality agreements" with AYS and the SDs, as joint contracting parties. The agreements required Expert Committee members to treat as strictly confidential and not disclose any non-public information provided by the SDs. The Expert Committee abided by these reuqirements. They thoroughly considered all information received, including non-public information; and this report's findings are based on all information that the Expert Committee obtained and reviewed, even though this report is not allowed to present confidential information.

The Consent Judgment defines the Expert Committee's scope of work. It requires the Expert Committee to prepare four reports over a 2-year time frame. This report, the Root Cause Phase report, identifies the sources of Cd and Pb in chocolate products. The Expert Committee will then prepare a Reductions Recommendations report (which will identify feasible means for reducing Cd and Pb levels in chocolate products), a Warning Trigger Phase report (which will comment on whether Proposition 65 warning levels for Cd and Pb should be modified), and a final report (which presents the Expert Committee's overall findings and recommendations).

The remainder of this document focuses exclusively on the Expert Committee's Root Cause Phase analysis. The Consent Judgment sets the following scope for the Root Cause Phase:

> The Root Cause Phase of the investigation is intended to identify any potential sources of lead and cadmium in chocolate across all phases of the cacao and Chocolate Products process and supply chains. For each source that the Committee identifies, the Committee should also identify the likelihood that each source would contribute lead or cadmium to chocolate (e.g., "common source," "infrequent source," "rare source," etc.). The Committee's conclusions may be based on literature review; consultation with SMEs and chocolate industry personnel; testing for lead/cadmium in soil, water, beans, ingredients, equipment, packaging, tools, etc.; and any information the Committee deems relevant and reliable.

From March 2019 to February 2020, the Expert Committee completed its research and developed Version 1 of the Root Cause Phase report, which was submitted in March 2020. The Experts subsequently made revisions to Table 3a of the report and issued the current version (Version 2) in March 2022.

2.2 Lines of Evidence Considered by the Expert Committee

The Expert Committee considered multiple lines of evidence when completing the Root Cause Phase report. These include:

- **Sampling data.** Cd and Pb sampling results weighed heavily in the Expert Committee's Root Cause Phase analysis. The experts considered analytical data from multiple media, such as cocoa beans, farm soils, process streams at cocoa bean processing and chocolate manufacturing facilities, and ingredients added in manufacturing processes. The experts closely scrutinized all sampling data to assess whether they are of a known and high quality.

  The sampling data presented in this report largely originated from three sources. First, the experts considered a large volume of sampling data provided by the SDs. Given the amount and importance of these sampling results, this report has a section dedicated entirely to reviewing the SDs' data (Section 3). Second, the experts considered sampling data reported in the peer-reviewed literature. Third, the experts conducted their own sampling of beans and soils in a country of origin to fill data gaps and to confirm their preliminary findings (see Sections 4 and 6).

- **Publications.** The Expert Committee considered insights and findings from scientific publications, largely relying on peer-reviewed literature. The experts reviewed graduate theses and unrefereed sources, as appropriate. During the Root Cause Phase analyses, the Expert Committee compiled an inventory of 240 potentially relevant publications, and more than 125 of these scientific publications are cited in this report. (Note: An electronic copy of the Expert Committee's document inventory is available upon request.)

- **Consultation with SMEs.** To inform their Root Cause Phase analyses on specific topics, Expert Committee members contacted outside SMEs. The experts made these contacts individually and informed the Project Manager of all contacts made. During the Root Cause Phase, the experts made more than 65 such contacts. Documentation of these is found in the quarterly reports that the Project Manager submitted to AYS and the SDs.

- **Direct observations.** The Expert Committee also considered their own observations from two field trips completed during the Root Cause Phase (see Section 2.3). The first field trip included tours of three industrial facilities in the United States that either processed cocoa beans or manufactured chocolate products. The second field trip was of supply chain activity in Ecuador. The latter trip included visits to cocoa farms, bean collection facilities where drying and fermenting occurred, and bean exporter facilities where pre-export bean cleaning and packaging occurred.

- **Professional judgment.** The Expert Committee members bring decades of experience in relevant scientific disciplines. Their professional judgment also factored into the Root Cause Phase conclusions, particularly for issues having limited or no information available from other lines of evidence.

Sections 3 through 7 document the lines of evidence that the Expert Committee considered when evaluating root causes of Cd and Pb in chocolate product. These sections also explain how the experts resolved conflicting lines of evidence.

2.3 Process for Developing the Root Cause Phase Report

In January 2019, the Expert Committee members and the Project Manager had entered into their consulting and confidentiality agreements with AYS and the SDs. The Project Manager then held conference calls with AYS and the SDs and with the Expert Committee members to discuss the overall chocolate investigation project and to plan for the kickoff meeting.

The project officially began at a 2-day kickoff meeting on March 11-12, 2019, at an ERG office in Arlington, Virginia. The meeting included background presentations from AYS and the SDs on the activities leading up to the Consent Judgment, the Consent Judgment requirements, and the supply chain for chocolate products. Expert

Committee members asked questions of both parties, then met with the Project Manager to initiate Root Cause Phase discussions.

Over the 9 months that followed, the Project Manager held standing conference calls with the Expert Committee to complete the Root Cause Phase report. These calls covered many topics, including the preferred organization of the report, Expert Committee writing assignments, initial assessment of Cd and Pb sources, and discussion of critical data gaps and processes for filling them. The Expert Committee met in person two times when developing this report:

- On June 25-27, 2019, the Expert Committee met near Philadelphia, Pennsylvania. During the first two days of this trip, the experts toured three nearby facilities that either processed cocoa beans or manufactured chocolate products. On the final day of this trip, the Project Manager facilitated a day-long meeting among the Expert Committee to discuss Root Cause Phase project status, to reach agreement on several preliminary findings, and to make plans for completing the Root Cause Phase report.

- On November 18-21, 2019, the Expert Committee met in Guayaquil, Ecuador. The primary purpose of this meeting was to observe the movement of cocoa beans from farm to port. The Expert Committee toured several sites during the first three days of this visit. These sites included multiple cocoa farms, two cocoa bean collection facilities (where bean fermenting and drying occur prior to transfer to an exporter facility), and two cocoa bean exporter facilities (where bean cleaning and packaging occurs prior to transport of beans to port, and some further bean drying may occur). On the final day of this trip, the Project Manager facilitated another day-long meeting among the Expert Committee. During this meeting, the experts discussed all elements of the Root Cause Phase, identified areas of agreement, and discussed areas of disagreement and how to address them; the Project Manager developed a list of action items for completing the Root Cause Phase report; and most notably, the Expert Committee members wrote summary statements for key findings. All four experts reached consensus on the written statements that appear in the Executive Summary (Section 1) of this report.

This Root Cause Phase report reflects information that was available to the Expert Committee as of February 15, 2020. Section 2 through 7 were drafted by different authors. The Project Manager drafted Section 2 (i.e., this section), and authorship responsibility for Sections 3 through 7 were split among the four experts, based on their areas of expertise. Sections 3 through 7 were then reviewed by all four Expert Committee members three times: drafts of individual report sections were reviewed in August and September 2019; a compiled draft of Sections 3 through 7 was reviewed in November 2019; and the complete draft of this report was reviewed in February 2020. The Project Manager provided copyediting and word processing support on all report sections. All four experts authorized the Project Manager to submit this version of the Root Cause Phase report to AYS and the SDs, with no dissenting opinions.

2.4 Organization of the Root Cause Phase Report

The remainder of this report is organized as follows:

- Section 3 presents the Expert Committee's assessment of the SDs testing data.

- Section 4 addresses "pre-harvest" sources of Cd and Pb in cocoa beans. Specifically, this section evaluates the presence of Cd and Pb in cocoa beans before the pods are harvested from trees.

- Section 5 addresses "harvest" sources of Cd and Pb in cocoa beans. This section examines the extent to which on-farm harvesting activities introduce Cd and Pb into beans. Activities considered in this section include removal of pods from trees, opening pods, removing contents from pods, and placing these contents into containers for transfer to locations for fermentation and drying.

- Section 6 focuses on "post-harvest" sources of Cd and Pb in cocoa beans. The section covers introduction of Cd and Pb to cocoa beans during drying and fermentation, whether those processes occur at the farm or at a bean collection facility. The section also considers the possibility of Cd and Pb contamination during transit from farm to port to factory.

- Section 7 evaluates contributions of Cd and Pb in the “manufacturing environment.” The section examines potential contributions from process water, non-cocoa ingredients, equipment surfaces, and wrappers at bean processing facilities and chocolate manufacturing facilities.
- Section 8 presents references for all citations in the report.
- Appendix A includes all tables cited in the report text.
- Appendix B includes all figures cited in the report text.
- Appendix C presents supplemental information on Pb in cocoa.
- Appendix D summarizes the soil and cocoa bean sampling that the Expert Committee conducted while in Ecuador.

3. Analysis of the Settling Defendant's Testing Data

3.1 Data Inventory

The Expert Committee received three sets of confidential testing and experimental data from the SDs. Table 1 lists the various data sources received. The first set of data, referred to here as "Batch 1," was received in March 2019 and included a single Excel file with several spreadsheets containing blinded and compiled Cd and Pb test level results in whole cocoa beans and some processing intermediary products (cocoa liquor, cocoa powder, cocoa butter, and chocolate). The Batch 1 data were compiled from presumably one or more SD submissions from beans collected in several countries ("origin countries").

In June 2019, the SDs sent additional data and supporting documentation to the Expert Committee in the form of Excel spreadsheets and PDF documents. These data and the supplemental information, referred to here as "Batch 2," were provided in response to Expert Committee questions. This batch included blinded and compiled results from testing whole cocoa beans and some processing intermediary products for Cd and Pb levels (as well as a small dataset for iron and aluminum levels). This batch also included results from testing "other ingredients" (e.g., sugar, milk powder) used in processing cocoa and supplemental documentation in the form of PDF files.

The third set of data, referred to here as "Batch 3," was also received from the SDs in June 2019. This batch included blinded, compiled data from test results of Cd and Pb in whole beans after separating the shell from the nib as well as supporting documentation in the form of PDF files. These data were also provided in response to SME questions. Batch 3 included additional documents listed in Table 1.

The SDs provided a fourth submission "Batch 4," which appear to be analyses of testing data conducted by the SDs and were not specifically requested by the SME. The Batch 4 documents are not itemized in Table 1. This supplemental information from "Batch 4" is not included in the discussion in this section of the expert report.

3.2 Evaluation of Data Completeness

Table 2 lists the generally required (or necessary) information that is typically supplied by analytical laboratories and sample collectors at the time that testing results are transmitted to their clients. These analytical test parameters and sample handling and preparation procedures are essential to fully understanding how the data were produced and for accurately and correctly interpreting the results. This important information is often summarized in a document called "standard operating procedures" (SOPs), provided by the analytical laboratory (see EPA, 2007).

Necessary and important information related to the Batch 1 data was, for the most part, not provided. Although the primary test method was given as "ICP Mass Spec" (Inductively Coupled Plasma–Mass Spectrometry or ICP-MS), which is appropriate for Cd and Pb analysis in environmental samples, no details about the method were made available to the Expert Committee.[1] Missing details of interest include such basic information as the equipment used, sample extraction methods, and limits of detection (LOD) or quantification (LOQ). Other key information (listed in Table 2) for the laboratory analyses were not provided. In addition, no information was provided about the sample collection protocols, data management and reporting, and quality assurance and quality control (QA/QC) performance evaluation. Essentially, the Batch 1 provides only numbers reported as Cd and Pb concentrations in test matrix (e.g., whole bean, liquor, powder), randomly inputted, with reference to the country of origin of the beans or intermediary products, when available. Furthermore, because data obtained from the various SDs were compiled into one dataset and blinded, it is impossible to sort data according to the laboratories providing the analysis (which would have been useful for comparing methods and analytical proficiency) or to be able to draw conclusions about how facility operations might impact bean contamination. Finally, it is important to note that the Expert Committee requested additional information from the SDs to assist the committee in understanding the purpose of the data collection, the methods used, the validity of the data, and analytical testing and reporting criteria. The response to the Expert Committee's request was generally that

[1] Twelve samples were analyzed using graphite furnace atomic absorption spectroscopy (GFAAS).

the information needed did not exist, was not readily available, or was difficult to compile given the blinding procedure employed to obtain information from the SDs.

The supporting information for Batch 2 data is better than for Batch 1, but it is still mostly incomplete. Batch 2 provides more details about the laboratory analytical methods used (in the form of regulatory citations to published methods) and the laboratory equipment. However, important information such as extraction methods, method calibration, and sample standards (spikes) to characterize measurement accuracy and precision was not provided by the SDs. Although some general information was provided for sampling procedures, it is not clear that this information pertains to all samples and analyses reported with Batch 2. Therefore, the sampling collection and handling information can be classified as partially complete for Batch 2. With respect to data reporting and management, most of the important or necessary information was not provided to the Expert Committee. The description of the methods used does refer generally to analytical LODs (or method LOQs) for Cd and Pb in foodstuff; however, specific values for the specific analyses were not provided. Therefore, there is no certainty as to how to apply the LODs when analyzing the data. As with Batch 1, no useful information on QA/QC and performance proficiency was provided to the Expert Committee.

The supporting information for Batch 3 data was the most complete of the datasets, but still lacking in some key details. In addition, although the supporting information clarified generalities about sample collection and analytical methodology and instrumentation, it is still not possible to link specific data parameters (e.g., LODs, method efficiency yields from internal spikes, standard reference materials, etc.) to the specific data submitted to the Expert Committee. However, the supporting information does allow the Expert Committee to make informed decisions and apply reasonable assumptions when evaluating and analyzing the Batch 3 data.

There is one matter of unresolved concern regarding the containers used in the collection of the SDs' samples. In the supplemental information provided with Batch 2 and 3 data, the use of "Whirl-Pak®" bags was indicated for the collection of bean and possibly other cocoa product samples for laboratory analysis of Cd and Pb. These bags are made of polyethylene plastic. An Expert Committee member contacted the manufacturer of Whirl-Pak bags via email to verify that the bags were free of Cd and Pb at levels that could interfere with the analytical analysis. In response, the manufacturer provided a letter to the Expert Committee member (attached to an email), dated November 9, 2015, which stated: "No heavy metals (i.e., antimony, arsenic, barium, cadmium, chromium, lead, mercury, selenium, or silver) are purposely added to this product in quantities that would violate governmental guidelines. To the best of our knowledge the summation of lead, cadmium, mercury, and hexavalent chromium in this product is less than 20 ppm." This statement would seem to indicate that although Cd and Pb are not added intentionally in the manufacturing process, there could be up to 20 ppm (20,000 ppb) Cd or Pb in the bag material. Although Cd and Pb levels in the bags are unlikely to be as high as 20,000 ppb, there is no verification or certification that confirms that the use of Whirl-Pak bags is not an important potential source of Cd or Pb in the cocoa samples. The concern would be over the leachability of the heavy metals from the bag into the collected samples; the rate of leaching is increased by acidity and heat. Note that cocoa liquor is heated to retain fluidity and might have a pH as low as 5.0.[2] Any cross contamination from the sample bags could interfere with analytical results.

Because the containers used to collect cocoa liquor were not specified in the supplemental documentation, the Expert Committee requested more information from the SDs related to the collection containers used to sample cocoa liquor. In response, the SDs informed the Expert Committee that the company that provided the SOPs on sample collection protocols stated: "We don't require our samplers to use whirlpak [sic] bags, but most do. If sterile Whirl-Pak bags are not used by samplers, they are instructed to use an equivalent, which would be a sterile plastic bag capable of holding 5-10 lbs of liquor." One expert added that agricultural scientists' widespread use of Whirl-Pak bags for sample collection suggests that metals likely do not enter the agricultural samples from the plastic bags; but he added that only experimental examination of metals leaching from Whirl-Pak bags under different conditions could clarify the matter.

Based on this information, the Expert Committee must assume that Whirl-Pak bags were used for both dry and liquid (e.g., liquor) samples to be submitted for analytical heavy metal testing. Without analysis of the trace

[2] This needs to be checked. This pH was reported by Blommer chocolates but it is unclear what the true pH range would be for cocoa liquor at the time of sampling in a facility.

metals content of the plastic bags used by the samplers and without Cd and Pb level testing data comparing liquor samples before and after storage in the plastic bags, the concern is that there could be cross-contamination of Cd and Pb in the liquor samples. It is unknown at this time whether the use of these bags impacted the test results in any way. However, if there were cross-contamination, it would more likely impact liquor samples with otherwise low Cd and Pb levels, which could also possibly affect the detection frequency calculations.

Finally, it should be noted that an evaluation of completeness of the data is not an evaluation of the validity or integrity of the dataset. Having a complete data set with all information provided helps to make a determination on validity, but an incomplete dataset does not automatically mean that the data are invalid. Therefore, when data are incomplete they can still be used by an analyst to the extent they feel comfortable, using the various quantitative and qualitative statistical methods available. Usually under these conditions, an analyst will describe the data with qualifiers in the context of the limitations of the dataset. This is the approach the Expert Committee took in analyzing the SD data.

3.3 Data Analysis Methods

3.3.1 Data Distribution

The data submitted to the Expert Committee in Batches 1-3 include several thousand data points, compiled and blinded. In order to interpret the data and draw conclusions, the use of descriptive and comparative statistics is helpful if not essential. However, as with any dataset used for toxicology, epidemiology, food or environmental sciences, etc., it is important to understand the nature of the data before applying statistical formulas.

Mean, mode, and median are measures of the central tendency (often referred to as the "average") of a dataset consisting of a range of values. Estimates of the central tendency usually assume that the set of values in a dataset are "normally distributed" (see Figure 1). A normal distribution is represented by a nearly symmetrical distribution of observed values in a dataset. Normally distributed data when plotted on an *x* and *y* axis look like a bell (hence the name "bell shape curve") with the high point of the bell being the center of the dataset and the downward curves that level out are the "tails." When data are normally distributed, the mean, median, and mode values are theoretically the same.

There are various methods[3] used to determine whether a dataset's values are normally distributed or skewed. In statistics, skewness is a measure of asymmetry or the tendency for the values to be more frequent around the high or low ends of the x-axis (Figure 2). In other words, skewness describes the amount of departure from horizontal symmetry. The skewness value can be positive or negative, or even undefined. A skewness of zero would mean that the data are perfectly symmetrical. However, data collected to measure chemicals in the environment or food rarely approach a skewness value of zero. The degree of skewness accepted as "normally distributed" data is far from a universally accepted value. Generally, if skewness is less than -2 or greater than 2, the distribution is highly skewed and is not considered to be normally distributed. If skewness is less than -1 or greater than 1, the distribution is skewed but still might be considered normally distributed for statistical analyses. If skewness is between -0.5 and 0.5, the distribution is approximately symmetrical.

Kurtosis tells you the height and sharpness of the central peak relative to that of a standard bell curve (Figure 2). Like skewness, there are some generally accepted values of kurtosis that if exceeded (e.g., -2 or greater than 2) then the data are likely not normally distributed. There are departures from these rules. For example, values for asymmetry and kurtosis between -2 and 2 are often considered acceptable in order to prove normal univariate distribution.

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[3] Measures of skewness (deviation from the bell curve) and kurtosis (flatness or sharpness of the peak) provide some indication as to the nature of the distribution of the data. The data can also be plotted as a histogram with frequency of data points plotted against the measured values. There are also statistical applications such as the Shapiro–Wilk test, the Anderson–Darling test, or a modified Kolmogorov-Smernov test.

Data provided to the Expert Committee in Batches 1-3 were evaluated for skewness and kurtosis[4]. In some cases, the data were also plotted in a histogram to obtain a visual interpretation of the data distribution. The variation in distribution from one dataset to another varied considerably. In general, most of the data would be considered not normally distributed using the reference values described above. Although, there are likely some normally distributed data in the different batches, for the purposes of consistency, all data submitted to the Expert Committee are considered to be not normally distributed. Descriptive statistics are applied to the data and interpreted accordingly.

The other consideration is whether the data are distributed in more than one "peak" or mode. While normally distributed unimodal data are described by the bell shaped curve (Figure 1), a bi-modally distributed data set would have two peaks. A bimodal dataset would be descriptive of two distinctly separate "populations" within the test subjects. In the case of chocolate product testing, a bimodal distribution would likely be the result of two distinctly different product contamination sources or distinctly different processing steps, each with its own contamination source. Descriptive statistics commonly used for normally distributed single mode data would not be appropriate for bimodal data, which is far more complex. The most reliable way to identify bi- or multi-modal data distributions is to use histogram plots to visually see if more than one peak is evident in the data distribution. Based on a visual examination of the spread of the SD data from Batches 1-3, it is likely that most of the data follow a unimodal distribution. No evidence for more than one mode was plainly visible.

3.3.2 Non Detects

Laboratory reports of chemical analyses of biological and environmental samples often include data points indicating the level of a contaminant could not be measured in the sample based on the methods and instrumentation used by the laboratory. These samples are usually described as below detection limit or "non detects." The best way to quantify and describe data that include non detects is to calculate the detection frequency. The detection frequency (most often reported as a percentage) is simply the number of samples with levels reported to be above the detection limit divided by the total number of samples.

Accounting for the detection frequency is an important analysis to consider when interpreting data. Data sets with detection frequencies of greater than 50 percent are normally considered robust enough to analyze using descriptive statistics. Data sets with detection frequencies of 100 percent describe a dataset for which there is strong evidence of universal exposure or contamination – or an indication that the chemical could be present in any samples tested (assuming a large number of samples were tested using the same methodology).

In addition to determining detection frequencies, values reported as "non detects" also play a role in descriptive statistics. As noted previously, the SD data did not include LODs or LOQs. Instead, the compiled data showed values denoted with the less than symbol ("<"), which is generally used by lab technicians in place of an estimated value for levels that are below the LOD or "non detects." The Expert Committee assumed that values denoted with the "<" symbol in the SD data are likely the reported LOD for that particular test value. However, the Expert Committee has no specific documentation to support this assumption with 100 percent certainty. In addition, it should be noted that the values denoted by "<" are highly variable within the dataset adding to the difficulty of comparing the data.

There are several options for treating "non detects" in statistical applications. One method is to assign a value of "zero" to all non detects. This method is typically rejected by statisticians and scientists based on the knowledge that a methodological "non detect" does not prove the absence of a chemical in the sample (i.e., zero concentration). Therefore, the designation of non detects as zero is not an acceptable option for biological or environmental chemical analysis. Another method is to use the LOD value as is. This method also tends to be rejected by statisticians since it would likely overestimate the actual level of a chemical that cannot be verified within the methodological uncertainty. Another method is to eliminate any value that is denoted with a "<" symbol and proceed with a smaller number of values for descriptive statistical applications. This method is used by some statisticians in conjunction with detection frequencies. However, in doing so, the analysis would be biased toward including only values above the detection range of the method and could skew the central

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[4] Worksheets showing test results for skewness and kurtosis for each dataset are not provided in this report but are available upon request.

tendency calculation. Also, by eliminating these non detects, other statistical descriptions based on the range of values would be misleading.

The method for handling non detects most commonly used in biological and environmental research is to divide the value identified as the LOD (or denoted by the "<" symbol) by 2 or the square root of 2 (√2). For non detect values in the SD data, the Expert Committee used what was presumed to be the LOD divided by √2 in its analysis of the data since this is the most widely accepted practice and is used by the Centers for Disease Control and Prevention in its National Health and Nutrition Examination Survey. It should be noted that when a value of zero was reported in the SD data (not a common occurrence), that value was treated as a non detect for the purposes of calculating detection frequencies, but was not considered when calculating descriptive statistics.

3.3.3 Descriptive Statistics

Descriptive statistics is a scientific tool to help analyze and interpret data in order to identify or describe any differences between one variable and another that are not expected to occur based on chance alone (the "null" hypothesis). The best way to ensure that the use of statistics does not mask the truth about the data is to apply them judiciously after the data have been characterized (such as for distribution type) and "cleaned" (e.g., evaluating data for outliers, assigning values for "non detects"). The use of quantitative statistics to describe differences between variables must be defensible and correctly interpreted. However, the use of statistics is not standardized and might vary considerably from one scientist to another, given the same data.

When data are not normally distributed, measures of central tendency and measures of the deviation from that central tendency are more likely subject to error and misinterpretation than data that are normally distributed. For this reason, the use of the median and the spread in terms of the range as the measure of central tendency and variability for the SD data were selected over the more common use of the arithmetic mean and standard deviation around the mean. A median denotes or relates to a value or quantity lying at the midpoint of a frequency distribution of observed values or quantities, such that there is an equal probability of falling above or below it. In other words, in a set of data arranged in order from lowest to highest values, the median will be the value in the middle where the same number of values are less than the median as are greater than the median. The median is also called the 50th quantile.

The interquartile range (IQR) describes the spread of values between the 25th and 75th quantiles of the data, and by definition includes the median value. As such, the median value is the central tendency of a data set and the range of values to the left and right of the median (ordered from lowest to highest value) denote the variability around the central data point. The IQR, when presented along with the median, provides a midpoint value with the tails to the left and right, which include 50 percent of all of the data in that dataset. The IQR is calculated by first dividing a rank-ordered dataset into four equal parts or "quartiles." The values that divide each part are called the first, second, and third quartiles; they are denoted by Q1, Q2, and Q3, respectively.[5] The value of Q1 is then subtracted from the Q3 value (Q3-Q1) to yield the IQR. Note, that an error bar (descriptive of the variability around the median) calculated as ± 1.5 x IQR captures roughly 99 percent of the distribution and is equivalent to the mean ±3 standard deviations for normally distributed data.

The median and IQR are calculated for the majority of the data provided to the Expert Committee in Batches 1-3. However, for very small datasets (e.g., less than 8-10 values), the calculation of the IQR is likely not going to be informative. Smaller sample numbers occur when sorting the data according to country of bean origin or production of chocolate products, for example.

In addition to the median values and the range and IQR of the dataset, the mean value including a measure of the standard deviation was included in most cases for comparison. Generally, when the mean and median are close to the same value, it can be assumed that the data are more normally distributed. Regardless, the calculation of a mean value and the standard deviation around the mean value are not incorrect or invalid. However, when using these values of central tendency with non-normally distributed data, the results should be interpreted with caution.

[5] Note the relationship between quartiles and percentiles: Q1 corresponds to 25th percentile, Q2 corresponds to the 50th percentile, and Q3 corresponds to the 75th percentile.

The calculation of central tendency and variability around that point is often used to quantify differences from one variable to another in the data. For example, for the SD data, it would be tempting to apply a statistical test comparing Cd or Pb levels in whole beans from one country to another. In fact, such a statistical comparison can be done theoretically. However, the data were presented to the Expert Committee in a complied and blinded format (while also missing some important information), which makes such comparisons problematic. For this reason, the Expert Committee agreed to limit the interpretation of the SD data to qualitative comparisons (e.g., looking for obvious differences by comparing medians and error bars in the data plots). As such, the data would be most useful to support or amend comparable data from the literature, which was conducted in a more transparent manner with fully reported results. This is not to say that some of the SD data could not stand alone. On a case-by-case basis, the results of the statistical presentation will be discussed in the context of the limits of the data in this report.

3.4 SD Data Summary

Tables 3-21 and Figures 3-15 summarize the SD testing data. The Expert Committee members considered these testing results when developing all other sections of the Root Cause Phase report. As Section 2 notes, the Expert Committee was bound by a non-disclosure agreement to not present raw SD data or to discuss or make available individual data points or other information obtained from the SD that could lead to a breach of confidentiality. Therefore, the data summaries and figures included in this report do not include data ranges or the minimum or maximum data points. Although these individual data points and ranges were available and considered by the Expert Committee when preparing the Root Cause Phase report, these data points were omitted from this report’s tables and figures to maintain confidentiality. The data summary tables only present calculated values (i.e., descriptive statistics) for the SD data.

4. Root Cause Assessment: Cocoa Bean Pre-Harvest

This section presents the Expert Committee's assessment of "pre-harvest" cocoa bean contamination with Cd and Pb. For purposes of this report, pre-harvest contamination refers to Cd and Pb found in cocoa beans (i.e., seeds of *Theobroma cacao L.*) before pods are removed from cocoa trees. These sections attempt to explain differences in Cd and Pb contamination trends among the main cocoa-growing regions of the world. This section presents separate assessments for Cd (Section 4.1) and Pb (Section 4.2) due to notable differences between these metals' "pre-harvest" contributions.

Sections 5 and 6, respectively, address contamination that may occur on farms and elsewhere during "harvest" and "post-harvest" activities.

4.1 Cadmium

Based on the cocoa bean data provided by the SDs (Table 3a and Figure 3), cocoa bean Cd levels ranged from 66.9 ppb to 3,082 ppb across the different countries sampled. The data also demonstrate geographical and regional differences in the Cd bean content. Cocoa beans from Latin America appear to have a relatively larger Cd problem than African regions—a finding that is supported by the literature (Mounicou et al., 2003; Bertoldi et al., 2016; Vītola and Ciproviča, 2016).

In order to determine if the cocoa tree has a natural predisposition to accumulate Cd in its beans, a number of studies analyzed bean samples taken directly from pods on the cocoa tree. These studies isolated pre-harvest contributions and prevented any potential contamination from external sources, such as during harvest and post-harvest processes. Table 22 summarizes results from these studies, which were conducted in different cocoa-producing countries. The table also presents "pre-harvest" Cd concentrations measured in cocoa bean samples that the Expert Committee collected while in Ecuador. Most of the studies were conducted in the Latin American region. Little or no reliable pre-harvest data are available from Africa or Asia.

Across the studies summarized in Table 22, Cd concentrations in pre-harvest cocoa beans ranged from 17 to 17,480 ppb. The highest value identified by the Expert Committee was in a sample from Colombia. The fact that Cd is present at this stage in the bean pre-harvest process indicates that Cd accumulation occurs during the natural growth processes of the cocoa tree. Similar to most terrestrial plants that take up Cd, the cocoa tree can absorb Cd from the soil through its roots (Barraza et al., 2017; Zug et al., 2019). Total soil Cd is a poor indicator of what is available for plants for uptake. Research has shown that only a portion of the total Cd in cocoa-growing soils is available to the cocoa tree for uptake. This has been demonstrated through strong significant correlations between Cd levels in the available soil portion and cocoa tissues, including beans (nibs and shells), leaves, and pod material (Ramtahal et al., 2015; Chavez et al., 2015; Gramlich et al., 2018). This soil portion is commonly referred to as "phytoavailable."

The data in Table 22 also show differences in cocoa bean Cd concentrations between and within some countries of origin. This observed variation may have resulted from differences in the levels of phytoavailable soil Cd in cocoa plantations and their source, which plays a significant role in the accumulation of Cd in the tissues of the cocoa tree, including cocoa beans. Additionally, recent studies suggest that genetic variation among cocoa trees may also be an influential factor.

4.1.1 Factors Influencing Cd Uptake in Cocoa

The Expert Committee reviewed available research and evaluated the following three factors for insight into what is potentially responsible for higher or lower cocoa bean Cd at the pre-harvest stage.

4.1.1.1 <u>Phytoavailable Soil Cd Affected by Soil Physicochemical Properties</u>

As noted above, phytoavailable soil Cd is a significant factor in understanding how Cd is taken up by the cocoa tree and into cocoa beans. The more phytoavailable soil Cd is, the higher the level of Cd is expected in the bean and other plant tissues. This relationship has been demonstrated in multiple Latin American and Caribbean studies (Chavez et al., 2015; Ramtahal et al. 2016; Argüello et al., 2019). A study done by Ankah (2012) in Ghana, typically known to have significantly lower Cd levels in beans, found that cocoa soils in the Western Ghanian Region had low phytoavailable soil Cd.

The phytoavailability of Cd in soils is greatly influenced by a number of soil chemical and physical properties. These primarily include soil pH, organic matter, macro- and micro-nutrients, salinity, and soil texture (Welch and Norvell, 2011; Adriano, 2001, Violante et al., 2010). Information on how each property influences Cd uptake follows:

- **pH.** Strongly acidic soil pH (<5.0) is a major factor in Cd uptake by many crops, as low pH increases phytoavailable soil Cd (Chaney, 2010) regardless of the source of soil Cd. In some (but not all) of the Latin American and Caribbean cocoa studies to date, low (<5.5) to very low (<5) soil pH was associated with higher Cd levels in cocoa beans (Barraza et al. 2017; Gramlich et al. 2018, 2017; Argüello et al., 2019). A similar trend was also demonstrated in Malaysia (Fauziah et al., 2001). A nearly neutral average pH 6 was found for soils in West Ghana by Ankah (2012), which may explain why those soils were low in phytoavailable Cd.

- **Organic matter.** Soil organic matter content also plays a key role in Cd phytoavailablity due to its ability to adsorb Cd (Meter et al., 2019). Studies conducted in Colombia (deWalque, 2018), Honduras (Gramlich et al., 2017), and Ecuador (Argüello et al., 2019) demonstrated that soils low in organic matter may result in enhanced Cd uptake in the cocoa tree, because the organic matter content of cocoa-growing soils is significantly and negatively correlated to Cd levels in the cocoa tissues analyzed. A similar relationship has been observed in plants for soils low in amorphous oxides of Fe and Mn and clays that are known to adsorb or chelate Cd in soils (Kabata-Pendias, 2010; Sarwar et al., 2010).

- **Nutrients.** The literature shows that soils deficient in Zn and higher in Cd result in increased Cd uptake by plants due to Cd being chemically similar and sharing the same root membrane transporters for Zn in plants (Adriano, 2001; Paul and Chaney, 2017). However, with respect to cocoa, a comprehensive review done by Meter et al. (2019) on studies that examined the relationship between Zn and Cd in soils and uptake in cocoa beans (Crozier, 2012; Arévalo-Gardini et al., 2017; Gramlich etal., 2017; Argüello et al., 2019) demonstrated conflicting views. It appears that the role of Zn as it relates to its effect on Cd uptake in cocoa is still unclear. Recently however, the occurrence of naturally Cd-rich black or marine shale soils with high levels of native Cd with high Cd:Zn ratio in Peru and Colombia have been found to cause exceptionally high Cd levels in cocoa beans in those small areas (Atkinson, 2019, personal communication). This trend has also been observed in Ecuador, as seen in Figure 16 (Argüello et al., 2019). Examples of locations with high Cd:Zn ratios in soils include areas impacted by mining operations and, as noted above, areas with marine shale parent rocks; in these areas, high Cd:Zn soil concentration ratios are a contributing factor to pre-harvest Cd uptake in cocoa.

- **Salinity and chloride.** Some irrigation and drainage waters contain high levels of soluble salts, including chloride, sulfate, and ions of calcium, magnesium, and sodium. Multiple researchers have observed increased Cd plant uptake in regions with elevated chloride levels in soils and irrigation water. This effect has been demonstrated for potatoes grown in irrigated calcareous soils in Australia (McLaughlin et al., 1994; 1999), durum wheat grown in areas with elevated soil chloride (Norvell et al., 2000; Wu et al., 2002), and sunflower grown in poorly drained alkaline soils (Li et al., 1994). Though not yet studied for cocoa, the Expert Committee finds it unlikely that high chloride in soils or irrigation waters contribute to high Cd in cocoa beans, because cocoa trees are generally grown in rain forest areas.

In most cases, studies have determined that Cd levels in cocoa plantation soils decrease with depth, with the majority of Cd being held in the upper soil horizon (Ramtahal, 2012; Chavez et al. 2015; Barraza et al., 2015; Barraza et al., 2019) or that "topsoils" were found to have higher Cd concentrations than "subsoils" (Gramlich et al., 2018). Researchers report different definitions for the depth of this top soil layer; however, most studies have identified it as being between 0-25 cm. The feeder root system where cocoa trees get most of their nutrients is concentrated in the first 20 cm of the soil layer (Moser et al., 2010; Neither et al., 2019; De Almeida and Valle, 2007), increasing the possibility of phytoavailable Cd uptake in this region.

4.1.1.2 <u>Genetic Factors</u>

The accumulation of Cd in plants has been shown to not only vary among plant species but also among cultivars. Cocoa plants can be classified into four main genetic groups: (1) Forastero, considered by its quality as bulk. (2) Criollo, categorized as fine and flavor cocoa. (3) Trinitario,a hybrid between Forastero and Criollo, which can be considered as bulk or fine cocoa; and (4) Nacional, a native variety from Ecuador defined as fine cocoa (Badrie et al. 2015). With many accessions under each genetic group, the possibility of genetic differences with respect to Cd uptake among cocoa cultivars exists.

To date, genetic field studies to assess these differences have only been done with known cultivars in Latin America and the Caribbean, which are typically associated with having Trinitario, Criollo and Nacional genotypes. Investigations done with varying cocoa varieties in Peru (Arévalo-Gardini et al. 2017), Ecuador (Barraza et al. 2017; Argüello et al. 2019), Honduras (Engbersen et a., 2019), and Trinidad (Lewis et al., 2018) all suggest that geneotypic differences exist and may influence Cd accumulation from soils into cocoa beans. However, further research will be required to confirm these findings. Investigations are currently being conducted in Trinidad to validate the genetic variation for Cd uptake and partitioning into cocoa beans for the high/low Cd-accumulating identified cultivars at their International Cocoa Genebank.

No known studies have been done on cultivar differences with respect to Cd uptake in cocoa in the African region. However, the Forastero genotypic group, which represents about 90 percent of the cocoa production worldwide, is particularly cultivated in Côte d'Ivoire, Ghana, Nigeria, and Cameroon (Muñoz et al., 2019) compared to the other regions.

4.1.1.3 Cadmium in Soils

Cd in soils can be derived from natural (geogenic) and anthropogenic sources. The Expert Committee findings on these source categories follows:

- **Natural sources of Cd in soils.** Natural occurrences, such as the weathering of parent rock materials and volcanic activity, have been reported to significantly contribute to soil Cd levels (Alloway and Steinnes, 1999; Hooda, 2010). In background areas far away from ore bodies, surface soil concentrations of Cd typically range between 0.1 and 0.4 ppm with a Cd:Zn ratio of 1 g Cd/100-400 g Zn; whereas in volcanic soil, Cd concentrations up to 4.5 ppm have been found (IPCS, 1992). Soils developed from some sedimentary rocks are also known to enrich soil Cd as high as 24 ppm (Lund et al., 1981; Lalor et al., 1998; Alloway and Steinnes, 2011) and even over 500 ppm in black shale derived soils (Garrett et al., 2008; Liu et al., 2017). "Alum or acid sulfate" soils may also be rich in Cd and in Cd relative to Zn (Mellum et al., 1998).

- **Anthropogenic sources of Cd in soils.** Anthropogenic Cd inputs are associated with atmospheric deposition (e.g., stack emissions from smelting or burning of coal or refuse), erosive deposition from industrial activities including mining, and application of soil amendments such as phosphate-based fertilizers, livestock manures, biosolids (municipal sewage sludges), composts, leaf litter, wastewater irrigation, or other waste disposal. Cd concentrations in soils collected from sites severely polluted through atmospheric deposition or transport of solid waste disposal from mining and smelting industries were as high as 750 ppm (Alloway and Steinnes, 2011). Additionally, Cd concentrations in phosphate-based fertilizers (e.g., triple super phosphate) can reach 300 ppm and therefore can also be a significant accumulative source of Cd input to agricultural soil systems, especially over a long period of time with repeated use (Grant, 2011).

4.1.2 Cadmium in Soils in Cocoa Plantations

As described in the previous section, great variability exists among sources of Cd present in soils in general. The differentiation between natural and anthropogenic sources is thus very important to determine the primary sources of soil Cd phytoavailable to the cocoa tree (Chavez et al., 2015). The following sub-sections review various natural and anthropogenic influences of Cd in cocoa plantation soils.

4.1.2.1 Natural (Volcanic or Geogenic) Soils

Volcanic soils contain high levels of Cd and, if phytoavailable, the Cd can be taken up by cocoa trees and concentrated in the beans (Fowler, 1999). Some countries, including those in Latin America, are known to have major occurrences of volcanic soils (Neall, 2006) and thus perceived by many to be the main source of Cd in cocoa beans. However, studies conducted thus far in relation to this (Ramtahal, 2012; Barraza et al., 2017) are speculative with no confirmatory data. On the other hand, though few, some studies suggest geogenic contributions. Work done by Gramlich et al. (2018) in Honduras demonstrated that Cd levels in cocoa-growing soils depended on the different geological substrates, where the highest were alluvial sediments. Similarly, a survey done in Ecuador by Argüello et al. (2019) showed that beans with the highest Cd levels were cultivated on alluvial soils (0.99–1.18 ppm Cd) developed on sedimentary material. An investigation by de Walque (2018) and Bravo et al. (2021) in cocoa-growing areas of Santander, Colombia, demonstrated that high bean Cd found in sampled farms were attributed to the significant soil Cd concentrations of natural parental rock origin. Further, Section 4.1.1.1 notes that areas with elevated ratios of Cd:Zn soil concentrations (e.g., marine shale derived soils) have been shown to have elevated pre-harvest Cd concentrations in cocoa beans. The literature currently demonstrates that natural sources of Cd in soils is not a widespread occurrence in the majority Cd-affected farms of varying cocoa-growing countries, thus should be considered an infrequent source.

4.1.2.2 Recycling of Organic Materials in Cocoa Understory

Deposited cocoa leaves and twigs and harvested pod husks (after collection of the beans) fall or remain on top of the soil in farms. Other decaying plant and organic materials eventually become part of the cocoa tree's litter zone and over time become part of the topsoil layer. It has been reported that litter decomposition contributes to the topsoil mineral composition at cocoa plantations (Hartemink, 2005; Ofori-Frimpong et al., 2007; Triadiati et al., 2011). Fauziah et al. (2001) partially attributed the Cd found in the top 0-40 cm of soils of various cocoa-growing areas of Malaysia to leaf litter recycling. Mite et al. (2010) attributed the Cd in the surface soils in some cocoa-growing areas of Ecuador to the recycling Cd-rich cocoa leaves that make up the litter. In a recent study also conducted in Ecuador, the authors indicate that the relatively higher accumulation of heavy isotope Cd signature in the topsoil is likely due to decomposing cacao leaf litter used as organic fertilizer (Barraza et al., 2019). An investigation done by Ramtahal (2012) in Trinidad and Tobago showed that the Cd in the litter was significantly correlated to, and was generally higher than, Cd levels in underlying topsoils (0-5 cm); this research also showed that deeper soils were not Cd enriched compared to the surface layer. This was further supported by studies done in Honduras (Gramlich et al., 2017) and Colombia (Albarrcín, 2017), which all demonstrated that litter in cocoa plantations is a significant source of Cd to upper (0-10 or 0-30 cm) surface soils. Due to the ubiquitous occurrence of Cd-containing recycled organic materials in cocoa plantations, this can be viewed as a common source.

4.1.2.3 Fertilizers

A review of the literature examined how fertilizer use may have impacted soil Cd levels; however, no publications identified to date reported the annual quantities of phosphate fertilizers (P-fertilizers) used in cocoa-producing countries, how those quantities changed over time, or the Cd concentrations in the fertilizers themselves. Nonetheless, much of the basis for suggesting P-fertilizers were an important source of Cd in cocoa farm soils was higher Cd concentrations in surficial soils than in sub-surface soils, assuming that the increase was due to application of fertilizer materials.

In Malaysia the excessive use of inexpensive and contaminated P-fertilizers may have contributed to significant levels of Cd in soils of cocoa plantations (Zarcinas et al., 2004). In Ecuador, P-fertilizers are considered to be important sources of Cd to some topsoils (0-20 cm), which are partly responsible for Cd contamination of cocoa (Mite et al., 2010). A study done by Barazza et al. (2017) suggested that Cd contents in some Ecuadorian cocoa farms are more than likely due to crop management practices, including the extensive use of fertilizers. Zug et al. (2019) demonstrated that the use of Cd-contaminated fertilizers in cocoa farms of the Huánuco Region, Peru, enhanced Cd concentrations of cocoa beans. Variability in Cd soil levels of a long-term cocoa field trial in Bolivia was partially attributed to Cd inputs from fertilizers, since the Cd concentration (2.5 mg Cd/kg P_2O_5) of an applied P-based fertilizer was considered to be high (Gramlich et al., 2017), even though it was lower than the European Union regulatory limit for Cd in phosphate-based fertilizers (40 mg Cd/kg P_2O_5). Ramtahal (2012) demonstrated that the significant levels of Cd found in locally-used fertilizers (as much as 35.3 mg Cd/kg P_2O_5) screened during his investigation on heavy metals in cocoa in Trinidad and Tobago can contribute to Cd contamination of agricultural soils, especially if applied regularly over many years.

Despite the findings from the aforementioned publications, P-fertilizers are currently expensive and surveys in cocoa-producing areas report little application of commercial P-fertilizers (World Cocoa Foundation, 2013). Based on the minimal evidence to support its widespread use and studies to pinpoint whether phytoavailable Cd is accummulated, fertilizers should be considered an infrequent source.

4.1.2.4 Industrial Activities and Contaminated Water Sources

Industrial activities such as mining and smelting of ores, burning of fossil fuels, and other sources may contribute to Cd contamination of soils (Meter et al., 2019). Research conducted in Nigeria assessing the impact of mining on heavy metals in cocoa, reported slightly higher levels of Cd in cocoa beans from mining districts than non-mining districts; however, levels were not significant (Danquah, 2015). Based on the literature surveyed, few cocoa-growing farms are located near industrial activity, thus direct atmospheric contamination from industrial activity does not appear to be a primary route of contamination.

In contrast, annual flooding of some agricultural lands by local streams in many countries during the wet season can result in sediments and soils being contaminated with heavy metals, such as Cd, from upstream industrial, domestic, and natural sources, if the metals are present at significant levels in the flood waters (Chapman and Wang, 2001). An investigation conducted by Izquierdo (1988) in the Barlovento region of Venezuela demonstrated that flooding contributed to higher Cd concentrations of soils and cocoa beans in the varying sampling locations where periodic floods occur from polluted rivers. A study done by Ramtahal (2012) in Trinidad found that Cd was detected mainly in the upper layers of the soil (0-10cm) in a cocoa estate located nearby a polluted river's edge, with increasing Cd concentrations at points of greater inundation. He attributed the contamination of nearby soils to possible continuiong sediment accumulation on the soil surface due to annual flooding of the plantation. In Honduras, Gramlich et al. (2018) reported that rivers that flood some alluvial cocoa-growing sites may have contributed to the levels of Cd in the surface soils through sediment deposition. Studies conducted by both Cardenas (2012) and Llatance et al. (2018) attributed possible soil Cd contamination of cocoa-growing estates in Tingo Maria and Pakun, Peru, respectively, to inundation from nearby mining-polluted rivers. Studies done in Ecuador by Argüello et al. (2019) demonstrated that beans with the highest concentration of Cd (5.28 –10.4 ppm) were from an estate in a cocoa-growing area that is potentially affected by Cd levels from an adjacent mining-polluted river due to flooding.

Not many investigations report on the use of irrigation water from Cd-contaminated sources in cocoa fields. However, Chavez et al. (2015) suggested that elevated levels of Cd found in surface soils (0-15 cm) of cocoa plantations adjacent to a river in the studied area in Ecuador were likely due to contaminated irrigation water. Additionally, though not reported for cocoa, run-off from Cd-enriched soil from higher slopes may add Cd soil levels of lower agricultural plains (McDowell, 2010) and natural river courses.

Overall, it appears that sources of Cd from industrial activity and other sources by the way of flooding could potentially contribute to Cd levels of cocoa-growing soils; however, based on minimal confirmatory evidence to pinpoint its phytoavailability, it should be considered an infrequent source.

4.1.3 Conclusion on "Pre-Harvest" Cadmium Sources

From the available information, the Expert Committee found soil to be one of the major sources of Cd in cocoa beans, which occurs through direct uptake of phytoavailable Cd by the cocoa tree during the pre-harvest stage. The Expert Committee therefore considers Cd in soils as a "common source" for the Root Cause Phase. The origin of Cd in these cocoa-growing soils is a mixture of natural and anthropogenic sources, is highly variable, and is country- and farm-specific as seen from many studies conducted in Latin America and the Caribbean. On the other hand, more data and evidence is still needed to fully understand why cocoa beans from the African region have lower Cd. Additionally, though the source of soil Cd is needed to help understand and possibly mitigate Cd uptake, soil physiochemical properties (e.g., soil pH, clay and/or organic material content, Zn levels) and the cocoa tree's genetics are also very important interactive factors.

4.2 Lead

This section reviews "pre-harvest" Pb contamination in cocoa beans, shells, and nibs and discusses the soil and plant factors that affect these contamination levels. The experts considered multiple lines of evidence to assess Pb contamination levels in cocoa beans before pods are removed from trees. The following sections review the experts' assessment of each line of evidence, concluding with their overall assessment for "pre-harvest" Pb levels.

4.2.1 Information from Scientific Publications

To evaluate scientific publications on Pb in cocoa beans, the Expert Committee considered underlying technical issues of Pb analysis over the last 50 years. Instrumental measurement of Pb in samples from soils and plants have improved remarkably over this time. Many studies from the 1970s and 1980s suffered from Pb contamination that occurred in the field, during sampling, and at the laboratory. Recent improvements to laboratory methods have addressed these issues and have led to remarkably altered understandings about Pb in foods and the environment. Appendix C.1 provides further details on the evolution of Pb sampling and analytical methods over recent decades.

The Expert Committee identified numerous publications (see Table 23) that reported Pb levels in different cocoa products either from field surveys, manufacturing surveys, or analytical method development studies. However, much of this research used methods that raise questions about data quality. Appendix C.2 reviews several older studies that the Expert Committee considered, but these studies' findings did not weigh heavily in the Root Cause Phase conclusions given data quality concerns.

The Expert Committee instead focused its synthesis of scientific publications on studies that (a) used clean room preparation, (b) appropriately low LOQs, and (c) clean preparation techniques to separate nibs from shells to measure Pb concentrations directly from cocoa pods on trees. Only two publications met these criteria. A review of these studies' findings pertaining to "pre-harvest" contamination follows:

- Rankin et al. (2005) cooperated with scientists in Nigeria to sample commercial cocoa beans from six farms and to sample chocolate products. Rankin, Flegal, and collaborators had been using stable Pb isotopes to look for the source of Pb in consumer products. They used clean laboratory procedures (Flegal and Smith, 1995) and isotope dilution thermal emission mass spectrometry to measure isotopes of Pb in samples. They measured the isotope ratios $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$. Because some Pb in ores is radiogenic (e.g., from decay of isotopes of uranium and thorium) and because deposits in different locations occurred at different times in geologic history, the isotope ratios can be related to specific sources of Pb. Beans harvested, fermented, and dried on six cocoa farms had an average Pb nib concentration of 0.51 ppb, dry weight, and a range of <0.13 to 1.78 ppb. Their farm samples contained 61-117 ppb Pb in/on shells compared to <0.4-1.78 ppb in nibs.

- Manton (2010) studied the source of Pb in cocoa products and assessed whether Pb in cocoa beans came from soils where the beans were grown. This study used clean sampling methods, isotope dilution thermal ionization mass spectrometry, and "clean laboratory practices" to measure Pb isotope ratios in multiple cocoa bean samples. Pb concentrations were measured in beans from different origins. First, a cocoa pod was taken from a cocoa tree growing in an arboretum in Fort Worth, Texas. Beans from this tree had a shell concentration of 1.1 ppb, dry weight, and a nib concentration of 0.53 ppb. Second, commercial whole bean samples were collected from several countries of origin. Shells were carefully separated from nibs under clean conditions (i.e., laminar flow high-efficiency particulate air filtered hood in a clean laboratory area). Measured Pb concentrations follow:

Country of Origin	Bean Shell Pb Concentration (ppb)	Bean Nib Pb Concentration (ppb)
Dominican Republic	834	0.83
Ecuador	1,606	1.4
El Salvador	1,063	1.4
Ghana	146	0.44
Ivory Coast	1,887	1.7
Madagascar	514	1.6
Mexico	1,189	1.2
Panama	215	0.58
Papua New Guinea	622	1.52
Peru	430	0.59
Trinidad	900	1.1
Venezuela	776	1.03

The above results, which are also plotted in Figure 17, demonstrate that shells from commercial cocoa beans have considerably higher Pb concentrations than these beans' nibs.

In summary, the two studies conducted using the most rigorous sampling and analytical methodologies (Rankin et al., 2005; Manton, 2010) both found Pb concentrations in cocoa bean nibs to be less than 2 ppb. The nib Pb levels suggest that "pre-harvest" Pb uptake into cocoa beans is limited. Both authors concluded that the majority of Pb contamination found in commercial cocoa beans likely occurred "post-harvest," though they disagreed about the source of this Pb "post-harvest" contamination (see Section 6).

4.2.2 Reported Concentrations in Cocoa Tissues

The agronomic studies of Pb in cocoa report remarkably few measured Pb concentrations. A few field studies sampled soils, plant leaves, or beans. However, in most cases, the beans were collected after fermentation and drying and therefore do not reflect "pre-harvest" conditions. No data have been reported on cocoa grown in soils known to be naturally high in Pb. Several studies have illustrated moderate or remarkable Pb contamination of beans during processing on farms and at a commercial research center, but those results reflect "post-harvest" contamination (see Section 6).

However, the SD testing data help fill this gap. As Section 3 explains, the SD testing data were not accompanied with important supporting documentation to confirm data quality. As a result, the Expert Committee cannot confirm whether the SD testing of cocoa beans was conducted in clean room settings with proper nib/shell separation techniques and appropriately low LOQs. Nonetheless, given the volume and potential relevance of these testing results, the Expert Committee considered the SD data as part of its "pre-harvest" Pb assessment.

The SD testing data included thousands of results for cocoa beans, but these are largely for whole bean samples (see Table 3b) that were collected after fermentation and drying and therefore reflect Pb contributions "pre-harvest" through "post-harvest" sources. However, the SD testing data also include results from samples where cocoa bean shells were separated from cocoa bean nibs. This is significant because nibs are less likely to be contaminated during "post-harvest" phases, and Pb contamination found in nibs are a better indication of "pre-harvest" sources.

Table 15b summarizes SD testing data for Pb contamination in 118 cocoa nib samples. Pb was detected in 34 percent of these samples. The median Pb concentration was 1.2 ppb, and the average concentration was 4.4 ppb. These contamination levels are consistent with those reported in the two scientific publications (Rankin et al., 2005; Manton, 2010) based on robust sampling and analytical methodologies. (Note: Table 15b also shows considerably higher Pb contamination levels in cocoa bean shells. This contamination is believed to result largely from "post-harvest" sources, as Section 6 discusses further.)

4.2.3 Insights from Expert Committee Testing Data

In November 2019, the Expert Committee traveled to Ecuador to tour cocoa farms and to observe the processes that take place from farm to port. At one farm, the Expert Committee collected three pods each from three different cocoa trees in order to measure "pre-harvest" Pb contamination (see Appendix D). After being cut from the tree, pods were placed into plastic bags and hand-carried to a laboratory in Guayaquil. At the laboratory, Expert Committee members broke open pods, scooped beans with a gloved hand into a plastic colander, and rinsed mucilage from beans using deionized water. For each tree, the beans from all three pods were then placed into an aluminum tray, which was then sealed in a plastic bag. These "pre-harvest" bean samples were oven-dried before shipment to the United States for homogenization and testing via ICP-MS. Analytical results follow:

- For the beans sampled from the first tree, the laboratory reported a Pb bean concentration of "4 J ppb." The J-qualifier was applied because the measured concentration was above the MDL (3 ppb) but below the minimum reporting limit (20 ppb).

- For the second tree, the beans had a reported Pb concentration of "15 J ppb." The J-qualifier was applied for the same reason, but the minimum reporting limit for this sample was 19 ppb.

- For the third tree, the beans had a Pb concentration of "7 J ppb." The minimum reporting limit for this sample was also 19 ppb.

These sampling results, though limited in number and spatial coverage, are generally consistent with findings presented in the previous two sections and provide further support for the Expert Committee's conclusion for "pre-harvest" Pb contamination.

4.2.4 Scientific Understanding of Pb Plant Uptake

In addition to the direct Pb measurements referenced in Sections 4.2.1 to 4.2.3, the Expert Committee reflected on current scientific understanding of Pb plant uptake. Many researchers have studied Pb enrichment patterns across different garden crops. The accumulation of Pb in edible crop tissues is now understood to be strongly related to the type of crop, as well as the plant available Pb levels in soils.

It is important to understand that very little controlled research has been conducted on Pb uptake by cocoa, or effects of Pb uptake on cocoa, compared with the extensive observational research (i.e., measurement of Pb in cocoa soils, cocoa crops, and cocoa containing products). Cocoa is a difficult plant species to study. It is a tree, not an annual plant, and fruits are not generated for several years after planting. So both "soil pot" studies and nutrient solution studies of element uptake by cocoa are difficult at best. Even the reported research on Pb uptake and toxicity to cocoa has been not very useful. In one study, deshelled cocoa beans were soaked overnight in $Pb(NO_3)$ solutions, rinsed, and effects of the soluble Pb pre-treatments on seed germination and seedling biochemistry were measured (Reis et al., 2015). Such studies have no value in understanding risks from Pb in cocoa, or the agronomy of Pb in cocoa. Moreover, the many studies that have examined Cd uptake in cocoa (see Section 4.1) either did not measure Pb or did not use sufficiently sensitive methods to detect Pb.

Among garden crops, all fruiting and seed crops (e.g., tomatoes, melons, cucumbers, peppers, strawberries, peas, beans, corn, etc.) have very low ability to transfer plant-root-absorbed Pb to storage tissues used as food. The technical basis for this natural limit is that these storage tissues are "phloem fed" from the leaves and stems. Phosphate in phloem fluid is quite high, needed for the development of growing point cells and storage tissue cells. The high phloem phosphate causes precipitation of Pb as pyromorphite within the phloem if it enters the phloem from leaves where the Pb is distributed via the xylem. A second group of phloem fed crops tissues is tubers such as potato. If potato is grown in high Pb soils (e.g., those contaminated from historic use of Pb-arsenate in orchards), Pb is not accumulated in peeled potatoes (Codling et al., 2016). Appendix C.3 provides further information on the scientific understanding of Pb uptake in non-cocoa crops; and Appendix C.4 describes the general processes by which plants accumualte Pb.

Based on this general knowledge of Pb uptake by fruiting and seed crops, one would not expect to see significant Pb accumulations in "pre-harvest" cocoa beans. This inference, based on the understanding of Pb uptake in a broader range of plant species, is consistent with the testing results reviewed earlier in this section.

4.2.5 Conclusion on "Pre-Harvest" Pb Sources

The Expert Committee reviewed multiple lines of evidence to understand "pre-harvest" Pb contamination of cocoa beans. Only two publications (Rankin et al., 2005; Manton, 2010) used clean room preparation, appropriately low LOQs, and clean preparation techniques to separate nibs from shells to measure Pb concentrations directly from cocoa pods on trees. These publications report "pre-harvest" concentrations of Pb in cocoa nibs and shells less than 3 ppb dry weight; and this finding is supported by other lines of evidence that did not rely on as rigorous methods. Thus, nearly all Pb in commercial cocoa beans is from "post-harvest" contamination, as Section 6 describes further.

5. Root Cause Assessment: Cocoa Bean Harvest

For purposes of this report, “harvest” refers to the process by which ripe pods are removed from trunks and branches of cocoa trees with their subsequent opening to extract wet beans. This section presents the Expert Committee’s findings regarding “harvest” contributions for both Cd and Pb.

5.1 Harvest Activities and Available Data

The process of harvesting and opening cocoa pods is generally the same across all cocoa-growing countries. Both of these steps (i.e., removing pods from trees and opening pods) are done manually, mainly using a well-sharpened machete or a wooden club. Though the Expert Committee did not identify any existing research evaluating Cd or Pb contamination of beans from the use of these tools, the likelihood of their contribution is negligible since the tools rarely comes into direct contact with beans.

The next step involves the removal of beans from opened pods—a process typically performed by hand. Upon removal from pods, beans are placed in a variety of vessels depending on country or individual farmer practices. These vessels may include plastic bags, tarpaulins, buckets, containers, or woven baskets. If these vessels utilized are not cleaned after each use and Cd or Pb contamination exists, there is a possibility of Cd or Pb transfer from vessel surfaces to freshly-harvested beans, due to leaching from the acidic mucilaginous outer bean coating. Research done by Ramtahal (2012) demonstrated that unwashed used bags from harvesting cocoa beans previously had significant Cd levels compared to ones that were washed; and this finding may apply to other unwashed vessels. However, in the Expert Committee’s judgment, the likelihood of these vessels significantly contaminating the entire mass of beans with Cd would be minimal. In some cases, freshly-harvested beans are placed directly onto overlapping banana leaves, which are then placed on the ground (Schwan and Fleet, 2014). If these beans inadvertently contact Cd-containing or Pb-containing soil/dust, bean contamination may occur. Nonetheless, similar to vessels, in the Expert Committee’s judgment, the likelihood of soil/dust significantly contaminating the entire mass of beans with Cd or Pb during the “harvest” stage would be minimal.

5.2 Conclusion on “Harvest” Sources

Though there may be the potential for Cd or Pb contamination of cocoa beans at the “harvest” stage, the Expert Committee believes that compared to other stages in the Root Cause Phase evaluation, the “harvest” stage is most likely not a source of contamination. However, more information will be needed to fully support this hypothesis, based on the limited data/evidence available in this study area.

6. Root Cause Assessment: Cocoa Bean Post-Harvest

For purposes of this report, the term "post-harvest" refers to activities that take place with extracted wet cocoa beans after harvest, from farm to port. These activities include movement of wet cocoa beans on farms and to offsite bean collection facilities, fermentation of cocoa beans, drying of cocoa beans, and transporting dried cocoa beans to and among bean collection facilities and ultimately to port. Sections 6.1 through 6.4 describe these activities and discusses potential sources of contamination. Because Pb was found to have such significant "post-harvest" contributions, a separate section (Section 6.5) reviews the Expert Committee's findings on this topic. Section 6.6 summarizes the Expert Committee's overall "post-harvest" findings.

6.1 Contributions from Transporting Wet Cocoa Beans

Depending on the proximity of fermentation facilities, wet cocoa beans are transported on farms in the same vessel in which they were originally placed after harvesting. This transport occurs using human, animal, or vehicular means and is country- and farm-specific. Other than the possible contamination from unclean vessels, the contribution of Cd and Pb from external elements to cocoa beans while being transported on farms has not been reported. However, the likelihood of these vessels significantly contaminating the entire mass of beans with Cd or Pb is minimal and thus should be considered an unlikely source. It is the Expert Committee's judgment that contamination would be partly surficial and not significantly affect the entire mass of beans.

6.2 Contributions from Fermenting Beans

Fermentation of cocoa beans is an essential step for many chocolate manufacturers as it provides the basis for good bean flavor. This process varies among and even within cocoa-growing countries. In Ecuador, the Expert Committee observed fermentation processes both at farms and at bean collection facilities. Two traditional fermentation processes have been reported:

- Some traditional practices involve heap-fermentations. These may be done on overlapping banana leaves on the soil surface of cocoa plantations or transported to concrete or wooden floors, where the beans are covered by more banana leaves, tarpaulins, or sacks. Similar to how freshly-extracted cocoa beans may become contaminated with Cd or Pb after removal from pods, fermenting cocoa beans may come into contact with Cd- and Pb-containing soil, dust, or unclean vessels. The likelihood of these significantly contaminating the entire mass of beans with Cd is minimal; and Section 6.5 discusses the contamination potential for Pb.

- Another typical practice is box-fermentation. These boxes or bins are usually wooden with slatted holes for drainage. The boxes are coated with residual cocoa bean mucilage from successive fermentations and drying that may contain Cd or Pb, because the boxes are rarely washed or cleaned. Ramtahal (2012) found significant levels of Cd (average 4 ppm) in mucilaginous box scrapings in a post-harvest study he conducted; Pb was not measured in this study. This suggests that beans may become contaminated with Cd through contact with the outer surface of unclean fermentation boxes through leaching. However, the likelihood of these vessels significantly contaminating the entire mass of beans with Cd is minimal.

Compared to other possible points, significant Cd contamination of beans during fermentation does not appear to be likely. The Expert Committee concludes that contamination would be partly surficial and not significantly affect the entire mass of beans. Refer to Section 6.5 for an overview of "post-harvest" Pb contamination.

6.3 Contributions from Drying Beans

Subsequent to fermentation, cocoa beans are removed from boxes or heaps for drying. Fermented beans are dried using two main methods, namely sun "or natural" and artificial drying (ICCO, 1998). The method of choice varies throughout and within cocoa-producing countries.

- Depending on the weather, beans may be sun-dried by spreading them out thinly during the day directly on soil, on thick mats, tarpaulins, concrete floors, or on perforated, raised wooden floors within or without cocoa houses (Beckett, 2009). In these cases, beans are typically turned at intervals, either by hand or with wooden rakes or paddles (Sukha, 2003). These drying surfaces may be potential points of bean Cd or Pb contamination if they are unclean. Preliminary investigations done by Ramtahal (2012) also reported significant Cd levels (average 4 ppm) in scrapings of wooden trays and tools used to turn beans during the drying phase, however, no further studies were done to determine their actual contribution; and this study did not measure Pb concentrations. Deposition of wind-blown Cd- and Pb-containing dusts and soils may also contribute to contamination during the on-farm drying phase. The extent to which this occurs depends on the drying location and proximity to soil surfaces, roadsides, and other sources. Section 6.5.3 presents unpublished data that speak further to contributions from drying beans.

- Alternatively, some cocoa processors use artificial drying, which provides much more controllable drying conditions and times. An artificial drier is usually comprised of a petrochemically-fueled burner (e.g., diesel, kerosene, liquified petroleum gas), with a fan that blows heated air under a heat exchanger situated below a perforated wooden drying floor. The beans are thinly spread out on this floor and turned regularly to ensure even drying (Sukha, 2003; Musa, 2012). No reports to date confirm whether or not artificial drying contributes to Cd or Pb contamination of beans, however, the use of clean fuels should minimize any contribution. Thus, drying with petrochemically-fueled burners should not be considered a likely source.

6.4 Contributions from Transporting Dried Cocoa Beans

Once the drying process is completed, fermented and dried beans are typically cleaned to remove debris, clumped and broken beans, before packing in jute bags for transport. Other than the possible contamination from unclean bags, the contribution of Cd and Pb from external elements to cocoa beans while being transported from farm to port has not been reported.

6.5 Overview of Post-Harvest Lead Contamination

As Section 4.2 notes, "pre-harvest" cocoa beans have Pb concentrations on the order of 1 ppb, dry weight. On the other hand, some cocoa beans in commercial markets, even in recent years, contain as high as >1,000 ppb, dry weight. As Table 17 shows, 4.3 percent of the 1,242 "whole bean" sampling results provided by the SDs had Pb concentrations greater than 100 ppb. These observations, along with the Expert Committee's assessment of "pre-harvest" and "harvest" contributions, suggest that "post-harvest" activities introduce Pb contamination to cocoa beans. This section reviews information that supports this finding.

6.5.1 Anecdotal Observations

In November 2019, the Expert Committee traveled to Ecuador to tour cocoa farms and to observe processing of beans as they move from farm to port. Although tours of one growing region in one country of origin clearly do not represent worldwide activities, several anecdotal observations from the Ecuador travel factored into the Expert Committee's Pb "post-harvest" findings:

- When touring cocoa-producing regions, the Expert Committee members observed dozens of locations where cocoa beans were placed outdoors on patios and other paved-surfaces for some combination of fermentation and drying. Most locations observed by the experts were within visual range (about 100 feet or less) of rural gravel roadways.

- Some cocoa bean fermentation and drying was observed at locations only accessible by dirt roads. This included a bean collection facility that received beans from several local farms and fermented and dried the beans onsite.

- Expert Committee members observed vegetation along rural roads with significant dust accumulations on their leaves. By inference, the dust that settled on tree leaves would presumably also settle onto surfaces (including wet beans) in open-air fermentation and drying sites. During the initial phase of open-air drying, bean surfaces are coated with a sticky mucilaginous pulp. Dust is likely to adhere to these surfaces and become part of the cocoa bean shell as the wet beans dry.

- More than one contact made during the travel in Ecuador indicated that motor vehicles in the country used leaded gasoline as recently as 5 years ago, even though various websites suggest that Pb phaseout occurred approximately 20 years ago. Although the Expert Committee searched the public domain for reputable information on the timeframe of the elimination of Pb in gasoline in Ecuador, no definitive documentation was found. Unleaded gasoline appears to have been introduced and was available in Ecuador in 1987, and leaded gasoline was targeted to be phased out in 1998-2000 (World Bank, 1997; MECA, 1998). The Lead Group, Inc. (2012), citing the Organization for Economic Cooperation and Development (OECD) International Lead Management Center (USA), stated that Ecuador eliminated Pb from gasoline products prior to 2002, which is consistent with the projections. However, the links to the OECD site have since been changed or removed from public access. Although definitive documentation for the date of elimination of leaded gasoline from the Ecuadorian market is not available to the Expert Committee, the Expert Committee concludes that leaded gasoline is no longer available in Ecuador, and it was likely banned approximately 20 years ago.

- Information about the presumptive banning of Pb in paint in Ecuador is even more difficult to locate than information about the phase out of leaded gasoline. In a 2016 news article, Ecuador was identified as one of ten countries in Latin America where lead-based paint is still sold, according to a report by a joint cooperative initiative led by the World Health Organization and the United Nations Environment Programme (Latin America Current Events, 2016). Other information suggests that new regulations to reduce Pb in paint for some applications (e.g., domestic use, toys) in Ecuador were adopted in or around 2019 (IISD, 2019), although this is far from confirmed. Empirical data appear to confirm that lead-based paint was available in Ecuador in 2005 (OK International, not dated) and probably later (Reuters, 2009). During a tour of a cocoa bean drying operation, the Expert Committee observed peeling paint and evidence of painted product contact surfaces. The Expert Committee concludes that leaded paint is most likely abundant in Ecuador. Peeling paint and paint dust observed in locations where beans are harvested and dried provide a potential source for lead contamination.

The Expert Committee did not base conclusions solely on these and other anecdotal observations. Rather, these observations were considered when reviewing the scientific literature (Section 6.5.2) and considering other lines of evidence (6.5.3) relevant to Pb "post-harvest" contamination.

6.5.2 Inferences from the Scientific Literature

As Section 4.2.1 indicated, Rankin et al. (2005) and Manton (2010) used stable Pb isotopes to examines sources of Pb contamination in cocoa beans. Their findings largely aligned for "pre-harvest" contributions, but they had different viewpoints regarding sources of "post-harvest" Pb contamination. Based on Pb isotope ratios in various samples, Rankin et al. (2005) concluded that Pb shell contamination originated from a source different from the soil where the plants grew. However, the authors did not sample soils where the beans were processed, and Pb from those soils may have contaminated shells—and subsequently transferred into chocolate products.

Manton (2006) sent a comment to *Environmental Health Perspectives* about the article by Rankin et al. (2005). The letter questioned the interpretation of Pb isotope data regarding sources of Pb contamination. Rankin et al. responded to this comment (Rankin and Flegal, 2006). However, as noted below, most of the two authors' data were in agreement, and also agreed with findings from Thompson (2007). Cocoa beans were nearly devoid of Pb before "post-harvest" activities occurred.

In Manton's more recent work (2010), residues of soil-like particles were observed in acid-digested samples of cocoa bean shells that contained elevated Pb concentrations. These data show clear evidence that any Pb in commercial cocoa bean-based foods arose from contamination of the shells during "post-harvest" handling. Manton also measured strontium (Sr), samarium (Sm), and neodymium (Nd) levels and isotope ratios in the shell samples and soils. The nibs and shell from the Texas cocoa bean had measurable levels of Sr, but Sm and Nb were not detectable; but soil sampling data from this location was not presented. Nonetheless, it is well known that plants have very little ability to absorb and translocate Sm and Nd from soils into storage tissues (Tyler and Olsson, 2001), while Sr is processed by plants similarly to Ca. The Sr, Sm, and Nd in the shell samples could confirm the age of the soil materials contaminating the shell samples, hence the source of the soil which contaminated commercial cocoa beans. A comparison of the age of the soil on the beans and the Pb on the beans using isotope ratios allowed Manton to establish that the increased Pb in commercial cocoa beans came from these African soils, likely where the beans were dried and clearly not where the beans were grown. This can be labeled "post-harvest" contamination. He concluded: "No measurable Pb contamination occurs during the transport of beans or the manufacture of chocolate." The data in this paper do not provide evident proof of the lack of any Pb enrichment during manufacturing of chocolate products.

These questions could be better addressed by obtaining new samples of beans from trees and from the same farm after fermenting and drying, along with samples of soils where the trees grew and where the fermenting and drying occurred. Additional knowledge from more recent research has shown that chemical processes and plant physiological processes alter the isotope ratios of elements absorbed by roots, translocated to shoots, and subsequently translocated to storage grains (Wiederhold, 2015). New studies of Cd isotopes in cocoa orchards showed that the heavier Cd isotopes were preferentially translocated to leaves and that litter fall both increased Cd concentration in the topsoil layer of cocoa orchards, but also the heavier Cd isotopes (Barraza et al., 2019). No similar study has been conducted regarding Pb in cocoa leaves, shells and nibs, and commercial cocoa beans, compared to soils in the orchard, and especially the soils of the bean fermenting and drying areas. Research of this type using the best methods for sampling and analysis and using modern isotope ratio science to attribute sources is needed to provide an unequivocal conclusion about the source of Pb in cocoa shells and chocolate products.

The conclusion from these extensive studies was that the Pb in cocoa beans is from local Pb contamination after the pods are harvested in the field, and not from modern aerosol Pb (automotive and stack emission Pb in urban aerosols) Pb in locations where cocoa beans are processed by manufacturers to produce cocoa liquor. Appendix C.4 presents summarizes scientific publications regarding localization of Pb within cocoa beans.

6.5.3 Other Considerations

When reaching "post-harvest" Pb conclusions, the Expert Committee considered three other data sources:

- Ramtahal (unpublished data) conducted a study that adds important knowledge about "post-harvest" sources of Pb in cocoa beans. This study involved sampling cocoa beans from two farms at different intervals during on-farm processing. Beans were sampled at Days 0, 2, 4, and 6 of fermentation, and after sun drying. The results are shown in Table 24. On Farm 1, bean shells became highly contaminated with Pb during fermentation and drying. On Farm 2, on the other hand, bean shells hardly gained Pb during the fermentation and drying. Nibs at Farm 1 became somewhat contaminated, but nibs at Farm 2 remained below the detection limit (<4 ppb). These data demonstrate that Pb contamination of cocoa beans occurs during on-farm processing. Many studies that analyzed nibs prepared under clean conditions found very low levels of Pb (e.g., Manton, 2010). This important study agrees with the evidence obtained by all the other studies summarized in this report.

- The Expert Committee attempted to locate soil surveys conducted in cocoa growing nations or regions, but none were identified that used rigorous methods. Some reported soil surveys appear to have serious analytical errors. For instance, Appendix C.2 presents a review of a study that evaluated soils in Nigeria (Aikpokpodion et al., 2013); but that work found unrealistically high Pb concentrations, inconsistent with concentrations reported in other work on Nigerian soils based on more rigorous methodologies (Rankin et al., 2005). Althought the Expert Committee found no scientific literature that reported Pb levels in soils where producers conduct sun-drying of fermented cocoa beans, anecdotal evidence suggests that roadside soils with access to sunlight are used for drying in some nations; and historic use of Pb in gasoline will have at least somewhat contaminated the roadside surface soil usable for sun drying of fermented cocoa beans over decades of using leaded gasoline.

  For reference, statistically-based national soil surveys that included "clean room" techniques and appropriate laboratory methods have been conducted on U.S. farm soils. Table 26 summarizes data from soil surveys done by the U.S. Department of Agriculture (USDA) and the U.S. Geological Survey (USGS). Although few farmland soils had elevated Pb levels, the geologically-based sampling by USGS showed a fraction of US soils (they included geographically spaced samples rather than the USDA farmland soils for 12 crops-based sampling strategy) are rich in Pb and other elements usually considered to be contaminants because of natural dispersion of elements surrounding ore deposits and from historic dispersal of mine wastes.

- The Expert Committee also used a “back-of-the-envelope” calculation to demonstrate that considerable increases in “post-harvest” Pb contamination levels are reasonable. This calculation is based on the fact that chocolate products are allowed to contain up to 1.75 percent shell; and this limit reflects the difficulty in removing shell fragments during bean processing. Assuming cocoa bean shells contain 1,000 ppb Pb, and the shell is 1.75 percent of chocolate products (other than cocoa butter), the residual shell would add 17.5 ppb of Pb to the product. In addition, although it has not been investigated, it is likely that fine soil particles rich in Pb are re-distributed from shell to nibs during cracking, winnowing, and other processes. For an “uncontaminated” soil with median Pb levels (17.8 ppm = 17,800 ppb), it would take only 5.6 mg of uncontaminated soil per gram of chocolate product to increase Pb contamination in the product by 100 ppb. Contaminated soils would add proportionally higher amounts of Pb to chocolate products at even lower soil residue levels.

Based on these and other considerations, the Expert Committee concluded that Pb in chocolate products is mostly due to contamination during on-farm processing (i.e., fermenting, drying) of harvested cocoa beans, and clearly not accumulated from soils in which the cocoa tree roots are growing and translocated into nibs on the tree. Drying of fermented beans on soil, especially roadside soils or other soils with Pb contamination from anthropogenic sources, causes beans, shells, and subsequently nibs prepared by existing commercial processing to contain significant amounts of Pb.

6.6 Post-Harvest Conclusion

After considering all information reviewed in this section, the Expert Committee reached separate conclusions for “post-harvest” contributions to Cd and Pb contamination:

- **“Post-harvest” conclusion for Cd.** The Expert Committee finds that the most significant source of Cd in cocoa beans occurs pre-harvest. While post-harvest activities might slightly change the Cd concentrations, these changes are believed to be minimal in comparison to pre-harvest contributions.

- **“Post-harvest” conclusion for Pb.** Based on information in the scientific literature regarding sources of Pb in cocoa products and observations made during a tour of a cocoa growing region, the Expert Committee finds that the most significant source of Pb in cocoa beans occurs “post-harvest.” This includes fermentation and drying of harvested beans both on-farm and off-farm. Scientific literature demonstrates that cocoa beans on the tree contain very low concentrations of Pb (less than 3 ppb dry weight). Cocoa beans have been demonstrated in commercial markets as high as >1,000 ppb dry weight. Pb in cocoa beans has not accumulated by uptake from soils in which the cocoa tree roots are growing and translocated into the nib. The most likely source of “post-harvest” Pb contamination is believed to be from the outdoor fermentation and drying of beans. Fermentation has been observed to occur in bags, covered piles, and wooden boxes exposed to exterior elements. Outdoor drying has been observed being performed along roadsides, on concrete patios, on drying tables, and on plastic tarps in direct contact with the ground. Soil and dust containing Pb from anthropogenic sources is believed to come into contact with the cocoa bean shell and serve as the primary source of Pb to the cocoa bean.

7. Root Cause Phase Assessment: Cocoa Bean Processing and Chocolate Manufacturing

The following is an assessment of the extent to which the industrial processing and manufacturing operations introduce Cd or Pb into chocolate products beyond the Cd and Pb that was already in raw material shipments of cocoa beans. This assessment considers the following items: processing water; non-cocoa based ingredients; production equipment surfaces; product packaging; and production environment dust. In addition to these items, this section also assesses the extent to which bean cleaning and shell removal processes impact Cd and Pb levels. Due to publicly available information not being available for many of these topics, the assessment of cocoa bean and chocolate processing operations are based largely on one expert's 30 years of professional experience in the chocolate industry and confirmed by observations made by all four experts during tours of three SD facilities. These facilities are representative of chocolate manufacturing facilities that supply chocolate products to the State of California for general consumer consumption.

Chocolate manufacturers must comply with FDA food safety regulations (21 CFR 117). These regulations include Good Manufacturing Practice (GMP) requirements for facilities and equipment. In addition, SD facilities are certified to one of the Global Food Safety Initiative (GFSI) benchmarked Food Safety Management System schemes. Regulatory inspections and certification audits assure that these facilities are operated and maintained to produce safe food.

Cocoa bean processing and chocolate manufacturing operations are not a likely source of Cd or Pb in chocolate products. Regulatory inspections and food safety certification audits assure that controls are in place to avoid the introduction of Cd or Pb through processing water, production equipment, product packaging, and environmental dust. Non-cocoa based ingredients that are used in typical chocolate formulations are not a likely source of Cd or Pb beyond that already in raw material shipments of cocoa beans. While not an additional source of Cd or Pb into chocolate products, bean cleaning and shell removal processes might play a key role in redistributing soil particles from cocoa bean shells and waste material to nibs. This redistribution can increase the amounts of Pb and (likely to a lesser extent) Cd in bean cleaning process streams. These processes are not presently controlled to manage Cd and Pb levels in nibs.

7.1 Contributions from Processing Water

There are two types of cocoa products: natural and alkalyzed. In natural products, cocoa nibs are processed into chocolate liquor and cocoa powder without additional ingredients, including water. In alkalyzed products, cocoa nibs are reacted with a solution of potassium carbonate and water to modify the color and flavor of the further processed chocolate liquor and cocoa powder. In some processes, cocoa powder is reacted directly with a potassium carbonate solution to modify the color and flavor of the powder. In all of these alkalyzed product cases, the added moisture is removed from the nibs or cocoa powder during a subsequent process step to reduce the water activity of the product.

The concentration and amount of potassium carbonate solution used during alkalyzation is propriatary to the manufacturer. However, the ratio of potassium carbonate to cocoa nibs is regulated by the FDA to a maximum of 3 parts potassium carbonate to 100 parts cocoa nibs (21 CFR 163.110). Based on one expert's professional experience, facility supplied drinking water would be used in batching potassium carbonate alkalyzing solutions. Given the amount of potassium carbonate permitted to be added to cocoa nibs, and the Cd and Pb content of drinking water, it is unlikely that alkalyzation would contribute Cd and Pb in an appreciable amount compared with the amounts present in raw materials (i.e.,cocoa beans). The Expert Committee attempted to confirm this with the SD testing data. However, those data did not include testing results for the Pb content of water and potassium carbonate used by SD facilities that alkalyze cocoa products. Nonetheless, a review of SD sample sets for chocolate products, including cocoa powder, did not reveal a difference between the Cd and Pb levels of alkalyzed and natural products—consistent with the Expert Committee's finding that process water has negligible contributions to chocolate product Cd and Pb levels.

7.2 Contributions from Non-Cocoa Based Ingredients

SD data provided to the Expert Committee included results for non-cocoa based ingredients that are used in typical chocolate formulations. These include dairy ingredients (e.g., milk powder, milk protein concentrate, condensed milk) and sugar. As Section 3 explains, the analysis of the SD data is limited in that the SD data do not report LOQ values for the Cd and Pb results listed as less than the LOQ. The following list summarizes the Expert Committee's interpretations for various non-cocoa based ingredients:

- **Dairy ingredients.** Sixty (60) SD dairy ingredient sample results were provided for Cd. All samples were below the LOQ. LOQ values were not provided. Dairy ingredients do not appear to be a likely source of Cd in chocolate products. Fifty-eight (58) SD dairy ingredient sample results were provided for Pb. Forty-five (45) samples were below the LOQ. LOQ values were not provided. Twelve (12) samples were between 5.1 and 12.9 ppb. One (1) sample was 90 ppb. Dairy ingredients generally do not appear to contribute to Pb levels in chocolate products beyond the Pb that is contributed from cocoa based materials. It is unclear why 1 out of 58 dairy ingredient samples had a Pb concentration of 90 ppb. This result is considered an outlier for this analysis.

- **Sugar.** Thirty (30) SD sugar sample results were provided for Cd. Twenty-nine (29) samples were below the LOQ. LOQ values were not provided. One (1) sample was 363 ppb. Based on the sample description, this material appears to be a blend of cocoa powder and sugar. The cocoa powder in the blend is most likely the source of the Cd in this sample. Sugar does not appear to be a likely source of Cd in chocolate products. Thirty (30) SD sugar sample results were provided for Pb. Twenty-seven (27) were below the LOQ. LOQ values were not provided. One (1) sample was 50 ppb. Based on the sample description, this material also appears to be a blend of cocoa powder and sugar. The cocoa powder in the blend is most likely the source of the Pb in this sample. Sugar generally does not appear to contribute to Pb levels in chocolate products beyond the Pb that is contributed from cocoa based materials.

- **Other ingredients.** Soya lecithin, flavors, and other ingredients are used at such a low percentage as to not be a contributory source. This is supported by a study conducted by Kruszewski et al. (2018) on measured Ni, Cd, and Pb in raw cocoa, materials added during manufacturing, and chocolates produced by three manufacturers in Poland. In the study, concentrations of Cd and Pb in sugar and lecithin were less than the LOQ value of 1.3 ppb.

- **Inclusions.** SD data provided to the Expert Committee did not include test results for non-cocoa based ingredients used as inclusions, such as raisins and peanuts. A review of the FDA Total Diet Study Analytical Results for 2014, 2015, 2016, and 2017 found the following results for raisins: fourteen (14) samples of raisins analyzed for Pb found all samples below the LOQ of 30 ppb; and fourteen (14) samples of raisins analyzed for Cd found all samples below the LOQ of 9 ppb. Raisins are among the lowest Cd foods even when grown on the high Cd:Zn ratio marine shale soils of California (Burau, 1983).

  A review of the FDA Total Diet Study Analytical Results for 2014, 2015, 2016, and 2017 found the following results for dry roasted salted peanuts. Fourteen (14) samples of peanuts analyzed for Cd found all samples greater than the LOQ of 11 ppb, with an average of 45 ppb. Fourteen (14) samples of dry roasted salted peanuts analyzed for Pb found all samples less than the LOQ of 38 ppb. Peanuts can be high in Cd depending on the soil and soil pH where the crops as grown, as well as the peanut cultivar. A survey of Cd in US peanuts (320 samples representing the states and soils where peanuts are produced) reported a mean Cd concentration of 78 ppb (range, 10-578 ppb) (Wolnik et al., 1983). The study reported low soil pH was a major cause of higher Cd in peanuts. In a study of cultivar variation in peanut, Bell et al. (1997) reported that when the mean whole kernel was 470 ppb Cd (range, 340-770 ppb), the testa (or skin) averaged 2,920 ppb Cd (range, 2,130-3,870 ppb); but a relatively high soil Cd was used in this test. The testa was 9 to 25 percent of the whole peanut Cd among cultivars studied. McLaughlin et al. (2000) established that peanut uptake of Cd occurred by the main root system, not the rootlets originating from the peanut hulls. The Expert Committee will revisit the implications of these studies in the Reductions Recommendations phase.

7.3 Contributions from Production Equipment Surfaces

Production equipment product contact surfaces are not a likely source of Cd or Pb into chocolate products. This includes, but is not limited to, contact surfaces found in the following types of chocolate and cocoa bean processing equipment: bean cleaning equipment; material conveying equipment; roasters; shell winnowers; liquor mills; piping systems including pumps and valves; mixers; conches; roll refiners; storage tanks; bulk tankers; and packaging equipment. Based on professional experience, a discussion with a noted chocolate and cocoa bean processing equipment manufacturer (Ladner, 2019 personal communication), and observations made during site visits, Cd and Pb have been confirmed not to be used as materials of construction for equipment product contact surfaces. Stainless steel, mild carbon steel, and hardened steel are typically used. In limited situations where brass is used as a product contact surface, it is specified by the chocolate manufacturer to not contain Pb. In addition, all SD facilities, as part of their site Food Safety Plans, are required to assure that product contact surfaces are safe for food contact.

7.4 Contributions from Product Packaging

Product packaging is not a likely source of Cd or Pb into chocolate products. In 1995, the FDA issued guidance to industry regarding the finding of Pb-based printing inks on wrappers of imported candy products (FDA Industry Letter, June 1995). This guidance was issued as a result of reports from FDA field offices and state and local health authorities finding Pb-based printing inks on wrappers of imported candy products. In the letter, the FDA stated that Pb-based printing ink on a food package causes the product to be in violation of the Federal Food, Drug, and Cosmetic Act. In 2009, Michael Kashstock, Ph.D., Senior Advisor Plant Products Branch, FDA Center for Food Safety and Applied Nutrition (CFSAN), stated that after the issuance of the 1995 FDA guidance to industry, many candy manufacturers converted their wrapper designs to not use Pb-based inks. Additionally, he stated that it had been nearly 13 years since the FDA encountered a candy wrapper known to leach Pb from its printing wrapper into the candy (Kashstock, 2009). To assure product safety and comply with legal requirements, suppliers of packaging materials for SD chocolate products do not use Pb-based printing inks. Pb-free printing inks are readily available.

7.5 Contributions from Production Environment Dust

Environmental dust from cocoa bean processing is not a likely source of Cd or Pb into chocolate products. Cocoa bean processing operations (e.g., bean cleaning, roasting, winnowing) generate dust into the manufacturing environment. In order to manage the microbiological risk associated with cocoa bean dust, bean processing areas are physically separated from chocolate and chocolate liquor processing areas. Hygiene controls are implemented to manage employee and equipment movement from bean areas to chocolate and chocolate liquor processing areas. Air handling equipment is designed to avoid the movement of air from bean areas to chocolate processing areas. Liquor milling and chocolate processing systems are generally enclosed with limited access to enviromental cross-contact. Observations made during site visits confirmed that the transfer of dust from bean processing areas to chocolate and chocolate liquor processing areas is well controlled and not a likely source of Cd or Pb into chocolate products. These observations are consistent with one of the expert's experience with similar processes at industrial chocolate manufacturing facilities.

7.6 Contributions from Bean Cleaning and Shell Removal Processes

While not an additional source of Cd or Pb into chocolate products, the Expert Committee believes that bean cleaning and shell removal processes play a key role in the redistribution of Cd and Pb containing particles from cocoa bean shells and adherent waste material to nibs. A review of published research and SD supplied data indicates that the Pb level in nibs, as measured after carefully removing the shell from a cocoa bean, is less than 3 ppb (see Section 4.2). SD supplied data for cocoa bean shells (119 samples, see Table 3-15) indicates a median Pb level of 327 ppb, with 10 samples exceeding 1,000 ppb. Visits to SD cocoa bean processing facilities has indicated that inbound cocoa beans contain cocoa and non-cocoa waste materials that may be a likely a source of Cd and Pb. Cd and Pb testing data on waste material is currently not available to the experts. The Expert Committee believes that as production equipment removes the shell from the cocoa bean and the nib is exposed, shell and other particles (e.g., soil, mucilage) are redistributed to the exposed nib. In an industrial scale cocoa bean processing facility, bean cleaning and shell removal processes are controlled to remove cocoa shell and non-cocoa waste material from inbound cocoa beans and to control the level of shell in nibs. Current FDA Defect Action Levels permit a maximum of 1.75 percent shell in nib (21 CFR 117.110 FDA Defect Action Levels). The Expert Committee could not establish if bean cleaning and shell removal processes are being specifically controlled to manage Cd and Pb levels in nibs, which are then processed into chocolate liquor. In the case of Pb, where the nib initially has a very low level, particle redistribution to the nib during bean breaking and winnowing is most likely a key vector for Pb into chocolate liquor.

The next question is how are nibs and chocolate products contaminated by shell-borne Pb during manufacturing? The Expert Committee has hypothesized that the metals might be found in fine soil particles that become part of the materials stuck with mucilage residues on the bean shells. For example, clay particles <2 µm in diameter that are coated with hydrous oxide of Fe and Mn have a strong ability to adsorb metals, such as Cd and Pb. It is possible that industry's current shell cracking and separation processes redistribute these fine shell particles, causing some of the Pb-rich fine soil particles to become adsorbed or attached by surface tension to nibs. Because the nibs are usually broken during the shell cracking processes, the nib particles have increased surface area that could hold more of the Pb-rich fine soil particles.

It is important to understand how Pb-contaminated shells (or Pb-contaminated soil particles redistributed to broken nibs during bean processing) might increase Pb concentrations in chocolate products. As noted earlier, chocolate products are allowed to contain up to 1.75 percent shell because of the difficulty in removing all shell fragments during bean processing. If shell contains Pb at 1,000 ppb, and shell is 1.75 percent of chocolate products (other than cocoa butter), the residual shell would add 17.5 ng of Pb per gram of chocolate product. In addition, although it has not been investigated, it is likely that fine soil particles rich in Pb are re-distributed from shell to nibs during cracking, winnowing, and other processes. For an uncontaminated soil with median background Pb levels (17.8 ppm = 17,800 ppb), it would take only 5.6 mg of uncontaminated soil per gram of chocolate product to add 100 ppb of Pb to the product.

The Expert Committee found no scientific literature that reported Pb concentrations in soils where beans are fermented and dried. However, anecdotal evidence suggests that bean drying in some nations occurs on roadside soils, and these soils are expected to have elevated Pb concentrations due to use of leaded gasoline for decades up until recent years. (Note: See Section 6 for further discussion of leaded gasoline use and phaseout dates in cocoa-producing countries.) The calculations in the previous paragraph, along with the observation that soil Pb concentrations in some cocoa-growing regions likely far exceed background, demonstrate that relatively small quantities of Pb-contaminated soils found on cocoa beans have the potential to increase Pb concentrations considerably in chocolate products. The Expert Committee plans to design and conduct a study to investigate this matter in 2020, during this project's Reductions Recommendations phase.

7.7 Cocoa Bean Processing and Chocolate Manufacturing Conclusion

Cocoa bean processing and chocolate manufacturing operations are not a likely source of Cd or Pb in chocolate products. Regulatory inspections and food safety certification audits assure that controls are in place to avoid the introduction of Cd or Pb through processing water, production equipment, product packaging, and environmental dust. Non-cocoa based ingredients that are used in typical chocolate formulations are not a likely source of Cd or Pb beyond that already in raw material shipments of cocoa beans. While not an additional source of Cd or Pb into chocolate products, bean cleaning and shell removal processes play a key role in the redistribution of Cd or Pb containing particles from cocoa bean shells and waste material to nibs. These processes are not specifically controlled to manage Cd or Pb levels in nibs. A study has been planned to assess the capability of the bean cleaning and shell winnowing processes to reduce and control the level of Cd and Pb in nibs.

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Appendix A. Tables

Table 1. Inventory of SD Data and Supporting Information Provided to the Expert Committee

Batch Number	File Name	Description of Contents
1	SAN FRANCISCO #3962467 v1 ISD Pd Cd Data Blinded Submission for SMEs	Excel spreadsheets containing blinded, compiled data from testing whole cocoa beans and processing intermediates for Cd and Pb levels.
2A	Attachment A - Iron results	Excel spreadsheet with blinded results from testing cocoa nibs and liquor for Fe levels.
2B	Attachment B - Aluminum results	Excel spreadsheet with blinded results from testing cocoa nibs and liquor for Al levels.
2C	Attachment C - Cadmium and lead results (6-13-19)	Excel spreadsheets containing blinded and compiled results from testing cocoa beans, processing intermediates, and other ingredients for Cd and Pb levels.
2D	Attachment 1 (6-13-2019)	Vendor sampling procedure, March 20, 2017, prepared by Silliker, Inc. Procedures relate to sterile collection of cocoa product samples in the processing line.
2E	Attachment 2 (6-13-2019)	Unknown author and date. Sterile sampling procedure for cocoa liquor and powder.
2F	Attachment 3 (6-13-2019)	Response to April 4, 2019 SME request for more information from ISDs regarding the sampling and analytical procedures for Batch 1 test data.
3A	Att D - 2016 lead and cadmium SHELL data	Excel spreadsheet containing 2016 blinded, compiled data from testing Cd and Pb levels in whole bean shells and nibs.
3B	Att E - lead and cadmium SHELL results 2017	Excel spreadsheet containing 2017 blinded, compiled data from testing Cd and Pb levels in whole bean shells and nibs.
3C	Att F - 2018 lead and cadmium SHELL results	Excel spreadsheet containing 2018 blinded, compiled data from testing Cd and Pb levels in whole bean shells and nibs.
3D	Att G - Lead and cadmium results summary	Appears to be part of an appendix to a report from unknown authors with some tables presenting Cd and Pb test results.
3E	Att 4 - MP 1288 rev.15 2018	Description of the ICP-MS method for trace metals after acid digestion prepared by Merieux NutriSciences, January 21, 2019.
3F	Att 5 - TM-205	Description of a method for the preparation of samples for trace metals analysis by microwave digestion prepared by Reading Scientific Services, Ltd (RSSL).
3G	Att 6 - TM201	Description of RSSL's method for ICP-MS analysis of heavy metals in aqueous digests of food.
3H	Att 7 - Eurofins method validation, cocoa liquor	Methods validation performed by Eurofins labs in support of heavy metal analysis methods and corresponding standard operating procedures, February 13, 2019.
3J	Att 8 - Roasting samples - SOP	Standard operating procedure for roasting whole beans and separating nibs from shells in preparation for testing. No author or date.

Table 2. Availability of SOPs and Other Reporting Elements for SD Testing Data

Supporting Documentation	Description	Information SDs Submitted to Expert Committee								
		Batch 1 Data			Batch 2 Data			Batch 3 Data		
		Yes	Partial	No	Yes	Partial	No	Yes	Partial	No
Experimental description, design, and procedures	Purpose of analysis, scope and applicability, summary of methods, QA/QC plan		x			x		x		
Sampling protocol	Sample collection procedure, sample containers used, transportation and storage, use of transportation/field blanks, chain of custody documentation			x		x			x	
Laboratory analysis	Analytical instrumentation used			x		x		x		
	Analytical method used	x			x			x		
	Extraction method specified (e.g., reagents used, container preparation)			x			x	x		
	Sample dilution			x			x		x	
	Method calibration/standardization/blanks			x			x	x		
	Use of sample spikes, split samples, replicates			x			x		x	
	Sample integrity (e.g., measure of degradation)			x			x			x
	Matrix effects specified			x			x		x	
Data reporting	Units of measurement	x			x			x		
	Data handling (e.g., calculations made, unit conversions, data management, statistics used)			x			x	x		
	Uncertainty range specified			x	x					x
	Verification of significant figures			x			x			x
	Limit of detection and/or quantification			x		x			x	
	Extraction efficiency (yield based on internal std.)			x			x		x	
	Sample interference or other troubleshooting procedures (if necessary)			x			x			x
Administrative	Certificates of laboratory proficiency for specified methods (laboratory certification)			x			x	x		
	QA/QC performance evaluation or report/certification of data quality and consistency			x			x	x		
	Other documentation including citations, references, SOP versions, methods manuals, etc.		x			x		x		

Table 3a. Batch 1 Whole Bean Cd Sampling Data, by Country of Origin

Location	DF	N	All Cd concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All countries	100%	1,887	410	418	186.3	577.5	124.2	866.3	467.8	439.0
Brazil	100%	34	94	83	76.5	159.0	51.0	238.5	123.5	81.0
Cameroon	100%	32	90	59	60.0	119.3	40.0	179.0	88.6	32.5
Columbia	100%	6	2,865	3,056	819.3	3,875.0	x	x	3,082.0	2,997.7
Dominican	100%	186	246	116	187.0	302.5	124.7	453.8	254.3	90.0
Ecuador	100%	1,097	511	317	410	727	273.3	1,090.5	617.2	374.1
Ghana	100%	96	70	29	60.0	89.3	40.0	134.0	74.6	24.3
Indonesia	100%	45	359	190	280.0	470.0	186.7	705.0	476.2	353.6
Ivory Coast	100%	166	60	15	55.0	70.0	36.7	105.0	66.9	25.0
Nigeria	100%	25	55	50	40.0	89.5	26.7	134.3	91.5	89.5
Papua New Guinea	100%	29	206	228	128.2	363.3	84.5	545.0	242.7	149.3
Peru	100%	71	542	248	434.0	682.0	289.3	1,023.0	575.4	212.8
Sao Tome	100%	9	78	21	64.0	85.0	x	x	75.4	17.9
Tanzania	100%	18	153	88	124.0	208.0	82.7	312.0	161.9	48.5
Trinidad	100%	8	410.5	207.3	345.0	552.3	x	x	445.6	170.0
Venezuela	100%	22	892	777.5	467.5	1,245.0	311.7	1,867.5	904.6	535.1

Key for Table 3a:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "all countries" and not in any other row in the table.

Table 3b. Batch 1 Whole Bean Pb Sampling Data, by Country of Origin

Location	DF	N	All Pb concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All countries	85.7%	1,242	10	20	5.5	25.0	3.7	37.5	23.5	53.5
Brazil	100.0%	19	22	23	10.0	33.0	6.7	49.5	25.7	21.9
Cameroon	100.0%	26	25	77	10.0	87.0	6.7	130.5	42.6	34.0
Columbia	100.0%	6	5	x	x	x	x	x	5.2	0.4
Dominican	83.5%	103	5	8	5.0	12.6	3.3	18.9	14.9	20.2
Ecuador	79.1%	747	10	5	5.0	10.0	6.7	15.0	18.1	41.4
Ghana	93.2%	74	25	15	10.0	10.0	6.7	15.0	19.8	10.3
Indonesia	100.0%	15	10	3	6.0	8.7	4.0	13.0	8.0	2.9
Ivory Coast	95.7%	138	25	9	24.0	32.5	16.0	48.8	49.5	113.4
Nigeria	100.0%	18	25	55	25.0	80.0	16.7	120.0	63.2	64.7
Papua New Guinea	100.0%	15	25	21	10.0	31.0	6.7	46.5	22.4	15.1
Peru	91.2%	34	10	7	6.7	13.4	4.5	20.1	13.5	11.5
Sao Tome	100.0%	6	19	21	10.0	31.5	x	x	22.7	15.2
Tanzania	100.0%	13	50	137	10.0	147.0	6.7	220.5	78.3	70.3
Venezuela	100.0%	6	35	65	68.2	133.4	x	x	63.0	64.9

Key for Table 3a:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "all countries" and not in any other row in the table.

Table 4a. Batch 1 Cocoa Powder Cd Sampling Data, by Country of Origin of Whole Bean

Location	DF	N	All Cd concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All data	100%	343	341.0	403.5	152.5	556.0	101.7	834.0	403.0	304.0
Blended	100%	55	444.0	183.5	366.6	550.0	244.4	825.0	492.7	186.4
Unknown	100%	288	274.0	415.0	143.0	558.0	95.3	837.0	385.9	319.0

Table 4b. Batch 1 Cocoa Powder Pb Sampling Data, by Country of Origin of Whole Bean

Location	DF	N	All Pb concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All data	100%	1,267	110.0	100.0	80.0	180.0	53.3	270.0	143.7	105.6
Blended	100%	571	110.0	84.5	80.0	164.5	53.3	246.7	127.8	127.8
Brazil	100%	194	240.0	160.0	160.0	320.0	106.7	480.0	265.7	151.4
Ivory Coast	100%	154	90.0	20.0	80.0	100.0	53.3	150.0	90.5	21.8
Unknown	100%	346	92.0	87.8	65.0	152.8	43.3	229.2	124.8	95.4

Key for Tables 4a and 4b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "all data" and not in any other row in the table.

Table 5a. Batch 1 Cocoa Powder Cd Sampling Data, by Producing Country

Producing Country	DF	N	All Cd concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All countries	100%	343	341.0	403.5	152.5	556.0	101.7	834.0	403.0	304.0
Brazil	100%	12	182.5	78.7	148.5	244.3	99.0	366.5	316.8	340.7
Cameroon	100%	6	197.0	22.2	195.3	217.5	130.2	326.2	205.7	15.4
Ecuador	100%	4	1,205.0	x	x	x	x	x	1,430.0	453.4
France	100%	12	202.0	365.5	119.5	485.0	79.7	727.5	391.7	386.8
Germany	100%	7	134.0	25.2	126.3	151.5	84.2	227.2	136.9	19.9
Indonesia	100%	18	469.0	188.7	422.3	611.0	281.5	916.5	546.0	242.4
Ivory Coast	100%	8	109.2	27.6	97.5	125.1	65.0	187.6	111.0	17.4
Malaysia	100%	17	369.0	189.5	319.0	508.5	317.5	762.7	439.1	217.2
The Netherlands	100%	51	183	180.5	138.0	318.5	92.0	477.7	240.6	135.2
United States	100%	84	305	319.2	152.8	472.0	101.9	708.0	376.5	257.3

Key for Table 5a:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "all countries" and not in any other row in the table.

Table 5b. Batch 1 Cocoa Powder Pb Sampling Data, by Producing Country

Producing Country	DF	N	All Pb concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All countries	100%	1,267	110.0	100.0	80.0	180.0	53.3	270.0	143.7	105.6
Belgium	100%	6	80.0	x	x	x	x	x	106.7	41.3
Brazil	100%	204	240.0	78.7	148.5	244.3	99.0	366.4	258.8	151.4
Cameroon	100%	12	120.0	67.2	107.3	174.5	71.5	261.7	132.5	53.6
Ecuador	100%	4	100.0	x	x	x	x	x	100.2	55.2
France	100%	12	55.0	33.5	51.0	84.5	34.0	126.7	69.8	34.3
Germany	100%	13	136.0	100.0	90.0	190.0	60.0	285.0	187.5	166.9
India	100%	6	100.0	x	x	x	x	x	136.7	56.8
Indonesia	100%	26	300.0	152.2	157.8	310.0	105.2	465.0	251.8	88.0
Ivory Coast	100%	18	166	80.0	99.3	179.3	66.2	268.9	148.5	53.0
Malaysia	100%	103	77.0	40.0	60.0	100.0	40.0	150.0	92.5	76.2
Mexico	100%	98	100.0	50.0	80.0	130.0	53.3	195.0	111.4	42.0
The Netherlands	100%	297	80.0	34.0	70.0	104.0	46.7	156.0	93.8	35.4
Spain	100%	106	180.0	77.0	142.0	219.0	94.7	328.5	184.2	51.5
United States	100%	180	93	62.0	75.8	137.8	50.5	206.7	113.6	70.8

Key for Table 5b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25^{th} quantile)
Q3 = third quartile (75^{th} quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "all countries" and not in any other row in the table.

Table 6a. Batch 1 Chocolate Liquor Cd Sampling Data, by Country of Origin of Whole Bean

Location	DF	N	All Cd concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
Combined	100%	560	160.0	285.0	75.0	360.0	50.0	540.0	287.1	342.1
Blended	100%	153	170	177.0	96.0	273.0	64.5	421.5	210.7	165.4
Dominican	100%	8	235.0	97.0	193.5	290.5	129.0	435.7	262.7	94.2
Ecuador	100%	83	760.0	295.0	604.0	899.0	402.7	1,348.5	768.1	247.4
Ghana	100%	12	75.7	16.8	73.8	90.6	49.7	123.6	82.5	11.6
Haiti	100%	7	410.0	472.0	312.5	784.5	208.3	1,176.7	625.9	474.6
Ivory Coast	100%	182	75.0	62.1	62.2	124.3	41.5	186.5	121.1	139.1
Nigeria	100%	10	71.8	20.5	63.5	84.0	42.3	126.0	67.0	29.8
Papua New Guinea	100%	14	181.0	103.5	162.0	265.5	108.0	398.2	232.8	119.8
Unknown	100%	75	280.0	294.0	86.0	380.0	57.3	570.0	301.0	278.1

Key for Table 6a:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "all countries" and not in any other row in the table.

Table 6b. Batch 1 Chocolate Liquor Pb Sampling Data, by Country of Origin of Whole Bean

Location	DF	N	All Pb concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
Combined	100%	2,182	29.0	22.9	19.0	41.9	12.7	62.9	37.4	35.5
Blended	100%	202	44.0	40.0	30.0	70.0	20.0	105.0	58.1	48.7
Brazil	100%	46	80.0	55.0	60.0	115.0	40.0	172.5	96.1	58.9
Dominican	100%	9	21.0	41.0	12.0	53.0	8.0	79.5	34.6	30.8
Ecuador	100%	116	44.5	25.2	34.8	60.0	16.8	90.0	53.3	26.7
Ghana	100%	81	20.0	10.0	20.0	30.0	13.3	45.0	28.7	22.3
Haiti	100%	7	64.0	22.0	29.5	56.8	19.7	85.2	71.0	42.3
Indonesia	100%	11	60.0	10.0	50.0	60.0	33.3	90.0	60.0	17.3
Ivory Coast	100%	645	39.8	21.7	28.3	50.0	18.9	75.0	42.8	28.2
Nigeria	100%	10	69.4	21.6	68.3	89.9	45.5	134.8	72.4	28.0
Papua New Guinea	100%	14	31.0	7.0	26.8	33.8	17.9	50.7	30.8	6.1
Tanzania	100%	10	75.0	27.5	60.0	87.5	40.0	131.2	71.4	21.7
Unknown	100%	1,024	20.0	14.8	13.2	28.0	8.8	42.0	25.1	30.9

Key for Table 6b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "all countries" and not in any other row in the table.

Table 7a. Batch 1 Chocolate Liquor Cd Sampling Data, by Producing Country

Producing Country	DF	N	All Cd concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
Combined	100%	560	160.0	285.0	75.0	360.0	50.0	540.0	287.1	342.1
Brazil	100%	12	96	6.7	92.8	99.5	61.9	149.2	94.0	10.5
Cameroon	100%	6	78.5	28.8	60.0	88.8	40.0	133.2	78.2	22.2
Dominican	100%	10	210.5	81.7	182.3	264.0	121.5	396.0	228.6	95.5
Ecuador	100%	73	802.0	262.0	650.0	912.0	433.3	1,368.0	802.3	234.9
Ghana	100%	13	83.0	17.0	72.0	89.0	47.3	133.5	82.2	12.1
Haiti	100%	7	410.0	472.0	312.5	784.5	208.3	1,176.7	625.9	474.6
Indonesia	100%	16	270.0	96.8	216.5	313.3	144.3	469.9	254.7	74.5
Ivory Coast	100%	117	85.0	101.0	70.0	171.0	46.7	256.5	146.2	162.5
Malaysia	100%	18	96.7	28.2	111.8	83.6	74.5	125.4	103.6	35.9
Papua New Guinea	100%	14	181.0	162.0	162.0	265.5	108.0	398.2	232.8	119.8
United States	100%	146	70.0	61.3	61.3	247.8	40.9	371.7	169.1	203.2

Key for Table 7a:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "combined" and not in any other row in the table.

Table 7b. Batch 1 Chocolate Liquor Pb Sampling Data, by Producing Country

Producing Country	DF	N	All Pb concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
Combined	100%	2,182	29.0	22.9	19.0	41.9	12.7	62.9	37.4	35.5
Brazil	100%	58	76.0	40.0	60.0	100.0	40.0	150.0	91.7	55.6
Cameroon	100%	6	61.5	34.8	44.5	79.3	29.7	118.9	65.5	27.6
Canada	100%	5	64.0	x	x	x	x	x	60.4	10.8
Dominican	100%	7	20.0	26.5	10.5	37.0	7.0	55.5	31.9	33.8
Ecuador	100%	109	44.0	27.0	33.0	60.0	22.0	90.0	52.4	25.7
Ghana	100%	53	20.0	19.0	20.0	39.0	13.3	58.5	30.8	23.2
Haiti	100%	7	64.0	33.0	42.0	75.0	28.0	112.5	71.0	42.3
Indonesia	100%	48	70.0	48.3	53.0	101.3	35.3	151.9	89.5	56.9
Ivory Coast	100%	595	30.0	18.0	22.0	40.0	14.7	60.0	35.8	22.0
Malaysia	100%	37	60.0	29.0	31.0	60.0	20.7	90.0	57.6	45.3
Mexico	100%	10	55.0	20.0	20.0	60.0	13.3	90.0	56.0	21.2
Papua New Guinea	100%	14	31.0	7.0	26.8	33.8	17.9	50.7	30.8	6.1
United States	100%	298	42.7	39.9	28.2	68.1	18.8	102.2	59.4	50.4

Key for Table 7b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "combined" and not in any other row in the table.

Table 8a. Batch 1 Cocoa Butter Cd Sampling Data, by Producing Country

Producing Country	DF	N	All Cd Concentrations Reported in ppb		
			Median	Mean	SD
Combined	70%	67	7.1	8.0	5.6
Brazil	100%	4	9.2	9.2	2.4
Indonesia	64%	11	7.1	6.9	3.2
Malaysia	33%	12	3.5	5.4	3.1
United States	100%	5	7.1	8.8	2.3

Table 8b. Batch 1 Cocoa Butter Pb Sampling Data, by Producing Country

Producing Country	DF	N	All Pb Concentrations Reported in ppb		
			Median	Mean	SD
Combined	81%	115	10.0	14.9	23.0
Brazil	100%	11	8.3	14.3	8.3
Cameroon	100%	4	19.0	19.5	11.0
France	100%	4	18.0	19.2	10.9
Ghana	100%	4	10.0	14.5	9.0
Indonesia	87%	15	10.0	22.3	43.2
Ivory Coast	100%	11	11.3	23.9	18.7
Malaysia	83%	23	10.0	8.6	5.2
United States	100%	5	11.3	10.9	17.4

Key for Tables 8a and 8b:

DF = detection frequency
N = number of samples
SD = standard deviation

Note: Some data points had no "producing country" entry specified. These sample results are included under "combined" and not in any other row in the table.

Table 9a. Batch 1 Chocolate with <65 Percent Cacao Cd Sampling Data, by Year

Location	DF	N	All Cd concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All	100%	357	92.7	114.0	21.0	135.0	14.0	202.5	117.6	167.7
2015	100%	107	60.0	148.5	21.5	170.0	14.3	255.0	110.1	136.6
2016	100%	158	95.9	87.5	24.3	11.8	16.2	17.7	81.7	58.4
2017	100%	87	56.0	179.0	10.0	189.0	6.7	283.5	182.1	272.2
2018	100%	3	x	x	x	x	x	x	208.0	x

Table 9b. Batch 1 Chocolate with <65 Percent Cacao Pb Sampling Data, by Year

Location	DF	N	All Pb concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All	100%	958	20.0	18.0	10.0	28.0	6.7	42.0	21.0	13.8
2015	100%	312	20.0	20.0	10.0	30.0	6.7	45.0	22.4	13.8
2016	100%	351	13.7	10.0	10.0	20.0	6.7	30.0	19.3	13.2
2017	100%	243	20.0	18.4	10.6	29.0	7.1	43.5	21.8	14.1
2018	100%	51	20.0	10.0	10.0	20.0	6.7	30.0	21.1	15.9

Key for Tables 9a and 9b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "location" entry specified. These samples results are included under "all" and not in any other row in the table.

Table 10a. Batch 1 Chocolate with >65 Percent and <95 Percent Cacao Cd Sampling Data, by Year

Year	DF	N	All Cd concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All	100%	111	169.0	115.0	113.0	228.5	75.3	342.7	178.8	87.1
2015	100%	43	183.0	179.3	123.0	302.3	68.3	453.4	214.1	114.1
2016	100%	57	126.0	70.0	112.0	182.0	74.7	273.0	146.9	17.7
2017	100%	10	227.5	78.5	170.0	248.5	113.3	372.7	198.1	74.9
2018	100%	1	x	x	x	x	x	x	x	x

Table 10b. Batch 1 Chocolate with >65 Percent and <95 Percent Cacao Pb Sampling Data, by Year

Year	DF	N	All Pb concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All	100%	312	40.0	30.0	20.0	50.0	13.3	75.0	36.4	19.2
2015	100%	99	30.0	28.9	11.1	40.0	7.4	60.0	29.3	17.5
2016	100%	125	40.0	28.0	20.0	48.0	13.3	72.0	35.7	17.7
2017	100%	74	50.0	20.0	40.0	60.0	26.7	90.0	46.3	18.1
2018	100%	14	44.0	47.5	12.5	60.0	8.3	90.0	40.6	26.4

Key for Tables 10a and 10b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)

IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25^{th} quantile)
Q3 = third quartile (75^{th} quantile)

Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Table 11a. Batch 1 Chocolate with >95 Percent Cacao Cd Sampling Data, by Year

Year	DF	N	All Cd concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All	100%	6	x	x	x	x	x	x	459.2	137.9
2015	100%	4	x	x	x	x	x	x	376.0	55.0
2016	100%	2	x	x	x	x	x	x	625.5	x

Table 11b. Batch 1 Chocolate with >95 Percent Cacao Pb Sampling Data, by Year

Year	DF	N	All Pb concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All	100%	76	70.0	72.7	17.3	90.0	11.5	135.0	61.1	36.4
2015	100%	23	17.3	62.7	17.3	80.0	11.5	120.0	47.7	33.8
2016	100%	18	70.0	62.0	28.0	90.0	18.7	135.0	65.9	35.7
2017	100%	19	70.0	40.0	60.0	100.0	40.0	150.0	70.5	33.1
2018	100%	16	65.0	82.7	17.3	100.0	11.5	150.0	64.0	41.9

Key for Tables 11a and 11b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)

IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25^{th} quantile)
Q3 = third quartile (75^{th} quantile)

Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Table 12a. Batch 2 Peeled Cocoa Bean Cd Sampling Data, by Country of Origin

Location	DF	N	All Cd Concentrations Reported in ppb		
			Median	Mean	SD
All countries	100%	25	152.0	320.2	308.0
Dominican	100%	7	152.0	196.1	110.4
Ecuador	100%	6	770.0	788.3	178.5
Ghana	100%	2	x	73.0	x
Ivory Coast	100%	4	x	52.3	8.2
Peru	100%	2	x	490.0	x

Table 12b. Batch 2 Peeled Cocoa Bean Pb Sampling Data, by Country of Origin

Location	DF	N	All Pb Concentrations Reported in ppb		
			Median	Mean	SD
All countries	22%	6	46.6	59.1	60.4
Unknown	100%	3	x	111.7	28.7

Table 13a. Batch 2 Peeled Cocoa Grains Cd Sampling Data, by Country of Origin

Location	DF	N	All Cd Concentrations Reported in ppb		
			Median	Mean	SD
All countries	100%	32	66.0	131.7	157.0
Ecuador	100%	3	x	560.3	146.9
Ghana	100%	3	x	53.5	7.9
Ivory Coast	100%	7	63.0	59.2	23.2
Papua New Guinea	100%	3	x	148.3	20.8

Table 13b. Batch 2 Peeled Cocoa Grains Pb Sampling Data, by Country of Origin

Location	DF	N	All Pb Concentrations Reported in ppb		
			Median	Mean	SD
All countries	28.1%	9	8.0	23.5	32.2

Key for Tables 12a, 12b, 13a, and 13b:

DF = detection frequency
N = number of samples
SD = standard deviation

Note: Some data points had no "location" entry specified. These sample results are included under "all countries" and not in any other row in the table.

Table 14a. Batch 2 Cocoa Powder Cd Sampling Data, by Producing Region

Producing Region	DF	N	All Cd concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All Regions	98%	44	228.5	209.7	144.3	354.0	96.2	531.0	286.0	33.4
Africa, Middle East, Asia	93%	13	311.0	347.5	247.5	595.0	165.0	892.5	438.5	66.7
Asia Pacific	100%	5	290.0	x	x	x	x	x	362.0	12.6
Europe, Middle East, Africa	100%	2	x	x	x	x	x	x	348.0	x
Latin America	100%	6	170.0	x	x	x	x	x	139.7	29.5
Europe	100%	9	71.0	68.0	128.5	196.5	85.7	294.8	157.1	40.2
North America	100%	9	100.0	304.0	95.5	399.5	63.7	599.3	113.4	167.9

Table 14b. Batch 2 Cocoa Powder Pb Sampling Data, by Producing Region

Producing Region	DF	N	All Pb concentrations reported in ppb							
			Median	IQR	Q1	Q3	Lower	Upper	Mean	SD
All Regions	96%	43	112.0	72.0	80.0	152.0	53.3	228.0	133.7	79.4
Africa, Middle East, Asia	89%	8	145.5	62.0	86.5	148.5	57.7	222.8	159.0	66.7
Asia Pacific	80%	4	157.5	x	x	x	x	x	158.8	25.3
Europe, Middle East, Africa	100%	2	x	x	x	x	x	x	302.0	x
Latin America	100%	6	170.0	x	x	x	x	x	195.7	111.9
Europe	100%	9	71.0	26.0	54.5	80.5	36.3	120.8	70.9	20.5
North America	100%	9	100.0	75.5	80.0	155.5	53.3	233.3	113.4	54.5

Key for Tables 14a and 14b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25^{th} quantile)
Q3 = third quartile (75^{th} quantile)
Lower = Q1 / 1.5
Upper = Q3 x 1.5
SD = standard deviation

Note: Some data points had no "producing region" entry specified. These sample results are included under "all regions" and not in any other row in the table.

Table 15a. Batch 3 Cocoa Bean Shell and Nib Cd Sampling Data from 2016 to 2018, by Country of Origin

Location	N	All Cd concentrations reported in ppb							
		Data for Nibs				Data for Shells			
		Median	IQR	Mean	SD	Median	IQR	Mean	SD
All Countries	118	365.2	643.2	594.5	702.9	739.7	1,076.3	1,076.2	1,181.7
Brazil	10	133.7	105.1	139.3	71.8	380.1	384.5	369.2	228.1
Dominican	10	350.4	70.7	345.4	88.5	654.3	197.8	636.3	140.1
Ecuador	30	1,065.3	884.9	1,322.3	961.3	1,655.6	1,112.8	2,249.7	1,668.0
Ghana	10	79.8	20.2	74.8	16.1	178.0	43.8	176.3	44.9
Haiti	2	x	x	567.1	x	x	x	424.7	x
Indonesia	10	666.0	x	708.5	479.9	963.2	x	1,014.7	571.8
Ivory Coast	10	61.8	8.5	62.2	8.1	130.0	34.5	130.4	22.7
Peru	20	583.5	177.4	651.5	293.6	1,293.1	496.6	1,347.9	519.6
Philippines	3	141.0	x	155.7	48.7	429.0	x	486.7	213.4
Papua New Guinea	10	155.7	86.6	170.2	52.1	469.0	182.0	481.0	137.4
Vietnam	3	x	x	281.5	x	x	x	717.3	x

Key for Table 15a:

N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
SD = standard deviation

Table 15b. Batch 3 Cocoa Bean Shell and Nib Pb Sampling Data, by Country of Origin

Location	N	All Pb concentrations report in ppb								
		Data for Nibs					Data for Shells			
		Median	IQR	Mean	SD	DF	Median	IQR	Mean	SD
All Countries	118	1.2	1.6	4.4	12.0	34.0%	341.3	273.3	522.1	938.0
Brazil	10	3.6	5.5	10.8	23.1	50.0%	191.0	344.4	341.6	343.0
Dominican	10	1.2	x	1.4	0.5	20.0%	426.0	171.2	566.6	601.1
Ecuador	30	1.2	1.3	5.3	18.3	37.6%	478.1	424.7	897.1	1,702.9
Ghana	10	x	x	x	x	ND	94.0	44.4	97.7	27.5
Haiti	2	x	x	2.5	x	50.0%	x	x	1,391.7	x
Indonesia	10	2.8	x	3.4	2.4	60.0%	414.7	x	485.1	212.6
Ivory Coast	10	x	x	x	x	ND	324.0	93.8	507.2	650.6
Peru	20	1.2	5.8	4.3	4.0	45.0%	328.8	106.9	378.1	170.1
Philippines	3	x	x	x	x	ND	266.0	x	239.3	56.9
Papua New Guinea	10	1.2	0.6	3.8	7.5	30.0%	304.5	249.2	310.4	198.1
Vietnam	3	x	x	17.2	1.9	100.0%	x	x	181.4	x

Key for Table 15b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25^{th} quantile)
Q3 = third quartile (75^{th} quantile)
SD = standard deviation
ND = not detected (LOD = 1.7 ppb)

Table 16a. Batch 3 Cocoa Bean Shell and Nib Cd Sampling Data from 2016 to 2018, by Country of Origin and Year

Location	N	All Cd concentrations reported in ppb							
		Data for Nibs				Data for Shells			
		Median	IQR	Mean	SD	Median	IQR	Mean	SD
2016 Samples									
All Countries	50	381.5	560.5	673.5	911.3	773.0	1,064.5	1,237.1	1,549.6
Brazil	5	134.0	x	151.4	75.6	401.0	x	393.2	263.1
Dominican	5	317.0	x	322.6	122.2	515.0	x	586.4	875.0
Ecuador	15	1,130.0	x	1,601.8	1,207.8	1,690.0	x	2,727.1	2,072.8
Ghana	5	76.0	x	71.8	13.9	166.0	x	163.0	33.5
Ivory Coast	5	65.0	x	66.3	8.0	124.0	x	134.0	26.6
Peru	10	569.5	x	570.5	615.3	1155.0	x	1,208.3	615.3
Papua New Guinea	5	172.0	x	176.4	60.6	426.0	x	497.0	181.2
2017 Samples									
All Countries	65	360.4	776.4	548.1	503.3	723.0	693.7	968.9	814.1
Brazil	5	133.3	x	127.1	74.2	359.2	x	345.2	215.5
Dominican	5	360.4	x	368.2	37.5	675.4	x	686.2	102.4
Ecuador	15	991.9	x	1,042.8	536.5	1,621.1	x	1,772.3	989.0
Ghana	5	84.0	x	77.7	19.2	198.0	x	189.6	54.4
Haiti	2	x	x	567.1	x	x	x	424.7	x
Indonesia	10	666.0	x	708.5	479.9	963.2	x	1,014.7	571.8
Ivory Coast	5	60.2	x	58.1	6.6	136.0	x	126.8	20.4
Peru	10	637.4	x	732.5	370.5	1,442.3	x	1,487.5	385.0
Philippines	3	141.0	x	155.7	48.7	429.0	x	486.7	213.4
Papua New Guinea	5	139.3	x	164.0	48.5	511.9	x	465.0	95.0
2018 Samples									
Vietnam	3	x	x	281.5	x	x	x	717.3	x

Key for Table 16a:

N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25th quantile)
Q3 = third quartile (75th quantile)
SD = standard deviation

Table 16b. Batch 3 Cocoa Bean Shell and Nib Pb Sampling Data, by Country of Origin and Year

Location	N	All Pb concentrations report in ppb								
		Data for Nibs					Data for Shells			
		Median	IQR	Mean	SD	DF	Median	IQR	Mean	SD
2016 Samples										
All Countries	50	x	x	x	x	ND	327.5	272.8	589.8	1,370.1
Brazil	5	x	x	x	x	ND	510.0	x	515.4	421.6
Dominican	5	x	x	x	x	ND	386.0	x	683.0	875.0
Ecuador	15	x	x	x	x	ND	440.0	x	1,137.5	2,397.4
Ghana	5	x	x	x	x	ND	102.0	x	102.3	31.3
Ivory Coast	5	x	x	x	x	ND	247.0	x	250.6	80.1
Peru	10	x	x	x	x	ND	340.5	x	338.8	112.8
Papua New Guinea	5	x	x	x	x	ND	285.0	x	256.8	144.6
2017 Samples										
All Countries	65	2.3	4.8	6.4	1.9	100%	364.6	324.8	485.7	400.9
Brazil	5	6.8	x	20.4	31.1	100%	173.0	x	167.7	107.1
Dominican	5	1.2	x	1.7	0.7	100%	472.3	x	450.2	115.9
Ecuador	15	2.5	x	9.4	25.7	73%	567.8	x	656.7	368.6
Ghana	5	x	x	x	x	ND	88.8	x	93.1	25.9
Haiti	2	x	x	2.5	x	50%	x	x	1,391.7	x
Indonesia	10	2.8	x	3.4	2.4	60%	414.7	x	485.1	212.6
Ivory Coast	5	x	x	x	x	ND	341.0	x	763.8	883.9
Peru	10	7.2	x	7.4	3.5	90%	312.4	x	417.4	212.0
Philippines	3	x	x	x	x	ND	266.0	x	239.3	56.9
Papua New Guinea	5	2.0	x	6.4	10.4	60%	341.6	x	363.9	245.4
2018 Samples										
Vietnam	3	x	x	17.2	1.9	100%	x	x	181.4	x

Key for Table 16b:

DF = detection frequency
N = number of samples
x = not calculated (due to small sample size)
IQR = interquartile range (Q3 – Q1)
Q1 = first quartile (25^{th} quantile)
Q3 = third quartile (75^{th} quantile)
SD = standard deviation
ND = not detected (LOD = 1.7 ppb)

Table 17. Percent of Batch 1 Whole Cocoa Bean Samples with Pb Concentrations above Specified Levels, by Country of Origin

Country of Origin	N	DF	Percent of Samples with Pb Concentration Greater Than or Equal to…					
			3 ppb	10 ppb	50 ppb	100 ppb	250 ppb	500 ppb
All countries	1,242	85.7%	84.8%	65.7%	10.0%	4.3%	0.7%	0.2%
Brazil	19	100%	100%	79.0%	10.5%	0%	0%	0%
Cameroon	26	100%	100%	100%	34.6%	7.7%	0%	0%
Columbia	6	100%	100%	0.0%	0.0%	0.0%	0%	0%
Dominican	103	83.5%	81.6%	52.4%	6.8%	1.0%	0%	0%
Ecuador	747	79.1%	78.7%	58.9%	7.8%	3.7%	0.8%	0%
Ghana	74	93.2%	93.2%	91.9%	1.4%	0%	0%	0%
Indonesia	15	100%	93.3%	60.0%	0%	0%	0%	0%
Ivory Coast	138	95.7%	95.7%	93.5%	18.1%	6.5%	2.2%	2.2%
Nigeria	18	100%	100%	100%	38.9%	2.2%	0%	0%
Papua New Guinea	15	100%	86.7%	86.7%	6.7%	0%	0%	0%
Peru	34	91.2%	91.2%	58.8%	2.9%	0%	0%	0%
Sao Tome	6	100%	100%	100%	0%	0%	0%	0%
Tanzania	13	100%	100%	100%	53.8%	38.5%	0%	0%
Venezuela	6	100%	100%	83.3%	33.3%	33.3%	0%	0%

Key for Table 17:

N = number of samples

DF = detection frequency

Note: Some data points had no "country of region" entry specified. These sample results are included under "all countries" and not in any other row in the table.

Table 18. Percent of Batch 1 Cocoa Powder Samples with Pb Concentrations above Specified Levels, by Country of Origin

Country of Origin	N	DF	Percent of Samples with Pb Concentration Greater Than or Equal to…					
			3 ppb	10 ppb	50 ppb	100 ppb	250 ppb	500 ppb
All countries	1,267	100%	100%	100%	94.1%	61.2%	13.0%	1.5%
Blended	571	100%	100%	100%	94.6%	61.6%	6.7%	0.4%
Brazil	194	100%	100%	100%	100%	95.9%	47.4%	7.2%
Ivory Coast	154	100%	100%	100%	100%	45.5%	0%	0%
Unknown	346	100%	100%	100%	87.3%	50.0%	10.1%	0.9%

Table 19. Percent of Batch 1 Cocoa Powder Samples with Pb Concentrations above Specified Levels, by Producing Country

Producing Country	N	DF	Percent of Samples with Pb Concentration Greater Than or Equal to…					
			3 ppb	10 ppb	50 ppb	100 ppb	250 ppb	500 ppb
All countries	1,267	100%	100%	100%	94.1%	61.2%	13.0%	1.5%
Belgium	6	100%	100%	100%	100%	33.0%	0%	0%
Brazil	204	100%	100%	100%	100%	94.6%	44.6%	6.9%
Cameroon	12	100%	100%	100%	100%	75.0%	0%	0%
Ecuador	4	100%	100%	100%	100%	50.0%	0%	0%
France	12	100%	100%	100%	75.0%	16.7%	0%	0%
Germany	13	100%	100%	100%	100%	69.2%	15.4%	15.4%
India	6	100%	100%	100%	100%	100%	0%	0%
Indonesia	26	100%	100%	100%	100%	96.2%	57.7%	0%
Ivory Coast	18	100%	100%	100%	100%	83.3%	0.06%	0%
Malaysia	103	100%	100%	100%	84.5%	32.0%	3.9%	0.01%
Mexico	98	100%	100%	100%	96.0%	67.3%	0%	0%
The Netherlands	297	100%	100%	100%	97.3%	43.8%	0%	0%
Spain	106	100%	100%	100%	100%	100%	15.1%	0%
United States	180	100%	100%	100%	97.2%	46.1%	3.1%	0.01%

Key for Tables 18 and 19:

N = number of samples

DF = detection frequency

Note: Some data points had no "producing country" entry specified. These sample results are included under "all countries" and not in any other row in the table.

Table 20. Percent of Batch 1 Chocolate Liquor Samples with Pb Concentrations above Specified Levels, by Country of Origin

Country of Origin	N	DF	Percent of Samples with Pb Concentration Greater Than or Equal to…					
			3 ppb	10 ppb	50 ppb	100 ppb	250 ppb	500 ppb
Combined	2,182	100%	100%	95.7%	20.1%	5.5%	0.4%	0.05%
Blended	202	100%	100%	97.5%	45.0%	13.9%	1.5%	0%
Brazil	46	100%	100%	100%	93.5%	32.6%	0%	0%
Dominican	9	100%	100%	77.8%	33.3%	11.1%	0%	0%
Ecuador	116	100%	100%	100%	37.9%	11.2%	0%	0%
Ghana	81	100%	100%	100%	11.1%	3.7%	0%	0%
Haiti	7	100%	100%	100%	57.1%	14.3%	0%	0%
Indonesia	11	100%	100%	100%	81.8%	9.1%	0%	0%
Ivory Coast	645	100%	100%	98.0%	25.4%	6.0%	0.2%	0%
Nigeria	10	100%	100%	100%	90.0%	20.0%	0%	0%
Papua New Guinea	14	100%	100%	100%	0%	0%	0%	0%
Tanzania	10	100%	100%	100%	90.0%	10.0%	0%	0%
Unknown	1,024	100%	100%	92.9%	4.9%	1.6%	0.4%	0.01%

Table 21. Percent of Batch 1 Chocolate Liquor Samples with Pb Concentrations above Specified Levels, by Producing Country

Producing Country	N	DF	Percent of Samples with Pb Concentration Greater Than or Equal to…					
			3 ppb	10 ppb	50 ppb	100 ppb	250 ppb	500 ppb
Combined	2,182	100%	100%	95.7%	20.1%	5.5%	0.4%	0.05%
Brazil	58	100%	100%	100%	86.2%	29.3%	0%	0%
Cameroon	6	100%	100%	100%	66.7%	16.7%	0%	0%
Canada	5	100%	100%	100%	80.0%	0%	0%	0%
Dominican	7	100%	100%	71.4%	28.6%	14.3%	0%	0%
Ecuador	109	100%	100%	100%	37.6%	10.1%	0%	0%
Ghana	53	100%	100%	100%	18.9%	3.8%	0%	0%
Haiti	7	100%	100%	100%	42.9%	14.3%	0%	0%
Indonesia	48	100%	100%	100%	83.3%	31.2%	4.2%	2.1%
Ivory Coast	595	100%	100%	99.5%	13.3%	2.7%	0%	0%
Malaysia	37	100%	100%	100%	51.4%	13.5%	0%	0%
Mexico	10	100%	100%	100%	60.0%	1.0%	0%	0%
Papua New Guinea	14	100%	100%	100%	0%	0%	0%	0%
United States	298	100%	100%	96.6%	42.3%	12.8%	10.1%	0.3%

Key for Tables 20 and 21:

N = number of samples

DF = detection frequency

Note: Some data points had no "country of origin" or "producing country" entry specified. These sample results are included under "combined" and not in any other row in the table.

Table 22. Cd Concentrations in Cocoa Beans Taken Directly from Pods on Trees ("Pre-Harvest") to Prevent Contamination before Analysis

Country	Range of Cd in Freshly-Harvested Cocoa Beans (ppb, dry weight)	Reference
Colombia	50 – 17,480	Albarracín, 2016
Ecuador	17 – 2,880	Chavez et al., 2015
	30 – 10,400	Argüello et al., 2018
Honduras	30 – 7,100	Gramlich et al., 2018
Malaysia	27 – 1,090	Fauziah et al., 2001
Peru	17 – 1,780	Arévalo-Gardini et al., 2017
	20 – 12,560	Zug et al., 2019
Trinidad	35 – 4,410	Ramtahal et al., 2016
	17 – 2,310	Lewis et al., 2018
Venezuela	1,500 – 4,500	Izquierdo et al., 1988

Note: In November 2019, the Expert Committee collected "pre-harvest" cocoa bean samples from three trees at a cocoa farm in Ecuador. Cd concentrations in these three samples were 725 ppb, 1,060 ppb, and 1,120 ppb. Appendix D describes this sampling in further detail.

Table 23. Publications Reviewed on Variation of Pb Contamination in Cocoa Materials

Country	Type of Study	Reference
Brazil	Product Survey	Villa et al., 2014
Ecuador	Agronomic Survey	Romero-Estevez et al., 2019
Ecuador	Agronomic Survey	Ubilla et al., 2018
Ecuador	Agronomic Survey	Huamaní-Yupanqui et al., 2012
France; Poland	Geographic Source	Mounicou et al., 2003
Ghana	Agronomic Survey	Nartey et al., 2012
Ghana	Product Survey	Danquah, 2015
Indonesia	Source Study	Assa et al., 2018
Israel	Product Survey	Yanus et al., 2014
Italy	Analytical Survey	Lo Dico et al., 2018
Malaysia	Manufacturing Study	Lee and Low, 1985
Malaysia	Agronomic Survey	Zarcinas et al., 2004
Multiple countries	Product Survey	SD testing data (see Section 3)
Nigeria	Agronomic Survey	Aikpokpodion et al., 2013
Peru	Agronomic Survey	Arvelo-Gardini et al., 2017
Poland	Manufacturing Study	Kruszewski et al., 2018
Trinidad and Tobago	Bean Handling Study	Ramtahal, 2018
United States	Analysis Methods	Gray and Cunningham, 2019
United States	Analytical Survey	Abt et al., 2018
United States	Food Surveys	US-FDA, 1991-2013

Table 24. Effect of Fermentation and Drying on Pb Concentrations in Cocoa Nibs and Shells from Two Farms in Trinidad and Tobago

Farm	Bean Component	Pb concentrations (ppb) at Different Days during Fermentation/Drying				
		Day 0	Day 2	Day 4	Day 6	Final
1	Nib	<4	14	35	18	17
	Shell	200	2,400	4,200	2,700	2,500
2	Nib	<4	<4	<4	<4	<4
	Shell	68	56	62	38	71

Source: G. Ramtahal, personal communication, 2019.

Table 25. FDA Total Diet Studies: Mean and Range of Pb Concentrations (ppb) in Cocoa-Containing Foods

Food Item	1991-2005 Total Diet Study Results			2006-2008 Total Diet Study Results			2006-2013 Total Diet Study Results		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Chocolate milk	<LOQ	13	1	<7	<7	<7	<7	8	0.3
Chocolate milkshake	<LOQ	23	5	<7	<7	<7	<7	8	0.3
Chocolate pudding	<LOQ	15	5	No data			No data		
Chocolate cake	<LOQ	26	10	<7	19	11	<7	21	6
Chocolate chip cookie	<LOQ	24	11	<7	9	8	<7	18	6
Candy bar	<LOQ	110	24	<10	16	14	<10	27	11
Brownie	<LOQ	32	11	<7	20	10	<7	32	10
Chocolate syrup	<LOQ	41	18	10	27	19	<7	27	16
Candy bar with nuts	<LOQ	31	7	<10	14	1	<10	14	0.4

Notes: LOQ levels were not available for the earliest sampling date. Chocolate pudding sampling results are not available for the two most recent sampling dates.

Table 26. Distribution of Cd and Pb Soil Concentrations in the United States

Measure	Data reported in Holmgren et al. (USDA)		Data reported in Smith et al. (USGS)	
	Cd (ppb)	Pb (ppb)	Cd (ppb)	Pb (ppb)
Minimum	<10	<1,000	<100	<500
25th Percentile	95	7,000	100	13,600
Median	200	11,000	200	18,100
75th Percentile	340	15,000	300	23,900
95th Percentile	780	23,000	700	44,500
Maximum	2,000	135,000	76,800	12,400,000

Source: 3,045 samples reported in Holmgren et al., 1993; and 4,841 soil samples reported in Smith et al., 2013.
Note: The highest Cd concentration in the USDA dataset was for marine-shale derived soils in California.

Table 27. Pb Concentrations in Soils and Carrots from Pb-Rich Historic Orchard Soils

Soil Series	State	Pb Concentration in Soils (ppb)	Pb Concentrations (ppb) in Carrot Tissues			
			Peeled Carrot	Whole Root	Peel	Shoots
Christiana	Maryland	20,000	210	200	150	170
Bagstown	Maryland	676,000	2,790	2,580	770	2,790
Hudson	New York	435,000	3,530	3,340	980	2,860
Spike	Michigan	350,000	2,670	2,570	1,090	2,320
Cashmont	Washington	961,000	7,300	7,150	1,530	5,590

Source: Codling et al., 2015.
Notes: The study used the Christiana soils from Maryland as a control.

Appendix B. Figures

Figure 1. Illustration of a Normal Distribution ("Bell-Shaped" Curve)

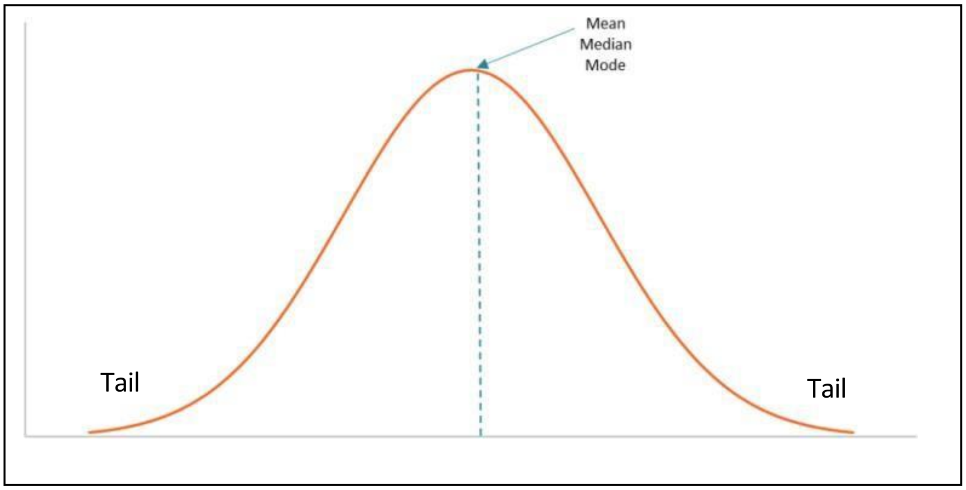
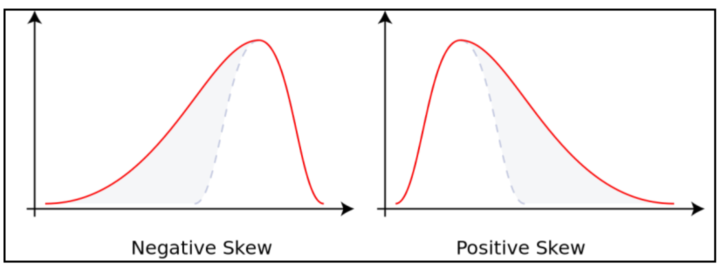


Figure 2. Illustrations of Data That Are Not Normally Distributed or Symmetrical



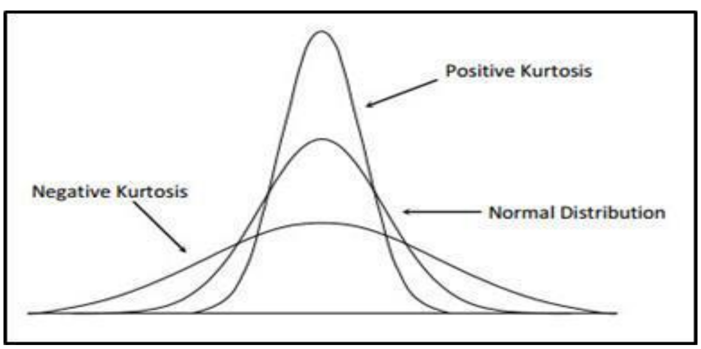
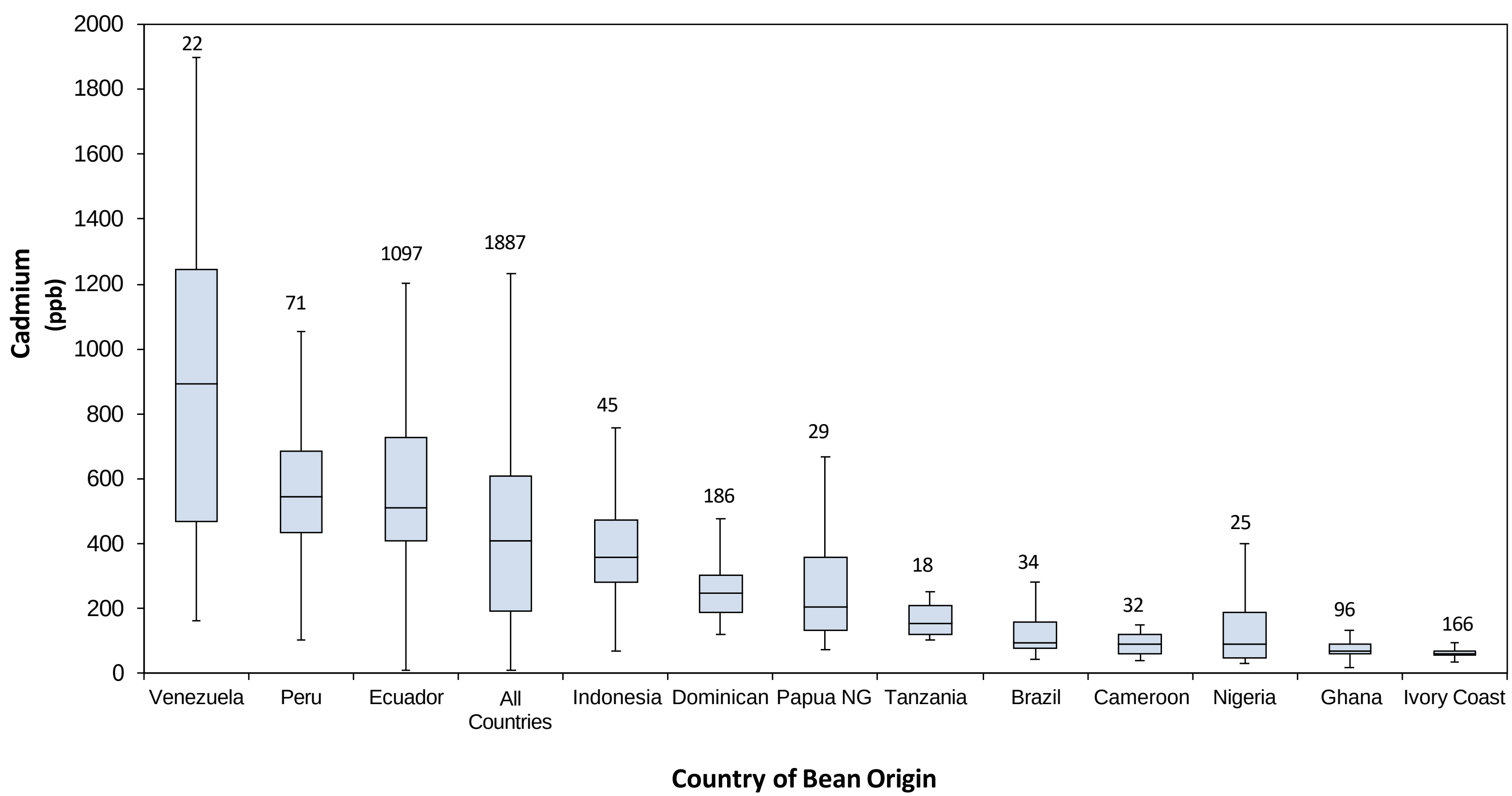


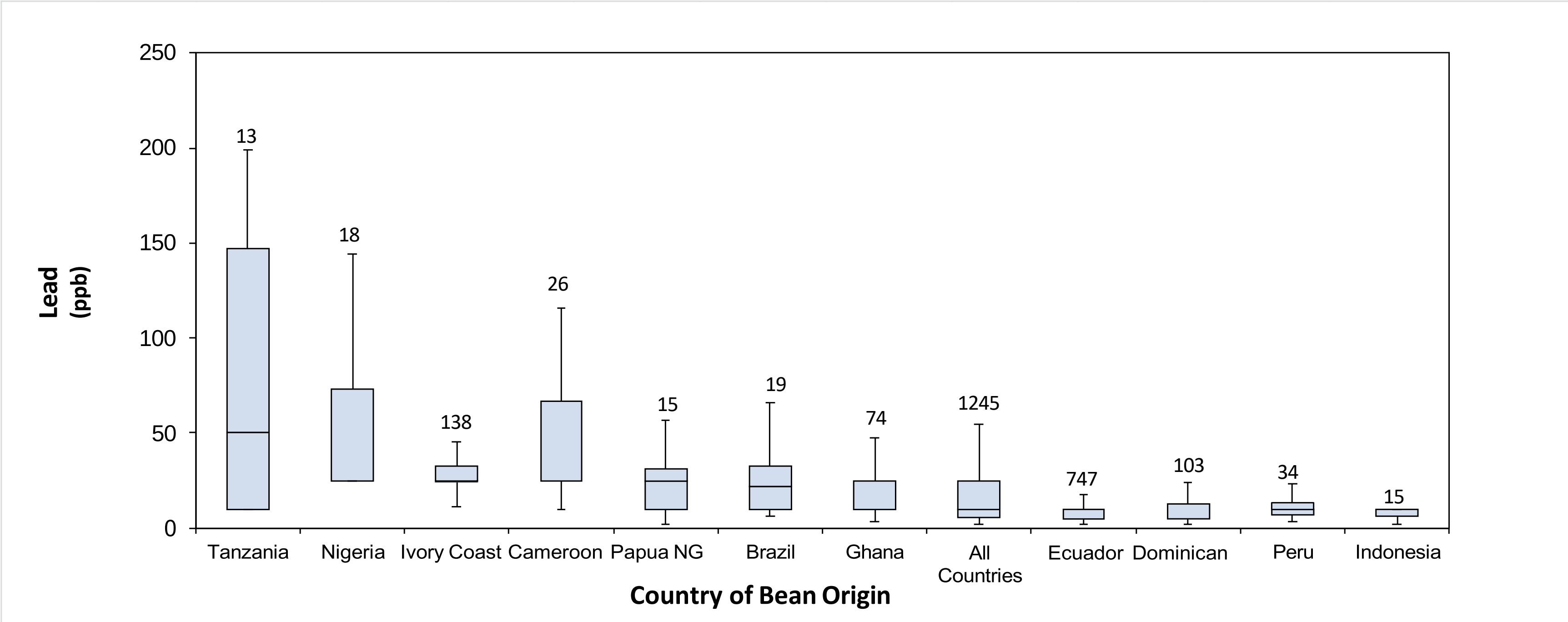
Figure 3. Batch 1 Whole Bean Cd Concentrations, by Country of Origin



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- "Whiskers" denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the "whiskers."

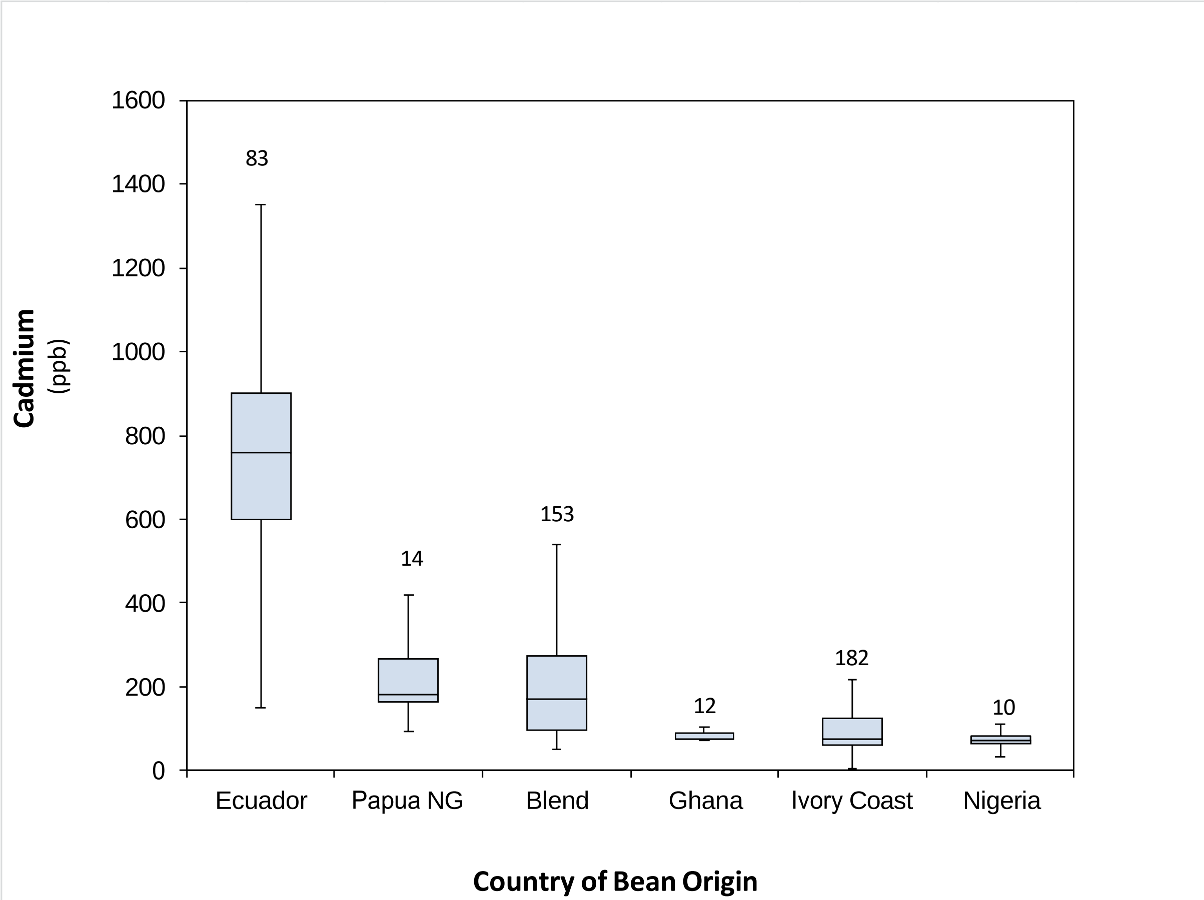
Figure 4. Batch 1 Whole Bean Pb Concentrations, by Country of Origin



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- "Whiskers" denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the "whiskers."

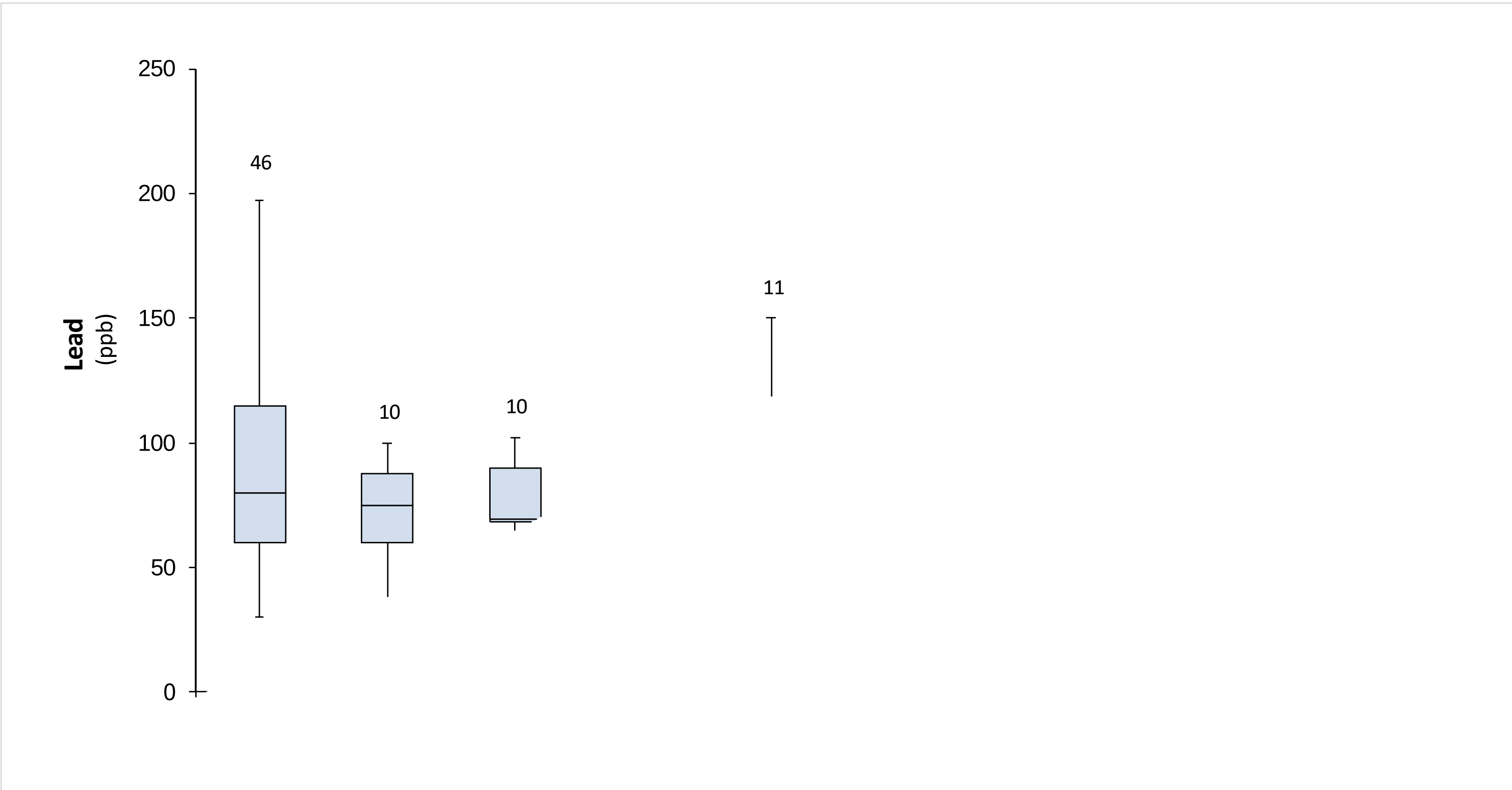
Figure 5. Batch 1 Chocolate Liquor Cd Concentrations, by Country of Origin



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- "Whiskers" denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the "whiskers."

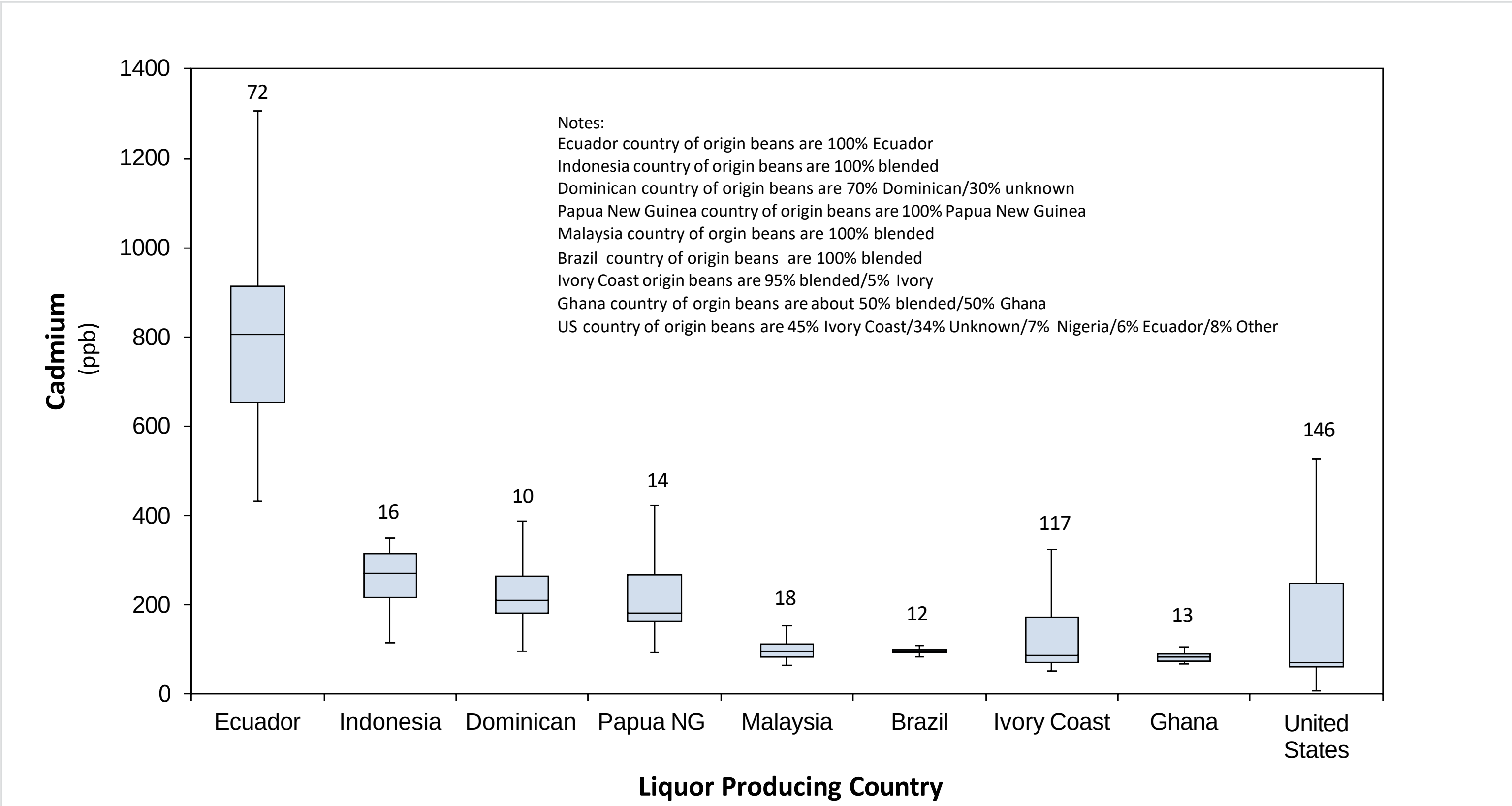
Figure 6. Batch 1 Chocolate Liquor Pb Concentrations, by Country of Origin



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- “Whiskers” denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the “whiskers.”

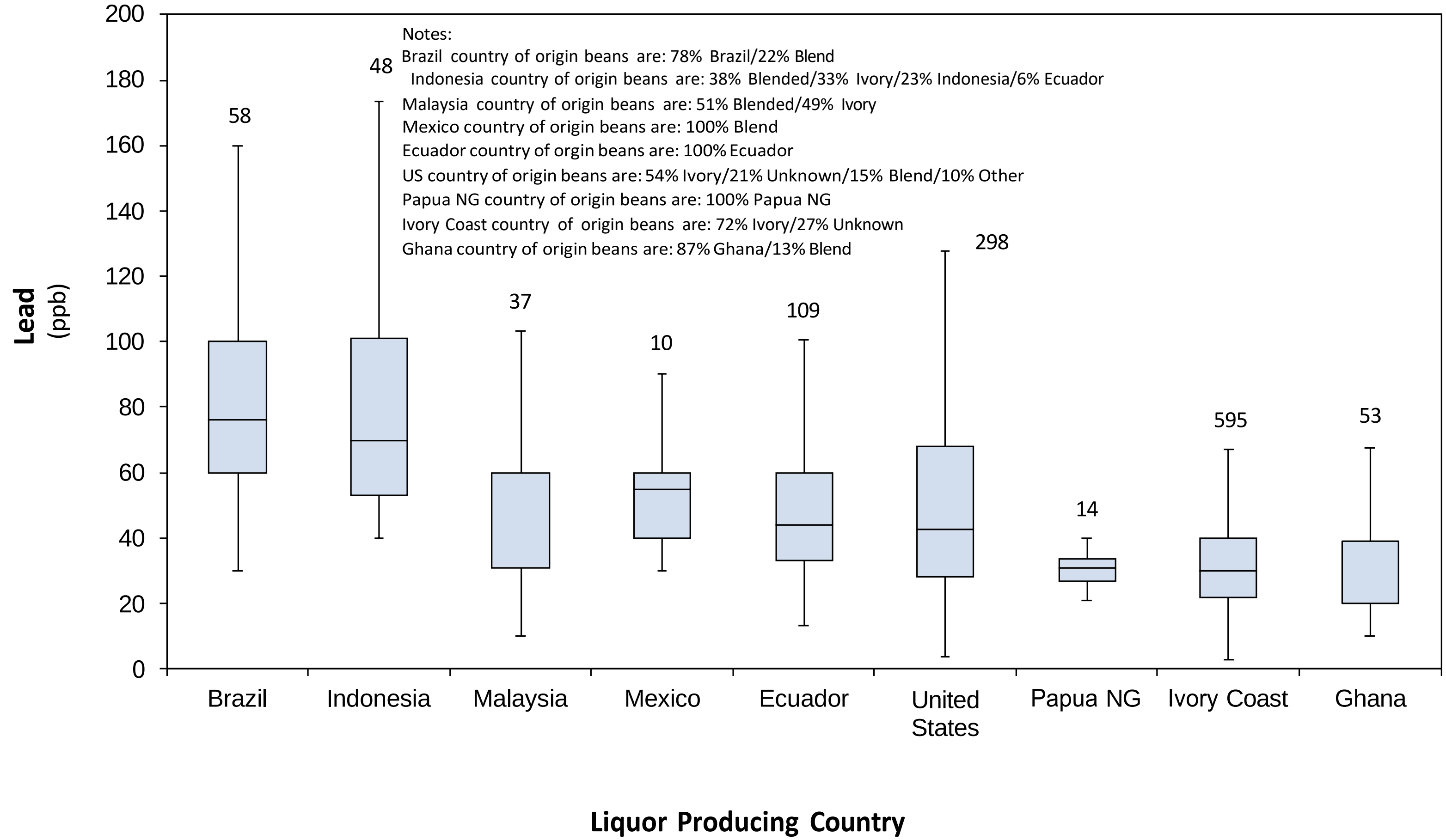
Figure 7. Batch 1 Chocolate Liquor Cd Concentrations, by Producing Country



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- "Whiskers" denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the "whiskers."
- Median Cd concentration for United States with Ecuadorian beans included is 600 ppb. The median Cd concentration for United States without Ecuadorian beans is 68.3 ppb.

Figure 8. Batch 1 Chocolate Liquor Pb Concentrations, by Producing Country



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- “Whiskers” denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the “whiskers.”

Figure 9. Batch 1 Chocolate Liquor Cd Concentrations for U.S. Facilities, by Country of Bean Origin

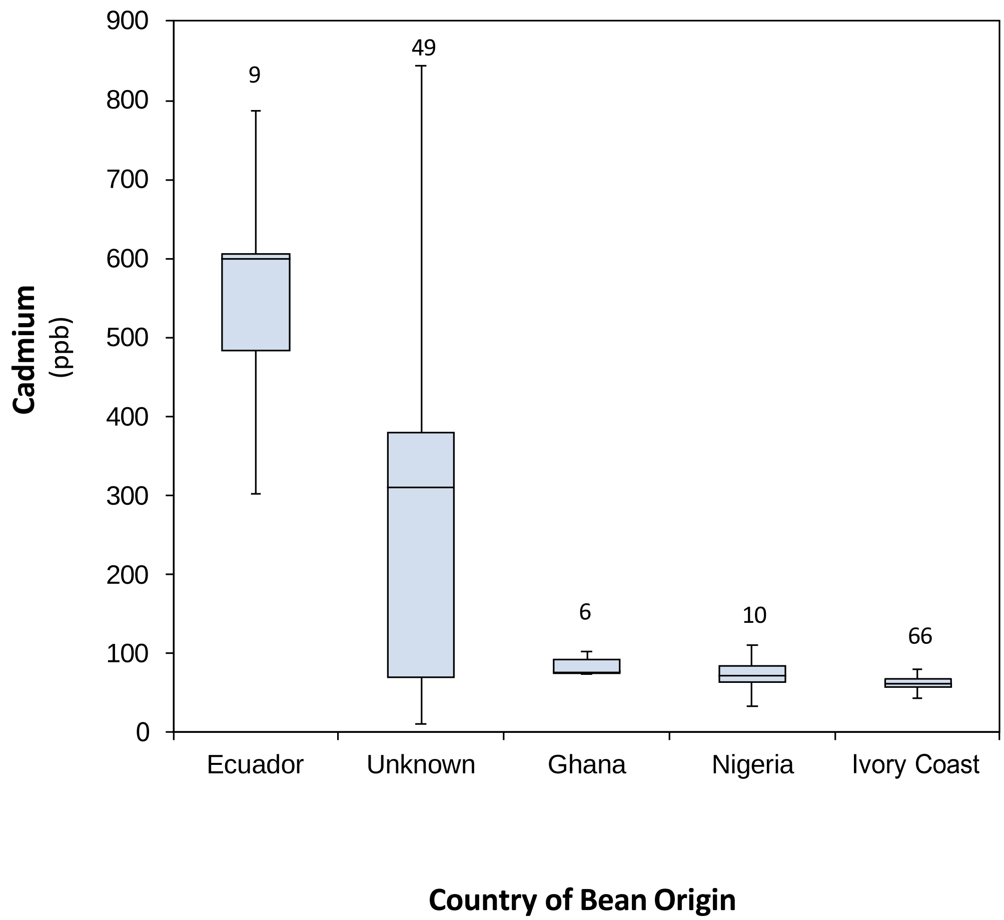
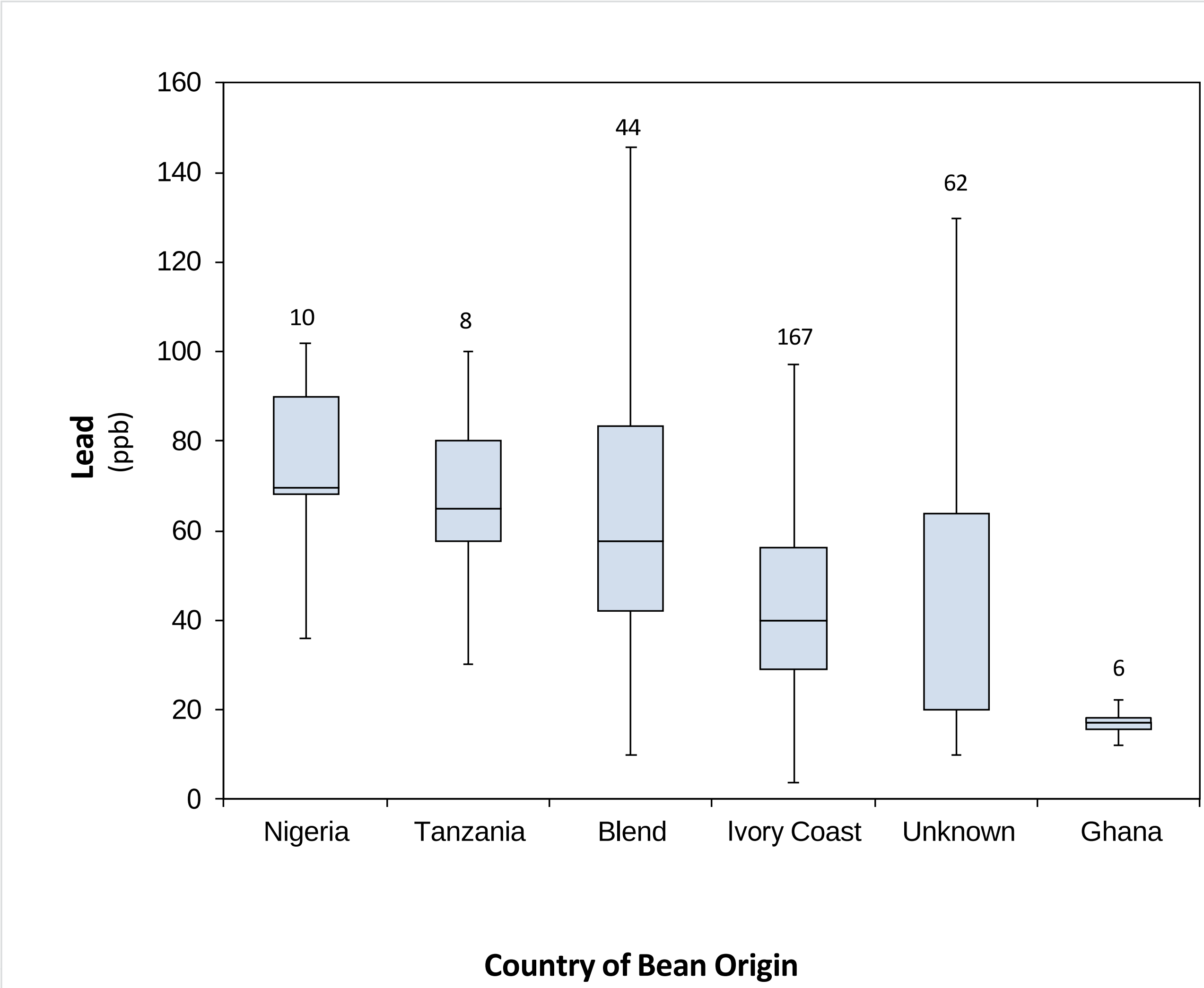


Figure 9. Batch 1: Liquor Sample Cadmium Levels Sorted by Liquor Producing Country

Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25^{th} quartile or the 75^{th} quartile.
- "Whiskers" denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the "whiskers."

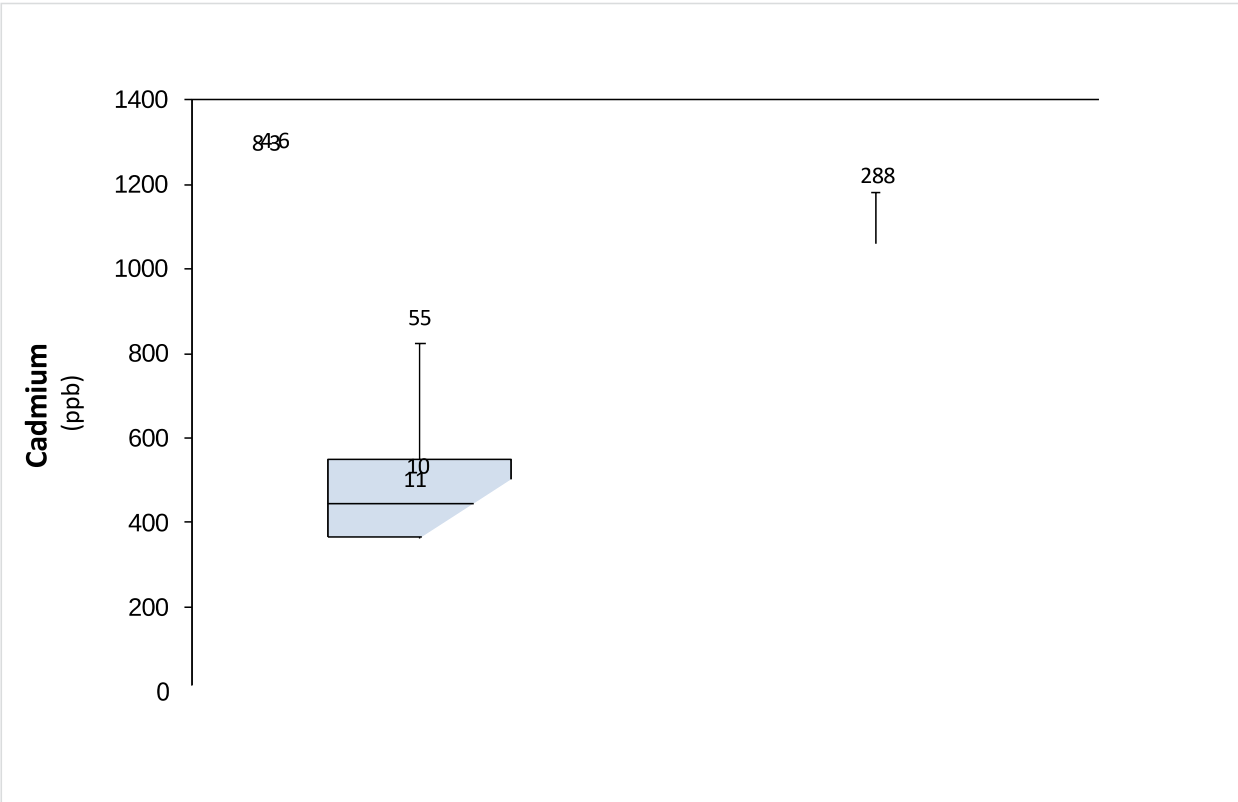
Figure 10. Batch 1 Chocolate Liquor Pb Concentrations for U.S. Facilities, by Country of Bean Origin



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- "Whiskers" denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the "whiskers."

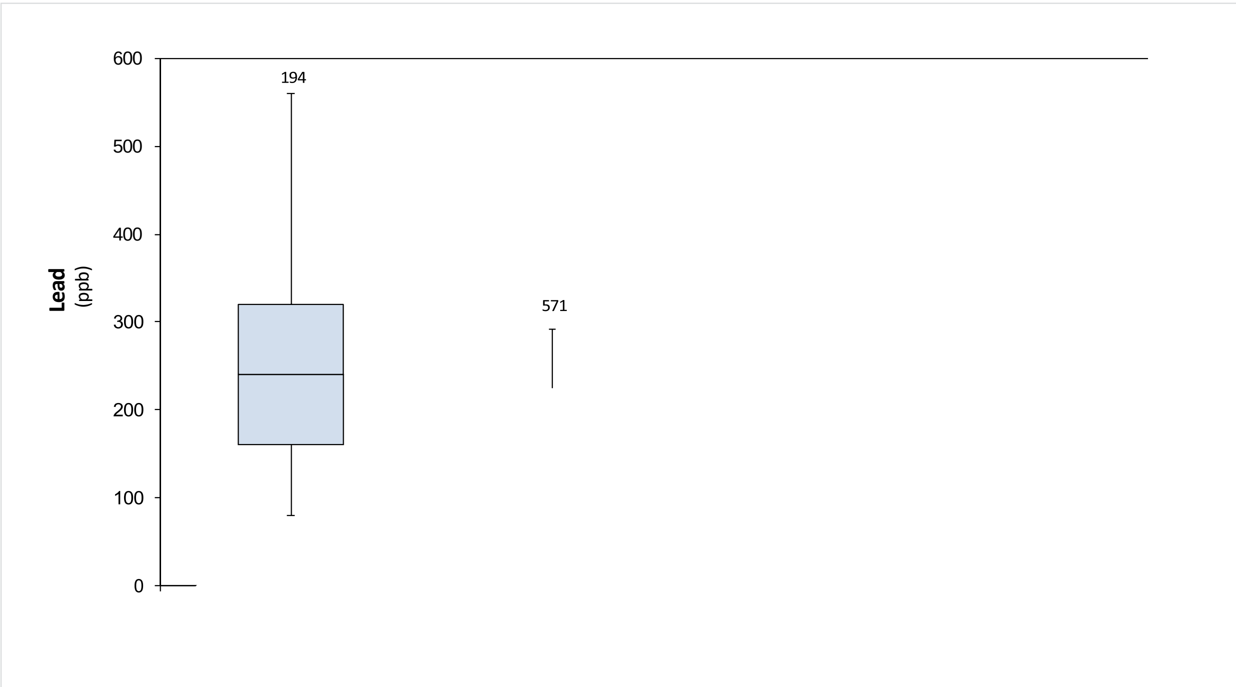
Figure 11. Batch 1 Cocoa Powder Cd Concentrations, by Country of Bean Origin



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- "Whiskers" denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the "whiskers."

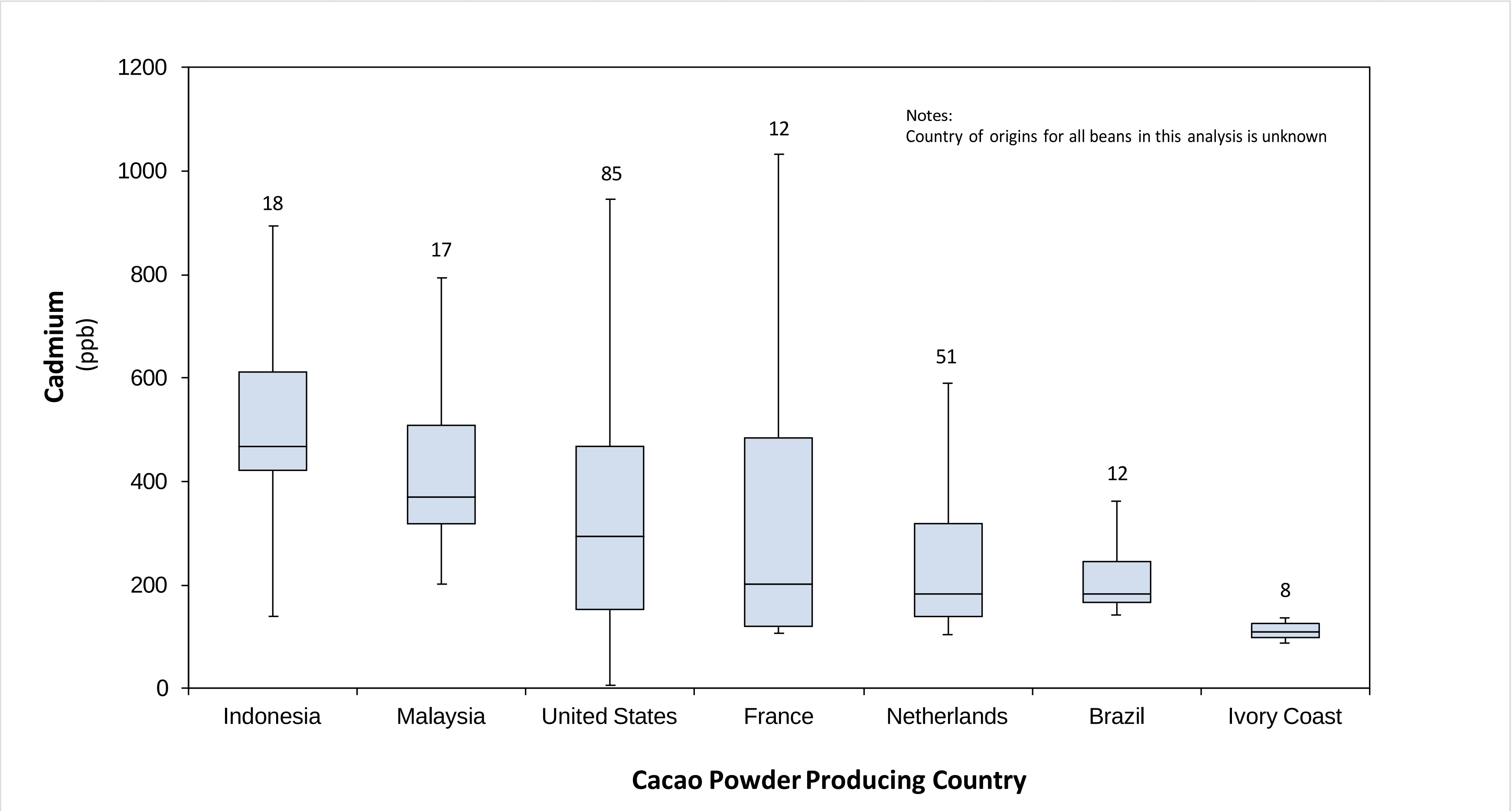
Figure 12. Batch 1 Cocoa Powder Pb Concentrations, by Country of Bean Origin



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- “Whiskers” denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the “whiskers.”

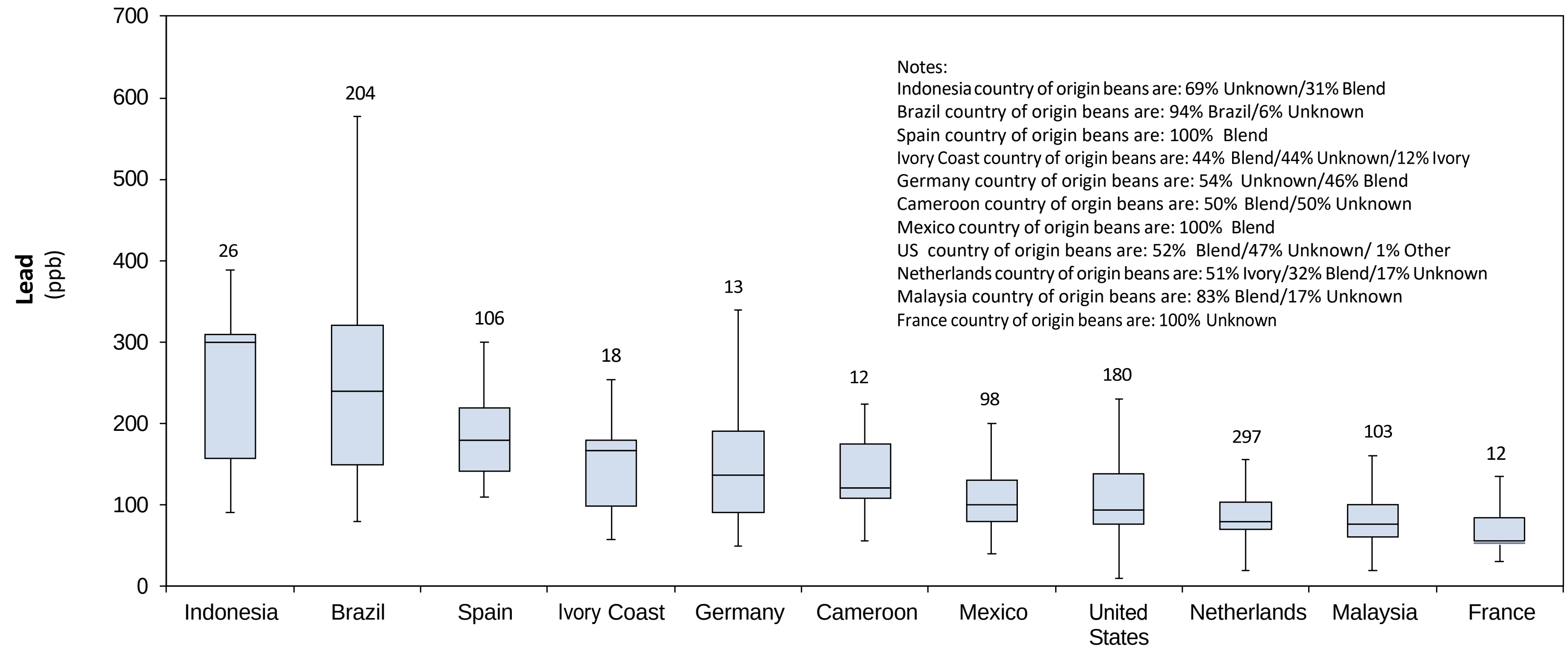
Figure 13. Batch 1 Cocoa Powder Cd Concentrations, by Cocoa Powder Producing Country



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- "Whiskers" denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the "whiskers."

Figure 14. Batch 1 Cocoa Powder Pb Concentrations, by Cocoa Powder Producing Country



Notes:

- Shaded boxes denote interquartile ranges (IQRs).
- Mid-line is the median of the samples; when midline is not showing, the median equals either the 25th quartile or the 75th quartile.
- "Whiskers" denote the upper and lower bound of the interquartile range (median ± 1.5 x IQR).
- Numbers of samples are shown above the "whiskers."

Figure 15. Batch 3 Cd and Pb Concentrations in Separated Shells and Nibs from Whole Cocoa Beans, Based on 2016-2018 SD Testing Data for All Cocoa Growing Regions Combined

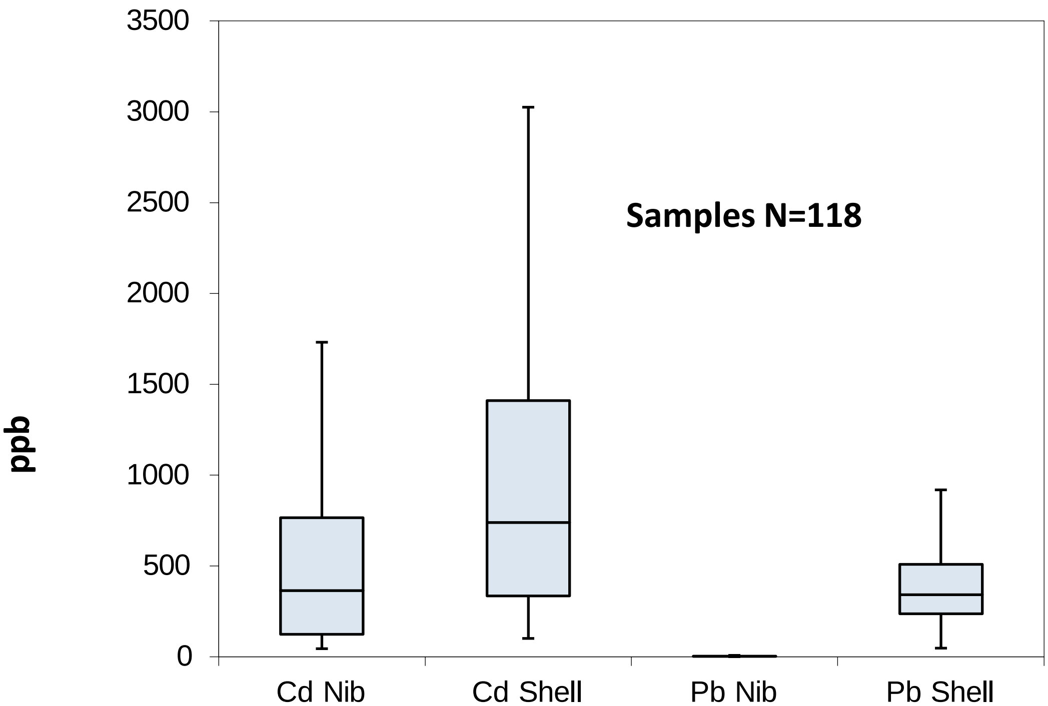
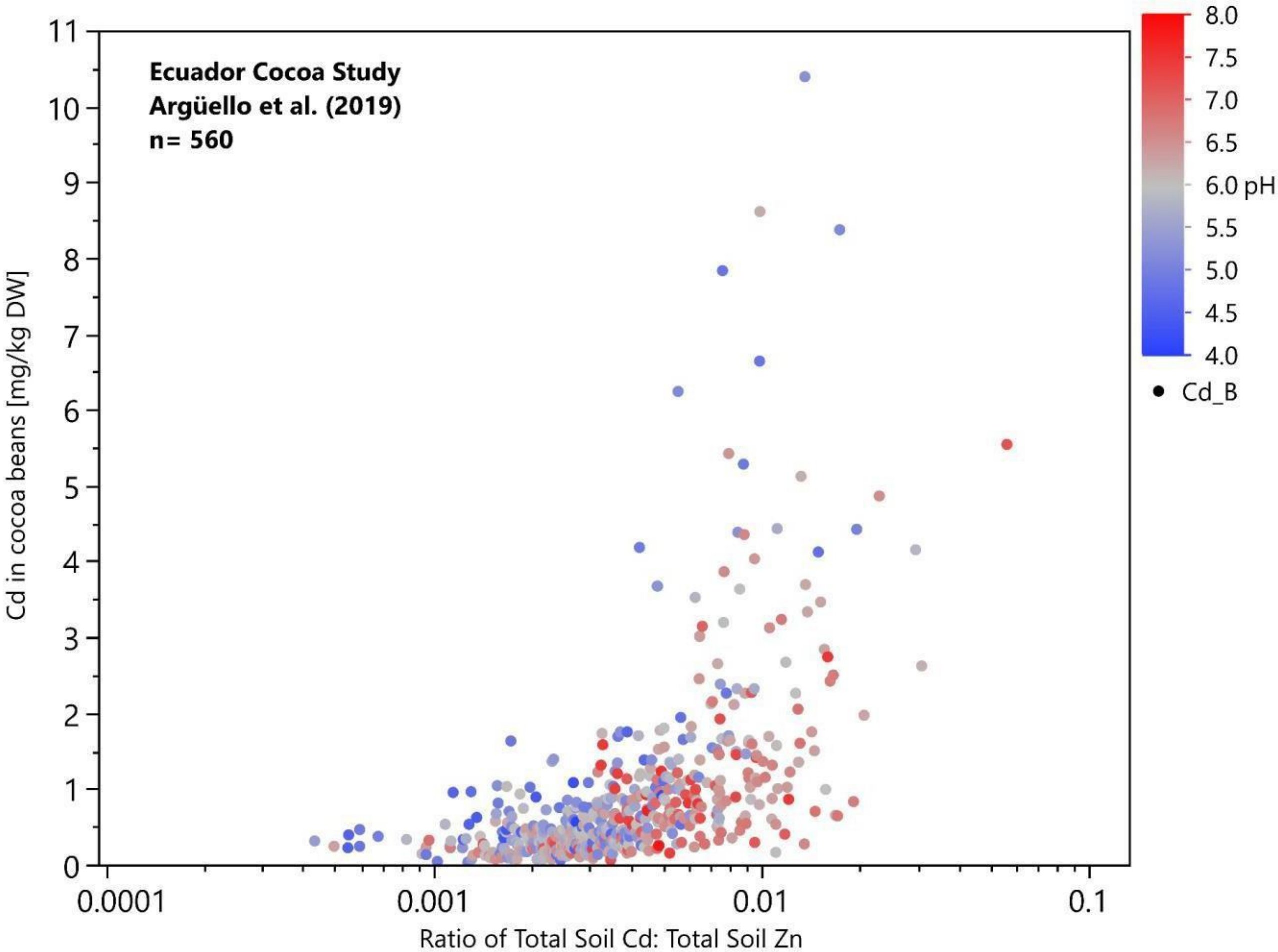
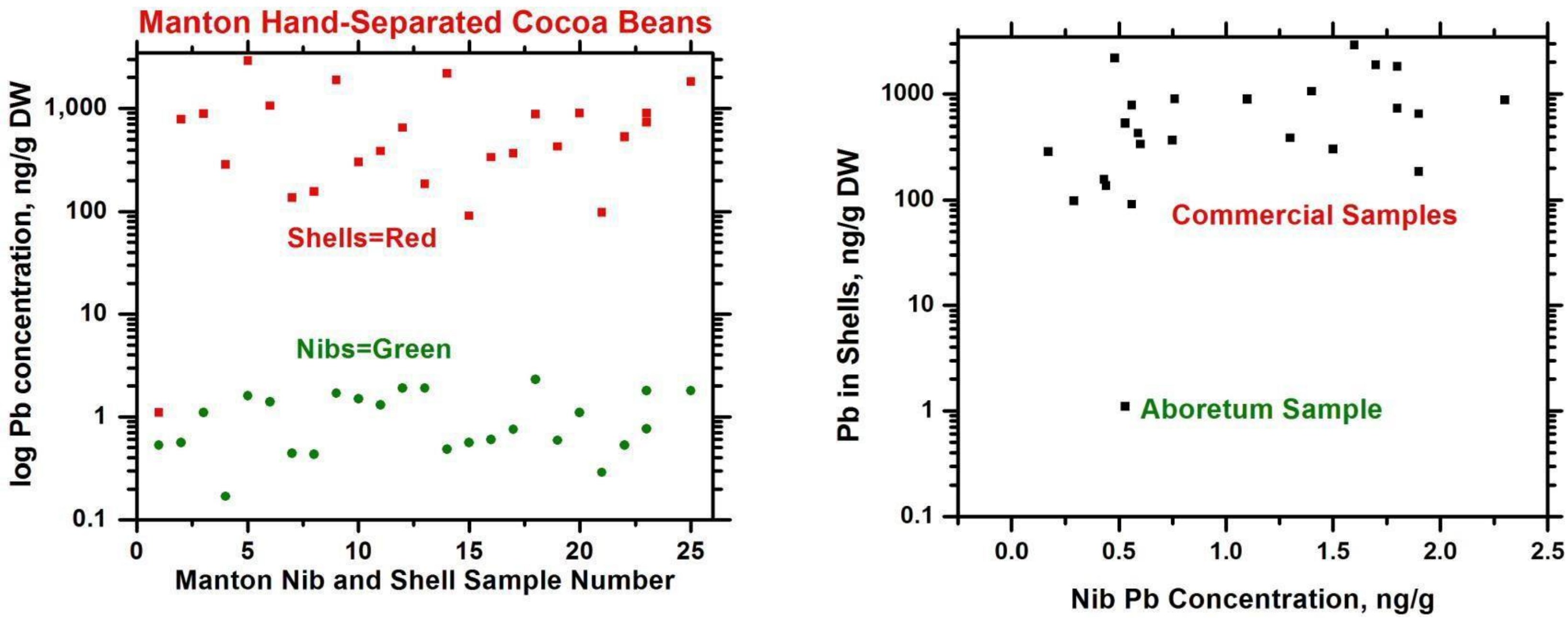


Figure 16. Relationship between Cd in Cocoa Beans and Zn:Cd Ratio in Soils in Ecuador



Data source: Argüello et al., 2019.

Figure 17. Summary of Pb Concentrations in Cocoa Beans Shells and Nibs Measured by Manton (2010)



Notes: Plot on the left shows Pb concentrations in shells (red) and nibs (green) on log scale.
Plot on the right shows Pb concentrations only in shells on log scale. Commercial samples are shown separate from the arboretum sample.

Appendix C. Supplemental Information on Pb in Cocoa

This appendix includes additional supporting information on Pb in cocoa that the Expert Committee considered and prepared when completing the Root Cause Phase report. The appendix is organized into five topics. The information is provided in the event that AYS or the SDs seek additional context on the range of information that the Expert Committee evaluated when reaching this report's conclusions.

C.1 Historical Perspective of Relevant Pb Sampling and Analytical Methods

Before about 1980, many errors in understanding of environmental Pb contamination occurred because tetraethyl lead use in gasoline contaminated settling dusts in urban areas, and because of Pb dusts released from interior Pb-based paints and primers for metal surfaces. Automotive exhausts increased Pb in urban dusts, including those in homes, in manufacturing facilities, and in laboratories, causing universal contamination with Pb. Further, accurate analysis of low concentrations of Pb in cocoa-related samples was difficult due to low Pb concentrations in uncontaminated nibs.

Examples of laboratory analytical methods and certain limitations for trace Pb measurement in cocoa samples follow:

- Simple flame atomic absorption spectroscopy (FAAS) (only valid with deuterium background correction) could not detect Pb in uncontaminated cocoa products
- Graphite furnace atomic absorption spectrometry (GFAAS), anodic stripping voltammetry (ASV), and inductively coupled plasma atomic emission spectrometry (ICP-AES) could measure Pb in some chocolate samples—but were not sensitive enough to measure Pb in uncontaminated cocoa nibs.
- Inductively coupled plasma mass spectrometry (ICP-MS) allowed measurement of low levels of Pb in cocoa products. This method could measure <1 ppb Pb (dry weight) if sufficient sample size was prepared for analysis.
- Thermal ionization mass spectrometry (TI-MS), especially isotope dilution thermal ionization mass spectrometry (ID-TI-MS), could accurately measure very low Pb concentrations and could also help identify Pb sources by measuring stable Pb isotopes in samples. The ID-TI-MS method requires preparation of samples without contamination, separation of the Pb from the sample matrix, and addition of a rare Pb isotope as the tracer or internal standard against which the other isotopes are quantified.

Over the years, many papers reported undetectable Pb, but many of those studies used low sample weights that were diluted to high volumes and used less sensitive analytical methods. For ID-TI-MS, large samples had to be prepared in Pb-free laboratories to allow detection of tracer isotopes used to calibrate the analyses. Best analysis programs include the analysis of Standard Reference Materials; a cocoa powder Standard Reference Material was recently introduced (NIST, 2015).

In recent decades, the U.S. Food and Drug Administration (FDA) has conducted several government programs to analyze metals in foods. In years before perhaps 1990, the methods were usually not sensitive enough to measure the levels of Pb present in chocolate products. Further, Pb contamination in urban laboratories often outweighed the Pb originally present in the food samples (Settle and Patterson, 1980). Patterson developed the use of isotope-dilution mass spectrometry to study Pb biogeochemistry. This development required clean room techniques to prevent sample contamination with Pb, because urban dusts caused extensive Pb contamination in comparison to the Pb levels in foods and pristine environmental samples (Settle and Patterson, 1980; Everson and Patterson, 1980; Patterson, 1980). These problems were revealed in reports of the Total Diet Survey by US-FDA. In earlier years, FDA was focused on radioisotope and pesticide contamination and lumped all collected samples into 12 food groups composited for analysis. More recently, and only after the worst errors in Pb contamination had been identified and addressed, FDA conducted analyses of individual foods. FDA used ASV analysis, then ICP-AES, and finally ICP-MS to conduct food sample analysis for trace elements. As Table 25 shows, FDA sampling results for foods containing cocoa or chocolate have generally found low Pb concentrations.

Important data on Pb in chocolate products came from recent FDA methods development research to accurately measure low levels of Pb in chocolate materials (Gray and Cunningham, 2019; Abt et al., 2018). Gray and Cunningham (2019) conducted an inter-laboratory study of the reliability of the FDA ICP-MS method developed for analyzing trace elements (e.g., Cd, Pb) in foods. One of the samples they used to check whether different labs could obtain correct results was a cocoa powder. FDA reported that its method had an LOD for Pb in the range of 0.004-0.2 ppb and an LOQ for lead in the range of 0.03 to 1.0 ppb. This study demonstrated that the FDA method could measure the trace Pb levels in certain food samples, as the cocoa powder considered in this study contained Pb at 10.4 ppb.

C.2 Review of Selected Scientific Publications on Pb Levels in Cocoa-Related Materials

As Section 4.2.1 explains, the Expert Committee based its "pre-harvest" Root Cause Phase findings for Pb largely on studies that (a) used clean room preparation, (b) appropriately low limits of quantification, and (c) clean preparation techniques to separate nibs from shells to measure Pb concentrations directly from cocoa pods on trees. Only two publications met these criteria. However, the Expert Committee obtained and reviewed many additional publications that did not meet these criteria (see Table 23).

The following list briefly reviews a selection of these other studies. The studies considered various cocoa-related materials, from farm to factory. The studies' findings, therefore, were considered for pre-harvest, harvest, post-harvest, and the manufacturing environment:

- Abt et al. (2018) collected various cocoa-containing food products and prepared them for analysis using the same FDA standard microwave digestion method used by Gray and Cunningham (2019) to mineralize food samples. Abt et al. used an ICP-MS operating in helium collision mode to mitigate polyatomic interferences. To assure quality in their analysis, they used the NIST (2015) Standard Reference Material 2384 (Baking Chocolate; 35.7±4.6 ppb) and in an "in house" cocoa powder reference material (107 ppb). Their LOD for Pb was 1.20 ppb, and their LOQ was 10.9 ppb—notably less sensitive than Gray and Cunningham (2019). Using these methods, Abt et al. (2018) analyzed Pb concentrations in the following materials: 57 dark chocolate products (30±20 ppb; range 2-110 ppb); 41 milk chocolate products (10±10 ppb; range 2-70 ppb); 39 cocoa powders (110±100 ppb; range 2-380 ppb); and 7 cocoa nib samples (3±4 ppb; range <LOD-10 ppb). Of the 7 nib samples, 3 were below the LOD, and 4 were between the LOD and the LOQ. The authors noted that 54 of the overall 154 cocoa product samples had Pb levels between the LOD and LOQ (i.e., trace levels). The low Pb levels in their nib samples support other research that reported "pre-harvest" cocoa nibs contain very low Pb concentrations (see Section 4.2.1). Slight Pb contamination of some raw nibs appears to have occurred. Notably, Pb concentrations in products rose as the fractions of cocoa solids in the products increased.

- Yanus et al. (2014) also used ICP-MS to analyze trace elements, including Pb, in commercial cocoa solids and chocolates collected in Israel. They used a similar microwave digestion method and ICP-MS, including use of ^{115}In as an internal standard to correct for matrix or aspiration variation among samples. They analyzed fractions of cocoa beans and products for Pb, reporting 103±9 ppb in cocoa powder; 67±1.5 ppb in cocoa butter; 1,289±193 ppb in shells; and 40±8 ppb in nibs. In a comparison of brands of chocolate products, they normalized to 70 percent cocoa solids and reported 86±18, 88±4.8, 230±87 and 119±13 ppb in four products. Concentration ranges were not reported for any sample type, and blank samples averaged 5.3±0.3 ng/mL.

- Villa et al. (2014) reported analysis of Pb in 30 samples of chocolates commercialized in Brazil. Measured Pb concentrations ranged from <21 to 138 ppb. They used acid digestion and analyzed Pb using graphite GFAAS. Although GFAAS is a relatively sensitive method, their reported LOQ was 21 ppb.

- An early paper attempted to measure metals in cocoa beans, processing intermediates, and products at a factory in Malaysia (Lee and Low, 1985). Although the dry ashing and use of ICP-MS for analysis would usually suggest useful analyses, the Pb levels reported were remarkable. Pb concentrations in raw and roasted beans exceeded 4,000 ppb; raw shells with 8,000 ppb; raw nibs with 3,300 ppb; roasted nibs with 3,300 ng Pb/g; and high levels in chocolate products. One potential explanation of the unexpectedly high concentrations was Pb contamination of samples—a possibility given that the study was conducted in the 1980s, likely before the phasedown of leaded gasoline in Malaysia. Another potential explanation for the elevated concentrations was laboratory analytical problems.

- Mounicou et al. (2003) analyzed cocoa powder, cocoa liquor, and cocoa butter using ICP-MS after wet acid digestion. They were testing whether multi-element analysis of cocoa samples could identify (fingerprint) the geographic source of the materials. The Pb concentrations ranged from 11 to 769 ppb. Although the authors attempted to characterize the bioavailability of the Cd and Pb in these samples, their methods were not compared to a feeding study, so the methods and interpretations are arbitrary. As has often been reported, nearly all Pb remained with the cocoa powder after pressing to release the cocoa butter. Although Cd and Pb varied among geographical locations, no conclusions could be made about specific geographic sources based on the multi-element analysis data.

- Zarcinas et al. (2004) conducted a geochemical survey of soils across peninsular Malaysia and collected mature edible crops (if available) at the points of soil collection. Across five soil samples, the average Pb concentration was 26,000 ppb, and the range was 18,000 to 38,000 ppb. In the cocoa samples, the average Pb concentration was 290 ppb, and the range was 100 to 1,200 ppb.

- Romero-Estevez et al. (2019) reported Pb levels in cocoa beans from nine production areas in Ecuador. The authors were provided fermented and dried random bean samples by the National Fine Flavor and Aroma Cacao and Coffee Reactivation Project of the Ecuadorian Ministry of Agriculture, Livestock and Fisheries. All samples were processed by microwave digestion and analyzed using GFAAS, but the Pb detection limit was 125 ppb. The Pb concentrations ranged from 502±57 ppb in the Napo production region to 1,966±184 in the Santo Domingo de Los Tsachilas production region. The authors found similar Pb results using AAS and GFAAS. The paper also compared the study's findings to (a) those of Mite et al. (2010) and (b) the Ecuadorian map from the Agency for Regulation and Phytosanitary and Zoosanitary Control. These comparisons revealed little correspondence among the different sampling, although wide ranges in the Agency data (i.e., up to 3,910 ppb in cocoa beans) covered all other results.

- Arvelo-Gardini et al. (2017) reported Pb concentrations in cocoa leaves and beans sampled from Peru's major growing regions. The collected leaves and pods were taken to the laboratory and washed with deionized water. Beans were removed from pods and washed, dried, and ground for analysis. Samples were digested with acids and analyzed by FAAS. Leaves averaged 1,200±320 ppb. Beans were 1,000±670 ppb in Cajamarca and Cuzco to 3,780±390 ppb in Piura. The original paper displays individual results graphically. It is unclear why beans collected from trees by scientists would contain high levels of Pb. One possible explanation for the reported concentrations is that the beans collected for analysis had already undergone fermentation and sun drying in the field.

- Kruszewski et al. (2018) measured Ni, Cd, and Pb in raw cocoa, materials added during manufacturing, and chocolates produced by three manufacturers in Poland. The authors used microwave digestion and GFAAS analysis. The LOD and LOQ for Pb were 0.4 ng/mL and 1.3 ng/mL, respectively. The manufacturers purchased beans from Ecuador and the Dominican Republic. Pb concentrations varied across materials. Beans and shells had 137 and 162 ppb (dry weight); cocoa fat had <1.3 ppb; cocoa powder had 575 and 155 ppb; cocoa mass was 155 and 585 ppb; sugar was <1.3 ppp; and other amendments were also <1.3 ppb. Samples taken from the production processing line contained 279 to 298 ppb (finished chocolate). In another company's production line, beans from Ecuador and Dominican Republic contained, respectively, 127 and 155 ppb at roasting. At Factory Z, Pb concentrations declined remarkably from roasting (127 and 155 ppb) to packaging (<1.3 and 30 ppb).

- Assa et al. (2018) measured levels of Pb and other elements in cocoa beans from South Sulawesi, Indonesia. The authors obtained cocoa beans that had been fermented 5 days in Styrofoam boxes and sun dried for 5 days at the Mars Research Station in Indonesia; and these beans were then analyzed for metals. Interestingly, Pb in nibs was below their detection limit of 100 ppb; but the shells of the three clones sampled contained 9,270, 11,100, and 5,810 ppb, showing extreme Pb contamination of the shells. One possible explanation is that greater vehicular traffic at the Mars Research Station yielded higher Pb contamination of beans during fermentation and drying compared to rural farm roadsides.

- Lo Dico et al. (2018) developed and validated a method for microwave digestion and ICP-MS (with internal standardization) analysis of trace elements in cocoa powder and chocolates. The method had a limit of repeatability of 3.12 ppb and a LOQ of 6 ppb. For 145 cocoa containing products collected across Italy in 2015, cocoa powder contained 417±32 ppb with a range of 49 to 1,228 ppb (dry weight). Chocolates with >50 percent cocoa contained median Pb of 133 ppb, with range 21-616 ppb. Chocolates with >30 but <50 percent cocoa contained median Pb of 170 ppb, with a range of 7-895 ppb. Finally, chocolates with <30 percent cocoa contained median 156 ppb, with a range of 17-545 ppb.

- Arévalo-Gardini et al. (2016; 2017) conducted a soil and plant survey in Peru by in which both Cd and Pb were measured. The soils in the cocoa plantation were not contaminated with Pb; mean soil total Pb was 10,700 ppb (range 5,500-21,800 ppb). The authors also evaluated how Pb concentrations vary with depth in the soil profile and found little evidence of accumulation in the topsoil layer: soil Pb was 11,700 ppb in the 0-5 cm depth and 10,000 ppb at 60-80 cm depth. The composition of cocoa beans and leaves were reported graphically in Arévalo-Gardini et al. (2017). The beans were not fermented and were oven dried before preparation for analysis. Leaf Pb concentrations were 1.2-2.5 ppb, and bean Pb levels were 0.8-3.3 ppb. Beans from Cajamarca were lowest (at 1.0±0.67 ppb) while beans from Piura were highest (at 3.78±0.39 ppb). Levels of Pb in leaves and beans were not significantly correlated. Because beans collected cleanly in the field and separated under clean conditions for analysis show very low Pb levels in nibs or shell, one possible explanation for the Pb levels found in the beans was that they were contaminated somewhere in the collection and analysis, though the publications provide no evidence of this.

- Ubilla et al. (2018) sampled 25 organic cocoa producers in the Vinces canton of Ecuador and measured Cd and Pb in the nibs and shells. The authors collected pods and prepared the beans by fermentation and then sun drying near the laboratory. The authors reported using AAS but did not provide details on detection limits. The bean Pb varied between non-detect and 5,400 ppb, while shell Pb varied between 210 and 7,580 ng Pb/g.

- Aikpokpodion et al. (2013) reported analyses of Pb and other elements in cocoa beans collected from plantations in Nigeria. Unfortunately, this work shows problems with inadequate analysis methodology. The authors collected ripe pods from trees in several provinces and analyzed Pb by flame AAS. Beans were reported to contain Pb at the following concentrations: 1,250±1,030 ppb (range of 400-3,450 ppb) for Ogun State; 1,970±1,100 ppb (range of 850-3,100 ppb) for Ondo State; and 1,660±1,640 ppb (range of 400-2,700 ppb) for Cross River State. However, based on the reported methodology and use of FAAS, the authors could not have detected "normal" Pb levels in pristine cocoa beans. The authors reported collecting intact pods in the field, and the beans were subsequently fermented at the University experimental fermentation unit for 6 days and dried. There is no apparent reason for these high Pb levels except error in analysis and contamination during sample preparation (e.g., Pb-based paint could have contaminated the fermentation unit). Note that the concentrations reported in this study are markedly higher than those reported by Rankin et al. (2005) for Nigerian beans. As Section 4.2.1 describes, the Rankin publication used appropriate sample preparation and laboratory analytical methods for cocoa bean analyses.

- Huamaní-Yupanqui et al. (2012) reported on Cd and Pb concentrations in soils and cocoa leaves and beans from some organic cocoa producers in Ecuador. Soil Pb concentrations (3,020 ppb, dry weight) and leaf Pb concentrations (580 ppb, dry weight) were within the normal range.

- Nartey et al. (2012) collected samples of soils, fertilizers, and cocoa beans from trees in unfertilized and chemically fertilized cocoa farms in Western Ghana. The authors analyzed metals using flame AAS. Pb concentrations in the fertilizers were low, as expected, as were Pb levels in the soils. The cocoa nibs contained Pb at 82 ppb (range 50-160 ppb), and the shells contained 1,610 ppb (range 560-3,510 ppb). It is difficult to understand these high Pb levels if the cocoa beans were collected directly from the trees.

- In a master's degree thesis, Danquah (2015) researched metals in cocoa from Ghana. Fermented cocoa beans were obtained from the marketing Ghana Cocoa Board from multiple locations within four cocoa production regions. The study also considered 1 kg of fermented organic beans from organic farms. All beans were processed in a microwave digestion system, and Pb was measured using GFAAS. The method had a reported sensitivity of 10 ppb in analysis of digested cocoa samples. Mean Pb in cocoa beans varied across regions. In beans from Brong Ahafo, average Pb was 84 ppb, with a range of 60 to 100 ppb. In beans from the Western region, average Pb was below the detection limit (<10 ppb). For beans obtained near mining districts, Pb concentrations ranged from non-detect to 83 ppb. Beans from organic farms were found to have lower Pb concentrations (mean of 22 ppb, and range of 10 to 30 ppb) than beans from conventional farms (mean of 48 ppb, and range of 30 to 60 ppb). This concentration difference was reported to be statistically significant ($p < 0.05$). Samples were also collected from a cocoa processing factor in Ghana. Pb was not detected in the cocoa butter, cocoa liquor, cocoa nib, and chocolate samples (detection limit of 10 ppb); but Pb was measured in cocoa shells (283±12 ppb) and cocoa powder (220±82 ppb).

- The SDs provided the Expert Committee a database of Cd and Pb analyses of cocoa beans and other cocoa-related materials. Section 2 describes the Expert Committee's assessment of the SD data, and the following list summarizes Pb measurements for different materials:

  - The SD data include 1,222 cocoa bean samples with Pb analyses. Nearly every sample had Pb concentrations below 100 ppb, dry weight. Two samples, both from the Ivory Coast, contained Pb concentrations greater than 500 ppb, dry weight; and 43 samples had Pb levels between 100 and 500 ppb, dry weight. These 43 samples came from Ivory Coast (6), Tanzania (5), Ecuador (23), Nigeria (4), Venezuela (2), Trinidad (2), and Dominican Republic (1). However, sample sizes varied from one country of origin to the next. The percentage of samples from each country that cocoa bean Pb concentrations greater than 100 ppb were: Ivory Coast (3.5%), Tanzania (26.3%), Nigeria (14.8%), Venezuela (18%), Trinidad (20%), Ecuador (3.2%), and Dominican Republic (1%). From these data, and other considerations presented earlier in this report, commercial cocoa beans from some countries are contaminated with Pb post-harvest.

  - The SD data included results from 107 cocoa butter samples. These were analyzed by ICP-MS to yield appropriate LODs, though specific LODs varied among laboratories. Most samples (i.e., 96 out of the 107 samples) had Pb concentrations that were non-detect or less than 10 ppb; 18 of the samples contained Pb between 10 and 100 ppb; and 2 contained more than 100 ppb of Pb. Because Pb^{2+} ions are not soluble in lipids, it is likely that this cocoa butter contamination is due to Pb particulate (i.e., shell or soil particles).

  - The SD data also included results for "cocoa powder, ingredient." Among the 1,217 samples with this descriptor, 46.6 percent had Pb concentrations less than 100 ppb; 34.3 percent had Pb concentrations between 100 and 200 ppb; 17.1 percent had Pb concentrations between 200 and 500 ppb; and 1.5 percent had Pb concentrations greater than 500 ppb. Considering the low Pb levels in "pre-harvest" beans, these "cocoa powder, ingredient" data clearly indicate that Pb contamination occurred between the tree and the point where the cocoa powder is formed.

  - The SD data included results for chocolate products of different cocoa solid content. Pb levels in chocolate products with >95 percent cocoa solids were anomalous compared to Pb levels in cocoa powder. Of the 76 samples reported for >95 percent cocoa solids, 38.2 percent had Pb concentrations less than or equal to 50 ppb; 52.6 percent had Pb concentrations between 50 and 100 ppb; and 9.2 percent had Pb concentrations greater than 100 ppb. A greater number of samples (916) were provided for chocolate products with cocoa solid content less than or equal to 65 percent. The breakdown of Pb contamination levels for these 916 samples was: 27.4 percent had Pb concentrations below 10 ppb; 43.7 percent had Pb concentrations between 10 and 20 ppb; 12.9 percent had Pb concentrations between 20 and 30 ppb; 9.7 percent had Pb concentrations between 30 and 40 ppb; and 3.6 percent had Pb concentrations greater than 50 ppb.

- FDA has conducted analysis of Pb concentrations in food products as marketed since about 1970. Table 25 summarizes selected results of FDA analyses for various cocoa-containing food items.

- An otherwise unpublished BS thesis from a Massachusetts Institute of Technology student reported a test of Pb levels and isotope ratios in chocolates marketed as "single source" products sold in the Boston area (Thompson, 2007). The author measured Pb and Pb isotope ratios using appropriate techniques in a clean geochemistry lab. The cocoa bean samples were very low in Pb, but some chocolates exceeded the FDA candy Pb limit; and the author noted an FDA recall of Dagoba chocolates in 2006. The author compared the measured data to literature information about isotope ratios in atmospheric particles and in rocks and soils from the regions where the single source chocolates were reportedly grown. The Pb ratios in chocolate products were between aerosol Pb and soil Pb ratios. Based on this, the author inferred that Pb contamination occurred after harvest but before manufacturing of chocolate. Two soil samples were obtained from Venezuela, but these were clearly not from an area where fermented cocoa beans would be sun dried. Therefore, the results of those soil samples were not relevant to this project's research questions.

C.3 Understanding of Pb Uptake in Selected Non-Cocoa Crops

Section 4.2.4 indicates that fruiting crops, seed crops, and tubers have very low ability to transfer plant-root-absorbed Pb to storage tissues used as food. This section presents additional information on Pb plant uptake observed in a broader range of non-cocoa crops.

Two major crop groups can carry significant levels of Pb when the crop is grown in Pb contaminated soils. These are (1) expanded hypocotyl "root" crops (e.g., carrot, radish) and (2) low growing leafy vegetables and herbs. Although some Pb is absorbed from the soil solution by roots of all crops, most of the initially absorbed Pb entering the epidermal cells is immediately precipitated in the epidermal root cells as Pb-phosphate (e.g., Malone et al., 1974; Kopittke et al., 2008a). Crops efficiently absorb phosphate from soils, and internal crop phosphate can react with Pb to form precipitates within the plant cells and transport channels even when the soluble phosphate is not high enough to form insoluble Pb compounds in the soil. Plant roots can secrete organic acids and protons into their rhizosphere to solubilize phosphate for improved uptake; the plant root-solubilized phosphate can react with external Pb to form pyromorphite in the rhizosphere (Cotter-Howells et al., 1999).

Crops grown on soils with very high Pb levels are able to transport some Pb into the xylem from the root system, and the translocated Pb enters stems and leaves at detectable increased levels. This was demonstrated in a study of corn grown on Pb salt spiked field soils (Baumhardt and Welch, 1972). In that study, a range of Pb concentrations were applied to a field in Illinois, with levels reaching 3,200 kg Pb/ha. The highest treatment had 27,600 ppb (dry weight) in corn diagnostic leaves, and 400 ppb (dry weight) in grain at harvest. Pb application amounts had no impact on Pb concentration in the grain. This research was not done under "clean room" sample preparation conditions, so all Pb measurements were likely over-estimated. Nonetheless, the extremely low transfer to grain is an example of the important role of Pb retention in plant tissues before reaching grain.

For the low-growing leafy and herb vegetable group, the most important Pb source in the edible crops has been shown to be soil particles adhering to leaves. Although this has been widely recognized for decades (with strong warnings to wash urban garden crops carefully), a recent study of New York City gardens illustrates the principles especially well. That study found that some leafy vegetables and leafy herbs often had higher than background Pb levels. Because soil splash can contaminate these crops, methods have been developed to estimate the soil content of crops. Cary and Kubota (1990) examined Cr accumulation by vegetation growing on a serpentine soil which contained over 10,000,000 ppb Cr. By measuring titanium (Ti) in both soil and crop, they could estimate the level of soil contamination of the leaves. TiO_2 has very low water solubility and essentially no uptake by plants and has been used as a "soil tracer" to investigate soil ingestion by grazing livestock for many years. Because soil Cr^{3+} also has very low solubility, little can be absorbed by roots. Cary and Kubota found that the estimated soil on the leaves, based on Ti levels, supplied all of the Cr in the plant shoots. Cary et al. (1984) applied those methods to vegetable crops and showed important soil contamination of several garden crops; they found that the levels of Ti, Fe, and Al in harvested garden leafy crops could be explained by the soil contamination of these crops. Because they used Ti as the "soil tracer" element, they had to either dissolve all of the metals in the crop with strong acids, or use X-Ray Absorption analysis of the Ti. In the more recent studies noted above in New York City gardens, McBride et al. (2014) measured Pb, Al, and Fe in urban garden leafy crops and found crop Pb was hardly correlated with soil Pb, but very well correlated with soil Fe and Al. Those researchers used Fe and Al as "soil contamination tracers" for urban garden crops. Although leafy vegetables and herbs can accumulate some Pb from soils, Pb levels in these crops remain comparatively very low unless the crops are grown in Pb rich soils where soil splash causes the crop Pb contamination. This shows that crops grown in gardens with high Pb levels are contaminated principally with soil/dust Pb adhering to the large leaf surface rather than through root uptake and translocation through the xylem. The greater the height of the sampled plant tissue is above the soil surface, the lower the soil contamination of that tissue has been found to be.

Another crop group is the "expanded hypocotyl root crops," such as carrot, radish, and turnip. The xylem (within the "core") of these crops goes thru the center of the edible root, surrounded by the cortex, with a lipophilic peel layer on the outside of the crop. Lipophilic xenobiotics (e.g., DDT, PCBs) can be accumulated in the peel layer. Some root-absorbed Pb is precipitated within the xylem, which is within the peeled carrot. Well-washed carrots have little Pb in the cortex, with slightly more in the peel. But most Pb in harvested carrots is accumulated inside the internal xylem channels. Codling et al. (2015) measured Pb in whole washed carrots grown on old orchard soils that contained high Pb levels (see Table 27). Subsequently Chaney et al. (2010) examined the localization of Pb within the carrot using Extended X-ray Analysis Fine Structure (EXAFS) and found that nearly all Pb in carrots grown on old orchard soils was located within the xylem part of the carrot.

Another lesson from study of crop Pb comes from testing of alternative crops for contaminated orchard soils. Orchards of apple, pear, and cherry were sprayed with lead arsenate as a pesticide from about 1900 to 1950 when DDT replaced Pb arsenate (Peryea, 2001). Very high levels of Pb and As accumulated in these soils. Because of shifting location of production of the tree fruit crops, conversion to other contracted food processing crops was a common goal of growers. But if they can't grow crops that might become Pb contaminated from these Pb rich soils, what else could they grow? Creger and Peryea (1992) conducted a field experiment with apricot and apple replanted on old orchard soils and found that although leaves did accumulate a little Pb, the fruits remained at non-detect levels. Peryea (2001) reviewed many aspects of the contaminated fruit tree orchard problems.

C.4 Pb Accumulation Processes in Plants

Plant roots can only accumulate soluble Pb^{2+} ions from the soil solution. But Pb^{2+} is very strongly adsorbed or precipitated (e.g., chloropyromorphite) in soils such that the low amount of soluble Pb^{2+} ions limits uptake. The epidermal cells of the plant roots can absorb soluble Pb^{2+} ions, and it is believed that Pb^{2+} ions enter on the Ca^{2+} transporter of epidermal cell membranes. Higher levels of Ca^{2+} inhibit Pb^{2+} uptake. But to study Pb^{2+} by roots thoroughly, one must use nutrient solutions with minimal phosphate or sulfate. These anions precipitate Pb, especially phosphate. Actually, additions of phosphate to Pb-contaminated soils is a technology used to reduce Pb uptake by all plants, and to convert the soil Pb into chloro-pyromorphite [$Pb_5(PO_4)_3Cl$], a highly insoluble Pb compound (Scheckel et al., 2014; Karna et al., 2018). Reviews of the chemical forms of Pb in soils have been published in recent years. These reviews clearly show the chemical reactions that make Pb have such low solubility. Also, as noted above, roots work to dissolve soil phosphate and that can cause formation of chloropyromorphite in their rhizosphere (Cotter-Howells et al., 1999).

But it is clear that if nutrient solutions are deficient in phosphate, plants can absorb and even translocate high amounts of Pb into their shoots. This was reviewed by Koeppe (1981). Malone et al. (1974) reported research with corn grown in nutrient solutions. When Pb was added to a solution with traditional high levels of phosphate, added Pb formed a layer of precipitate on roots, and formed Pb-phosphate within the root cells; some of that Pb was subsequently excreted to the root cell membrane.

Recent detailed research by Kopittke et al. (2008a) used modern methods to examine the localization of Pb after uptake by roots, and the chemical forms of Pb observed in roots. They used nutrient solutions with low but maintained concentration of phosphate which simulated soil solution (Kopittke et al., 2008b). They developed nutrient solutions which maintained low chemical activity of Pb^{2+} ions with maintained activities of phosphate, calcium and other nutrients. They observed that Pb could be absorbed by epidermal cells, but upon absorption the Pb reacted with cell accumulated phosphate to largely generate pyromorphite, the Pb mineral with very low solubility. Over hours to days, part of that Pb precipitate was actually excreted from the root cells. They could identify the chemical form of Pb in the root cells using EXAFS, the synchrotron radiation technique that can identify chemical forms of metals in plant tissues, and show its localization within a few microns. The conclusion regarding Pb uptake by roots is that some can be absorbed if it is soluble in the soil, but that most is trapped in the epidermal cells and little reaches the xylem for transport to shoots. And in the case of cocoa, hardly any Pb enters the cocoa beans on the tree (e.g., Manton, 2010).

C.5 Localization of Pb within Cocoa Beans

As Section 4.2 explains, cocoa nibs harvested under "clean" conditions, prepared for analysis under "clean room" conditions, and analyzed using sufficiently sensitive methods have Pb concentrations on the order of 1 ppb; whereas shells from these same beans have considerably higher Pb concentrations (Manton, 2010).

Recently a new technique was applied to the localization question, the Laser-Ablation-Inductively Coupled Plasma-triple quadropole mass spectrometry (LA-ICP-TQMS). A focused laser is passed across a prepared flat cocoa bean cross-section surface. The materials volatilized by the laser are aspirated into and separated by the mass spectrometer and the localization demonstrated in maps of distribution of Pb, Cd, and other elements. Thyssen et al. (2018) used this method to examine element distribution in cocoa beans. They obtained a commercial cocoa bean grown in Colombia, fermented six days, and dried before shipping to Germany. As expected, the Pb concentration in the shell was much greater than in the nib (their Figures 3 and 4), distinctly different from the localization of Cd in the same samples (the distribution of Cd and Pb are contrasted in their Figure 5). The authors did not measure total concentrations of Cd and Pb in their cocoa bean samples. Because this sample was a commercial cocoa bean that had been fermented and dried in Colombia before being shipped to Germany, the high levels of Pb in the outer shell likely reflect the contamination of the bean post harvest.

If one considers the alternative hypothesis of the shell adsorbing Pb from soils onto charged cation binding sites of the shell surface at the locations where the beans were dried (based on Meunier et al., 2003 as interpreted by Rankin et al., 2005), one should consider that the soil would adsorb Cd less strongly and likely obtain higher "Ca-exchangeable" soil Cd^{2+} than Pb^{2+}. As a result, one would expect higher Cd at the shell than Pb, if this was the technical process that increased Pb in commercial cocoa shell. But it was clear that shell was much higher in Pb than Cd. These questions can only be settled by similar testing of clean sampled beans from the tree compared to commercial beans, as noted above. In the case of clean sampled beans, Cd in the shell should be much higher than Pb in the shell layer, and Cd would be distributed throughout the nibs. In the bean pod, Cd is much more soluble than Pb, and Pb is likely precipitated by phosphate along the translocation pathways feeding bean development.

Present hypotheses on how commercial cocoa shells contain higher levels of Pb than nibs include: (1) for clean sampled shell, Pb arrived in the phloem fluid which feeds the developing seeds but is mostly precipitated at the shell; (2) Pb^{2+} ions (e.g., from soil, environment) are chemisorbed onto charged sites of the shell; and (3) the agglomeration of soil particles rich in Pb from local contamination of drying area soils onto the shell during drying of the kernels post fermentation. The wet sticky fermented mucilage on the surface of shells is likely to bind fine soil particles during the drying process if they are in contact with soil particles rather than a plastic tarp or other inert low Pb (dust free) drying surface.

One hypothesis for the accumulation of high levels of Pb by cocoa shells is that chemisorption of soluble soil Pb occurs onto charged sites in the shell. Meunier et al. (2003) tested use of waste cocoa shells as an adsorbent to remove Pb from Pb salt solutions with model studies in the laboratory. Such studies are not relevant to cocoa shell accumulating Pb from soil solution by exchange or adsorption processes. Valid tests with soil as the Pb source for possible chemisorption of Pb by shell have not been reported. But several research groups have tested removal of Pb and other metals from aqueous solutions by adsorption on ground cocoa shell. Because soluble Pb compounds are used in testing the adsorption process, high Pb sorption was observed (e.g., Meunier et al., 2003). But when Pb is at equilibrium in soils, the soluble fraction of soil Pb able to rapidly react with—and become adsorbed chemically on the shell surface—is quite low, which would restrict any adsorption of soil Pb from soil particles and soil solution. But as noted above, at the levels of soil exchangeable Cd which cause high Cd in beans, the shell would be expected to be strongly enriched in Cd, which is not observed (shell Cd is similar to nib Cd levels). These shell Cd vs. nib Cd data clearly contradict the shell "adsorption of Pb from soil" hypothesis rather than adherence of soil particles.

Thus, soil particle adherence with mucilage residue on shells of cocoa beans is the simple direct cause of increased Pb concentration in commercial cocoa beans and many chocolate products. The highly variable levels of Pb in bean drying soils, and variable soil contact on different farms, contributes to the variability of Pb in beans.

Appendix D. Expert Committee's Sampling Data Collected in Ecuador

As part of their Root Cause Phase research, the Expert Committee members travelled to Guayaquil, Ecuador, to view various in-country cocoa farming and bean processing operations. On November 18, 2019, the experts toured a cocoa farm and a "market" where local farmers delivered cocoa beans for fermentation and drying. The experts collected soil samples and cocoa bean samples from both locations. This appendix describes the sampling methods and results.

Prior to travelling to Ecuador, the Expert Committee prepared a sampling plan that outlined all proposed details for sample collection and analysis. The Expert Committee followed this plan during their travels. An overview of the sampling follows:

- **Sample collection at the farm in Ecuador.** While touring a farm outside of Guayaquil, the Expert Committee members focused their sampling at three cocoa trees, where they collected soil samples and cocoa pods. The three trees were located at least 20 meters apart. At each tree, an Expert Committee member first collected three cocoa pods, which were cut from the tree and transferred to a sealable plastic bag. This expert also collected three soil samples. For each soil sample, the expert scraped the organic layer to the side to allow sampling of mineral soil only, used a tube sampler to collect the top 5 cm of soil, removed the tube from the soil, separated the top 2.5 cm from the rest of the soil in the tube, and transferred the top 2.5 cm of soil into a sealable plastic bag; the three soil samples from beneath a given tree were placed into the same plastic bag.

- **Sample collection at the "market" in Ecuador.** After touring the farm, the Expert Committee members toured a small "market" that received beans from local farms for fermentation and drying, prior to shipping the cocoa beans to an exporter company. At this "market," the Expert Committee collected cocoa bean samples at different stages in the fermentation and drying process. Some beans had just arrived at the "market" and had not been completely fermented, whereas other beans had been at the market several days and were nearly completely dried. The bean samples were collected with a gloved hand from fermentation bags, drying surfaces, and the ground. Soil samples at the "market" were sandy material along the driveway where vehicles entered the "market" to drop off beans. All samples were immediately labeled and placed in sealable plastic bags.

- **Sample processing at laboratory in Ecuador.** The Expert Committee members hand-carried all samples from the field to a laboratory at Escuela Superior Politecnica del Litoral (ESPOL), a public university in Guayaquil. There, the Expert Committee members processed cocoa bean samples by breaking open pods, scooping beans with a gloved hand into a plastic colander, and rinsing mucilage from beans using deionized water. All beans from a given tree were then placed into an aluminum tray, which was then sealed in a plastic bag. The bean samples were dried in an oven at ESPOL and refrigerated prior to shipment to the United States for analysis.

  The Expert Committee members also processed soil samples at the ESPOL laboratory. Using a gloved hand, an Expert Committee member broke up each soil sample in the plastic sampling bag before pouring the contents onto a clean plastic sheet. The samples were then passed through a stainless steel soil sieve (2 mm) before being placed in a new plastic sealable bag. The soil samples were dried in an oven at ESPOL and then refrigerated prior to shipment to the United States for analysis.

  While at the laboratory, the Project Manager affixed labels to all samples and completed chain-of-custody forms for the analysis.

- **Sample analysis by laboratory in United States.** After sample collection, the Expert Committee left the soil and bean samples in the custody of Dr. Eduardo Chavez (ESPOL). Dr. Chavez shipped the samples via Federal Express to Eurofins Frontier Global Sciences Inc. in Bothell, Washington. The samples were later transferred to ALS Group USA for analysis by ICP-MS. Every sample was analyzed for concentrations of Al, Cd, Fe, and Pb according to EPA Method 6020A. The Project Manager received the sampling results on February 13, 2020; and he forwarded the results to the Expert

Committee members. Electronic copies of the sampling results, chain-of-custody forms, and sampling plan are available upon request.

- **Results.** The following tables present the sample results, exactly as communicated by the analytical laboratory.

Table D-1. Expert Committee Sampling Results from Cocoa Farm in Ecuador

Sample ID	Matrix	Concentration (mg/kg)			
		Al	Cd	Fe	Pb
Tree 1 – bean	Cocoa bean	3.2	0.725	30.7	0.004 J
Tree 2 – bean	Cocoa bean	1.7 J	1.12	27.6	0.015 J
Tree 3 – bean	Cocoa bean	1.9 J	1.06	29.5	0.007 J
Tree 1 – soil	Soil	13,700	1.47	31,200	19.8
Tree 2 – soil	Soil	14,900	1.21	33,200	19.4
Tree 3 - soil	Soil	18,800	1.40	36,400	23.1

Table D-2. Expert Committee Sampling Results from Cocoa Bean "Market" in Ecuador

Sample ID	Matrix	Concentration (mg/kg)			
		Al	Cd	Fe	Pb
Market - 1A	Cocoa bean	93.3	0.912	111	0.043
Market - 1B	Cocoa bean	133	1.26	143	0.040
Market - 1C	Cocoa bean	76.3	1.06	91.5	0.047
Market - 2A	Cocoa bean	77.8	1.17	120	0.047
Market - 2B	Cocoa bean	116	0.902	122	0.097
Market - 2C	Cocoa bean	83.8	0.676	81.2	0.040
Market - 3A	Cocoa bean	9.0	0.260	34.3	0.006 J
Market - 3B	Cocoa bean	6.9	0.371	30.3	0.004 J
Market - 4A	Cocoa bean	419	1.33	341	0.216
Market - 4B	Cocoa bean	704	1.11	603	0.251
Market - 5A	Cocoa bean	17.9	1.57	35.0	0.014 J
Market - 5B	Cocoa bean	12.7	1.34	29.7	0.007 J
Market - Soil 1	Soil	8,670	0.804	17,400	7.87
Market - Soil 2	Soil	8,340	0.287	22,500	7.38
Market - Soil 3	Soil	8,030	0.213	21,600	6.04

Descriptions of "Market" cocoa bean samples:

- Market 1 - These beans were collected from bags near the "market" entrance; the beans had been at the market for 3-4 days and had already fermented but not dried.
- Market 2 - These beans were collected from the drying area; the beans had already fermented; they had been drying for close to 3 days. The beans were ready for transport, after one more day of sun drying.
- Market 3 - These beans were collected from bags that were in the bed of a pickup truck that had recently arrived at the "market"; the beans were partially fermented.
- Market 4 - These beans had recently arrived from farms, but they were picked up from the ground surface (and were not in bags).
- Market 5 - These beans had also recently arrived from farms, but the beans were still in canvas bags at the market; and the beans were not in contact with the ground surface.

Attachment 2: Reductions Recommendations Report

Version 1 of the Experts' Reductions Recommendations Report was submitted to AYS and the SDs on April 12, 2021.

When preparing the Phase 3 report, some Experts noted revisions that were needed to this draft. First, the text descriptor for "magnitude of reduction" ratings in Tables B-14, B-19, B-20, and B-21 were changed from "Unknown" to "Unknown or not quantifiable." Second, the text descriptor for a "magnitude of reduction" rating in Table B-22 was changed from "D" to "Unknown or not quantifiable." Those errors have been corrected, and the Reductions Recommendations Report in this attachment is referred to as Version 2.0 and is dated March 2022.

Clarifications and additional text were included in the following paragraphs:

- In Section 4.1.5.2, a new paragraph was added at the end of the "Background" section.
- In Section 4.3.2, a text edit was included in the first paragraph of the "Background" section.
- In Section 4.3.6, two sentences were added at the end of the second paragraph of the "Background" section.
- The "PbBAP" abbreviation was replaced with "Pb-BAP" throughout.
- A note was added beneath Table 5 in Section 5.2.1.
- One Expert submitted an additional Pb research recommendation and Cd research recommendation, which have been added to the end of Sections 7.1 and 7.2, respectively.
- Two text edits were incorporated in Section 7.2.

The final paragraph in Section 2.3 was revised to explain the difference between the report versions and to remove the reference to the report being a "draft." Additionally, all headers were changed from "Version 1" to "Version 2.0."

Expert Investigation Related to Cocoa and Chocolate Products:

Reductions Recommendations Report

Submitted to:

As You Sow and the Settling Defendants

Submitted by:

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Note: All authors contributed equally to the development of this report. The authors' names are listed alphabetically.

March 2022

CONTENTS

List of Abbreviations

AYS	As You Sow
BAP	better agricultural practice
Cd	cadmium
CGIAR	Consultative Group for International Agricultural Research
CODEX	Short for Codex Alimentarius, a collection of food safety standards, guidelines, and codes
EU	European Union
FDA	Food and Drug Administration
Fe	iron
GFSI	Global Food Safety Initiative
GMO	genetically modified organism
GMP	good manufacturing practice
MADL	Maximum Allowable Dose Levels under Proposition 65
Mn	manganese
NGO	non-governmental organization
OEHHA	Office of Environmental Health Hazard Assessment
Pb	lead
Pb-BAP	better agricultural practice for Pb reductions
PPE	personal protective equipment
QA	quality assurance
SDs	Settling Defendants
SIN	shell-in-nib
TTT	train-the-trainer
USDA	United States Department of Agriculture
Zn	zinc

1.0 Executive Summary

In this second report, the Expert Committee was charged with identifying, evaluating, and recommending "feasible" strategies to reduce cadmium (Cd) and lead (Pb) concentrations in chocolate products while considering all phases of chocolate production, from farm to factory. Feasibility as defined in the Consent Judgment means "capable of being accomplished in a successful manner within a reasonable period of time, taking into account public health, and economic, environmental, social, and technological factors." In addition, the Expert Committee was charged with evaluating each strategy based on scalability, meaning whether the strategy could be implemented within the range of capabilities across the chocolate producing spectrum relative to the size and resources available to the potential implementing entities.

The Expert Committee identified 30 potential Cd and Pb reduction strategies from the available literature (e.g., CAOBISCO/ECA/FCC, 2015; CODEX, 2020; Meter et al., 2019) and from its own deliberations. Nearly every strategy evaluated would directly or indirectly reduce Cd or Pb concentrations and therefore would result in a public (consumer) health benefit due to measurable reductions of Cd and/or Pb in consumable chocolate products. Furthermore, the Expert Committee agreed that each strategy would be proposed as alternatives to providing warning labels or notification as required under Proposition 65; therefore Proposition 65 warning requirements were not included in the strategy list.

The 30 proposed strategies were grouped according to whether the primary reduction measure was for Cd, Pb, or both, targeting three areas key for chocolate production: agricultural practices, manufacturing practices, and business practices. Because the majority of the available research and data on heavy metal contamination in chocolate products is for Cd, the number of known potential Cd reduction strategies outweighs those available for Pb, particularly for agricultural practices. Strategies to limit Pb in cocoa beans are based on the Expert Committee's finding in the Root Cause Report that Pb on beans comes from environmental sources of dust and soil that contaminate the wet shell. During manufacturing, most of the contaminating Pb goes into the waste stream and is discarded. However, during the bean breaking process, some of the originally shell-bound Pb is redistributed to nibs as fines, which raises the Pb levels in chocolate products. Although the concentration of Pb in the nibs of freshly harvested cocoa beans ranges from 1-5 ppb, Pb concentrations in chocolate products can be 100 ppb or higher due to this manufacturing process. Therefore, the Expert Committee generally agrees the avoidance of soil and dust contact during fermentation and drying could be the most effective means to prevent Pb contamination.

Sections 4 through 6 of this report include descriptive summaries of each strategy. Individual reduction strategies are intended for specific chocolate industry stakeholders. Agricultural practices are intended for exporters and local traders (purchasing decisions); farmers (planting decisions, genetics, soil amendment practices, and post-harvest handling practices); governmental agencies and non-governmental organizations (NGOs) (supporting farmers through extension outreach); and universities and research organizations (plant breeding research). Manufacturing practices are intended for chocolate and cocoa manufacturers. Business practices are intended for manufacturers (certification schemes); governmental agencies and NGOs (local education and training); and exporters and local traders (cocoa bean testing).

Using the available scientific evidence for Cd and Pb reduction measures in the scientific literature and personal experience and professional judgement, the Expert Committee applied both qualitative and quantitative ratings in evaluating feasibility and in deriving a stratified confidence ranking of each strategy. Additionally, the Experts conducted two studies to inform their analyses:

- A Bean Cleaning and Winnowing Study (see Appendix C) was performed at a major North America cocoa processing plant operated by one of the largest companies in the industry. The study investigated the impact of the bean cleaning and shell removal processes on Cd and Pb concentration. The mechanical cleaning process, which is typical of the industry, was able to reduce cocoa bean mean Pb concentration by 58 percent, from 95.2 ppb to 39.7 ppb. When compared to wet cleaning beans with water and detergent, there was no significant difference between the reduction obtained by mechanical cleaning versus wet cleaning. With regards to winnowing, the study concluded that nib Pb concentration is a function of particle size. Nib Pb concentration increases as nib particle size decreases. Smaller nib particles have a higher surface area to volume ratio, which provides for more contact area with Pb containing material (i.e., shell, soil, light, and fine material) during bean breaking and winnowing. The study concluded that approximately 70 percent of nib Pb concentration is a result of contact during bean breaking and winnowing.

- A Bean Abrasion Study (see Appendix D) to further explore results of the Bean Cleaning and Winnowing Study, which found that fine particles separated during winnowing carried a large proportion of bean Pb. The Bean Abrasion Study tested whether bean-to-bean abrasion could release these Pb-rich particles as a Pb-reducing treatment. Several "shaking" methods were used with 200 g of dry beans in 500 mL polyethylene bottles: roller, side-to-side, and vigorous hand shaking just short of breaking beans. Because little or no fine particles (< 2 mm) were released by any of these shaking methods, only a small amount of broken shell, the Experts concluded that the fine particles were not easily released, or were generated during or after the heating step before breaking and winnowing at cocoa bean processing facilities.

The Expert Committee's approach for reviewing each strategy involved several iterations of discussion and scoring around eleven questions developed to address Cd and Pb reduction potentials, timeframes for implementation, six feasibility factors (public health impact, environmental impact, social impact, economic impact, technological considerations, and scalability), and the Expert Committee's overall confidence that the strategy would result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products.

Because the definition of feasibility in the Consent Agreement lacks specific detail, the Expert Committee developed its own interpretations of the six feasibility factors, with some additional but limited guidance from the AYS and the SDs. Specifically, the Expert Committee agreed that all the feasibility factors would be evaluated based on whether the implementation of the strategy would provide a potential benefit, detriment, or be case-neutral. For the public health feasibility factor, the Expert Committee evaluated whether the strategy would unintentionally introduce a public or occupational health risk during implementation. Likewise, for environmental and social impacts, the Expert Committee evaluated whether the implementation of the strategy would introduce an unintended impact on the environment or society or even a potential benefit. Economic impacts were considered only in terms of potential monetary costs to the industry, growers, or consumers; no other economic factors were considered by the Expert Committee. (Note: None of the Expert Committee members is trained or educated in the field of economics and credentialed economists were not consulted during the Committee's deliberations.) With respect to scalability and the availability of underlying technology, the Expert Committee agreed to evaluate each strategy based on the strength of evidence that the technology and means to implement the strategy exist across the universe of cocoa production, or a portion thereof, and that the strategy (e.g., the available or proposed new technology) would be effective for cocoa applications.

The Expert Committee used the rating scheme in Appendix A to score strategies. Quantitative scoring for each strategy and for each feasibility question was conducted three times by individual Expert Committee members over the course of developing this report with the third scoring being the final results (Appendix B). The compiled results of the scoring were mathematically analyzed by determining the percent of maximum score (percent of maximum points available) for each factor and for the confidence rating. A total score was calculated as was a separate score for confidence. The scoring was blinded in the final evaluation so that the scores submitted by individual members are not identifiable.

To group the scoring results into a meaningful presentation, the Expert Committee agreed to categorize each strategy according to whether the confidence score was "High," "Medium," or "Low." Based on the range of confidence scores (from 0 to 94 percent), the High grouping represents the top third, the Medium grouping represent the middle third, and the third grouping includes the bottom third. This same approach could also have been presented for the total feasibility scores, however the Expert Committee agreed that the confidence score is a more meaningful summary of the scoring results than the feasibility rankings. It should be noted that the three-tiered grouping of total scores for each strategy for the most part follows that of the confidence scores, with only three strategies falling on the borderline between the High and Medium groupings. The Expert Committee reached a consensus on the final groupings of these strategies.

The Expert Committee realized that reaching a consensus on each individual feasibility score would not be possible given the project timeline, data and information limitations, and the variation among the backgrounds, experiences, and perspectives of the Expert Committee members. To compensate for this, the discussion section of each strategy description summary (see Sections 4 through 6) provides a narrative describing the results of the feasibility ranking. These discussions acknowledge variations in the Experts' scoring and include individual comments on the uncertainties of the available information. The purpose of this discussion is to provide a transparent descriptive (qualitative) record of the Expert Committee's feasibility scoring to complement the quantitative scoring results.

The results of the final confidence scores are presented in Table 1 listed from the highest to the lowest relative ranking. Although the strategies presented in Table 1 are listed in a linear manner, the three categories of strategy approaches (better agricultural, manufacturing, and business practices) should be considered as a matrix or a menu of options for the following reasons:

1. The three categories represent different approaches to achieving Cd and Pb reductions and are therefore meant to be considered as complementary and in some cases supportive of the other strategies.
2. Some strategies offer a direct approach to reducing Cd and/or Pb, while other strategies offer an indirect approach. Therefore, selecting a strategy based only on direct reduction potential would not consider the other "foundational" strategies that would be required to ensure peak effectiveness of those direct strategies.
3. Reduced scalability and/or local resource availability might limit the application of some of these strategies in growing regions or manufacturing facilities.
4. Temporal considerations (e.g., time to implementation) need to be considered along with the feasibility and confidence scoring. Strategies that can be implemented in 1 to 5 years might offer a short-term solution but over the long-term might not be sustainable. Some strategies would likely take more than 5 years to implement but offer a more sustainable solution.
5. Further research and data will be required to refine the implementation potential for several strategies and allotting funding for research in a matrix plan will be more effective than considering each strategy as an individual option.

Table 2 presents the results of the Expert Committee's scoring in a matrix format to facilitate the development of a more holistic implementation plan.

The Experts' conclusions are based on the information available to the Expert Committee as of December 31, 2020.

Table 1. Reduction Strategies Listed in Order from Highest to Lowest Confidence Score

Strategy Title (Report Section Number Shown in Parentheses)
Strategies with "High" Confidence Scores
Better Agricultural Practices (Cd): Exporters to Stop Purchasing Beans from Regions with High Cd Phytoavailability (4.1.1)
Better Agricultural Practices (Cd): Farmers to Stop Planting New Orchards in Regions with High Cd Phytoavailability (4.1.2)
Better Agricultural Practices (Cd): Use Soil Amendments to Increase Soil pH (4.1.3)
Better Agricultural Practices (Pb): Prevent Pb Contamination of Beans during Fermenting and Drying (4.4.1.1)
Better Manufacturing Practices (Cd): Blend Beans or Liquor as a Cd Control Measure (5.1.1)
Better Agricultural Practices (Cd): Use Scion Grafts to Reduce Cd Uptake from Soils (4.1.5.1)
Better Agricultural Practices (Cd): Develop and Plant Rootstocks That Accumulate Less Cd from Soils (4.1.5.2)
Better Agricultural Practices (Cd): Use Zinc Sulfate Soil Amendments to Reduce Cd Uptake from Soils (4.1.4)
Better Agricultural Practices (Pb): Prevent Pb Contamination of Whole Wet Beans during Transport (4.4.1.2)
Better Manufacturing Practices (Pb): Establish Bean Cleaning/Winnowing QA Practices for Pb Contamination (5.1.2)
Better Business Practices: Incorporate Better Agricultural Practices into Cocoa Sustainability/Certification Programs (6.1.1)
Better Business Practices: Provide Education/Training at the Local Level to Implement Reduction Strategies (6.1.2)
Better Agricultural Practices (Cd): Use Self-Rooted Cocoa to Reduce Cd Uptake from Soils (4.1.5.3)
Better Agricultural Practices (Cd): Use Molecular Breeding Techniques to Identify Genotypes That Accumulate Less Cd (4.1.5.4)
Better Business Practices: Test Surfaces of Cocoa Beans for Pb Contamination at Point of Purchase (6.1.3)
Strategies with "Medium" Confidence Scores
Better Business Practices: Offer Incentives to and Provide Funding for Local Growers (6.2.1)
Better Manufacturing Practices: Develop and Use New Mechanical Techniques to Clean Beans (5.2.1)
Better Business Practices: Certify Management Systems to GFSI Schemes (6.2.2)
Better Agricultural Practices (Pb): Test Painted Surfaces for Pb (4.4.2.1)
Better Agricultural Practices: Test Water from Irrigation Sources and Use Alternate Water Sources, if Needed (4.2.1)
Strategies with "Low" Confidence Scores
Better Agricultural Practices (Cd): Use Amendments Recommended by CODEX But Not Included in Other Strategies (4.3.1)
Better Agricultural Practices (Cd): Use Zinc Sulfate Foliar Sprays to Reduce Cd Levels in Cocoa Beans (4.3.3)
Better Agricultural Practices (Cd): Phytoextract Cd from Soils Using Hyperaccumulators (4.3.5)
Better Agricultural Practices (Cd): Use Mineral Soil Amendments (4.3.2)
Better Agricultural Practices (Cd): Use Fertilizers Rich in Certain Elements (4.3.6)
Better Agricultural Practices (Cd): Adopt Agroforestry or Monoculture Techniques (4.3.7)
Better Agricultural Practices (Cd): Use Foliar Sprays Rich in Iron and Manganese (4.3.4)
Better Agricultural Practices (Cd): Manage Fermentation Practices to Reduce Cd in Beans (4.4.1.1)
Better Manufacturing Practices: Use Chemical Washing Techniques to Clean Beans (5.3.1)
Better Agricultural Practices (Cd): Use Microbial Inoculation Techniques (4.3.9)

Table 2. Reduction Strategies Grouped by Chocolate Production Sector and Confidence Scores

Better Agricultural Practices That Apply to…		Better Manufacturing Practices	Better Business Practices
…Cd	…Pb		
Exporters to Stop Purchasing Beans from Regions with High Cd Phytoavailability	Prevent Pb Contamination of Beans during Fermenting and Drying	Blend Beans or Liquor as Cd Control Measure	Incorporate Better Agricultural Practices into Cocoa Sustainability and Certification Programs
Farmers to Stop Planting New Orchards in Regions with High Cd Phytoavailability	Prevent Pb Contamination of Whole Wet Beans during Transport	Establish Bean Cleaning and Winnowing QA Practices for Pb Contamination	Provide Education and Training at the Local Level to Implement Reduction Strategies
Use Soil Amendments to Increase Soil pH	Test Painted Surfaces for Pb	Develop and Use New Mechanical Techniques to Clean Beans	Test Surfaces of Cocoa Beans for Pb Contamination at Point of Purchase
Use Scion Grafts to Reduce Cd Uptake from Soils		Use Chemical Washing Techniques to Clean Beans	Offer Incentives to and Provide Funding for Local Growers
Develop and Plant Rootstocks That Accumulate Less Cd from Soils			Certify Management Systems to GFSI Schemes
Use Zinc Sulfate Soil Amendments to Reduce Cd Uptake from Soils			
Use Self-Rooted Cocoa to Reduce Cd Uptake from Soils			
Use Molecular Breeding Techniques to Identify Genotypes That Accumulate Less Cd			
Test Water from Irrigation Sources and Use Alternate Water Sources, if Needed			
Use Amendments Recommended by CODEX But Not Included in Other Strategies			
Use Zinc Sulfate Foliar Sprays to Reduce Cd Levels in Cocoa Beans			
Phytoextract Cd from Soils Using Hyperaccumulators			
Use Mineral Soil Amendments			
Use Fertilizers Rich in Certain Elements			
Adopt Agroforestry or Monoculture Techniques			
Use Foliar Sprays Rich in Iron and Manganese			
Manage Fermentation Practices to Reduce Cd in Beans			
Use Microbial Inoculation Techniques			

Note: Green shaded cells are strategies with “High” confidence scores; blue shaded cells are strategies with “Medium” confidence scores; and orange shaded cells are strategies with “Low” confidence scores.

2.0 Background

This section presents background information on the Expert Committee and describes how the Experts developed the Reductions Recommendations Phase report. This section does not present the Experts' technical findings. Those are included in this report's Executive Summary and discussed in Sections 4 through 6.

2.1 Formation and Operation of the Expert Committee

The initiating event for this project was discovery of Cd and Pb in chocolate products purchased in California at levels that triggered Notices of Violation under the state's Proposition 65. The party that discovered these contamination levels (AYS) and several companies in the chocolate industry (the SDs) entered into the Consent Judgment that formed the Expert Committee and directed the Experts to prepare this report.

As stipulated by the Consent Judgment, AYS appointed one Expert Committee member; the SDs appointed another; and AYS and the SDs jointly agreed upon and appointed the remaining two. The names and affiliations of the four Expert Committee members appear on the title page of this report. AYS and the SDs also mutually identified and jointly appointed a Project Manager, who provided administrative and logistical support to the Expert Committee, facilitated discussions during Expert Committee meetings, ensured that the Expert Committee completed its work according to the budget and schedule, and provided word processing and editorial support for this report. Mr. John Wilhelmi of Eastern Research Group, Inc. (ERG) served as the Project Manager.

The Expert Committee members and the Project Manager performed their work under "consulting and confidentiality agreements" with AYS and the SDs, as joint contracting parties. The agreements required Expert Committee members to treat as strictly confidential and not disclose any non-public information provided by the SDs. The Expert Committee abided by these requirements. They thoroughly considered all information received, including non-public information. This report's findings are based on all information that the Expert Committee obtained and reviewed, even though this report is not allowed to present confidential information.

The Consent Judgment defines the Expert Committee's scope of work. It requires the Expert Committee to prepare four reports over a 2-year time frame. In March 2020, the Expert Committee completed the Root Cause Phase report, which identified the sources of Cd and Pb in chocolate products. This report, the Reductions Recommendations report, identifies feasible means for reducing Cd and Pb levels in chocolate products. The two remaining reports to be completed in 2021 are the Warning Trigger Phase report (which will comment on the Proposition 65 warning levels for Cd and Pb) and a final report (which will present the Expert Committee's overall findings and recommendations).

The remainder of this document focuses exclusively on the Expert Committee's Reductions Recommendations Phase analysis. The Consent Judgment sets the following scope for this project phase:

> After identifying the likely sources of lead/cadmium in cocoa beans and Chocolate Products, the Committee will identify Feasible methods for reducing lead/cadmium in the Chocolate Products. As with the Root Cause Phase of the investigation, the Committee's recommendations will be Consensus Based and result from the Root Cause Phase as well as further literature review, consultation with outside subject matter experts, review of test results, and any other information the Committee deems relevant and reliable.

The Expert Committee was charged with considering feasible reduction strategies that could be implemented from farm to factory. The Consent Judgment defines "Feasible" as:

> …capable of being accomplished in a successful manner within a reasonable period of time, taking into account public health, and economic, environmental, social, and technological factors. In considering whether an action or performance level is Feasible, consideration shall be given, among other things, to scaling as to the size and resources of the potential implementing enterprise involved, the implementing enterprise's place and role within the chain of commerce, the prior demonstration of the viability of the concept or technology at issue at both the research and actual commercial application scale,

From April 2020 to March 2021, the Expert Committee completed its research and developed this Reductions Recommendations Phase report.

2.2 Lines of Evidence Considered by the Expert Committee

The Expert Committee considered these lines of evidence when preparing the Reductions Recommendations Phase report:

- **Sampling data.** The Expert Committee conducted two sampling studies during this project phase. Their "Bean Cleaning Study" measured concentrations of Cd and Pb in numerous process streams at a cocoa bean processing facility; and their "Bean Abrasion Study" examined the degree to which a moderately abrasive technique removes Pb bound to the outer shell of cocoa beans. More information on these studies, including their measurement results, are presented in Appendixes C and D. Refer to the Root Cause Phase report for the cocoa bean sampling that the Experts conducted in Ecuador.

- **Publications.** The Expert Committee considered insights and findings from scientific publications, largely relying on peer-reviewed literature. The Experts reviewed graduate theses and unrefereed sources, as appropriate. During the Root Cause Phase and Reductions Recommendations Phase of this project, the Expert Committee compiled an inventory of more than 370 scientific publications, many of which are cited in this report. (Note: A spreadsheet of the Expert Committee's document inventory is available upon request.)

- **Consultation with SMEs.** To inform their Root Cause Phase analyses on specific topics, Expert Committee members contacted outside SMEs. The Experts made these contacts individually and informed the Project Manager of all contacts made. During the Reductions Recommendations Phase, the Experts made more than 40 such contacts. Documentation of these is found in the quarterly reports that the Project Manager submitted to AYS and the SDs.

- **Direct observations.** The Expert Committee also considered their own observations from two field trips completed during the Root Cause Phase (see Section 2.3). The first field trip included tours of three industrial facilities in the United States that either processed cocoa beans or manufactured chocolate products. The second field trip was of supply chain activity in Ecuador. The latter trip included visits to cocoa farms (including a farm that trained others on best practices), bean collection facilities where drying and fermenting occurred, and bean exporter facilities where pre-export bean cleaning and packaging occurred.

- **Professional judgment.** The Expert Committee members bring decades of experience in relevant scientific disciplines. Their professional judgment also factored into the Reductions Recommendations Phase conclusions, particularly for issues having limited or no information available from other lines of evidence.

Sections 4 through 6 document the lines of evidence that the Expert Committee considered when identifying and evaluating Cd and Pb reduction strategies. These sections also explain how the Experts resolved conflicting lines of evidence.

2.3 Process for Developing the Reductions Recommendations Phase Report

The Expert Committee spent most of 2020 developing this report. Their work began with identifying a list of strategies that might reduce Cd or Pb concentrations in chocolate products. The Experts considered multiple information sources when identifying candidate strategies. For example, they considered strategies referenced in the Consent Judgment, relevant strategies recommended in Codex Alimentarius (CODEX Code of Practice, or the international "food code"; see CODEX, 2020), strategies identified in peer-reviewed publications (e.g., Meter et al., 2019), and strategies noted during the Expert Committee's brainstorming sessions. Over the first 6 months of this project, Experts revised their strategy list multiple times by adding strategies to the list, removing strategies from the list, combining multiple strategies, and breaking strategies into multiple others. The Experts eventually arrived at the final list of 30 reduction strategies presented in this report. The Experts organized these strategies into three categories: those that pertain to agricultural practices (see Section 4), manufacturing practices (see Section 5), and business practices (see Section 6).

The Expert Committee then evaluated the identified reduction strategies. Their evaluations were based on a reduction strategy rating scheme that the Experts prepared and used to characterize each strategy's potential magnitude of Cd or Pb reductions, the time frame over which reductions are expected to occur, different elements of feasibility (as outlined in the Consent Judgment), scalability, and overall confidence that reductions will occur. The Experts scored the strategies three times. The first two sets of scores are considered preliminary and are not presented here. After the second round of scoring, the Experts revised their draft strategy text and discussed every strategy during a series of standing conference calls. The final round of scoring was completed in November 2020, and Appendix B presents the scoring results. Section 3 describes the strategy evaluation and consensus building process in greater detail.

As the Executive Summary of this report explains, the Experts agreed to base their final rankings on the overall confidence assessment of the reduction strategies (see question 11 in Appendix A). The magnitude of the composite rankings led to assigning each strategy a "High," "Medium," or "Low" ranking. These strategies were then carried forward into the Executive Summary of this report. Each strategy, regardless of its ranking, has a detailed description in Sections 4, 5, or 6 of this report. These strategy descriptions were developed using a consistent format, agreed upon by all four Experts. Authorship responsibility for the strategies in Sections 4 through 6 were split among the four Experts, based on their areas of expertise. The entire draft report was then reviewed by all four Expert Committee members multiple times. Experts' comments on the interim drafts were resolved during videoconferences. All four Experts authorized the Project Manager to submit this version of the Reductions Recommendations Phase report to AYS and the SDs, with no dissenting opinions.

This Reductions Recommendations Phase report reflects information that was available to the Expert Committee as of December 31, 2020. Recognizing that scientists continue to investigate strategies for reducing Cd and Pb in cocoa beans and chocolate products, the Expert Committee originally presented this report as "Version 1." In March 2022, minor corrections were made to prepare this "Version 2," which is being submitted as the final report.

2.4 California's Proposition 65

The primary charge to the Expert Committee under the Reduction Recommendations Phase is to "make findings and recommendations on feasible measures that may be taken, if any, to meaningfully reduce levels of lead and cadmium found in Chocolate Products." To achieve this goal, the Expert Committee researched and developed several remedial reduction options that if implemented to their fullest extent either individually or in combination with other options have a medium to high likelihood of successfully reducing levels of Cd and/or Pb in chocolate products. Sections 4 to 6 of this report presents these reduction strategies.

The Expert Committee acknowledges that another option, i.e., meeting the product warning requirements under California's Proposition 65, is another strategy to be considered in the development of a Cd/Pb reduction remediation plan. As noted previously, Proposition 65 (also known as the Safe Drinking Water and Toxic Enforcement Act of 1986) was an initiative approved by California voters in 1986 over growing concerns that existing laws were not adequate to protect the public from exposure to toxic chemicals. The intent of Proposition 65 was to assist Californians in making informed decisions about protecting themselves from chemicals known to cause cancer, birth defects, or other reproductive harm.

Among other things, the law requires: 1) the State of California publish and maintain a list of chemicals known to cause cancer or birth defects or other reproductive harm (https://oehha.ca.gov/proposition-65/proposition-65-list); 2) businesses to provide a "clear and reasonable" warning before knowingly and intentionally exposing anyone to a listed chemical—these requirements apply to a wide range of products, including food items (https://oehha.ca.gov/proposition-65/businesses-and-proposition-65); and 3) the State to develop guidance or "safe harbor" levels for chemicals listed under Proposition 65 as a means to help identify triggers for notification and other actions required under Proposition 65 (https://oehha.ca.gov/proposition-65/general-info/current-proposition-65-no-significant-risk-levels-nsrls-maximum). By law, a notification or warning must be given for listed chemicals unless exposure is low enough to pose no significant risk of cancer (i.e., below no significant risk levels) or is significantly below levels observed to cause birth defects or other reproductive harm (i.e., below maximum allowable dose levels)[1]. It should be noted that a business may choose to provide a warning simply based on its knowledge, or assumption, about the presence of a listed chemical without attempting to evaluate the levels of exposure. For reference, the current maximum allowable daily exposure levels for Cd and Pb in consumer products under Proposition 65 are 4.1 µg/day and 0.5 µg/day, respectively.

The Expert Committee discussed early on whether it should formally evaluate the feasibility of the Proposition 65 warning requirement and include it in the list of proposed Cd/Pb reduction strategies. However, because the emphasis in the Consent Judgment is for the Expert Committee to identify and evaluate potential alternatives to the Proposition 65 warning requirement, the Expert Committee ultimately agreed to include only this brief summary discussion of Proposition 65. The Expert Committee acknowledges that Proposition 65 warnings should be considered a contingency if no other voluntary options are deemed feasible (Kuusipalo, 2017).

The text associated with Proposition 65 is based on the concept of "right-to-know." Right-to-know legislation and mandates are embedded in public and environmental protection legislation, rules, and regulations. Examples of right-to-know requirements include public notification of industrial discharges of hazardous materials into the environment, notification of occupational hazards in the workplace, notification of drinking water quality and contamination, food labeling, pharmaceutical drug labeling, and personal care product labeling (FDA, 2020; Evans, 2019; OSHA, 2017; Blette, 2008; Baram, 1986; Degnan, 1997).

Since its inception, Proposition 65 warnings and notifications have given consumers, workers, and the general public information about the presence of listed chemicals in products or in their environment that may not have been adequately controlled under other State or federal laws. In addition, Proposition 65 information has increased public awareness about the adverse effects of exposures to listed chemicals. For example, Proposition 65 has resulted in greater awareness of the dangers of alcoholic beverage consumption for increasing cancer risk and reproductive risks during pregnancy (https://www.p65warnings.ca.gov/fact-sheets/alcohol-and-cancer; https://www.p65warnings.ca.gov/fact-sheets/alcohol-and-fetal-alcohol-spectrum-disorders-fasds). Alcohol consumption warnings are one of the most recognizable health warnings issued as a result of Proposition 65.

Although the product warning requirement has been the focus of litigation over the course of Proposition 65's history (CEH, 2017), a second impact of the law is of equal importance to note. The education of the public about toxic chemicals has created both a demand and market reward for less-toxic products. Furthermore, the desire to avoid adding warning labels to products has provided an incentive for manufacturers to remove listed chemicals from their products (see for example TÜV SÜD, 2013 and Rechtschaffen and Williams, 2005). Examples of products that have been reformulated as a result of notices of violation or litigation include ceramic tableware, artificial turf, household faucets, children's jewelry, potato chips, candy, and vitamin supplements. Other examples include trichloroethylene, which causes cancer, is no longer used in most correction fluids; reformulated paint strippers do not contain the carcinogen methylene chloride; and toluene, which causes birth defects or other reproductive harm, has been removed from many nail care products. In addition, a Proposition 65 enforcement action prompted manufacturers to decrease the lead concentration in ceramic tableware, jewelry, and purses; and it prompted wineries to eliminate the use of lead-containing foil caps on wine bottles (SGS, 2020; Cox and Hirsch, 2019; CEH, 2017; Cox and Green, 2010; LA Times, 1989).

A recent analysis of the "hidden successes" of Proposition 65 describes three areas of the law's far-reaching influence on toxic chemical reduction in California and other states, including the triggering of direct chemical regulation, the amplification of exposure limits for toxic chemicals, and the exertion of behind-the-scenes influence on business behavior (e.g., pressure to reformulate a consumer product) (Polsky and Schwarzman, 2021). In other words, Proposition 65 has induced "quiet compliance" without the need for litigation, in which manufacturers voluntarily take steps to comply by providing their suppliers with specifications so that the ingredients in their products avoid or significantly limit exposure to listed chemicals (CA OAG, 2020). Proposition 65 has also succeeded in spurring significant reductions in California of air emissions of listed chemicals, such as ethylene oxide, hexavalent chromium, chloroform, and diesel exhaust; and it caused reductions in indoor

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[1] Safe harbor levels are developed by the Office of Environmental Health Hazard Assessment of the California Environmental Protection Agency at the request of or to provide guidance to businesses in determining when warnings are required: https://www.p65warnings.ca.gov/faq/businesses/what-are-safe-harbor-numbers.

exposures, such as hair and nail salon worker exposures to formaldehyde and other toxic solvents, and formaldehyde gas release from the building materials in portable classrooms.

Although Proposition 65 has benefited Californians and other consumers across the United States, it has come at a cost for companies doing business in the state. Businesses have incurred expenses to test products, develop alternatives to listed chemicals, reduce discharges, provide warnings, and otherwise comply with this law. Furthermore, information "overload" that could be associated with repeated warning on numerous products can leave the public numb and desensitized to the content of the warnings reducing their effectiveness. For this reason, consumer health would likely benefit more from reformulation or reduction in chemical concentrations in consumer products rather than the issuance of warnings.

2.5 Organization of the Reductions Recommendations Phase Report

The remainder of this report is organized as follows:

- Section 3 describes the Experts' strategy evaluation and consensus building processes.
- Section 4 presents the Expert Committee's ratings of strategies related to agricultural practices.
- Section 5 presents the Expert Committee's ratings of strategies related to manufacturing practices.
- Section 6 presents the Expert Committee's ratings of strategies related to business practices.
- Section 7 lists research recommendations identified by the Experts.
- Section 8 presents references for all citations in the report.
- Appendix A presents the final rating scheme the Experts used to evaluate the strategies.
- Appendix B shows the Experts' ratings for individual strategies.
- Appendix C summarizes the "Bean Cleaning Study" conducted by the Expert Committee.
- Appendix D summarizes the "Bean Abrasion Study" conducted by the Expert Committee.
- Appendix E presents a suggested protocol for conducting an experiment on dry abrasive removal of Pb bound to whole cocoa bean shells.
- Appendix F presents a suggested protocol for conducting an experiment on colorimetric determination of Pb on whole cocoa bean shells.

3.0 Strategy Evaluation Process

In this report, 30 proposed strategies to reduce Pb and Cd concentrations in cocoa beans and in final chocolate products are described. The Expert Committee initially identified more than 30 potentially relevant reduction strategies from the Consent Judgment, in Codex Alimentarius (CODEX Code of Practice, or the international "food code"), from the publicly available scientific literature (e.g., Meter et al., 2019), and from the many ideas expressed by individuals during the Expert Committee's brainstorming sessions. Following several facilitated discussions, the Experts reduced and refined the longer list of proposed strategies to the final 30, which were then researched, analyzed, evaluated, and ranked by the Expert Committee. The Experts organized these strategies into three categories: those that pertain to "better" agricultural practices (see Section 4), "better" manufacturing practices (see Section 5), and "better" business practices (see Section 6). As part of the charge to the Expert Committee, the strategies were evaluated and ranked based on their feasibility and potential for success. The following text describes the evaluation and ranking processes in more detail.

Evaluation Method

A detailed draft description of each strategy was developed by one of the four Experts. Each Expert was assigned several strategies to research and develop into a summary description based on their areas of expertise, interest, and knowledge. Each of the 30 strategies were then reviewed and discussed at length by the Expert Committee over the course of several weeks during facilitated conference calls. Revisions to the content of the strategies were made by the authors to address technical issues raised by the Experts during discussions and from individual's comments submitted to each author prior to two preliminary or "trial" evaluations (not presented in this report) and then the final evaluation (Appendix B).

In order to accomplish a transparent and defensible evaluation and ranking, the Expert Committee developed a quantitative reduction strategy rating tool, which was revised three times over the course of the Expert's deliberations (Appendix A). The evaluation tool (or "scheme") was finalized on November 9, 2020, via consensus. The purpose of the rating scheme was to provide a quantitative scoring system by which each Expert could apply objective reasoning and professional judgement to evaluate the relative potential for each strategy to achieve six predetermined feasibility factors and to meet the characteristics necessary for successful implementation and reduction of Pb and/or Cd in cocoa beans and chocolate products.

The Expert Committee's evaluations were guided by six feasibility factors listed in the Consent Judgment: public health, environmental, social, economic, scaling, and technology. In addition, the Experts rated each strategy's potential magnitude of Cd and/or Pb reduction, the time frame over which reductions might occur, and the evidence supporting the reduction potential. An additional factor of "confidence" was added by the Experts in the rating scheme. The confidence factor was double-weighted (worth twice as many points as any other rated factor) and was meant to capture the Expert's judgment based on the evidence that the strategy could successfully meet the reduction potential and feasibility of implementation.

The Consent Judgment does not provide detailed definitions or explanations for any of the six feasibility factors. The Expert Committee on several occasions asked the SDs and AYS for additional guidance. However, apart from some clarification, it was left for the Expert Committee to develop its own definitions and scope for the six feasibility factors, as described here:

1. Public Health: The Experts evaluated public health feasibility on whether the strategy could be implemented without introducing unintended adverse impacts on public health. It should be noted the Experts did not include a separate rating for potential public health benefits following implementation. The rationale for omission of such a rating is that only strategies that had real potential to reduce Pb and Cd in chocolate products were considered by the Experts. Therefore, by inference, all the strategies if implemented without unintentionally introducing a health hazard would benefit public health by reducing Pb and Cd in chocolate products.

2. Environmental: The Experts evaluated environmental feasibility on whether the strategy could be implemented without introducing unintended adverse impacts on the environment or provide a potential benefit. The environment was determined to be the land area comprising the cocoa growing regions and any natural resources within the area (e.g., surface, water, groundwater, watersheds).

3. Social: The Experts evaluated social feasibility on whether the strategy could be implemented without introducing unintended adverse impacts on society or provide a potential benefit. Although the Experts did not specifically define a population in which to evaluate social impacts, for the most part the Experts generally focused on the cocoa growing community.

4. Economic: The Experts evaluated economic feasibility on whether the strategy could be implemented without prohibitive or recoverable costs to the industry and/or consumers or whether there could be a cost-benefit. It should be noted the Expert Committee did not consult a credentialed economist for assistance during its deliberations and none of the Experts have backgrounds in economics.

5. Scaling: The Experts evaluated the feasibility of implementing the strategy across the cocoa industry, including all cocoa growing regions, in-country processing and exporting, and manufacturing. In addition, the Experts evaluated the evidence supporting the perceived scalability of the strategy as part of the overall scoring for this feasibility factor.

6. Technology: The Experts evaluated technological feasibility on whether the technology needed to implement the strategy was developed, in use, and shown to be effective. The Experts also considered the potential feasibility for the development of new technologies that have not been invented for use in growing or processing cocoa.

The rating scheme assigned scores from 0 to 4 points for the six feasibility factors and for the strength of evidence for Pb and Cd reduction. As mentioned previously, the eighth scored factor, "confidence," was assigned a double-weighted score of up to a maximum of 8 points (range of 0 to 8 points). The Experts' ratings for magnitude and time frame of reduction were not scored and left as qualitative information for the Experts to consider when evaluating "confidence." In total, a maximum score for any one Expert was 36 points and for all four Experts combined, 144 points. None of the strategies scored 144 points but all scored at least 40 total points. It should be noted that the results of the evaluations presented in Appendix B are "blinded," meaning the names of the Experts have been removed and replaced with the generic Expert 1, Expert 2, etc. In addition, the order in which the results for each Expert are presented has been randomized from one strategy to another, such that any observable patterns in scoring from one strategy to another are purely coincidental.

Ranking Method

Once the final evaluation scores were available and compiled, the Experts discussed various ways to analyze and present the data. It was agreed by all Experts that the combined scores (combined for all four Experts for all scored rating questions or subset of questions) would be presented in three tiers based on the upper third, middle third, and lower third of the range of results. This scaling of the results is comparable to the scaling of an exam where the highest score achieved is the top end of the scale and the lowest score received is the bottom end of the range.

Three different ranges of compiled scores were considered: combined feasibility scores, combined confidence scores, and combined overall score (feasibility plus confidence scores). The scores are presented as a percentage of the maximum allowable points. For example, the overall score results are presented as the number of points received by all four Experts combined divided by the maximum allowable points (144) times 100. Therefore, for a strategy that received a combined 100 overall points from all four Experts, the result is presented as 69 percent (i.e., 100/144 x 100). The maximum allowable score for combined confidence is 32 points and the maximum allowable score for feasibility is 112 points.

The tiered ranking for the three different scoring ranges are as follows:

1. Tiering for Overall Scores: High ≥60 percent; Medium ≥44 and <60 percent; Low ≥28 and <44 percent.

2. Tiering for Feasibility Scores: High ≥63 percent; Medium ≥48 and <63 percent; Low ≥33 and <48 percent.

3. Tiering for Confidence Scores: High ≥63 percent; Medium ≥31 and <63 percent; Low 0 <31 percent.

The scoring results for all 30 strategies presented as three different ranking schemes are provided in Table 3.

The Expert Committee discussed the merits of presenting the final strategy rankings based on the final combined feasibility, combined confidence, or combined overall scores. The rank order of the strategies differs for several of the strategies between these methods. The Expert Committee agreed they would present the final rankings based only on the combined confidence scores as provided in the Executive Summary. The Experts recommend the combined confidence rankings be used for planning purposes. The other rankings for feasibility and overall scores are provided in Table 3 for informational purposes only.

Consensus Building

Reaching consensus was an important goal of the Experts during the Reduction Recommendation Phase. Every attempt was made to reach consensus on the strategy identification, analysis, evaluation, and ranking process. To this end, consensus was reached on the following:

1. The Experts agreed to include the 30 strategies in the Reduction Recommendation report.

2. The Experts agreed to group the strategies into three categories: "better" agricultural practices, "better" manufacturing practices, and "better" business practices. The Experts anticipate this grouping will be helpful later during the planning process.

3. The Experts agreed on a format and the content for preparing the strategy descriptions.

4. The Experts agreed on the interpretations and definitions of each of the feasibility factors as well as the characteristics of Cd/Pb concentration reductions.

5. The Experts agreed on using a quantitative evaluation tool for scoring and ultimately ranking the strategies.

6. The Experts agreed to the wording of each question, the various responses, and the scoring allocation used in the evaluation "scheme."

7. The Experts agreed to present the evaluation scores in Appendix B in a blinded, randomized manner to retain anonymity in the results.

8. The Experts agreed not to attempt to reach consensus on each individual scoring parameter for the 30 strategies because of limitations in time and the differences in backgrounds and experiences of the four Experts. The Experts agreed this would be counterproductive. However, it should be noted that with some exceptions, the scoring was relatively consistent among the Experts as noted in the Discussion section of each strategy description.

9. The Experts agreed to use a statistics-based, three-tiered scaling system to present the results in groupings of High, Medium, and Low.

10. The Experts agreed to recommend the combined confidence rankings for future planning purposes (as opposed to the ranking for feasibility or overall score).

Table 3. Summary of Experts' Reduction Strategy Scores, in Order of Decreasing Confidence Score

Strategy	Experts' Scores (percent)		
	Confidence	Feasibility	Overall
Exporters to stop purchasing beans from regions with high Cd phytoavailability	94%	66%	72%
Farmers to stop planting new orchards in regions with high Cd phytoavailability	81%	71%	73%
Blend beans or liquor as a Cd control measure	75%	79%	78%
Use soil amendments to increase soil pH	75%	60%	63%
Prevent Pb contamination of beans during fermentation and drying	71%	75%	78%
Establish bean cleaning and winnowing quality assurance practices for Pb contamination	69%	78%	76%
Incorporate better agricultural practices into cocoa sustainability/certification programs	69%	76%	74%
Provide education/training at the local level to implement reduction strategies	69%	70%	69%
Prevent Pb contamination of whole wet beans during transport	69%	66%	67%
Use scion grafts to reduce Cd uptake from soils	69%	64%	65%
Develop and plant rootstocks that accumulate less Cd from soils	69%	64%	65%
Use zinc sulfate amendments to reduce Cd uptake from soils	69%	58%	60%
Use self-rooted cocoa to reduce Cd uptake from soils	63%	66%	65%
Use molecular breeding techniques to identify cocoa genotypes that accumulate less Cd	63%	59%	60%
Test surfaces of cocoa beans for Pb contamination at point of purchase and reject beans with elevated Pb levels	63%	57%	58%
Offer incentives to and provide funding for local growers	50%	63%	60%
Certify management systems to GFSI schemes	44%	72%	66%
Develop and use new mechanical techniques to clean beans to reduce Pb contamination	44%	47%	47%
Test painted surfaces for Pb	38%	63%	58%
Test water from irrigation sources and use alternate water sources, if needed	31%	62%	55%
Use zinc sulfate foliar sprays to reduce Cd levels in cocoa beans	19%	44%	38%
Use amendments recommended by CODEX but not included in other strategies	19%	43%	38%
Use fertilizers rich in certain elements	13%	42%	35%
Use mineral soil amendments	13%	40%	34%
Phytoextract Cd from soils using hyperaccumulators	13%	33%	28%
Manage fermentation processes to reduce Cd in beans	6%	47%	38%
Adopt agroforestry or monoculture techniques	6%	42%	34%
Use chemical washing techniques to clean beans to reduce Pb contamination	6%	38%	31%
Use foliar sprays rich in iron or manganese	6%	38%	31%
Use microbial inoculation techniques	0%	41%	32%

Key: Green shaded cells have "High" scores; blue shaded cells have "Medium" scores; and orange shaded cells have "Low" scores.

4.0 Strategies Related to Agricultural Practices

This section describes the Cd and Pb reduction strategies that the Expert Committee identified for agricultural practices. These strategies apply to certain actions that could be taken in countries of origin to prevent Cd or Pb contamination of cocoa beans during the pre-harvest, harvest, and post-harvest stages. Strategies with the highest confidence scores for Cd are presented first (see Section 4.1), followed by those with medium confidence scores for Cd (see Section 4.2) and those with low confidence scores for Cd (see Section 4.3). Section 4.4 then reviews agricultural strategies pertaining to Pb. The tables in Appendix B indicate how the Experts scored the strategies.

4.1 Agricultural Strategies to Reduce Cd with High Combined Confidence Scores

Eight reduction strategies related to agricultural practices received high combined confidence scores. The following sub-sections describe these strategies and their feasibility considerations.

4.1.1 Exporters to Stop Purchasing Beans from Regions with High Cd Phytoavailability

Overview of Strategy

The Expert Committee believes that one method the chocolate industry can use to reduce Cd levels in cocoa beans and chocolate products is to purchase beans only from growing regions where the beans and/or soil phytoavailable Cd levels are reliably below some limit set for their purchases. The cost of analyzing each load of beans being delivered by farmers or intermediate marketing companies is too high to support marketing programs and to support normal bean markets. Inexpensive rapid methods such as x-ray fluorescence is not sensitive enough to measure Cd in cocoa beans. Thus, rapid practical approaches are needed.

Bean Cd concentration is controlled by the phytoavailability of soil Cd, and the genetics of the cocoa cultivar being grown. Field soil and cocoa bean sampling can support development of national or regional maps that show where beans with higher and lower Cd levels are reliably produced. Development of such maps is a normal agricultural technology for many issues such as Cd. Regional or national surveys of Cd levels in cocoa beans and soils (with varied density of samples in the several countries) have been conducted in at least Brazil, Colombia, Ghana, Honduras, Ecuador, Peru, Trinidad, and Venezuela. Available surveys identified where low and high Cd beans have been produced and considered soil association information and soil pH, Cd and zinc (Zn) levels, and bean Cd levels. Some high bean Cd levels result from very low soil pH, and others due to Cd enrichment of the soil by natural processes or historic contamination. If the chocolate producers purchase beans only from farmers who can attain specific limits, only these beans with limited Cd will be purchased. In some cases, industry has co-funded national soil-cocoa bean surveys to identify the lower bean Cd producing areas (e.g., Chavez et al., 2015; Argüello et al., 2019). Both the CODEX Code of Practice (2020) and the Bioversity International review (Meter et al., 2019) note that restricting purchases based on previous bean Cd levels from a specific farm, or on soil and plant properties that affect Cd concentration in beans, is a method to meet international purchasing Cd limit goals. The data required to establish the maps of bean Cd or soil Cd phytoavailability have been owned by the purchasing companies or the National Cocoa Boards that funded the surveys and map preparation.

Background

Bean Cd is controlled by the phytoavailability of soil Cd and the genetics of the cocoa cultivar grown. Cocoa beans grown on some soils in South American and Latin American nations exceed bean Cd purchase goals of industry. These Cd problem soils are relatively acidic, enriched in Cd by natural processes, or contaminated by mine wastes or other materials. These soils may contain such high Cd levels or phytoavailability of soil Cd that the bean Cd levels would make it difficult to use them in making chocolate products that meet European Union (EU) or California Cd limits. Traditional agronomic solutions to this kind of problem (part of the production area produces crop unacceptable to purchasers, and beans exceeding purchase Cd goals are highly related to soil properties or soil Cd phytoavailability) include conducting surveys of what soil and plant genotype characteristics cause high Cd in the cocoa beans and preparing maps from the survey data. Soil associations reflect soil parent materials and common soil chemical and physical properties including Cd and Zn levels and soil pH levels. Several factors have been identified that substantially increase Cd levels in cocoa beans: Very acidic soil (increases Cd solubility and uptake), or higher natural soil Cd and Zn levels or natural higher soil Cd:Zn ratio, can each cause higher Cd accumulation in cocoa beans. Cocoa beans from some farms have exceeded 10 mg Cd/kg, greatly in excess of EU limits for chocolate products, while other soils regularly produce beans with lower than 0.6 mg/kg dry weight.

It appears that either national cocoa marketing managers or companies that want to purchase cocoa beans in a country have funded a number of soil-plant surveys conducted by university scientists or the national cocoa marketing boards. Some of these surveys have been published (e.g., Colombia: Albarrcín et al., 2019; Ecuador: Argüello et al., 2019; Brazil: Araujo et al., 2017; Peru: Arévalo-Gardini, 2017; Ecuador: Barraza et al., 2017b; Ecuador: Chavez et al., 2015; Honduras: Gramlich et al., 2017; Venezuela: Lanza et al., 2016; Trinidad & Tobago: Ramtahal et al., 2016; Ghana: Takrama et al., 2015; Peru: Zug et al., 2019). During their visit to Ecuador, the Expert Committee was shown a more detailed map of cocoa and soil Cd (and pH) levels than were included in the peer-reviewed publications reporting the studies.

The major soil factors that cause higher Cd accumulation in cocoa beans are discussed in the Root Cause Phase report. The soil factors found to have greatest impact include soil pH, soil Cd concentration, soil Cd:Zn ratio, soil organic matter, and soil clay levels (McLaughlin et al., 2021). High levels of metal-sorbents such as manganese (Mn) and iron (Fe) hydrous oxides may also reduce Cd accumulation by cocoa trees (these are usually coatings on clay particles); high soil organic matter is the most important sorbent at lower pH levels.

Reliance on maps of current levels of cocoa bean Cd, soil Cd, soil pH, soil Cd:Zn, etc. would allow purchasers to obtain the beans with an average limited Cd concentration they seek based on their cocoa processing management. The results of these measurements can be used to develop an equation based on soil properties that predicts bean Cd well and then the equation joining all these Cd phytoavailability controlling factors can be used to select areas for bean purchase. Regional soil Cd phytoavailability maps such as that in Argüello et al. (2019) are a strong example of this approach. Analysis of soil is much less expensive than analysis of cocoa beans for Cd and other elements, and the soil analyses can identify management factors the grower could adopt to produce beans with lower Cd levels.

Discussion

The Expert Committee generally agrees that purchasing beans only from growers who produce low Cd beans grown on soils with low soil Cd phytoavailability would result in lower Cd concentrations in chocolate products. The magnitude of this reduction could be greater than 25 percent, although the available data do not allow for an accurate quantification of the magnitude of reduction. The Expert Committee also agrees that mapping cocoa growing regions using historic data or newly generated data on bean Cd and/or soil Cd phytoavailability is essential to identifying potentially high or low Cd soil/phytoavailability areas in cocoa growing regions. Development of bean Cd or soil Cd phytoavailability maps to guide purchasing is a common agricultural practice for other agricultural commodities.

This strategy would have initial costs associated with implementation. However, once Cd soil maps are available, growers could potentially adopt better agricultural practices (e.g., increasing soil pH; applying Zn fertilizer; changing to a lower Cd accumulating cocoa cultivar) as described elsewhere in this section of the report to effectively reduce Cd levels in the beans produced on their land. The Expert Committee generally agrees that this approach could result in some growers losing income or land use where soils have high and unmitigable Cd levels and high phytoavailability relative to other regions.

The Expert Committee agrees that in order to implement this strategy effectively, growers and the chocolate industry would need to commit one to five years to establish mapping and implement Cd mitigation strategies to reduce Cd soil levels and phytoavailability. The Experts also generally agree that this reduction strategy is technically feasible and probably scalable to most cocoa growing regions and could be implemented without potential for unintended adverse public health and environmental impacts or impacts that could be controlled or prevented.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Two Experts predict that the level of Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent whereas the other two Experts are unsure as to the level of reduction.

Time frame for potential reduction: In order to implement this strategy, purchasers must have information on the areas where low and high Cd beans are produced within a growing region. Once maps are established, two Experts predict that it will take 1 year for Cd reduction in chocolate products to be observed and the other two Experts predict it will take 1 to 5 years.

Strength of evidence for reduction: The Experts agree that a reduction in bean Cd levels from trees grown on low phytoavailable Cd has been reliably demonstrated in an experimental setting in peer-reviewed publications and in other empirical data that were available to the Expert Committee.

Potential effects on public health: The Experts agree that this reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic effects: Three of four Experts gave a rating indicating that this strategy could be implemented without prohibitive costs to the chocolate industry with one of these three Experts concluding that the chocolate industry would benefit from the implementation of this strategy. The fourth Expert thinks that the extent of economic impact could not be quantified or is not known.

Potential for adverse environmental impacts: Two of the Experts think that the reduction strategy could be implemented without potential for unintended adverse environmental impacts. Two Experts think that the reduction strategy might have unintended adverse environmental consequences, which could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures. An example of an unintended consequence may be soil disturbance and erosion that could harm sensitive ecosystems due to remediation of soils to reduce cocoa accumulation of Cd.

Potential social impacts: The Experts agree that this reduction strategy may impact cocoa growers, causing negative social impacts on the community. For example, if cocoa growers with high phytoavailable Cd soils resort to amending soils in an attempt to produce low Cd cocoa beans or if they are forced to abandon producing cocoa beans, it could cause economic hardship for the growers and the community.

Scalability of potential reduction: Two Experts think there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms. The other two Experts think that there is only demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms, or if applicable, to a smaller subset based on need or practicality.

Technological feasibility of method: The Experts agree that the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications, and has been demonstrated to be effective; or at least it has been developed for cocoa applications, if not widely used. The Expert Committee notes that this methodology has already been adopted by purchasers in several nations.

Confidence: Three Experts have a very high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believe there is abundant evidence to support this statement. The fourth Expert has a medium to high degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 94 percent, a feasibility score of 66 percent, and an overall score of 72 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-1 for the Experts' individual scoring of this strategy.

4.1.2 Farmers to Stop Planting New Cocoa Orchards in Regions with High Cd Phytoavailability

Overview of Strategy

This strategy advises identification of agricultural lands in cocoa growing areas that are suitable, suitable with soil amendments, or unsuitable for new plantings due to predicted high soil Cd phytoavailability. This is similar to the strategy discussed in Section 4.1.1, but deals with new plantings rather than existing orchards. This strategy was supported by the Code of Practice (CODEX, 2020) and the Bioversity Review (Meter et al., 2019). Soil Cd concentration, soil Cd:Zn ratio, soil pH, and levels of soil hydrous Mn and Fe oxides and organic matter strongly affect Cd accumulation by plants, including cocoa. An approach to assure that cocoa beans will not exceed Cd limits demanded by purchasers is to plant new orchards only on soils that have a high probability of limiting Cd accumulation by the trees (low Cd phytoavailability) or amending the soil to reduce future cocoa crop Cd levels. Soil-plant surveys provide a connection between soil properties, soil Cd, and cocoa accumulation of Cd. Appropriate soil sampling and analysis can aid in deciding whether to transplant a cocoa orchard on a specific land area and to identify remedial soil amendments that could be incorporated into the topsoil before transplanting cocoa seedlings in order to assure acceptable Cd levels in future cocoa bean crops. Other strategies in Section 4.1 describe options (e.g., use of soil amendments) for lowering potential soil Cd phytoavailability.

Background

High soil Cd concentration, low soil pH, high soil Cd:Zn ratio, low levels of soil hydrous oxides of Fe and Mn, soil clay and organic matter levels, and cocoa genotype have been demonstrated to affect Cd accumulation in cocoa beans. Some cocoa beans grown in South American and Latin American nations are higher than markets desire in Cd because some soils are very acidic, enriched in Cd by natural processes, contaminated by mine wastes or other processes, or have low Cd sorptive properties such that the beans accumulate levels of Cd that would make it difficult to use those beans to make chocolate products that meet EU or California Cd limits. In order to assure that new orchards do not produce beans that cannot meet the purchasers' demands regarding Cd concentrations, appropriate soil sampling and analysis, coupled with correlations obtained from national soil-cocoa bean sampling and analysis projects, can identify soils that offer a high probability of meeting purchasing Cd limits or can comply if soils are modified to lower soil Cd phytoavailability. Also, cocoa cultivars/genotypes vary in Cd accumulation and genotype should be considered in decisions to establish new cocoa orchards (see discussions of genetic strategies in Sections 4.1.5). Soil factors that cause higher Cd accumulation in cocoa beans are discussed in other parts of this report.

Discussion

The Experts generally agree that a strategy of planting new cocoa orchards in soil with low phytoavailable Cd would likely result in the production of low Cd beans, at least for the short-term. This approach relies on soil-plant surveys, analytical testing, and land mapping to identify soils (i.e., low Cd phytoavailability) that are more favorable for planting new cocoa orchards or to support pre-remediation decisions to use better agricultural practices that could reduce Cd soil levels. With this approach, investment in new orchards would increase the probability that cocoa beans produced would have lower measurable Cd concentrations compared to cocoa grown in areas with high Cd soil/phytoavailability areas.

Because marketable cocoa beans are available for harvest only about 5 years after establishing a new cocoa orchard, the Expert Committee generally agrees that in order to implement this strategy effectively, growers and the chocolate industry would need to commit at least 5 years before measurable reductions in Cd levels in cocoa beans are observed. The Experts also generally agree this reduction strategy is technically feasible and probably scalable to most cocoa growing regions. In addition, the Experts agree this strategy could be implemented without potential for unintended adverse public health, environmental impacts, or social impacts, or with potential impacts that could be controlled or prevented.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Two Experts predict that the level of Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent whereas the other two Experts are unsure as to the level of reduction.

Time frame for potential reduction: Three Experts predict that it would likely take more than 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. One Expert predicts the time frame would be 1 to 5 years.

Strength of evidence for reduction: Three Experts think that a reduction in Cd levels in cocoa beans using these methods has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts. The fourth Expert thinks there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts).

Potential public health impacts: Three Experts think this reduction strategy could be implemented without potential for unintended adverse public health impacts. The fourth Expert thinks the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts with proper exposure prevention methods.

Potential economic impacts: Three of four Experts gave a rating indicating that this strategy could be implemented without prohibitive costs to the chocolate industry. The fourth Expert thinks the reduction strategy could not be implemented without considerable and prohibitive costs that could not be recovered over the long-term due to potential changes in land value that could force farmers to switch to growing other crops.

Potential environmental impacts: Two Experts provided a rating indicating the reduction strategy could have unintended adverse environmental consequences, which could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures. An example of an unintended consequence may be soil disturbance and erosion that could harm sensitive ecosystems due to remediation of soils to reduce cocoa accumulation of Cd, especially for those farms on high slopes. A third Expert thinks this reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks the reduction strategy, if implemented, could have environmental benefits.

Potential social impacts: Three Experts agree that this reduction strategy could be implemented without potential for unacceptable adverse social impacts. The fourth Expert thinks the strategy could have positive social impacts (i.e., benefits).

Scalability of potential reduction: The four Experts agree that there is demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms, or if applicable, to a smaller subset based on need or practicality.

Technological feasibility of method: Two Experts gave ratings indicating the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications, and has been demonstrated to be effective. The other two Experts provided ratings that indicate the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available.

Confidence: Three Experts have a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believe there is sufficient evidence to support this statement. The fourth Expert has a very high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant.

Conclusion

This strategy received a combined confidence score of 81 percent, a feasibility score of 71 percent, and an overall score of 73 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-2 for the Experts' individual scoring of this strategy.

4.1.3 Use Soil Amendments to Increase Soil pH

Overview of Strategy

Soil pH is one of the most important soil chemical properties that can affect Cd phytoavailability and its consequent uptake in plants (see Section 4.1.1.1 of the Root Cause Phase Report). Acidic soils (low pH) have been shown to enable Cd uptake in cocoa trees resulting in increased Cd levels in cocoa beans. The application of appropriate alkaline amendments to raise soil pH could reduce Cd phytoavailability thereby reducing its transfer into cocoa beans and reducing the Cd levels in chocolate products.

Background

Data from research studies demonstrating the effectiveness of alkaline materials in reducing Cd uptake in crops is well-documented in the published scientific literature. Both the Code of Practice for the prevention and reduction of Cd contamination in cocoa beans (CODEX, 2020) and a report evaluating potential mitigation solutions for Cd in cocoa (Meter et al., 2019) have also recommended this approach. Acidic soils have an influence on the uptake of Cd in many crops including cocoa (Contreras et al., 2005; Chavez et al., 2015; Gramlich et al., 2017, 2018; Ramtahal et al., 2018; Zug et al., 2019; Argüello et al., 2019). As the pH of soils decreases, the adsorption of Cd by soil colloids, hydrous oxides, and organic matter lessens resulting in increased soil Cd mobility and its phytoavailability (Osman, 2018). To correct soil acidity, various forms of calcium- and magnesium-rich alkaline liming materials such as limestone [$CaCO_3$], dolomitic limestone [$CaMg(CO_3)_2$], quicklime [CaO], or slaked lime [$Ca(OH)_2$] in combination with other materials can be used. The practice of liming to increase soil pH has also been shown to effectively reduce Cd accumulation in a number of crops including cocoa in both greenhouse/pot trial and field experiments.

A study conducted by Ramtahal et al. (2019) in Trinidad showed that soil amendment rates of 4.5 metric tons $Ca(OH)_2$ ha^{-1} and 6 metric tons $Ca(OH)_2$ ha^{-1} significantly reduced Cd concentrations in the leaves of the cocoa tree by 37 percent and 20 percent respectively, 3 months after soil application with the effect lasting up to 9 months. Although this study reported its effect for leaves, the results can also be extended to Cd levels in cocoa beans because numerous studies report that a significant correlation exists between cocoa leaf and bean Cd levels (Ramtahal et al., 2016; Barraza et al., 2017a; Lewis et al., 2018; Argüello et al., 2019). A recent greenhouse experiment conducted in Ecuador by Argüello et al. (2019) concluded that liming with agricultural limestone (4 metric tons per hectare) was able to reduce Cd levels in cocoa leaves by a factor of 1.7 compared to the control. This study also observed that in order to ensure the effectiveness of lime application to reduce Cd, it should be incorporated into the surface and subsurface soil layers thoroughly; however, this process still needs to be optimized. The Code of Practice produced by CODEX (2020) also documented a field study by Davila (2018) in Peru. The study reported that three rates of dolomite per plant 1.8 kg (1.81 metric tons per hectare), 2.7 kg (2.72 metric tons per hectare), and 3.6 kg (3.63 metric tons per hectare) applied to cocoa-growing soils reduced bean Cd levels by 0.52 ppm, 0.47 ppm, and 0.45 ppm, respectively. However, the experimental findings of this study could not be reviewed by the Expert Committee as the reference provided could not be found. Nonetheless, other replicated field trials currently in progress in Peru are evaluating this approach, and those studies are expected to provide further clarification (Atkinson, 2020a, personal communication).

In other studies, pot trials using 3 g $CaCO_3$ kg^{-1} of soil were able to significantly reduce Cd uptake in lettuce, cabbage broccoli, white amaranth, and purslane on average by 40 to 50 percent (Tan et al., 2011). A greenhouse study with spinach saw a reduction in shoot Cd by 35 percent and 70.5 percent compared to the control when treated with 2 g $CaCO_3$ kg^{-1} and 2 g $CaCO_3$ kg^{-1} plus 1 percent organic matter, respectively (Kumarpandit et al., 2017). With respect to field investigations, liming at 6.8 metric tons of $CaCO_3$ per hectare decreased the Cd concentration in rice grains by 70 to 80 percent (Chen et al., 2018). The addition of 3 metric tons $Ca(OH)_2$ per hectare to tobacco-growing soils decreased the Cd levels in leaves by 35 percent (Tsadilas et al., 2005). Applications of slaked lime and “GSA” (slaked lime mixed with different mixing ratios of other inorganic and organic materials such as biochar with lime, sepiolite, and zeolite) were able to significantly reduce Cd levels in the grains of wheat with a rate of 4.54 metric tons $Ca(OH)_2$ per hectare (Hamid et al., 2019a).

For perspective: Compared to the application rates of some nutrient fertilizers, lime and other alkaline amendments are required in greater quantities (as much as 50 to 100 times more per hectare, but only every 3 to 10 years) to ameliorate soils. In addition, the effectiveness of liming is dependent on a number of variables. These include the neutralizing capacity of the material used as some materials have the ability to ameliorate faster due to their chemical composition and particle size; the physicochemical properties of some soils may facilitate easier amelioration than others; how well the amendments are physically incorporated in soils; and climatic conditions and terrain, which may promote leaching. The needed frequency of liming may also vary due to inherent soil characteristics, weather conditions, and landscape. These factors could affect how long amelioration effects last. Nonetheless, in general, some field studies have shown that reapplication may be required after 1 year, especially when soil pH is lower than 5.2 where exchangeable Al accumulates and must be precipitated by the added limestone product.

Additionally, the application of any soil amendment at the field level mainly consists of two steps: transportation of the material and the method by which it is added to the soil. These are also influenced by the acreage, terrain, soil and crop characteristics, available equipment, and the associated labor. Taking these factors into consideration, the transport of amendments to treat short-term crops are generally managed well with easier access and equipment. On the other hand, due to the sometimes challenging landscape where a perennial crop like cocoa is grown, the hauling of the material within the field may not be a simple task. Additionally, in order to ensure amendments are effectively applied in soils, they are typically incorporated using machinery and other tools that provide tillage in agricultural fields. However, due to the extensive feeder root system found in the upper 0-15 centimeters of cocoa-growing soils (Nygren et al., 2013), any form of digging may cause harm to the plant. Moreover, the labor required to facilitate this process should also be taken into consideration.

In addition, it must be noted that liming soils may affect the availability of other soil micronutrients such as Zn, particularly in low Zn soils. Thus, it is recommended that under those conditions, a Zn fertilizer be added to prevent any Zn deficiency complication when these soils are limed in attempt to reduce Cd uptake.

Discussion

Overall, the Expert Committee generally agrees that there is considerable research, with promising greenhouse and field data, showing how this technology could be used to reduce Cd levels in a number of crops, including cocoa in a 1 to 5 year time frame. Cd reductions of up 25 percent or more could be achievable but there is some uncertainty around this estimate. However, the Experts have concerns regarding the practicality of its application in the field and the scalability of this practice. The Experts also share some concerns regarding the scalability, technological feasibility, and practicality of implementing this strategy in the field. Specifically, the Experts have concerns that the logistics of the application of soil amendments on cocoa farms due to acreage, terrain, soil, and crop characteristics, available equipment, and the associated labor needs present implementation challenges. However, the importance of very low soil pH in cocoa Cd accumulation suggests practical methods to apply and incorporate limestone on acidic cocoa soils should be addressed. The Experts generally agree this strategy could be implemented without potential for unintended adverse public health, environmental impacts, or social impacts, or with potential impacts that could be controlled or prevented.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Two Experts predict that the level of Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent whereas the other two Experts predict the reduction levels could be 10 to 25 percent.

Time frame for potential reduction: Two Experts predict that it would likely take 1 year from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. The other two Experts predict the time frame would be 1 to 5 years.

Strength of evidence for reduction: The Experts agree that a reduction in Cd levels in cocoa beans using these methods has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts

Potential public health impacts: Three Experts gave a rating that indicates they think this reduction strategy could be implemented without potential for unintended adverse public health impacts with proper exposure prevention methods (e.g., PPE). The fourth Expert thinks this reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: Two Experts gave a rating indicating that this strategy could be implemented without prohibitive costs to the chocolate industry. Two Experts gave a rating indicating that the reduction strategy could not be implemented without considerable and potentially prohibitive costs based on anticipated high labor and material costs.

Potential environmental impacts: Three Experts provided a rating that indicates they think the reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert gave a rating indicating this reduction strategy could have unintended adverse environmental consequences, which could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures.

Potential social impacts: The Experts agree that this reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think the scalability of the proposed reduction strategy is unknown and potentially challenging due to unknown cost, amendment availability, and labor; and further that scalability is dependent on the implementation capacity of each country as it relates to their available resources within the cocoa sector. One Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms; however, scaling is still possible. The fourth Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa farms.

Technological feasibility of method: Three Experts gave ratings that indicated they think the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective.

Confidence: Two Experts have a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believe there is sufficient evidence to support this statement. One Expert has a very high degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant. The fourth Expert has a medium degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believes there is sufficient evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 75 percent, a feasibility score of 60 percent, and an overall score of 63 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-3 for the Experts' individual scoring of this strategy.

4.1.4 Use Zinc Sulfate Soil Amendments to Reduce Cd Uptake from Soils

Overview of Strategy

In addition to ameliorating Zn deficiency in soils, the application of $ZnSO_4$ fertilizer has proven to be an effective method for reducing Cd uptake into grains or the edible parts in a number of crops, including recent research with cocoa grown in pots. Based on these findings, it is believed that this strategy could also be used to reduce Cd accumulation in low Zn cocoa trees thereby inhibiting Cd transfer into cocoa beans.

Background

The effect of soil amendment with Zn in the form of $ZnSO_4$ to reduce Cd uptake in crops has been well-documented in the literature. Both the Code of Practice for the prevention and reduction of Cd contamination in cocoa beans (CODEX, 2020) and a report evaluating potential mitigation solutions for Cd in cocoa (Meter et al., 2019) have also assessed the soil application of $ZnSO_4$ as a probable strategy.

Due to the chemical similarity and competitive nature of Cd and Zn metal ions in soils and at roots of crops, soils with Cd and deficient in Zn are likely to give preferential uptake to Cd by plants. Research has shown that the application of Zn to these soils results in an antagonistic effect hindering Cd accumulation in plants. Research has also shown that Zn fertilizers can reduce Cd accumulation by crops even when the soil is Zn sufficient for the crop.

There are reports for its effect in cocoa, however, the validity of some of these data still need to be verified. For example, Meter et al. (2019) reported that a preliminary field study conducted by a scientist (Davila, 2018) in Peru demonstrated a modest reduction in the level of Cd in cocoa beans with increasing rate of application of $ZnSO_4$. at 0.09, 0.18, and 0.27 kg per plant. Unfortunately, further details about this experiment could not be reviewed by the Expert Committee. Additionally, the Code of Practice produced by CODEX (2020) documented another field study by scientists in Ecuador (SENESCYT, 2011) that reported a 56 percent reduction in Cd in cocoa-growing soils (from 1.35 mg/kg to 0.59 mg/kg) when 200 kg Zn ha^{-1} was applied; however, no data were reported on the amendment's effect on the levels of Cd and Zn in the tissues of the cocoa tree. Furthermore, the reference provided for this study could not be found to review their experimental findings. Nonetheless, there are other replicated field trials currently in progress in Peru to evaluate this approach, which is anticipated to provide further clarification (Atkinson, 2020a, personal communication).

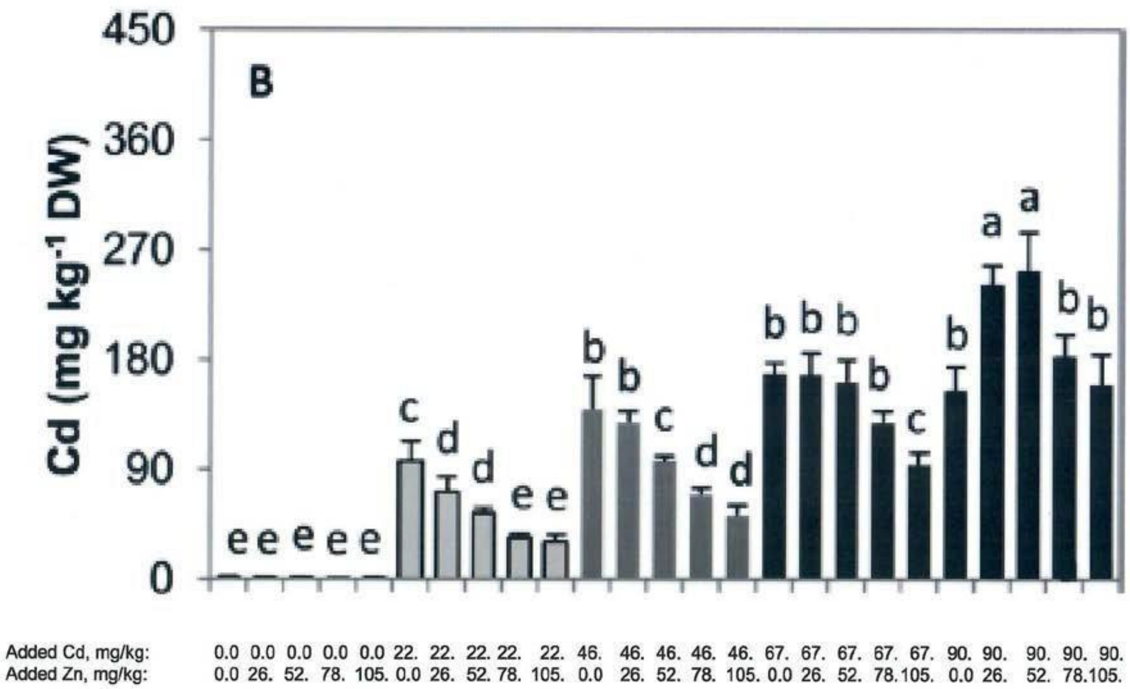
On the other hand, a recent greenhouse trial using CCN-51 cocoa seedlings by dos Santos et al. (2020) showed some promising results. The application of increasing rates of Zn (26, 52, 78, and 105 mg Zn kg^{-1}) to soil with varying Cd concentrations in this study strongly inhibited Cd accumulation by the roots and leaves (the rates of Zn fertilizer were added to soil with 22 mg/kg added Cd to allow easier analysis of the Cd in the cocoa shoots; this is a high soil Cd, yet added Zn substantially reduced Cd in the cocoa shoots). The strong inhibition of Cd uptake-translocation by added Zn also indicates that Cd in cocoa is taken up on the same transporter as Zn, likely the ZIP1 gene (see Sections 4.1.5 for further clarification), due to the direct effect observed on the Cd levels in the cocoa tissues as a consequence of increasing rates of Zn application to the soil. See Figure 1 (on the following page) for a summary of relevant results from the dos Santos et al. (2020) publication.

In other studies, zinc sulfate amendments have been used in greenhouse trials to effectively reduce Cd in spinach where the addition of an equivalent rate of 5–20 kg Zn ha^{-1} decreased Cd levels in spinach leaves by 19 to 28 percent and in roots by up to 42 percent (Gray and Wise, 2020). Decreased lettuce leaf concentrations of Cd, between 33 to 75 percent, have been observed with increasing rates of zinc sulfate amendment application (10-100 mg Zn kg^{-1}) (Chaney et al., 2009). Field studies conducted on cabbage, radish, and tomato saw an enhanced reduction of up to 74 to 84 percent in Cd levels in their edible parts when 30 kg Zn ha^{-1} was applied (Li et al., 2014). In another field experiment involving wheat, Khoshgoftarmanesh et al. (2013) found that the application of 40 kg ha^{-1} $ZnSO_4$ decreased the Cd concentrations in the grains of multiple wheat cultivars.

Also, the application of any soil amendment at the field level mainly consists of two steps: transportation of the material and the method by which it is added to the soil. These are also influenced by the acreage, terrain, soil and crop characteristics, available equipment, and the associated labor. Taking these factors into consideration, the transport of amendments to treat short-term crops are generally managed well with easier access and equipment. On the other hand, due to the sometimes challenging landscape where a perennial crop like cocoa is grown, the transportation to deliver the material may not be a simple task. Additionally, in order to ensure amendments are effectively applied in and incorporated into the rooting zone of soils, the amendments are typically incorporated using machinery and other tools that provide tillage in agricultural fields. However, due to the extensive feeder root system found in the surface (0-15 cm) of cocoa-growing soils, any form of digging may cause harm to the roots/plant. Moreover, the labor required to facilitate this process should also be taken into consideration.

It must be noted, however, that the application of excessive amounts of ammonium based fertilizers and sulfur based fertilizers such as $ZnSO_4$ to agricultural soils can result in soil acidification (Goulding, 2016). Thus it is recommended that the application of $ZnSO_4$ to soils, particularly acidic soils, should be accompanied with an alkaline material such as limestone to counteract acidification effects. For perspective: Fertilizer Zn is usually applied in the main rooting zone between 0.5 and 1.0 m from the trunk of the cocoa trees. If one adds 50 g of $ZnSO_4 \cdot 7H_20$ and incorporates it in the 15 cm depth of topsoil, the soil would be 24 mg /kg higher in Zn. And it would require 17.8 g $CaCO_3$ to neutralize the acidity added with the Zn salt. Because strong acidity and low Zn interact to promote higher Cd uptake into cocoa, if the pH is very low, limestone should be added to raise the topsoil pH to 6 or above if one is adding amounts of Zn fertilizer designed to reduce Cd uptake rather than simply correct Zn deficiency.

Figure 1. Summary of dos Santos et al. (2020) Cd Uptake Study



Notes: Figure reproduced from dos Santos et al. (2020). The figure displays the effect of added Zn on Cd accumulation by CCN-51 *Theobroma cacao*. Strong inhibition of Cd uptake by Zn is evidence that the ZIP1 transporter is the main mechanism for Zn and Cd uptake by cocoa (Dos Santos et al., 2020). Experiment has to be qualified because the Cd and Zn salts were applied to the top of the medium in pots of soil in which the seedlings had been established from seed. And the level of added Cd is much too high to represent common cocoa soils. But the principles of Zn inhibiting Cd accumulation are clearly observed in the experiment.

Discussion

The Expert Committee generally agrees that there is considerable research, with promising greenhouse data and field data still pending verification, showing how this technology could be used to reduce Cd levels in a number of crops, including cocoa in a 1 to 5 year time frame. Cd reductions of up 25 percent or more could be achievable but there is some uncertainty around this estimate. The Experts also share some concerns regarding the scalability, technological feasibility, and practicality of implementing this strategy in the field. Specifically, the Experts have concerns that the logistics of the application of soil amendments on cocoa farms due to acreage, terrain, soil and crop characteristics, available equipment, and the associated labor needs present implementation challenges. The Experts generally agree this strategy could be implemented without potential for unintended adverse public health, environmental impacts, or social impacts, or with potential impacts that could be controlled or prevented.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Two Experts think the level of Cd reduction in chocolate products from implementing this strategy could be 10 to 25 percent; one thinks the reduction levels could be greater than 25 percent; and the fourth Expert thinks the extent of reduction cannot be quantified or is not known.

Time frame for potential reduction: Three Experts predict it would take 1 to 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. The fourth Expert predicts it would likely take 1 year or less.

Strength of evidence for reduction: Two Experts think the reduction strategy has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts. Two Experts think there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts).

Potential public health impacts: Two Experts gave a rating that indicates the reduction strategy could be implemented without potential for unintended adverse public health impacts with proper exposure prevention methods (e.g., PPE). Two Experts think the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: Two Experts gave a rating indicating that this strategy could be implemented without prohibitive costs to the chocolate industry. Two Experts gave a rating indicating that the reduction strategy could not be implemented without considerable cost or that the extent of economic impact cannot be quantified or is not known based on the limited field experience.

Potential environmental impacts: Three Experts provided a rating that indicates they think the reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert gave a rating indicating this reduction strategy might have unintended adverse environmental consequences, which could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures.

Potential social impacts: The Experts agree that this reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think the scalability of the proposed reduction strategy is unknown and potentially challenging due to unknown cost, amendment availability, and labor; and further that scalability is dependent on the implementation capacity of each country as it relates to their available resources within the cocoa sector. One Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms; however, scaling is still possible. The fourth Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa farms where soil analysis indicates Zn application would likely reduce bean Cd or increase bean yields.

Technological feasibility of method: Two Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. One Expert thinks the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but is not widely available. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective.

Confidence: Two Experts have a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believe there is sufficient evidence to support this statement. One Expert has a medium to high degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement. The fourth Expert has a very high degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant.

Conclusion

This strategy received a combined confidence score of 69 percent, a feasibility score of 58 percent, and an overall score of 60 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-4 for the Experts' individual scoring of this strategy.

4.1.5 Use Plant Breeding or Genetic Methods to Produce Improved Cocoa Cultivars

The Expert Committee evaluated four different Cd reduction strategies that pertain to developing improved cocoa plant cultivars using various plant breeding (or genetic) methods to achieve reduction of Cd accumulation in cocoa beans. The intent of these strategies is to use conventional breeding and molecular genetics methods to develop new cocoa plant cultivars that demonstrate a reduced capacity for Cd uptake from soil or transport into the bean. Once developed, these "low Cd accumulators" would replace cocoa cultivars for regions that currently produce beans with elevated Cd levels. These four strategies are discussed in Sections 4.1.5.1 to 4.1.5.4, and the following paragraphs provide background information that applies to all four strategies.

Cd levels in some cocoa beans grown in South America and Latin America have higher Cd levels than markets seek. This is because the cultivars currently grown may accumulate high levels of Cd in beans from certain soils. The phytoavailability of Cd in some of these soils is relatively high compared to cocoa production soils in Africa, due to factors such as low soil pH and higher soil Cd concentration (see Root Cause Phase report). The Expert Committee evaluated various better agricultural practices to lower Cd levels in beans, and these fall into two categories: reducing soil Cd phytoavailability (e.g., see Sections 4.1.3 and 4.1.4) and breeding cocoa plants that absorb and translocate lower amounts of Cd to shoots and beans, as discussed in the four genetics strategies.

A wide diversity of cocoa cultivars is grown around the world. Plant breeders try to develop improved commercially valuable cultivars by conducting research, making genetic crosses ("hybrids"), and selecting improved strains from the progenies of those crosses. An apparently improved genotype is tested in many locations to verify the desired properties in the field. If the genotype is found to have the desired properties for cocoa, the genotype may be released to growers as a new "cultivar." Desired characteristics of cocoa cultivars include specific flavor qualities sought by industry, disease resistance, and increased yield. Combining these multiple properties in new selections from breeding programs is already difficult without making limited Cd accumulation in beans a major genetic selection factor.

However, cocoa cultivars are often grown on soils with high enough Cd phytoavailability that Cd levels in some harvested beans are too high to comply with EU and California requirements for chocolate products. The four genetics strategies documented in Sections 4.1.5.1 to 4.1.5.4 examine plant breeding approaches to develop cocoa plants that accumulate less Cd in beans.

Breeding has been central to reducing food-chain Cd for non-cocoa crops, including rice, confectionery sunflower, flax, durum wheat, soybean, and pak choi (Wang et al., 2021). Traditional breeding involves growing diverse cultivars under uniform soil conditions and assessing how Cd accumulation in edible plant tissue varies among them. Breeders have to combine the best "crop" properties with the low Cd accumulation trait to generate new cultivars that might be adopted by the industry in order to alleviate Cd problems of some cocoa growers.

Recently, researchers have examined DNA sequences in conjunction with evaluating Cd accumulation to improve the probability of identifying a genotype with all desired characteristics. This approach allows breeders to inexpensively identify DNA markers that make it much easier, less expensive, and more reliable to breed high quality crop cultivars with lower Cd accumulation potential. One only needs to verify the genetic marker for low Cd is present in genotypes that are favorable for all other properties of the crop normally selected by breeders. This new "molecular" breeding approach substantially reduces the time and cost, and increases the reliability of achieving the desired genetic improvement.

In cocoa, the fruits and seeds are the plant part where Cd concentrations need to be lowered. To reach market penetration, cocoa nib breeding must account for genetic traits involved in making a competitive cultivar. These traits include yield; resistance to pod, foliar, and root diseases; flavor; Cd accumulation; and adaptation to the region where cocoa is grown.

Reliance on genetic modification in breeding lower Cd crops has become important in recent decades. Molecular breeders can build strains with the desired traits for commercial cocoa by adding specific genetic changes to keep Cd from reaching the nibs. This can be accomplished through several means, which may start by identifying and expressing: (1) the transporter protein important for Cd uptake by roots; (2) the transporter protein that pumps Cd into root cell vacuoles; (3) the root transporter that pumps Cd into the xylem for transport to shoots; (4) a transporter that absorbs Cd into leaf cells; (5) a transporter that pumps leaf Cd into leaf vacuoles; (6) the transporter that moves leaf cell Cd into phloem for transport to fruits; or (7) the transporter that moves Cd from phloem into the forming pod or seeds. Cocoa is unusual in that flowers and pods are developed along the trunk and limbs of the tree, not on the petioles or tips of branches. Thus the immediate source of Cd that is accumulated into the pod and seeds is not known: part could come from the roots directly through xylem or in shoot phloem connections to the pod that carry the energy and nutrients which support pod and bean growth. When growing cocoa trees from seeds produced in plant breeding, it takes about 5 years before the modified trees produce beans; and researchers therefore need many years to demonstrate whether the modifications resulted in trees having all the desired traits without unwanted outcomes. On the other hand, when investigating scions or rootstocks (defined below), demonstration of effectiveness may occur more rapidly.

Tree crops differ from ordinary field crops in terms of how genetic changes can be implemented. A method used for both tree crops and field crops involves planting a genetically modified seedling in the field and evaluating effectiveness in mature crops. However, scions of tree crops such as cocoa can also be grafted onto existing rootstocks in the orchard. Researchers may identify improved rootstock ability to limit Cd uptake and translocation, while grafting scions with the desired properties (e.g., disease resistance, flavor, and yield). Less time is needed for grafted plants to reach the fruiting stage.

Low Cd genotypes could be a very effective long-term solution to reduce Cd levels in cocoa beans. It would take time and investment to convert existing orchards to new lower Cd cultivars, but these could be first applied to areas with Cd problem soils as soon as new cultivars are available. Molecular breeding using selection based on genetic markers correlated with low nib-Cd could speed development of new lower Cd genotypes compared with traditional breeding approaches. Both the transporter gene(s) and promoter gene(s) for the transporter gene may vary naturally, or may be altered using modern technology to obtain much lower Cd in cocoa beans. The four genetic strategies provide further details on how the Cd reductions can be achieved. It should be noted that in some circumstances (e.g., areas with high Cd:Zn ratios in soils or extremely low soil pH), incorporation of soil amendments (see Sections 4.1.3 and 4.1.4) might be needed to achieve the lower bean Cd benefit from even new low Cd genotypes.

The Expert Committee evaluated the merits and uncertainties of four genetic approaches with demonstrated potential for reducing Cd accumulation in cocoa nibs. These approaches are scion grafting (see Section 4.1.5.1), rootstock grafting (see Section 4.1.5.2), self-rooted cocoa (see Section 4.1.5.3), and molecular breeding (see Section 4.1.5.4). Of these four approaches, only molecular breeding would involve growing cocoa trees that might be considered genetically modified organisms (GMOs).

4.1.5.1 Use Scion Grafts to Reduce Cd Uptake from Soils

Overview of Strategy

This strategy involves grafting cuttings of improved genotypes with desired characteristics, including lower translocation of Cd to beans, to an existing cocoa root system. This strategy is based on the fact that some cocoa shoot genotypes translocate less Cd to cocoa beans, due to physiological or genetic mechanisms. Alternatively, usual genetic crossing and evaluation of progeny seeds for Cd accumulation may identify genotypes with very low Cd transfer to seeds. These genotypes would still need to have the flavor, yield, and other properties of the best genotypes presently available to growers.

Background

Finding or breeding low Cd cocoa genotype scions is a scientifically valid approach to achieve reliably, persistently lower Cd in cocoa beans. Furthermore, the grafting of preferential lower Cd scion genotypes onto existing plants in growers' orchards would be a beneficial longer-term better agricultural practice to lower Cd accumulation in market quality cocoa beans, with a relatively quicker time to maturation than other breeding methods. When an orchard change in cultivars is needed to remain competitive, cocoa growers have replaced about 10 percent of their trees with new scions per year. Resources are needed to support the research and breeding efforts required to develop preferential low Cd cocoa scion genotypes for cocoa. Once the new lower Cd scions are developed, they would need to be marketed in such a way as to make it worth the growers' effort and expense to change orchards to lower nib Cd cultivars. Because older trees become less productive over time, scion replacement programs are often conducted after about 30 years post-planting (Umaharan, personal communication, 2020a).

Incorporating new scion grafts as a Cd control measure could alleviate potential erosion of bare soil that would otherwise occur when completely removing and replacing cocoa trees. Although replacing complete orchards with new scion grafts or transplants might present an expensive initial investment, using these grafts could result in a much quicker Cd reduction (and therefore a lesser economic impact over the longer term) than other breeding approaches. However, the Expert Committee did not conduct a complete cost and economic analysis of this issue.

Discussion

The Expert Committee generally agrees that finding solutions to replace existing cocoa plants that produce high Cd beans with plants that produce low Cd beans could be a potential long-term, sustainable solution to persistently high Cd bean production in some cocoa growing regions. Finding or breeding low Cd cocoa genotype scions is one genetic approach to potentially achieve a measurable reduction of Cd in cocoa bean production in these areas. Scion grafts also provide a relatively quicker time to production than other breeding methods. Older trees become less productive over time, so scion replacement programs are often conducted after about 30 years post planting cocoa. Growers replace about 10 percent of their trees with new scions per year.

The Experts are somewhat uncertain as to how effective grafting of low Cd accumulating scions would be in reducing Cd levels in cocoa beans and how long after implementation measurable reductions would be observed. However, the Experts generally agree implementing this strategy would not impose negative public health, environmental, and social impacts. Economically, the Experts agree that there could be significant initial costs for research, development, and field application of low Cd scion grafts, however the cost over the long- term could be fully recovered. It should be noted that no formal cost and economic analysis was conducted. The Experts share some concerns over the potential scalability and technological development of low Cd scions, however as a whole, the Expert Committee is relatively confident these obstacles could be overcome.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Three Experts think the extent of reduction cannot be quantified or is not known. The fourth Expert thinks the level of Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent.

Time frame for potential reduction: Two Experts predict it would take 1 to 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. Two Experts think the timing of the reduction is not known.

Strength of evidence for reduction: Three Experts gave a rating that indicates there is inconsistent evidence of a reduction or no evidence of a reduction, but anticipate one occurring. The fourth Expert thinks the reduction has been reliably demonstrated either by practical implementation on a large farm or manufacturing facility or during large scale field trials and documented in the scientific literature by a reputable organization or by a government agency.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: Three Experts gave a rating indicating that this strategy could be implemented without prohibitive costs to the chocolate industry. The fourth Expert thinks the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: The Experts agree the reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but scaling is still possible. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa farms. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms.

Technological feasibility of method: Three Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications, and has been demonstrated to be effective.

Confidence: Two Experts have a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believe there is sufficient evidence to support this statement. One Expert has a very high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant. The fourth Expert has a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 69 percent, a feasibility score of 64 percent, and an overall score of 65 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-5 for the Experts' individual scoring of this strategy.

4.1.5.2 Develop and Plant Rootstocks That Accumulate Less Cd from Soils

Overview of Strategy

This strategy involves developing and planting rootstocks that accumulate less Cd from soils or translocate less of the root-absorbed Cd to the shoots; such improved rootstocks can support scions with market qualities. This is the second of four genetics strategies included in this report. Roots of some genotypes may transfer less Cd to shoots because they either absorb lower amounts of Cd from soils or store Cd in roots more effectively. Such genotypes could be used as rootstocks for grafting scions with the desired cocoa quality properties while accumulating less Cd into the beans.

Background

Genetic modification of cocoa plant roots to absorb less Cd from soils or to pump Cd into root cell vacuoles might give near total retention of Cd in the roots, as has been shown in rice, tobacco, and some other crops. For example, commercial eggplant in Japan has to be grafted onto another *Solanum* species that accumulates and translocates to shoots and fruits much lower levels of Cd in order to produce eggplant fruits that meet Japanese Cd limits (Yamaguchi et al., 2011). After the genetic improvement is proven to have occurred (by genetic measurements), a plant Cd uptake trial would be needed to confirm effectiveness *in vivo* and that the new low Cd rootstock can be reproduced by cuttings and used to replace trees in orchards with soil properties that cause higher Cd accumulation than desired. The genotype used for modification of root uptake of Cd need not have the many shoot properties needed in cocoa bean production (e.g., resistance to foliar and fruit disease, yield, flavor) but should be resistant to root disease problems known to breeders. These improved rootstock genotypes could support fairly rapid replacement of trees of existing high Cd accumulating cultivars using scions with the most desired properties for yield and cocoa quality.

In terms of technical feasibility, a genotype variation with low transport of Cd from the roots to the shoots has not yet been reported in cocoa. Alternatively, developing cocoa genotypes with over-expressed HMA3 genes to keep Cd in the roots (or alternatively trapping Cd in leaves) could provide the needed reduction in bean Cd for general cocoa production. High expression of *T.c.*HMA3 in leaves using a strong cocoa promoter for foliar genes might also be a highly effective method to produce low Cd cocoa beans using only cocoa genes.

Because reduced Cd uptake by a rootstock can reduce bean Cd in all scions, and making genetic change could be achieved much more quickly in rootstocks than in scions which require many properties to be maintained, modification of the cocoa HMA3 gene or its promoter to pump most root absorbed Cd into vacuoles could provide the needed reductions required for fine flavor genotypes important to the industry. This could be the most rapid solution, and could be used with all scions. The literature indicates that most cocoa trees in the field are grafted plants.

Discussion

The Expert Committee generally agrees that finding solutions to replace existing cocoa plants that produce high Cd beans with plants that produce low Cd beans could be a potential long-term, sustainable solution to persistently high Cd bean production in some cocoa growing regions. Finding or breeding low Cd cocoa genotypes rootstocks is one genetic approach to potentially achieve a measurable reduction of Cd in cocoa bean production in these areas.

The Experts are somewhat uncertain as to how effective grafting of low Cd accumulating rootstocks could be in reducing Cd levels in cocoa beans and how long after implementation measurable reductions would be observed. However, the Experts generally agree implementing this strategy would not impose negative public health, environmental, and social impacts. Economically, the Experts agree that there could be significant initial costs for research, development, and field application of low Cd rootstock grafts, however the cost over the long-term could be fully recovered. It should be noted that no formal cost and economic analysis was conducted. The Experts share some concerns over the potential scalability and technological development of low Cd rootstocks. A genotype variation with low transport of Cd from roots to shoots has not yet been reported in cocoa. However, the Expert Committee is relatively confident these obstacles could be overcome.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Three Experts think the extent of Cd reduction cannot be quantified or is not known. The fourth Expert thinks the level of Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent.

Time frame for potential reduction: Two Experts think the timing of the reduction is not known. One Expert predicts it would take more than 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. The fourth Expert predicts it would take 1 to 5 years.

Strength of evidence for reduction: Three Experts gave a rating that indicates there is inconsistent evidence of a reduction or no evidence of a reduction, but anticipate one occurring. The fourth Expert thinks the reduction has been reliably demonstrated either by practical implementation on a large farm or manufacturing facility or during large scale field trials and documented in the scientific literature by a reputable organization or by a government agency.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: Three Experts gave a rating indicating the strategy could be implemented without prohibitive costs to the chocolate industry. One Expert gave a rating indicating the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: The Experts agree the reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think there is no documented or demonstrated potential the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but scaling is still possible. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa farms.

Technological feasibility of method: Three Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective.

Confidence: Two Experts have a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believe there is sufficient evidence to support this statement. One Expert has a very high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant. The fourth Expert has a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 69 percent, a feasibility score of 64 percent, and an overall score of 65 percent (Table 3). The Expert Committee rated this strategy in the High category based on the combined confidence score. Refer to Table B-6 for the Experts' individual scoring of this strategy.

4.1.5.3 Use Self-Rooted Cocoa to Reduce Cd Uptake from Soils

Overview of Strategy

This strategy pertains to developing and using self-rooted cocoa to reduce Cd uptake from soils, the traditional approach to plant breeding of improved cocoa cultivars. This is the third of four genetics strategies included in this report. This strategy would focus conventional cocoa plant breeding resources to produce cultivars that accumulate lower bean Cd levels, as well as meet other desired or required traits (e.g., high yield, fine flavor, disease resistance). The breeding approach to obtain lower Cd cocoa beans has been recommended by both the Code of Practice (CODEX, 2020) and the Biodiversity International (Meter et al., 2019) reviews.

Background

Breeding improved cocoa cultivars has been a continuous practice in many nations. For years, the primary objectives of the breeding included better disease resistance, higher yields, improved market qualities (fine flavor), and plant nutrition. Breeding to reduce cocoa bean Cd concentrations had not been an objective until the EU announced limits on Cd in chocolate products. Traditional plant breeders examine intact plants rather than roots (see Section 4.1.5.1) and shoots (see Section 4.1.5.2) to obtain desired properties of the progenies. Breeding intact plants also differs from "molecular breeding" or "bioengineering" (see Section 4.1.5.4), which is conducted to improve some specific property of an otherwise desirable genotype.

In whole plant selection in breeding, existing genotypes with desired properties are crossed genetically to make progenies with possibly improved qualities. For cocoa, breeding is presently based on crossing strains with some good properties and evaluating the progenies in the field for the full range of desired properties (e.g., yield, crop quality, disease resistance, fine flavor, and Cd accumulation). This approach evaluates both the parent lines in order to select parents for crossing and progenies of the crosses. It is relatively slow because it takes 5 years to get fruits and beans to evaluate relative Cd accumulation and other cocoa quality properties of the new genotype. Such research might demonstrate that progenies from such crossing experiments show improved low Cd rootstocks; and if the shoots also had the desired shoot properties, the strain might be a candidate for intact plant breeding success. As noted above, it is a slow process to have proof of this strategy's effectiveness.

Limited research on genetic variation in cocoa Cd accumulation has been published in peer-reviewed journals; and additional genetic variation of Cd accumulation may be proprietary information in some nations. For example, Lewis et al. (2018) measured Cd in soils, leaves, and cocoa beans for 100 genotypes growing in the International Cocoa Genebank orchard in Trinidad. The orchard soil had mean Mehlich-3 extractable Cd mean concentration of 137 ppb and mean pH of 4.96, which provide relatively high phytoavailable Cd conditions for screening. For beans, the mean Cd concentration was 990±43 ppb (mean±standard error); the maximum Cd concentration was 2,310 ppb; bean Cd concentration varied 13-fold among genotypes. For leaves, the mean Cd concentration was 2,150±69 ppb and the maximum Cd concentration was 5,240 ppb; and leaf Cd concentration varied 7-fold among genotypes. These findings suggest traditional breeding could contribute to a reduction of cocoa bean Cd levels. Because the orchard studied exhibited significant spatial variation in soil Cd and pH, the authors adjusted plant Cd levels for the phytoavailable soil Cd measured at each sampled tree (based on Mehlich-3 extractable Cd). They also observed significant variation in the ratio of Cd concentrations between beans and leaves and between shells and nibs. Theoretically, these relationships might be used to breed lower Cd cocoa nibs. But it is not certain that the ratio of nib-Cd to bean-Cd or to leaf Cd are constant during fruit development or between years, so the selection criteria are still being defined and improved. Umaharan (2020b, personal communication) reported that the Trinidad research program has now evaluated about 600 genotypes in the orchard sampled for the Lewis et al. (2018) paper, strengthening the possibility of finding the genetic variation needed to breed lower Cd commercial cultivars in the future.

In a recently published study of genetic variation in Cd uptake and tolerance in cocoa, Arévalo-Hernandez et al. (2021) tested the relative accumulation of Cd by 53 diverse cocoa genotypes in a 6-month greenhouse pot study using large pots (5 kg) of prepared soil. The researchers added Cd salt to the soil; soil Cd at harvest was 28 mg/kg. They did not add Zn (soil had only 20 mg Zn/kg). And the soil pH at harvest was 5.46 providing high Cd phytoavailability. The added Cd in this study had extremely high phytoavailability due to the high Cd:Zn ratios in the Cd-salt amended soil (more Cd than Zn). These high ratios might have produced results that are not predictive of genetic responses on normal soils with high Cd phytoavailability. This high Cd level caused Cd phytotoxicity in some genotypes. Shoot Cd in the +Cd treatment varied from about 0.100 to 25.0 mg/kg dry weight. The currently important genotypes were generally low in shoot Cd accumulation in this research (e.g., shoot Cd concentration was 2.00 mg/kg, dry weight, for CCN-51). However, a test with these conditions is unlikely to identify needed low Cd uptake germplasm under real world conditions. Selection of low uptake by seedlings in greenhouse pots may not predict leaf or bean Cd in mature trees growing in the field. Moreover, increasing soil Cd phytoavailability without a corresponding 100-fold higher increase in soil Zn could give artifacts in relative Cd accumulation among the tested cocoa genotypes. Genetic screening at low pH, no higher than 5.0 mg/kg Cd in soil, and 100-times higher Zn than Cd would provide more useful screening conditions to find low Cd uptake and translocation in cocoa seedlings relevant to the breeding goals. Research is needed to establish field relevant screening methods for greenhouse evaluation of crossing progenies. Although the experiment of Arévalo-Hernandez et al. (2021) was well conducted for a soil with low pH and added Cd levels, the CCN-51 would have been expected to accumulate much higher Cd levels in shoots based on other papers including some of the same research team. The range of genetic variation may be representative of potential variation in existing cultivars of cocoa, but comparing Cd accumulation in shoots of cocoa in other experiments suggest this experiment under-estimated the genetic potential for Cd uptake. (Note: The authors' goal was to screen for Cd tolerance, but the data show relative Cd accumulation as well.)

A study by Engbersen et al. (2019) examined variation in bean and leaf Cd among 11 cocoa cultivars in one commercial orchard in Honduras. They found insignificant variation of Cd in leaves, but significant variation of Cd in beans. In more detailed examination of three cultivars, significant genetic variation was observed in mature beans, but not in immature beans, suggesting that Cd loading to the beans during the bean filling process possibly varied genetically. This observation further suggested to the researchers that Cd transfer from the leaves to beans might provide breeding opportunities. In other field collections of soils and cocoa leaves and beans, genetic diversity was observed (Arévalo-Gardini et al., 2017; Argüello et al., 2019) but the range of cultivars examined did not identify low Cd accumulating cocoa genotypes needed to achieve lower bean Cd levels.

One difficulty with breeding cocoa for fruit or bean traits is the 5-year wait after planting before fruits are available for bean Cd analysis to evaluate the breeding project's success (lower bean Cd). Modern genetic technologies allow identification of gene variants in a species that cause studied variation, for example, in Cd accumulation or transport to beans. Fuller fundamental understanding of the biochemistry and genetics of uptake and translocation of soil Cd by cocoa is believed to offer more rapid and effective breeding of lower Cd in cocoa beans whether by traditional breeding or by bioengineering with only cocoa genes or introduced genes to attain much lower Cd in cocoa beans. If this strategy involves using genetic material from cocoa germplasm to engineer lower Cd genotypes of cocoa, this approach is not considered to be a genetically modified organism (GMO). In contrast, transferring genes from other species to reduce bean Cd would make the progeny GMO, which is presently not acceptable in chocolate manufacture (see Section 4.1.5.4).

Research to find or make improved lower Cd cocoa cultivars using conventional plant breeding methods is one agronomic solution to reduce Cd in cocoa. However, the approach is slow and may not be sufficiently effective. Breeding lower Cd cocoa requires finding or making genotypes that accumulate less Cd into roots, translocate less Cd to shoots, retain Cd in leaf cells, or otherwise transfer less Cd to nibs during fruit and bean formation. Although some research has begun in this field, significant progress has not been reported. Others are examining GMO methods to alter cocoa genetically to achieve lower Cd in beans. Section 4.1.5.4 discusses the GMO methods further.

Discussion

The Expert Committee generally agrees that finding solutions to replace existing cocoa plants that produce high Cd beans with plants that produce lower Cd beans could be a potential long-term, sustainable solution to persistently high Cd bean production in some cocoa growing regions. Finding or developing low Cd cocoa cultivars using conventional plant breeding methods is one genetic approach to potentially achieving a measurable reduction of Cd in cocoa bean production in these areas. However, conventional breeding methods often take a considerably long time (i.e., multiple generations) to develop all the desirable characteristics. For example, even after genes conferring low Cd in cocoa beans are identified, it might be necessary to combine the low Cd genetic hybrid with the genes that increase crop yield, provide disease resistance, and possibly to refine flavor profiles in order to develop commercially competitive cultivars with low bean Cd.

The Experts are somewhat uncertain as to how effective conventional breeding of low Cd self-rooting cocoa plants could be in reducing Cd levels in cocoa beans and how long after implementation measurable reductions would be observed. However, the Experts generally agree implementing this strategy would not impose negative public health, environmental, and social impacts. Economically, the Experts agree that there could be substantial initial costs for research, development, and field application of low Cd self-rooted plants, however the cost over the long-term could be fully recovered. It should be noted that no formal cost and economic analysis was conducted. The Experts share some concerns over the potential scalability and technological development of conventionally bred low Cd self-rooted cocoa plants. However, the Expert Committee is relatively confident these obstacles could be overcome in the long-term.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Three Experts think the extent of reduction cannot be quantified or is not known. The fourth Expert predicts that the level of Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent.

Time frame for potential reduction: Two Experts predict it would take more than 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. Two Experts think the timing of the reduction is not known.

Strength of evidence for reduction: Three Experts gave a rating that indicates there is inconsistent evidence of a reduction or no evidence of a reduction, but anticipate one occurring. The fourth Expert thinks the reduction has been reliably demonstrated either by practical implementation on a large farm or manufacturing facility or during large scale field trials and documented in the scientific literature by a reputable organization or by a government agency.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: Two Experts gave a rating indicating this strategy could be implemented without prohibitive costs to the chocolate industry. One Expert gave a rating indicating this strategy is expected to have economic benefits to the industry and/or the consumer over the long-term. The fourth Expert gave a rating indicating the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: The Experts agree this reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think there is no documented or demonstrated potential the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but scaling is still possible. Two Experts think there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms.

Technological feasibility of method: Three Experts gave a rating indicating they think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective.

Confidence: Two Experts have a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believe there is sufficient evidence to support this statement. Two Experts have a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 63 percent, a feasibility score of 66 percent, and an overall score of 65 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-7 for the Experts' individual scoring of this strategy.

4.1.5.4 Use Molecular Breeding Techniques to Identify Cocoa Genotypes That Accumulate Less Cd

Overview of Strategy

This strategy pertains to using molecular breeding techniques to identify cocoa genotypes that accumulate less Cd from soils. This is the fourth genetics strategy included in this report. Of the four genetics strategies, if foreign genes are transferred to attain lower bean Cd, it would involve GMO.

Background

The most promising approaches to reduce Cd by breeding lower Cd genotypes of cocoa might be based on molecular technologies (e.g., "biotechnology"). A review of cocoa biotechnology (Wickramasuriya and Dunwell, 2018) summarizes the history of obtaining the gene sequence of cocoa and methods shown to date to modify the sequence of cocoa genes to attain specific goals.

Research on other plant species has identified specific genes related to Cd accumulation in shoots, seeds, etc. Higher expression of an existing cocoa gene might be achieved by using a different "promoter", the section of DNA that regulates the expression of a gene. Developing genotypes with a stronger HMA3 gene or stronger promoter of the native species HMA3 gene to store nearly all root absorbed Cd in root cell vacuoles has been well-studied in non-cocoa plants. Transport of Cd from soil to roots to shoots is believed to be under genetic control in several ways: (1) uptake by a "ZIP" type Zn transporter into root cell cytoplasm; (2) storage in root cell vacuoles by a HMA3 transporter; (3) pumping into the xylem for export to the shoots usually by the HMA2 transporter; (4) transport from leaves and stems to the developing cocoa pod and beans; and (5) uptake into the developing nibs (cotyledons) (Hart et al., 2002; dos Santos et al., 2020). For some crops, defective HMA3 genes allow much higher Cd translocation to shoots (Yamaguchi et al., 2011; Harris and Taylor, 2013; Wang et al., 2012; Hirata et al., 2019). On the other hand, overexpression of HMA3 in rice and soybeans effectively limited Cd translocation to plant shoots and grain (Ueno et al., 2010; Wang et al., 2018; Hirata et al., 2019; Shao et al., 2018).

Another molecular approach is suggested from a study of a Cd hyperaccumulator, *Sedum plumbizincicola*. The inactivation of the normal expression of HMA3 in leaves of this species made them sensitive to Cd phytotoxicity (Liu et al., 2017). Thus normal expression of HMA3 in this species resulted in leaves pumping Cd into leaf cell vacuoles and making the species Cd tolerant. This foliar expression of HMA3 has not been tested with other crops; however the expression of natural *T.c.*HMA3 in leaves might trap any shoot Cd in leaves and limit Cd transport to developing cocoa beans. Overexpression of *T.c.*HMA3 in leaves using a strong cocoa promoter might produce exceptionally low Cd cocoa beans. Such genetic constructs are under study by Dunwell et al. (Dunwell, 2020, personal communication).

Studies of cocoa genes possibly related to Cd accumulation were reported by Lewis et al. (2018) and Moore et al. (2020) of the Dunwell research group. Moore et al. (2020) cloned 19 diverse cocoa genes and transformed yeast to express the cocoa NRAMP and HMA genes.

In addition to characterizing genotype Cd levels in soil-grown cocoa plants, researchers have begun to look for evidence of genes in cocoa that significantly affect plant Cd concentrations. For example, Ullah et al. (2018) cloned genes believed to be involved in controlling Cd accumulation by cocoa roots and studied their expression in yeasts. They focused on the NRAMP family of genes, but there is currently no evidence that NRAMP proteins are involved in Cd accumulation from soils by crops other than rice.

In general, molecular manipulation of the HMA3 gene or its promoter provides a potential genetic approach to strongly reduce Cd in cocoa. Using highly effective HMA3 genes or promoters from other plant species may be the fastest, low-cost method to obtain cocoa genotypes with genetically very low Cd levels in beans when grown on all soils. But if other species genes are needed, it would make GMOs.

Molecular breeding includes using DNA measurement techniques to determine if a desired gene is present in plant tissue of breeding progenies. For example, very young roots and shoots can be tested for the expression of HMA3, the promoter for HMA3, or other genes which might strongly reduce bean Cd rather than waiting for field grown plants to measure Cd accumulation levels. All progenies without the needed Cd-lowering gene(s) can be discarded quickly rather than after years of field study. Only progenies with genes which cause lower bean Cd would be further tested in the field.

Overexpression of cocoa HMA3 by a non-cocoa promoter would be GMO, and not allowed in cocoa markets. But using the CRISPR-Cas9 system (see Lander, 2016) to improve the promoter of HMA3 or the structural gene for HMA3 in roots or shoots (by making DNA-bases to a form found in any natural cocoa germplasm which would make the proteins much more effective in limiting Cd entry to the shoots) is not currently regulated as GMO by the U.S. Department of Agriculture (USDA) (see Nature Plants, 2018) and offers the possibility of a relatively greater reduction in cocoa bean Cd than other genetics strategies. Changing single bases or one codon in the DNA of the promoter or structural genes for HMA3, ZIP1, etc., might give the desired reduction in cocoa bean Cd, but is not yet allowed unless the same difference in that base or codon has been shown to exist in cocoa germplasm.

Discussion

The Expert Committee generally agrees that finding solutions to replace existing cocoa plants that produce high Cd beans with plants that produce low Cd beans could be a potential long-term, sustainable solution to persistently high Cd bean production in some cocoa growing regions. Developing low Cd cocoa cultivars using molecular plant breeding methods, which require incorporation of foreign DNA into an organism (often referred to as genetically modified organisms or GMO), is one genetic approach to potentially achieving a measurable reduction of Cd in cocoa bean production in these areas. However, in the past 20 years, new technology referred to as the CRISPR/Cas9 System has been developed using technology that "rewrites" existing genetic code; and this technology might be used instead to avoid GMO designation by USDA if the revised gene would be the same as a natural gene present in a cocoa genotype. It is believed that CRISPR/Cas9 editing of DNA without using foreign DNA will be allowed in the near future in the US, and later in the EU. The current research on the molecular manipulation of the HMA3 gene or promoters from cocoa appears to provide one promising genetic approach to developing cocoa with lower Cd levels. Compared to conventional breeding methods, bioengineering generally takes less time and is more targeted toward meeting the breeding goals and achieving the desirable plant characteristics (e.g., increased crop yield, disease resistance, refined flavor profiles) in order to develop commercially competitive cultivars with low bean Cd. However, GMO crops (using DNA from other species) have perceived or demonstrated negative impacts on the environment (e.g., impacts on native plant breeding) and a considerable proportion of consumers reject GMO foods based on health concerns.

The Experts are somewhat uncertain as to how effective molecular breeding of low Cd self-rooting cocoa plants could be in reducing Cd levels in cocoa beans and how long after implementation measurable reductions would be observed. However, the Experts generally agree implementing this strategy would not impose negative public health or environmental impacts with the application of adequate environmental prevention measures and surveillance. On the other hand, the Experts were uncertain as to whether there could be negative social (and possibly economic) impacts due to potential rejection of GMO food (if GMO methods were used to achieve the needed changes). Economically, the Experts agree that there could be substantial initial costs for research, development, and field application of molecularly bred low Cd plants, however the cost over the long-term could be fully recovered. It should be noted that no formal cost and economic analysis was conducted. The Experts share some concerns over the potential scalability and technological development of low Cd self-rooting cocoa plants. However, the Expert Committee is relatively confident these obstacles could be overcome in the long-term.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Three Experts think the extent of reduction cannot be quantified or is not known. The fourth Expert predicts the level of Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent.

Time frame for potential reduction: Two Experts think the timing of the reduction is not known. One Expert predicts it would take more than 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. The fourth Expert predicts it would take 1 to 5 years.

Strength of evidence for reduction: Three Experts gave a rating that indicates there is inconsistent evidence of a reduction or no evidence of a reduction, but anticipate one occurring. The fourth Expert thinks the reduction has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: Two Experts gave a rating indicating this strategy could be implemented without prohibitive costs to the chocolate industry. One Expert gave a rating indicating this strategy is expected to have economic benefits to the industry and/or the consumer over the long-term. One Expert thinks the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: Two Experts gave a rating indicating the reduction strategy might have unintended adverse environmental consequences, which could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures. Two Experts think the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. One Expert thinks the reduction strategy may have unacceptable adverse social impacts over concerns regarding potential consumer rejection of GMO cocoa.

Scalability of potential reduction: Two Experts think there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but that scaling is still possible. One Expert thinks there is demonstrated potential the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms, or if applicable, a smaller subset based on need or practicality. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms.

Technological feasibility of method: Three Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective.

Confidence: Three Experts have a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with low probability the reductions could not be achieved, and believe there is sufficient evidence to support this statement. The fourth Expert has a very high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant.

Conclusion

This strategy received a combined confidence score of 63 percent, a feasibility score of 59 percent, and an overall score of 60 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-8 for the Experts' individual scoring of this strategy.

4.2 Agricultural Strategies to Reduce Cd with Medium Combined Confidence Scores

One Cd reduction strategy related to agricultural practices received a medium combined confidence score. The following sub-section describes this strategy and its feasibility considerations.

4.2.1 Cd: Test Water from Irrigation Sources and Use Alternate Water Sources, if Needed

Overview of Strategy

Test irrigation sources for Cd/Pb/chloride/etc. water concentrations and use alternate sources of water if contamination levels would raise concern about pre-harvest cocoa bean Cd concentration.

Both the Code of Practice document (CODEX, 2020) and the Bioversity Review (Meter et al., 2019) noted the need to check irrigation water quality. The likely most efficient approach to evaluate irrigation water sources would be a national government program to learn regional patterns of metal contamination and chloride in stream waters and other potential irrigation sources rather than individual farmers arranging to have the water source at their individual farm analyzed. Although it is often believed that cocoa is grown in rain forests, so no irrigation would be needed, seasonal variation in rainfall could limit tree growth or health such that irrigation is used, both flood and sprinkler methods, on different farms. In addition, for some farms, stream water floods part of a cocoa orchard near the streams and can leave deposits of particles rich in contaminant metals or increase soil chloride levels substantially. However, because *Theobroma cacao* evolved in rain forest environments, cocoa did not evolve salt tolerance (Umaharan, 2020a, personal communication), so a role of chloride in Cd uptake by cocoa is extremely unlikely.

Background

Cocoa orchards are often irrigated with locally available water supplies when rainfall is inadequate to sustain the trees. Such irrigation waters could affect Cd in cocoa beans by several mechanisms: 1) the water contains dissolved or particulate Cd and other elements that will increase soil Cd concentration and phytoavailability; and 2) the water contains high enough levels of chloride to promote Cd uptake by plants.

Irrigation water can become contaminated with Cd, Zn, and Pb from upstream sources, including runoff water from mines and mine wastes. Large areas in Japan, China, and Thailand produce rice grain with levels of Cd that comprise chronic lifetime risk (renal proximal tubular dysfunction and osteomalacia) to long term consumers of rice grown on contaminated paddy soils because upstream mines contaminated stream waters used to irrigate rice (e.g., Kobayashi, 1978). Farm families who grew their personal rice on such contaminated soils suffered the adverse effects of long term excessive diet Cd over decades at many locations (Chaney, 2015).

Industrial activities such as mining and smelting of ores, burning of fossil fuels, and other sources may contribute to Cd contamination of soils (Meter et al., 2019). Based on the literature, few cocoa-growing farms are located near industrial activity, thus direct atmospheric contamination from industrial activity does not appear to be a primary route of soil and bean contamination.

In contrast, annual flooding of some agricultural lands by local streams in many countries during the wet season can result in sediments and soils being contaminated with heavy metals, such as Cd, from upstream industrial, domestic, and natural sources, if the metals are present at significant levels in the flood waters (Chapman and Wang, 2001). An investigation conducted by Izquierdo (1988) in the Barlovento region of Venezuela demonstrated that flooding contributed to higher Cd concentrations of soils and cocoa beans in the various sampling locations where periodic floods occur from polluted rivers. A study done by Ramtahal (2012) in Trinidad found that Cd was detected mainly in the upper layers of the soil (0-10 cm) in a cocoa estate located nearby a polluted river's edge, with increasing Cd concentrations at points of greater inundation. He attributed the contamination of nearby soils to possible continuing sediment accumulation on the soil surface due to annual flooding of the plantation. In Honduras, Gramlich et al. (2018) reported that rivers that flood some cocoa-growing fields may have contributed to the levels of Cd in the surface soils through sediment deposition. Studies conducted by both Cardenas (2011) and Llatance et al. (2018) attributed possible soil Cd contamination of cocoa-growing estates in Tingo Maria and Pakun, Peru, respectively, to inundation from nearby mining-polluted rivers. Studies done in Ecuador by Argüello et al. (2019) demonstrated that beans with the highest concentration of Cd (5.28 –10.4 mg/kg) were from an estate in a cocoa-growing area that was potentially affected by Cd deposition from an adjacent mining-polluted river due to flooding.

Not many investigations report on the use of irrigation water from Cd-contaminated sources in cocoa fields. However, Chavez et al. (2015) suggested that elevated levels of Cd found in surface soils (0-15 cm) of cocoa plantations adjacent to a river in the studied area in Ecuador were likely due to contaminated irrigation water. (Note: Cocoa litter increases concentration of Cd in topsoils in orchards over time; therefore, older cocoa orchards would be expected to have higher Cd concentrations in topsoils.) Additionally, though not reported for cocoa, run-off from Cd-enriched soil from higher slopes may add Cd soil levels of lower agricultural plains (McDowell, 2010) and natural river courses. Also in Peru, three cases of local higher Cd in soil and cocoa beans is believed to be caused by stream water flooding of cocoa soils (Atkinson, 2020b, personal communication).

Overall, it appears that sources of Cd from industrial activity and other sources, by the way of flooding, could potentially contribute to Cd levels of cocoa-growing soils. However, based on minimal confirmatory evidence to pinpoint the soil Cd contamination and Cd phytoavailability, it should be considered an infrequent source of high soil and excessive cocoa bean Cd levels.

A role for chloride in excessive cocoa Cd has been hypothesized, but more careful analysis indicates that chloride is very unlikely to play a role in Cd accumulation by cocoa. Researchers examined effects of high sulfate and chloride in irrigation water or mixed with soils, and found that chloride, but not sulfate, caused higher Cd in salt tolerant and Cd accumulating crops used in testing (spinach, Swiss chard) (Bingham et al., 1984, 1986). These species were used because they are "salt tolerant" compared with many food crops. Key field and laboratory studies by McLaughlin et al. (1994; 1995; 1997a; 1997b) showed that high chloride in soil or irrigation water from a saline river in Australia caused substantially higher Cd levels in potato tubers—high enough to violate the

Australian limits for Cd in potatoes. They conducted additional analysis of soil, irrigation water, and soil solution to better understand the causation in the field (McLaughlin et al., 1999), and then did controlled experiments to try to understand how chloride causes high Cd uptake.

Smolders, McLaughlin, and co-workers (1998; 1996a; 1996b) tested the effect of chloride vs. nitrate or sulfate with soluble Cd on uptake by spinach. Again, high chloride but not sulfate or nitrate caused substantially increased Cd in the chard shoots. They examined the formation of ion complexes of Cd with chloride and sulfate and found that these anions formed about equally strong complexes with Cd (Smolders et al., 1998), so the explanation cannot be that the activity or solubility of free Cd^{2+} was altered differently by these anions. Fundamental studies, coupled with modeling of solution chemistry, indicated that either $CdCl^{+}$ is absorbed by the high affinity Zn transporter or another transporter in roots.

In cocoa farm areas with limited rainfall, but not irrigated with saline waters, soluble salts may accumulate from fertilization and not leach through the soil. Poorly drained soils can accumulate high levels of soluble salts, Na, K, Ca, Mg, Cl, SO_4, and NO_3. Flaxseed, confectionery sunflower kernels, and durum wheat are grown on the chloride affected soils in the northern Great Plains of the United States and in Canada. These are relatively salt tolerant crops and are well adapted to this climate (Norvell et al., 2000; Li et al., 1995; Wu et al., 2002; Gao et al., 2011a). Each of these crops accumulates increased levels of Cd when growing on soils with natural chloride enrichment. Sales of the crops produced on such high chloride soils may not meet limits for crop Cd levels in international markets.

For chloride to be an issue in Cd accumulation by cocoa, cocoa would have to be “salt tolerant” to the saline waters. Plant species adapted to saline soils have been found to accumulate higher Cd when the soil or irrigation water contain high levels of chloride. But cocoa did not evolve under saline soil conditions and has not evolved salinity tolerance (Umaharan, 2020b, personal communication). Thus, although a role for chloride in cocoa Cd has been considered by international workgroups, available evidence indicates that cocoa intolerance of salinity rules out any role of chloride in cocoa Cd.

Discussion

The Expert Committee concluded in the Root Cause Report that historic deposition of suspended particles in flood or irrigation water and parent rock rich in Cd have caused substantial Cd contamination of cocoa farm soils and crops, especially in South American cocoa growing regions. Irrigation of cocoa soils with water contaminated by mine wastes (and from other anthropogenic sources) may therefore increase soil Cd levels potentially resulting in increased Cd concentrations in cocoa beans. Similarly, intermittent flooding of cocoa farm soils with contaminated water may also increase soil Cd contamination levels. However, the Expert Committee acknowledges that at this time the impact of contaminated irrigation water on Cd levels in cocoa has not been reported. Nevertheless, the Expert Committee generally agrees that knowledge of the composition of contaminated irrigation waters may prevent their use or trigger remediation measures in cocoa growing regions. The Expert Committee also notes that finding alternative water sources for irrigation may be difficult in some areas within a growing region, limiting the scalability of this strategy to potentially a smaller subset of cocoa farms.

The Expert Committee generally agrees the implementation of the reduction strategy would not result in negative public health, social, and environmental impacts (and could potentially result in a benefit to the environment). In addition, although one Expert thinks the economic impact is not known or quantifiable, there is a general sense that the strategy could be implemented without prohibitive costs to the chocolate industry.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Three Experts think the extent of reduction cannot be quantified or is not known. One Expert thinks the level of Cd reduction in chocolate products from implementing this strategy could be 10 to 15 percent.

Time frame for potential reduction: Two Experts think the timing of the reduction is not known. One Expert predicts it would take more than 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. One Expert predicts it would take 1 to 5 years.

Strength of evidence for reduction: Two Experts gave a rating indicating they think there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts). One Expert thinks there is inconsistent evidence of a reduction or no evidence of a reduction, but anticipates one occurring. One Expert cannot be certain a reduction will be realized.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: Three Experts gave a rating indicating the strategy could be implemented without prohibitive costs to the chocolate industry. The fourth Expert thinks the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: Two Experts gave a rating indicating the reduction strategy could have environmental benefits. Two Experts think the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: The Experts agree that the strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think the scalability of the proposed reduction strategy is unknown and potentially challenging because it is dependent on the implementation capacity in each growing region within a country as it relates to their available resources within the cocoa sector and also without knowledge of the availability and quality of secondary sources of irrigation water, it is difficult to assess scalability. One Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but scaling is still possible. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms.

Technological feasibility of method: Two Experts thinks the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective. Two Experts gave a rating indicating they think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications.

Confidence: Two Experts have a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believe there is sufficient evidence to support this statement. One Expert has a low to medium degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions might not be achieved, with some evidence to support this statement. The fourth Expert has a low degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions might not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 31 percent, a feasibility score of 62 percent, and an overall score of 55 percent (Table 3). The Expert Committee rated this strategy in the **Medium** category based on the combined confidence score. Refer to Table B-9 for the Experts' individual scoring of this strategy.

4.3 Agricultural Strategies to Reduce Cd with Low Combined Confidence Scores

The following reduction strategies related to agricultural practices received low combined confidence scores. The following sub-sections describe these strategies and their feasibility considerations.

4.3.1 Use Amendments Recommended by CODEX But Not Included in Other Strategies

Overview of Strategy

Depending on the physicochemical properties of soils, a number of other soil amendments (i.e., beyond those addressed in Sections 4.1.3, 4.1.4, and 4.3.2) could be used to immobilize phytoavailable Cd potentially reducing Cd uptake into plants. The feasibility of these amendments to mitigate Cd in cocoa was evaluated.

Background

According to the CODEX Code of Practice, several soil amendments beyond those addressed in Sections 4.1.3, 4.1.4, and 4.3.2 of this report may have the potential to reduce Cd uptake and transfer into cocoa beans. These include sugarcane byproducts, organic-rich materials, clay minerals, and other inorganic minerals among others, which are each dependent on soil characteristics (CODEX, 2020). SENESCYT (2011) as reported by CODEX (2020) showed that when cocoa-growing soils were treated with 1 metric tons per hectare of vinasse (a byproduct of sugarcane) in Ecuador, the soil Cd concentration decreased from 4.87 mg/kg to 2.38 mg/kg and bean Cd was reduced by 45 percent (SENESCYT, 2011). However, the experimental findings of this study could not be reviewed by the Expert Committee as the reference provided could not be found; and one Expert noted that the cited results are questionable, based on the magnitude of Cd reductions attributed to soil amendments reported in many other studies. Nevertheless, studies in rice suggest that vinasse enhances roots of plants with iron plaque (amorphous and crystalline iron oxyhydroxides), which sequesters heavy metals such as Cd acting as a barrier for uptake into plants (Li et al., 2019). However, there are concerns with regards to the environmental impact of sugarcane vinasse. Due to its low pH, electric conductivity, and chemical constituents, it may cause changes in chemical and physicochemical properties of soils, rivers, and lakes, which could adversely affect agricultural soils and biota (Christofoletti et al., 2013). CODEX (2020) also documented a field study by SENESCYT (2011) where 1 metric tons per hectare of cachaza (another sugarcane byproduct) reduced cocoa bean Cd levels by 44 percent and is assumed to function similarly to vinasse because of its composition. However, this finding was similarly unavailable to be reviewed by the Expert Committee.

Organic-rich amendments such as compost, animal manures, humus, and vermicompost can reduce Cd solubility by forming insoluble complexes (Bernal et al., 2009) or by indirectly affecting other chemical properties, such as pH (Shahid et al., 2017). Studies done by Dávila et al. (2020) in Peru concluded that compost and poultry manure applied at high rates of 30, 60, and 90 metric tons per hectare can effectively reduce cocoa bean Cd levels by a 90 percent average. In contrast, Florida et al. (2019) found no significant difference in cocoa bean Cd concentrations when 1.5 and 3 metric tons per hectare of compost was applied to soils of a CCN-51 cocoa plantation in Peru and could be attributed to the smaller quantity applied. On the other hand, studies have shown that manures may also be a significant source of Cd depending on their origin (Jinadasa et al., 1997). In Ecuador, 1-2 metric tons per hectare of humus reduced soil Cd levels by an average of 35 percent (SENESCYT, 2011). However, this experimental finding could not be reviewed by the Expert Committee as the reference provided could not be found. An *in vitro* (greenhouse pot) experiment conducted by Chavez et al. (2015) showed that vermicompost can also reduce available levels of Cd in soils, and this reduction may have been a result of the vermicompost's effect on soil pH. In contrast, another *in vitro* (greenhouse pot) study by Zenteno et al. (2013) demonstrated that vermicompost had a lower potential to reduce soil Cd phytoavailable levels.

Clay minerals have also been well documented to immobilize Cd levels in soils (Hamid et al., 2019b). They are made up of layered aluminosilicates, which are negatively charged and make them good cationic adsorbents because of their relatively large surface areas (Wu et al., 2009). One such clay mineral, zeolite, has been shown to reduce Cd levels in cocoa-growing soils by 50 percent in a field experiment in Ecuador when 2 metric tons per hectare was applied (SENESCYT, 2011). On the other hand, an *in vitro* study carried out by Chavez et al. (2015) found no significant changes in available soil Cd when treated with natural zeolite and suggested that synthetic forms of the material may be more effective. Other inorganic materials such as gypsum ($CaSO_4$) have similarly reduced Cd uptake in crops including rice (Zhang et al., 2019) and wheat (Abbas et al., 2017) in greenhouse experiments. In contrast, gypsum has been found to increase Cd concentrations in the seeds of poppies in another greenhouse study (Salardini et al., 1993), which may have been due to the fact that gypsum causes acidification of soils and this is known to increase Cd phytoavailability and uptake. Nevertheless, as it relates to cocoa, SENESCYT (2011) also found that 1 metric tons per hectare of $CaSO_4$ reduced Cd levels in soils and cocoa beans by approximately 38 percent and 46 percent respectively; however, this finding could not be verified. One Expert added that the reported Cd reductions attributed to gypsum amendments are curious (i.e., 1 ton per hectare mixed with the 15 cm topsoil layer should not be able to reduce soil Cd concentration this much), and he suspected that applying gypsum amendments would cause soil acidification, which would actually increase Cd uptake.

Additionally, the application of any soil amendment at the field level mainly consists of two steps, which include the transportation of the material and the method by which it is added to the soil. These are also influenced by the acreage, terrain, soil and crop characteristics, available equipment and the associated labor. Taking these factors into consideration, the transport of amendments to treat short-term crops are generally managed well with easier access and equipment. On the other hand, due to the sometimes challenging landscape where a perennial crop like cocoa is grown, the hauling of the material within the field may not be a simple task. Also, in order to ensure amendments are effectively applied in soils, they are typically incorporated using machinery and other tools that provide tillage in agricultural fields. However, due to the extensive feeder root system found in the upper surface layer (0-15 cm) of cocoa-growing soils, any form of digging may cause harm to the plant. Moreover, the labor required to facilitate this process should also be taken into consideration.

Discussion

As discussed above, CODEX identifies several potential soil amendments in addition to those listed and evaluated separately by the Expert Committee in Sections 4.1.3, 4.1.4, and 4.3.2. The amendments covered in this section are reported to be effective to some degree in reducing Cd levels in soils and some agricultural crops, including cocoa. However, the Expert Committee generally agrees that further research (e.g., well-designed replicated field trials) is needed to validate these strategies for use in cocoa. The Experts also generally share some concerns over the scalability and technological readiness of the specific soil amendments recommended by CODEX for application in the field. Although the Experts generally agree the strategy could be implemented without potential for negative public health impacts (assuming adequate worker protection practices are used) and social impacts, the Experts provided a wide variation of responses to the potential for negative environmental impacts. The Experts generally share concern that the economic impacts cannot be quantified or are unknown, although one Expert thinks the strategy could be implemented without prohibitive costs.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Three Experts think the extent of reduction cannot be quantified or is not known. One Expert predicts that the level of Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent.

Time frame for potential reduction: Two Experts predict it would take 1 to 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. Two Experts think the timing of the reduction is not known.

Strength of evidence for reduction: Two Experts gave a rating indicating there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts). Two Experts cannot be certain a reduction will be realized.

Potential public health impacts: Three Experts think the reduction strategy could be implemented without potential for unintended adverse public health impacts. One Expert thinks the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts with proper worker exposure prevention methods.

Potential economic impacts: Three Experts gave a rating indicating the extent of economic impact cannot be quantified or is not known. One Expert thinks this strategy could be implemented without prohibitive costs to the chocolate industry.

Potential environmental impacts: Two Experts think the reduction strategy could have unintended adverse environmental consequences such as soil leaching resulting in the contamination of agricultural soils, groundwater, and biota in sensitive ecosystems. However, these Experts think the impacts could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures. One Expert thinks the reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks the reduction strategy could have unintended adverse environmental consequences that would present a challenge to implementation.

Potential social impacts: The Experts agree the strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think the scalability of the proposed reduction strategy is unknown and potentially challenging because of resource availability and different capacities in growing regions. One Expert thinks there is demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms, or if applicable, a smaller subset. One Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but scaling is still possible.

Technological feasibility of method: Two Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. One Expert thinks the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available. One Expert thinks the technology needed to implement the reduction strategy has not been developed.

Confidence: Three Experts have a low to medium degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions could not be achieved, with some evidence to support this statement. The fourth Expert has a low degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 19 percent, a feasibility score of 43 percent, and an overall score of 38 percent (Table 3). The Expert Committee rated this strategy in the **Low** category based on the combined confidence score. Refer to Table B-10 for the Experts' individual scoring of this strategy.

4.3.2 Use Mineral Soil Amendments

Overview of Strategy

Mineral soil amendments, such as those rich in hydrous oxides of Fe and Mn, are characteristically known to adsorb heavy metals in soils reducing metal phytoavailability. It was thus hypothesised that this approach could be used to decrease the phytoavailability of Cd in cocoa-growing soils limiting the transfer of Cd into cocoa beans.

Background

A review of the literature has shown that mineral soil amendments can significantly affect the mobility of soil Cd decreasing its availability to plants, but their effectiveness is highly dependent on near neutral soil pH. The mechanism occurs primarily through adsorption and desorption reactions of the metal onto the soil colloids surface (Swift and McLaren, 1991). Fe oxides have a significant capacity for Cd adsorption and can immobilize Cd efficiently (Liu et al., 2014). Mn oxides are considered to be even stronger Cd adsorbents because they are capable of forming complexes with Cd ions and have good chemical stability under basic and even somewhat acidic soil conditions (Zhang et al., 2017). Mn oxides adsorb Cd better at lower pH levels than do Fe oxides (which are weak Cd adsorbents below pH 6). However, many studies demonstrating the success of these amendments have been focused mainly in rice (Okazaki et al., 2008; Zhang et al., 2012; Suda and Makino, 2016) with little evidence to support this approach in other crops and no testing with (greenhouse or field) cocoa. Additionally, the Mn transporter gene (NRAMP5) that facilitates high Cd uptake in rice is not involved in Cd accumulation from soils by other crops including cocoa. Thus the response associated with rice after treatment with hydrous oxides of Mn and Fe may not be the same for cocoa (see Sections 4.1.5 for further clarification).

Nevertheless, there have been exploratory studies to understand soil-plant relationships in cocoa orchards that could support the use of Mn and Fe oxides for eventual Cd mitigation. A study done by Argüello et al (2019) in Ecuador found that phytoavailable Mn explained 8 percent of the variation in bean Cd levels in a regression model with total soil Cd, pH, and total organic carbon. Additionally, field investigations done in Bolivia (Gramlich et al., 2017) and Honduras (Gramlich et al., 2018) found that Fe was positively correlated to phytoavailable Cd in cocoa-growing soils.

Also, the application of any soil amendment at the field level mainly consists of two steps: transportation of the material and the method by which it is added to the soil. These are also influenced by the acreage, terrain, soil and crop characteristics, available equipment and the associated labor. Taking these factors into consideration, the transport of amendments to treat short-term crops are generally managed well with easier access and equipment. On the other hand, due to the sometimes challenging landscape where a perennial crop like cocoa is grown, the transportation to deliver the material may not be a simple task. Additionally, in order to ensure amendments are effectively applied in soils, they are typically incorporated using machinery and other tools that provide tillage in agricultural fields. However, due to the extensive feeder root system found in the surface (0-15 cm) of cocoa-growing soils, any form of digging may cause harm to the roots/plant. And because any effect of applying Fe or Mn hydrous oxides would require incorporation in the rooting depth to be effective in adsorbing Cd and reducing Cd uptake, such a practice is unlikely to be useful in lowering Cd accumulation by cocoa trees. Moreover, the labor required to facilitate this process should also be taken into consideration.

Discussion

The Expert Committee generally agrees that although technology needed to implement the reduction strategy has been developed, the evidence supporting the effectiveness of adding high amounts of hydrous oxides of Fe and Mn as Cd-sorbents to mitigate Cd in cocoa is limited. The Experts also generally share the concern that applying 50-100 tons per hectare of Fe/Mn oxides and incorporating the oxides in the rooting depth, which is required to effectively administer these minerals, would not be practical in established cocoa orchards. The Experts also generally agree that concerns over the scalability of this strategy would limit its application across different growing regions, dependent on the available resources within these regions.

In general, the Experts agree the strategy could be implemented without negative social, environmental, and public health impacts, assuming worker and environmental protection measures are implemented. The Experts share concern that the economic impacts are not quantifiable or are not known although one Expert thinks the costs to implement the strategy could be prohibitive.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: The Experts agree the extent of reduction cannot be quantified or is not known.

Time frame for potential reduction: One Expert predicts it would take 1 to 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. Three Experts think the timing of the reduction is not known.

Strength of evidence for reduction: One Expert gave a rating indicating there is inconsistent evidence of a reduction. One Expert thinks there is no evidence of a reduction, but anticipates one occurring. Two Experts cannot be certain a reduction will be realized.

Potential public health impacts: Two Experts think the reduction strategy could be implemented without potential for unintended adverse public health impacts. Two Experts think the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts with proper worker exposure prevention methods.

Potential economic impacts: Three Experts gave a rating indicating that the extent of economic impact cannot be quantified or is not known. One Expert thinks this strategy could not be implemented without considerable and prohibitive costs that could not be recovered over the long-term.

Potential environmental impacts: Three Experts think the reduction strategy could be implemented without potential for unintended adverse environmental impacts. One Expert thinks the reduction strategy could have unintended adverse environmental consequences resulting in the contamination of agricultural soils, groundwater, and biota in sensitive ecosystems. However, these impacts could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures.

Potential social impacts: The Experts agree the strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think the scalability of the proposed reduction strategy is unknown and potentially challenging because of resource availability and different capacities in growing regions. Two Experts think there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but scaling is still possible.

Technological feasibility of method: The Experts agree the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications.

Confidence: Two Experts have a low to medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions could not be achieved, with some evidence to support this statement. Two Experts have a low degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 13 percent, a feasibility score of 40 percent, and an overall score of 34 percent (Table 3). The Expert Committee rated this strategy in the **Low** category based on the combined confidence score. Refer to Table B-11 for the Experts' individual scoring of this strategy.

4.3.3 Use Zinc Sulfate Foliar Sprays to Reduce Cd Levels in Cocoa Beans

Overview of Strategy

Foliar zinc sulfate ($ZnSO_4$) sprays have been typically used to ameliorate Zn deficiency in crops. However, research has shown that it is also a useful method for inhibiting Cd translocation in grains or edible parts of plants. It was thus hypothesised that this method could be used to reduce the transfer of Cd into cocoa beans of cocoa trees.

Background

This strategy originated from the literature as a possible mitigation technique to reduce Cd levels in edible tissues of plants as a result of correcting their nutrient (e.g., Zn) deficiency. A report that evaluated potential mitigation solutions for Cd in cocoa by Meter et al. (2019) indicated that through foliar application of $ZnSO_4$, the transfer of Cd into fruits can be inhibited in fruit crops. The Expert Committee thus decided to evaluate this strategy for its use in cocoa.

The application of foliar $ZnSO_4$ has been shown to reduce Cd levels in the grains of wheat (Khoshgoftarmanesh et al., 2013; Saifullah et al., 2014, 2016) and rice (Duan et al., 2018; Wang et al., 2018). Fahad et al. (2015) found 50 percent reduction in Cd in rice grain (the Zn fertilization doubled grain yield which reduced grain Cd by half) and Saifullah et al. (2016) a Cd reduction of 74 percent in wheat grains when treated with foliar sprays of $ZnSO_4$. It is believed that Zn applied through foliar sprays increases the Zn concentration of foliar cells, sequestering Cd, thereby inhibiting its translocation to the fruits or bearing parts of the plant. Though the strategy has only been demonstrated in annual crops, it is possible for the same to be extended to perennial trees like cocoa, with significant Cd levels in its tissues. Research is currently being conducted in Peru to evaluate the effect of foliar $ZnSO_4$ sprays on Cd accumulation in cocoa beans, however, there are no results to date (Atkinson, 2020a, personal communication). Additionally, there is no other evidence from the available literature on the effect of this strategy on Cd accumulation in cocoa beans.

Discussion

The application of foliar $ZnSO_4$ has been reported to reduce Cd levels in some crops such as wheat and rice. This strategy was evaluated by the Expert Committee because of its potential to also reduce Cd uptake in perennial trees like cocoa. However, at this time there is no validated evidence that foliar $ZnSO_4$ application would effectively reduce Cd accumulation in cocoa beans in the field. The Experts generally agree the strategy could be implemented without negative social, public health, and environmental impacts assuming worker and environmental protection is enforced. However, the Expert Committee collectively gave relatively low scores for economic feasibility, scalability, and technology, which resulted in a relatively low combined confidence score for this strategy.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: The Experts agree the extent of reduction cannot be quantified or is not known.

Time frame for potential reduction: Two Experts think the timing of the reduction is not known. One Expert predicts it would take 1 to 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. The fourth Expert predicts it would take 1 year.

Strength of evidence for reduction: Two Experts gave a rating that indicates there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts). One Expert thinks there is no evidence of a reduction, but anticipates one occurring. One Expert cannot be certain a reduction will be realized.

Potential public health impacts: Two Experts think the reduction strategy could be implemented without potential for unintended adverse public health impacts. Two Experts think the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts with proper worker exposure prevention methods.

Potential economic impacts: The Experts agree that the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: Two Experts think the reduction strategy could be implemented without potential for unintended adverse environmental impacts. Two Experts think the reduction strategy might have unintended adverse environmental impacts that could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures.

Potential social impacts: The Experts agree that the strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think there is demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms, or if applicable, a smaller subset based on need or practicality. One Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but anticipates that scaling is still possible. One Expert thinks the scalability of the proposed reduction strategy is unknown and potentially challenging due to unknown availability of resources in cocoa countries.

Technological feasibility of method: Three Experts agree the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. One Expert thinks the technology needed to implement the reduction strategy has not been developed.

Confidence: Two Experts have a low degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time. One Expert has a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believes there is sufficient evidence to support this statement. The fourth Expert has a low to medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence the reductions could not be achieved, with some evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 19 percent, a feasibility score of 44 percent, and an overall score of 38 percent (Table 3). The Expert Committee rated this strategy in the Low category based on the combined confidence score. Refer to Table B-12 for the Experts' individual scoring of this strategy.

4.3.4 Use Foliar Sprays Rich in Iron and Manganese

Overview of Strategy

Foliar application of Fe and/or Mn salts can be used to reduce Cd accumulation by cocoa beans in the field. Solutions of $FeSO_4$ or $MnCl_2$ have been used as a foliar spray application to supply Fe^{2+} and Mn^{2+}, which leaf cells can absorb.

Background

In soils, the hydrous oxides of Fe and Mn play important roles in adsorption of heavy metals including Cd. Such adsorption is much more effective at near neutral pH than at acidic pH. The Code of Practice (CODEX, 2020) and the Bioversity Review (Meter et al., 2019) included foliar application of Fe and Mn as a possible treatment to reduce Cd concentration in cocoa beans. Although some have hypothesized that foliar application of such sprays might reduce Cd movement to cocoa beans, no research has been reported showing whether or not such foliar sprays might reduce Cd in cocoa beans. The lack of testing for this effect in cocoa, or in studies with other plant species, indicates there is no experimental support for this strategy. Foliar application of soluble Zn fertilizers (see Section 4.3.3) may be an effective method to limit Cd transfer to cocoa beans. But no field or laboratory studies of using Fe or Mn fertilizers to reduce Cd transfer to beans was identified.

Discussion

There is no available evidence that demonstrates using foliar spray application of Mn or Fe would be effective in reducing Cd levels in cocoa beans. Therefore, the Expert Committee generally agrees this strategy if implemented would not give the desired results. The Experts generally share the concern that scalability and economic impacts are not known or could be prohibitive. On the other hand, the Experts generally agree the strategy could be implemented without negative social, public health, and environmental impacts assuming worker and environmental protection is enforced.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: The Experts agree the extent of reduction cannot be quantified or is not known.

Time frame for potential reduction: The Experts agree the timing of the reduction is not known.

Strength of evidence for reduction: The four Experts cannot be certain a reduction will be realized.

Potential public health impacts: Two Experts think the reduction strategy could be implemented without potential for unintended adverse public health impacts. Two Experts think the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts with proper worker exposure prevention methods.

Potential economic impacts: The Experts agree that the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: Three Experts think the reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks the reduction strategy could have unintended adverse environmental impacts that could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures.

Potential social impacts: The Experts agree that the strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think there is no documented or demonstrated potential the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but anticipates scaling is still possible. One Expert thinks there is demonstrated potential the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms, or if applicable, a smaller subset based on need or practicality. One Expert thinks the scalability of the proposed reduction strategy is unknown.

Technological feasibility of method: Two Experts think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. One Expert thinks the technology needed to implement the reduction strategy has not been developed. The fourth Expert thinks the technology is ineffective.

Confidence: Three Experts have a low degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time. The fourth Expert has a low to medium degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions might not be achieved, with some evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 6 percent, a feasibility score of 38 percent, and an overall score of 31 percent (Table 3). The Expert Committee rated this strategy in the **Low** category based on the combined confidence score. Refer to Table B-13 for the Experts' individual scoring of this strategy.

4.3.5 Phytoextract Cd from Soils Using Hyperaccumulators

Overview of Strategy

Phytoextraction was suggested as a solution to excessive cocoa Cd in the CODEX Code of Practice document (CODEX, 2020) and the Meter et al. (2019) review. Phytoextraction is a soil Cd decontamination technology in which unusual plant species that bioaccumulate very high concentrations of Cd into their shoots are grown on the soil and their shoots harvested and removed to reduce Cd in the soil. Some rare plants (labeled hyperaccumulators) accumulate 100 to 1,000 times higher Cd concentrations than normal crop plants when both are grown on contaminated soils. The phytoextraction crop shoots would have to be safely disposed as a hazardous waste.

Background

Chaney (1983) proposed growing metal hyperaccumulator plant species as a method to decontaminate soils. Since that date, much research has been conducted. Growing hyperaccumulators for phytoextraction of Cd from soils needing remediation to reduce Cd risk has been one major focus of phytoextraction research. Initially, *Noccaea caerulescens* (previously *Thlaspi caerulescens*) "Prayon" genotype was grown. This genotype accumulated too little Cd per crop (<5 t/ha with 100 mg Cd/kg = 0.5 kg/ha/yr) to make it useful for soil decontamination. Thus, genetic diversity for high Cd accumulation was sought. Reeves et al. (2001) found unusual genotypes (now called "Ganges") that accumulated about 10-fold higher Cd than the Prayon types grown on the same soil. Combining use of "Ganges" genotypes with acidification to maximize annual Cd removal, plus optimum fertilizer management, one could attain about 5 t biomass/ha with more than 1,000 mg Cd/kg dry shoots when growing the plants in soils containing high levels of Cd and Zn. This is 5 kg Cd/ha/yr, which would give effective Cd decontamination in a few years. In a greenhouse pot study, Wang et al. (2006) measured 40 percent removal of Cd from the pot of Zn-smelter contaminated soil in a single cropping managed at lower pH. But for lesser contaminated soils, annual removals are substantially lower.

N. caerulescens is a European plant adapted to temperate climate and pests. But cocoa soils are in tropical areas where the environment and plant pathogens are different from those to which *N. caerulescens* has adapted. Simmons et al. (2015) tested growing the "Ganges" types on rice soils in Thailand which needed Cd removal. That research showed that if fungicides were sprayed on the plants repeatedly, they could be grown in that climate.

After years of research on *N. caerulescens* in Europe, researchers in China discovered three species of Sedum that could possibly be used to phytoextract Cd; *Sedum alfredii* and *Sedum plumbizincicola* have been field tested (e.g., Fan et al., 2019). But these species all suffer from low biomass yields and insufficient Cd hyperaccumulation to provide a rapid Cd phytoextraction technology.

Phytoextraction of Cd from existing cocoa orchards would be complicated. The phytoextraction crop must be grown under the cocoa trees. In established orchards, the soils are uneven, shaded, and have low fertility. Phytoextraction crops require fertilizers similar to those required by major crop plants, not the low fertility of cocoa orchards. Establishing a *Sedum* crop in a cocoa orchard would require extensive greenhouse operations to produce the seedlings and much labor to transplant the seedlings to the field. After growth for 6 to 12 months, the biomass would have to be cut under the trees and removed from the orchard. The harvest would be required at least annually until soil Cd had been reduced as much as needed for safer cocoa production. Disposal of the biomass would be a significant cost because it would be a hazardous waste due to the high Cd concentration, and no value would be attained from the biomass, only the cost of safe disposal. It is unlikely any of these species could be used to phytoextract Cd from cocoa soils in an economically acceptable technology. And lowering soil pH to promote phytoextraction of Cd would cause increased Cd levels in cocoa beans during the phytoextraction period which would be unacceptable.

Discussion

The Experts generally agree that phytoextraction of Cd using hyperaccumulators has shown promise and benefits for other crops. If such methods could be applied to cocoa, Cd reductions of 25 percent or higher could be observed. However, its use in reducing Cd levels in cocoa is complicated and has not been reliably demonstrated to be effective or economical. The Experts gave a wider variation in ratings for some of the other feasibility factors.

Application: The Experts agree that this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: Two Experts predict that the level of Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent. One Expert predicts the reduction would be 10 to 25 percent. One Expert is unsure as to the level of reduction.

Time frame for potential reduction: Two Experts predict it would take more than 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. Two Experts are unsure as to the time frame of reduction.

Strength of evidence for reduction: Two Experts gave ratings that indicate there is suggestive evidence of a reduction in Cd using this methodology (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts). One Expert thinks a reduction in Cd using the methodology described in this strategy has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts. One Expert is not certain that a reduction in Cd will be realized using this methodology.

Potential public health impacts: Three Experts think the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts with proper exposure prevention methods. The fourth Expert thinks the reduction strategy may have unmitigable, unintended adverse public health consequences due to the production of contaminated biomass waste.

Potential economic impacts: Three of four Experts gave a rating indicating that this strategy could not be implemented without prohibitive costs to the chocolate industry or that the economic impact cannot be quantified or is not known. Reasons for concerns over economic impacts include the cost of labor to implement the strategy and costs associated with retrieval of waste material and its disposal. The fourth Expert thinks that the reduction strategy could be implemented without prohibitive costs.

Potential environmental impacts: Two Experts provided a rating that indicates the reduction strategy could have unintended adverse environmental consequences, which could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures. One Expert thinks the reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks the reduction strategy could have unmitigable environmental impacts if implemented due to improper disposal of Cd contaminated biowaste.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. The fourth Expert thinks the strategy could have negative social impacts.

Scalability of potential reduction: Three Experts gave a rating indicating there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, but anticipate scaling is still possible. The fourth Expert thinks scalability of the proposed reduction strategy is unknown and potentially challenging due to prohibitive costs.

Technological feasibility of method: Three Experts think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. The fourth Expert thinks the technology needed to implement the reduction strategy has not been developed.

Confidence: Three Experts have a low degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time. The fourth Expert has a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believes there is sufficient evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 13 percent, a feasibility score of 33 percent, and an overall score of 28 percent (Table 3). The Expert Committee rated this strategy in the **Low** category based on the combined confidence score. Refer to Table B-14 for the Experts' individual scoring of this strategy.

4.3.6 Use Fertilizers Rich in Certain Elements

Overview of Strategy

Fertilizers rich in varying elements such as phosphorus (P), potassium (K), nitrogen (N), and others are primarily used to improve the soil fertility to enhance plant growth and productivity. Additionally, some of these elements when applied to Cd-contaminated nutrient-deficient agricultural soils have been shown to reduce Cd concentration in crops. The possibility thus exists that nutrient-rich fertilizers could be used an as effective strategy to mitigate Cd uptake in cocoa.

Background

Applying nutrients to soils in the form of fertilizers is a normal practice to achieve better plant growth and crop yield in agriculture. Specific nutrients/elements required by plants have direct effects on Cd availability in soils and consequently its uptake. Some of these direct effects include a reduction in soil Cd solubility favored by precipitation and adsorption, competitive ion blocking between Cd and other chemically similar elements for the same membrane transporters, and sequestration of Cd in vegetative parts to prevent translocation in grain/edible parts (Sarwar et al., 2010). In contrast, reports suggest that these fertilizers can also increase Cd levels in crops through soil Cd contamination and other influential changes in soil chemical properties.

Reviews of the literature including the Code of Practice (CODEX, 2020) and the Bioversity International paper (Meter et al., 2019) reported a number of these fertilizers and their effects on Cd uptake in crops including cocoa. For example, the application of P-fertilizers has been reported to reduce the availability of Cd in the soil through immobilization and the levels of Cd in a number of crops, including lettuce, cabbage, and broccoli (Tan et al., 2011) and potato (Siebers et al., 2013). Though there is no specific evidence to suggest its direct effectiveness in the beans or vegetative parts of cocoa, there have been studies within cocoa orchards that demonstrate soil-plant tissue relationships indicative of promise. In Bolivia, Gramlich et al. (2017) found a negative effect of P soil concentration on available Cd levels and a negative but weak effect on Cd levels in pod husks, which implies that the addition of P to soils can reduce Cd uptake. On the other hand, due to Cd impurities inherent in P-fertilizers, these fertilizers have also been documented to increase Cd accumulation in a number of crops, including green beans (Mendes et al., 2006), radish (Hong et al., 2008), and wheat (Gao et al., 2011b). With respect to cocoa, research done in Peru by Zug et al. (2019) found a modest but positive relationship between bean Cd levels and the use of P fertilizers. Added P fertilizers usually acidify soils which would increase Cd uptake. The acidification due to phosphates and ammonium phosphates should be corrected with limestone.

In addition to P, it has been shown that keeping soils well supplied with N and K reduces Cd bioaccumulation from soils and are preferred due to these soils' limited Cd concentration. However, when KCl fertilizers are applied compared to other K compounds, the added chloride can significantly increase Cd accumulation by wheat (e.g., McLaughlin et al., 1995; Grant et al., 2008). Through root growth stimulation, N-fertilizers, when applied with K, can increase the ionic strength of the soil thus reducing Cd mobility (Schaefer et al., 2020). It however depends on what type of N-based fertilizer is used, application rate, timing, and plant type (He et al., 2015). In contrast, documented studies have reported that N-fertilizers increase Cd concentration in plants usually due to acidification resulting from oxidation of the ammonium from the fertilizer. A review done by Yang et al. (2020) explained that regardless of the form of N in N-fertilizers, they enhance Cd uptake, translocation, and accumulation in plants. From their studies in Peru, Zug et al. (2019) similarly observed that the use of N-fertilizers significantly increased Cd concentrations in the cocoa beans (analysis of field samples rather than a controlled experiment with randomization). Additionally, a study done with in situ Cd-contaminated soil determined that three K fertilizers (KCl, K_2SO_4, and KNO_3) all increased Cd accumulation in rice, wheat, and pak choi (Wang et al., 2019). It must be noted, however, that the application of excessive amounts of ammonium based fertilizers to agricultural soils can result in soil acidification (Goulding, 2016), which can result in the lowering of pH over time and cause greater Cd uptake.

Additionally, the application of any soil amendment at the field level mainly consists of two steps: transportation of the material and the method by which it is added to the soil. These are also influenced by the acreage, terrain, soil and crop characteristics, available equipment, and the associated labor. Taking these factors into consideration, the transport of amendments to treat short-term crops are generally managed well with easier access and equipment. On the other hand, due to the sometimes challenging landscape where a perennial crop like cocoa is grown, the hauling of the material within the field may not be a simple task. Also, in order to ensure amendments are effectively applied in soils, they are typically incorporated using machinery and other tools that provide tillage in agricultural fields. However, due to the extensive feeder root system found in the upper surface (0-15 cm) of cocoa-growing soils, any form of digging may cause harm to the plant. Moreover, the labor required to conduct this process should also be taken into consideration.

Discussion

The effectiveness of a number of these nutrient fertilizers to minimize Cd uptake in cocoa is not clear, especially for the commonly strongly acidic cocoa soils in South America and the Caribbean. As discussed above, there have been conflicting reports in a number of crops with only a few studies conducted in cocoa. The available results in cocoa appear to demonstrate an increase in Cd levels rather than a decrease. Additionally, the use of ammonia fertilizers can cause soil acidification over time, which increases Cd uptake in plants, and most P- fertilizers have been reported to contain Cd. The Experts generally agree that issues around scalability and economics and technological concerns reduce the overall feasibility level of this strategy.

Application: Three Experts think this strategy applies primarily to Cd reduction. The fourth Expert thinks the strategy applies to both Cd and Pb.

Potential magnitude of reduction: The Experts agree the potential magnitude of reduction is not known or quantifiable.

Time frame for potential reduction: Three Experts predict it would take 1 to 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. One Expert is unsure as to the time frame of reduction.

Strength of evidence for reduction: Two Experts gave ratings that indicate there is suggestive evidence of a reduction in Cd using this methodology (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts). Two Experts are not certain that reductions would be realized.

Potential public health impacts: Two Experts think the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts. Two Experts think the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts with proper worker exposure prevention methods.

Potential economic impacts: Two Experts gave a rating indicating that the extent of economic impact cannot be quantified or is not known for this strategy. One Expert thinks the reduction strategy could be implemented without prohibitive costs. The fourth Expert thinks the strategy could not be implemented without prohibitive costs to the chocolate industry.

Potential environmental impacts: Three Experts gave a rating indicating this reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks the reduction strategy could have unintended adverse environmental consequences, which could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures.

Potential social impacts: The Experts agree this reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts gave a rating indicating there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, however, scaling is still possible. Two Experts think scalability of the proposed reduction strategy is unknown and potentially challenging due to availability of resources in cocoa countries.

Technological feasibility of method: Three Experts think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. The fourth Expert thinks the technology needed to implement the reduction strategy has not been developed.

Confidence: Two Experts have a low to medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions might not be achieved, with some evidence to support this statement. Two Experts have a low degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 13 percent, a feasibility score of 42 percent, and an overall score of 35 percent (Table 3). The Expert Committee rated this strategy in the **Low** category based on the combined confidence score. Refer to Table B-15 for the Experts' individual scoring of this strategy.

4.3.7 Adopt Agroforestry or Monoculture Techniques

Overview of Strategy

This strategy addresses use of monocultures vs. agroforestry systems at cocoa orchards, and whether switching between the two might reduce Cd levels in cocoa nibs. Cocoa orchards are commonly organized/planted as either a monoculture of trees spaced about 3 m apart in the rows with 3 m between rows or in agroforestry systems organized under taller shade and/or N-fixing trees with greater distance between shade trees than between cocoa trees. Some agroforestry systems have random localization of shade and cocoa trees, while others are planted in organized spaced arrangements (e.g., Nygren et al., 2013). Although cocoa was originally grown as part of forests, commercial production has led to more organized plantings such as monoculture with cultivars selected for greater tolerance of full sunlight. Different nations and different parts of nations often traditionally follow one or the other management system, especially on highly sloping soils. But there has been very little experimental testing of whether cocoa beans have lower Cd or Pb when grown in monoculture versus agroforestry. Because these trees are grown in tropical rain forest environments, the cocoa roots are largely very shallow, less than 10-15 cm deep with some deeper roots to stabilize the trees or obtain nutrients from deep in the soil profile (Nygren et al., 2013). Thus the roots of cocoa trees commingle with roots of shade trees, and volunteer plants (weeds) that grow "understory." Deposited "litter" recycles nutrients to all plants growing in these systems.

Background

Depending on the farmer's selection, cocoa orchards may be arranged as monoculture cocoa or agroforestry orchards with taller shade trees or shade and nitrogen-(N)-fixing trees arranged with the cocoa trees. Cocoa evolved as an understory species in forests and was initially farmed this way. But as cocoa bean markets increased, higher production was sought. Both organized agroforestry using N-fixing trees to reduce fertilizer costs and monoculture production systems are important in cocoa production. Some argue that cocoa seedlings need shade to thrive. But many newer orchards are monoculture. Some cocoa breeders and agronomists consider that more recent cocoa breeding has selected for tolerance to full sun exposure so that monoculture was competitive with agroforestry. Higher light reaching the cocoa leaves should produce more cocoa beans. Monoculture does use the land area more efficiently, but additional fertilizers must be applied to support the cocoa trees in monoculture, while N-fixing shade trees can supply all the needed N in agroforestry systems. The Expert Committee visited two orchards in Ecuador that were monoculture systems. Banana orchards were in the same general growing areas, but they were separate monoculture orchards.

Both the CODEX Code of Practice (CODEX, 2020) and the Bioversity Report (Meter et al., 2019) suggested that changing from either agroforestry to monoculture or from monoculture to agroforestry might reduce Cd in cocoa beans. However, the Experts found no replicated field experiment that directly tested this question and thus cannot suggest this may have an effect on Cd or Pb in cocoa beans.

Two papers were identified in peer-reviewed journals that reported Cd accumulation in cocoa beans grown in monoculture versus agroforestry. In the paper by Gramlich et al. (2017), researchers sampled different orchards in the same general area of Bolivia. At one experimental farm, comparisons were being tested for cocoa grown under monoculture versus agroforestry with an "organic" versus "conventional" fertility management program variable in both. They sampled soils, leaves, fruits, and roots of cocoa in both systems, and separated beans from pods for analysis of nutrients and metals. Two cocoa cultivars (ICS-1 = Imperial College Selection-1 and TSH-565 = Trinidad Selection Hybrid-565) were grown in each orchard management system. Only a small insignificant portion of the variance in bean and pod Cd was explained by management, soil, or plant factors. However, the researchers' multiple regressions showed lower leaf Cd concentrations in agroforestry systems than in monoculture. The regressions were conducted with DGT-extractable Cd, cocoa cultivar, and soil organic matter all in the same equation to predict leaf Cd concentrations. Together these variables explained about 60 percent of the variance in bean or pod Cd concentrations.

No other specific comparison of cocoa Cd levels for trees grown under monoculture versus agroforestry production systems has been reported. However, a possibly relevant study was reported by Zug et al. (2019). They considered that the plant species growing under the cocoa trees might have some influence on Cd accumulation in the cocoa. They collected and identified many plant species that occurred under the trees being sampled for analysis of Cd in plant tissues and in soils. The sampled orchards were grown under agroforestry; they sampled 40 trees on 20 farms in the Huánuco Region of Peru. Only farms that cultivated both cultivar CCN-51 and one of the "fine flavor" cultivars (ICS-1, ICS-6, ICS-39, ICS-95, or TSH-565) were sampled to allow a cultivar-by-location evaluation. Although two farms had alkaline soils, most soils were strongly or very acidic, as low as pH 4.26. They reported higher cocoa bean Cd from trees with higher nearby vegetation biodiversity in a 5 m by 5 m area under each sampled tree. Although some planted agroforestry farms use evenly spaced specific shade tree species, these farms had variable shade trees species and locations in relation to the cocoa trees sampled. They listed the many species they found as understory vegetation. Some of the farms sampled had unusually high soil and cocoa bean Cd levels from natural Cd mineralization of the soil parent materials. On average, the "fine flavor" cultivars had slightly higher Cd than did CCN-51, but the difference was not significant. Bean Cd was strongly correlated with soil Cd, but perhaps mostly because of the wide range of soil and bean Cd levels in this study.

A recent paper by Scaccabarozzi et al. (2020) evaluated soil, site, and management factors affecting Cd in cocoa soils in Peru, but they have not yet reported Cd levels in cocoa beans. The authors were queried for details of bean Cd in their sampling, but we have not obtained any data on bean Cd from that study in relation to orchard management.

Recently, basic research studies of cocoa farms in Africa have evaluated many agronomic factors including the density of roots of cocoa and shade trees, which are usually N-fixing shade trees in recently established orchards with the cocoa trees and shade trees at specific distances apart. Interestingly, both the cocoa and shade trees have nearly all of their roots within the top 0-15 cm depth of the soil. Conducting such tests is difficult and laborious, but they do give a picture of the shallow rooting of cocoa, which is important to understanding of soil Cd phytoavailability to cocoa. The study by Nygren et al. (2013) measured fine and coarse roots of cocoa and non-cocoa species in the topsoil layer and deeper; Cd measurements were not part of that study.

Another basic research on culture patterns was reported by Arévalo-Gardini et al. (2017). They evaluated plant nutrition and soil fertility of cocoa grown in "Improved Natural" and "Traditional Agroforestry" in the Peruvian Amazon (Arévalo-Gardini et al., 2017). But no data were reported on Cd in the ecosystems.

Discussion

The Expert Committee notes that there are no validated studies or reports in the scientific literature evaluating the benefit of agroforestry versus monoculture practices in reducing Cd concentrations in cocoa beans. The Experts generally agree that issues around scalability and economics and technological concerns reduce the feasibility level of this strategy.

Application: The Experts agree this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: The Experts agree the potential magnitude of reduction is not known or quantifiable.

Time frame for potential reduction: Three Experts are unsure as to the time frame of reduction. The fourth Expert predicts it would take more than 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels.

Strength of evidence for reduction: Three Experts are not certain that reductions would be realized using this methodology. The fourth Expert thinks there is suggestive evidence of a reduction in Cd using this methodology (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts).

Potential public health impacts: The Experts agree the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts.

Potential economic impacts: The Experts agree the extent of economic impact cannot be quantified or is not known for this strategy.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. The fourth Expert thinks this reduction strategy could have unacceptable adverse social impacts because farming practices and local culture (generational culture) might be negatively impacted by changing land use and growing practices necessitated by converting from one form of agricultural method to another.

Scalability of potential reduction: Three Experts gave a rating indicating that they think there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, however, scaling is still possible. The fourth Expert thinks scalability of the proposed reduction strategy is unknown and potentially challenging due to technological uncertainties associated with this reduction strategy.

Technological feasibility of method: Two Experts think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. One Expert thinks the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, but has not been demonstrated to be effective. The fourth Expert thinks the technology needed to implement the reduction strategy has not been developed.

Confidence: Three Experts have a low degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time. The fourth Expert has a low to medium degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions could not be achieved, with some evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 6 percent, a feasibility score of 42 percent, and an overall score of 34 percent (Table 3). The Expert Committee rated this strategy in the **Low** category based on the combined confidence score. Refer to Table B-16 for the Experts' individual scoring of this strategy.

4.3.8 Manage Fermentation Practices to Reduce Cd in Beans

Overview of Strategy

This approach looks at how specific steps within the cocoa bean fermentation process could be managed in order to reduce Cd levels. These steps may include drainage of mucilage before fermentation begins, use of selected yeast strains, use of *Lactobacillus* or other bacteria, and changes to fermentation pH, time frames, and temperatures.

Background

The fermentation process is designed to degrade the pulp of freshly harvested cocoa beans and initiate biochemical changes in the cotyledon by enzymes and naturally existing microorganisms (CODEX, 2020). In addition to this practice being very crucial in the development of chocolate flavor characteristics, studies have shown that fermentation may have an effect on the level of Cd in beans. An investigation done by Ramtahal (2012) demonstrated that the Cd concentration of cocoa bean nibs and shells increased as fermentation progressed. Though a similar trend was observed for Cd levels in shells, Vanderschueren et al. (2020) found that nib levels instead decreased during the course of fermentation and attributed this to acetic and lactic acid bacteria-related pH changes (< 5.0) in beans, which might result in an outward migration of Cd from nib to shell. In this vein, they proposed that nib Cd can be reduced if the nib pH is sufficiently acidified during fermentation. However, there is concern as to how an intentional acidification might affect the overall flavor of completely fermented and dried beans used for chocolate production. There have also been consideration of other bacteria (e.g., *Bacillus* and *Lactobacillus* [Meter et al., 2019]) and yeast strains (e.g., *Saccharomyces cerevisiae* [Rojas et al., 2017]) that may have a high capacity to retain Cd in the fermentation process. However, there is no additional evidence to support their effect in cocoa beans to date.

Additionally, the mucilage, the sugary pulp that coats the outside of freshly harvested beans, has also been found by scientists to contain Cd. As such, it was hypothesized that its removal before the fermentation process may result in reduced bean Cd levels. A study carried out by Reyes (2018) in Peru showed that draining off the mucilage before fermentation of the cocoa beans reduced the mucilage content and consequently the Cd concentration in the bean. However, there are concerns with the experimental data reported by Reyes (2018) due to the mucilage Cd levels in his study being excessively higher than Cd levels in the nibs and shells. This trend is contrary to reports conducted by Ramtahal (2012) in Trinidad and De Mesmaeker (2019) and Vanderschueren et al (2020) in Ecuador; their studies determined significantly lower levels of Cd in the mucilage than both nibs and shells. It thus brings into question whether draining the mucilage would really have such a significant effect on reducing Cd concentration in cocoa beans during fermentation, especially if Cd levels are already negligible.

Discussion

The Expert Committee generally agrees that there are technological and scalability issues that limit the feasibility of this reduction strategy. For example, the Experts discussed the potential that some of these fermentation practices may jeopardize essential flavor attributes for chocolate making. Additionally, the Expert Committee generally agrees that there are not sufficient reliable data currently available to support the effectiveness of this strategy to mitigate Cd levels in beans.

Application: The Experts agree this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: The Experts agree the potential magnitude of reduction is not known or quantifiable.

Time frame for potential reduction: Two Experts are unsure as to the time frame of reduction. One Expert predicts it would take 1 to 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Cd levels. The fourth Expert predicts it would take 1 year.

Strength of evidence for reduction: Three Experts think there is suggestive evidence of a reduction in Cd using this methodology (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts). The fourth Expert is not certain that reductions would be realized using this methodology.

Potential public health impacts: Three Experts think the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts. The fourth Expert thinks the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts with proper exposure prevention methods.

Potential economic impacts: Two Experts think the reduction strategy could be implemented without prohibitive costs (i.e., implementation of strategy would be cost neutral or the cost could be absorbed by the industry and/or the consumer). Two Experts think the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: The Experts agree this reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: The Experts agree this reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts gave a rating indicating there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, however, scaling is still possible. Two Experts think scalability of the proposed reduction strategy is unknown and potentially challenging due to uncertainties in the technology.

Technological feasibility of method: Three Experts think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. The fourth Expert thinks the technology needed to implement the reduction strategy has not been developed.

Confidence: Three Experts have a low degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time. The fourth Expert has a low to medium degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions could not be achieved, with some evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 6 percent, a feasibility score of 47 percent, and an overall score of 38 percent (Table 3). The Expert Committee rated this strategy in the **Low** category based on the combined confidence score. Refer to Table B-17 for the Experts' individual scoring of this strategy.

4.3.9 Use Microbial Inoculation Techniques

Overview of Strategy

Microbes may influence the phytoavailability of metals in soils according to laboratory studies on other plant species. Soils that cause excessive Cd accumulation by cocoa might be inoculated with bacteria or fungi to reduce Cd uptake by an unknown mechanism.

Background

The CODEX Draft Code of Practice (2020) and the Bioversity Report (Meter et al., 2019) both mention inoculation of soils with microbes as a possible method to reduce Cd accumulation in cocoa beans. In many reports of laboratory studies and a few reports of field studies, inoculation with bacteria or fungi have altered uptake of soil metals in other plant species. One example of research related to cocoa soils is the study by Bravo et al. (2018), who hypothesized that if they could find natural Cd tolerant microbes in cocoa farm soils, such strains might be used to inoculate other cocoa soils in order to reduce Cd uptake by cocoa. They obtained acidic cocoa farm soils from northeastern Colombia where cretaceous sedimentary rocks and shales are known to carry Cd mineralization (up to 3.74 mg Cd/kg soil with high Cd:Zn ratio). They used a novel technique with high Cd salt and glucose addition to a soil slurry to select and characterize Cd tolerant microbes. They found a correlation between soil Cd and the "colony forming units" or density of Cd tolerant bacteria in the tested soils. However, they did not test whether inoculation of cocoa soils with the identified microbes had any effect on Cd accumulation by cocoa.

A test of whether inoculation with three strains of *Streptomycetes* bacteria could reduce the phytotoxicity of Cd to cocoa, and the uptake of Cd by cocoa, was reported by Revoredo and Hurtado (2017). They considered this a test of the "bioremediation" ability of the microbes for Cd. They germinated cocoa seeds after not-treating or treating the seeds with the three strains of the bacterium. They sterilized the soil, added 0, 100, or 200 mg Cd/kg soil, added the microbial inoculation, and then transplanted seedlings for study. They harvested one seedling from each treatment on four dates up to 3 months after transplanting, then measured yield and analyzed Cd in the shoots. One strain, "C2" caused a small reduction in shoot Cd; for the non-inoculated seeds, the non-inoculation and inoculation 100 mg Cd/kg soil treatment had 148 and 89.3 mg Cd/kg, and the 200 mg Cd/kg soil treatment had 169 and 133 mg Cd/kg. There was no reduction in cocoa shoot Cd with the other two strains. Although the study had an appropriate technical approach, the use of 100 and 200 mg Cd/kg added to a test soil makes the results have little relevance to practical reduction of Cd in cocoa beans. However, the reduction in cocoa shoot Cd indicates that similar studies with relevant soils, cocoa cultivars, Cd test levels, and cocoa farm soils levels might show more helpful results. The observed effects in this pot study with heavy inoculation may not occur in the field when practical levels of inoculation would have to be used to minimize costs.

Studies of mycorrhizal fungi inoculation to reduce metal phytotoxicity or accumulation have been reported for other crops. Janouskova et al. (2005) found that mycorrhiza could reduce Cd phytoextraction by a transgenic tobacco in lab studies. A subsequent study by the same group found that mycorrhiza inoculation could increase fixation of Cd in soils using an arbitrary test of Cd fixation (Janouskova et al., 2005). Tullio et al. (2003) isolated mycorrhiza spores from a Cd-polluted soil and a non-polluted soil and found that the mycorrhiza obtained from the polluted soil had greater tolerance to soil Cd. Further, Hildebrandt et al. (2007) wrote a review of interactions of arbuscular mycorrhiza and heavy metals.

A paper by Sandoval-Pineda et al. (2020) evaluated the varied mycorrhizal fungi that occurred in Colombian cocoa soils with low (1.5 mg Cd/kg) or high (27.3 mg/kg) total Cd concentration; these soils had pH of 4.2 and 5.9, respectively. They noted the discussion among South American agronomy researchers of possible strategies, including microbial inoculation of soils for mitigation of Cd in cocoa. The high Cd soil had an unusually high Cd:Zn ratio, but total Zn levels were not reported. The species of mycorrhiza present in the two soils were evaluated both by microscopic examination and by growing onion as a "trap crop," a common technique in study of the occurrence of mycorrhiza species. The species found differed between the test soils. This was a preliminary study before a possible wider examination of soil Cd, Zn, pH, etc., and occurrence of mycorrhiza in soils and cocoa roots.

Ramtahal et al. (2012) conducted a controlled greenhouse pot experiment to see if inoculation of cocoa seedlings by a commercial "biofertilizer" labeled as containing mycorrhiza would reduce Cd accumulation by cocoa seedlings. They sterilized the test soil and then inoculated the treatment pots with the commercial "biofertilizer" product before transplanting cocoa seedlings with several harvest dates after transplanting seedlings. They found that inoculation actually somewhat increased Cd accumulation by the seedlings. At harvest they checked the roots for the microscopic evidence of infection by the mycorrhiza and found mycorrhiza infection had not been successful (the product may have contained no living mycorrhiza). They noted that they had tested only one soil, one cultivar of cocoa, and one strain of mycorrhiza and that additional tests might be appropriate.

However, no field studies have shown that practical rates of inoculation of soils with microbes has reduced Cd accumulation in cocoa. Further, because most tests in which mycorrhiza are believed to alter metal phytoavailability are laboratory studies with very high metal and microbial inoculation rates, these treatments are not relevant to cost-effective field practice. Successful mycorrhiza inoculation of many examined plant species requires use of mycorrhiza-infected roots of a species that easily establishes the infection of other roots in the same soil. Mycorrhiza are noted for increasing phosphorus uptake by roots of many species growing on soils with low phytoavailable phosphate and many lab and field tests of that technology have been reported. Mycorrhiza inoculation has become a practical commercial technology for a number of high value plant species in many countries to adapt the plants to soils with low fertility.

Discussion

The Expert Committee generally agrees that that the available research on soil/root microbial inoculation methodology does not support the hypothesis that inoculation of cocoa roots with microbes will reduce Cd accumulation in cocoa beans under conditions relevant to normal cocoa production. Further research would be required to evaluate the potential that a microbial or fungal inoculation method could reduce cocoa accumulation of Cd.

Application: The Experts agree this strategy applies primarily to Cd reduction.

Potential magnitude of reduction: The Experts agree the potential magnitude of reduction is not known or quantifiable.

Time frame for potential reduction: The Experts are unsure as to the time frame of reduction.

Strength of evidence for reduction: Three Experts are not certain that reductions would be realized using this methodology. The fourth Expert thinks there is suggestive evidence of a reduction in Cd using this methodology (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts).

Potential public health impacts: Two Experts think the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts. Two Experts think the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts with proper exposure prevention methods.

Potential economic impacts: Three Experts think the extent of economic impact cannot be quantified or is not known for this strategy. The fourth Expert thinks the reduction strategy could be implemented without prohibitive costs (i.e., implementation of strategy would be cost neutral or the cost could be absorbed by the industry and/or the consumer).

Potential environmental impacts: Three Experts think this reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks the reduction strategy could have unintended adverse environmental consequences, which could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. The fourth Expert thinks the reduction strategy could have positive social impacts.

Scalability of potential reduction: Two Experts gave a rating indicating there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, however, scaling is still possible. Two Experts think scalability of the proposed reduction strategy is unknown and potentially challenging due to uncertainties in the effectiveness of the technology.

Technological feasibility of method: Two Experts think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. Two Experts think the technology needed to implement the reduction strategy has not been developed.

Confidence: The four Experts have a low degree of confidence that the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 0 percent, a feasibility score of 41 percent, and an overall score of 32 percent (Table 3). The Expert Committee rated this strategy in the **Low** category based on the combined confidence score. Refer to Table B-18 for the Experts' individual scoring of this strategy.

4.4 Agricultural Strategies to Reduce Pb Contamination on the Outer Cocoa Bean Shell

The Expert Committee proposed and evaluated three strategies intended to reduce Pb (and possibly a small proportion of Cd) from environmental contamination on the outer bean shell during transportation of beans on-farm as well as to processing and buying areas and during fermentation and drying at the origin's growing and processing areas. The Pb better agricultural practices (Pb-BAPs) described here represent a compilation of ideas raised by the Expert Committee during their deliberations in the Root Cause and the Reduction Recommendations Phases and varied practices known to occur in Ecuador, Trinidad, and as described in the literature. In addition, many of the practices listed below are also recommended in a report published by the Chocolate, Biscuits, and Confectionery of Europe, European Cocoa Association and Federation of Cocoa Commerce (CAOBISCO/ECA/FCC, 2015).

The context of these reduction strategies is that the Expert Committee determined in the Root Cause Phase that the majority of Pb total concentration in chocolate products occurs from environmental exposure of the outer surface (shell) of wet whole beans during the fermenting/drying processing to Pb contaminated soil and dust. The results of a small pilot study conducted by the Expert Committee in Ecuador suggest that the amount of Pb contamination found on the outer shell appears to be dependent on the concentration of Pb in the soil/dust, the surface area of the shell coming in contact with soil/dust, and possibly the contact duration and the stage of drying (wet beans would tend to accumulate more soil/dust on the shell). Because cocoa bean nibs tested for Pb immediately after harvesting contain less than 1-5 ppb Pb, the Expert Committee concludes that improved management to protect the beans from environmental sources of Pb during transportation, fermenting, and drying would considerably reduce the levels of Pb in the commercial cocoa beans and in chocolate products.

In order to implement BAPs to the fullest extent, the Expert Committee recommends combining these practices with "better business practices" such as incorporation into industry self-certification and guidance documentation (see Section 6.1.1), employee training and "train-the-trainer" programs (see Section 6.1.2), and local incentives and/or subsidies (see Section 6.2.1). In addition, these strategies would likely need to be evaluated regionally and locally for scalability and validation to ensure the most efficient and effective implementation.

BAPs to control Pb contamination of whole wet beans during on-farm transport, during fermentation and drying, and during transportation to processors and buyers are described below for three types of prevention/mitigation measures. The Expert Committee discussed consolidating these practices into one all-encompassing strategy. However, for the purposes of the quantitative evaluation process and because these three practices differ in terms of methods, applicability, and overall reduction efficiency, it was ultimately agreed that these practices would remain separately presented and evaluated strategies. In some cases, all three Pb-BAP strategies described here might be implemented in combination to achieve the greatest reduction of Pb contamination prior to shipping out of the country of origin, depending on resource availability and capacity in cocoa growing regions.

4.4.1 Agricultural Strategies to Reduce Pb with High Combined Confidence Scores

Two Pb-BAP reduction strategies related to agricultural practices received high combined confidence scores. The following sub-sections describe these strategies and their feasibility considerations.

4.4.1.1 Prevent Pb Contamination of Beans during Fermenting and Drying

Overview of Strategy

The Expert Committee agrees that the most substantial source of Pb contamination on whole wet beans is very likely to originate from historically Pb contaminated soils and dust in cocoa bean processing areas. Protecting wet beans from the accumulation of dust and fine particles contaminated with Pb is the most effective preventative measure for reducing the levels of Pb on the outer shell prior to the beans arriving at the chocolate facilities. Therefore, this Pb-BAP defines guidance for farmers and processing facilities to prevent environmental soil and dust contact with whole wet beans during fermenting and drying by utilizing mostly easy to implement and relatively low-cost methods for keeping the wet beans clean (that is, free from contact with soil and dust).

Background

As previously noted, the Expert Committee determined in the Root Cause Phase that the major contributor to the Pb contamination in chocolate products occurs from environmental exposure of the wet bean outer shell during the fermenting/drying processing to Pb contaminated soil and dust. The amount of Pb contamination found on the outer shell appears to be dependent on the concentration of Pb in the soil/dust, the surface area of the shell coming in contact with soil/dust, and possibly the contact duration and the stage of drying (wet beans would tend to accumulate more soil/dust on the shell). Because cocoa bean nibs tested for Pb immediately after harvesting contain only very low levels of Pb, the Expert Committee agrees that improved management to protect the beans from environmental sources of Pb during fermenting and drying when the beans are most likely to contact contaminated soils and dust would considerably reduce the levels of Pb in the commercial cocoa beans and in chocolate products. Ensuring that fermenting and drying beans cannot be contaminated by airborne dust or direct soil contact, vehicle exhaust (in areas where leaded gasoline is still available), Pb paint chips, or other environmental sources of Pb contamination would go a long way to achieving the industry's goal to reduce Pb concentration in chocolate products.

Stored dried beans might also be susceptible to some environmental contamination from airborne dust, vehicle exhaust, and other types of environmental contamination. However, the Expert Committee agrees that the likelihood for Pb contamination in stored dried beans is very small relative to the contamination potential for wet beans. Therefore, the Expert Committee does not propose any additional Pb-BAPs for stored beans aside from those practices already employed to store dried beans in sown or sealed, food-grade clean bags, off the floor, and inside clean warehouses prior to being shipped to the chocolate facilities.

The following Pb-BAPs should be implemented individually or in combination to reduce Pb contamination of whole wet beans during fermenting and drying:

1) Prior to fermentation and drying, sort and discard any pieces of foreign materials (e.g., rocks, soil clumps, metal, wood, plastic, rubber) that might also be a source of Pb contamination.

2) To the extent possible, locate fermentation and drying areas away from roads and parking areas in a space with adequate protection from direct soil contact and airborne dust.

3) Ensure that fermenting and drying containers (e.g., bags), platforms, and any equipment are unpainted (or Pb-free paint only) and kept reasonably clean between fermentations and prior to and during drying.

4) To the extent possible, fermentation and drying should take place on clean Pb-free surfaces including raised platforms (e.g., on unpainted wood platforms) off the ground so that the beans are not in direct contact with soil, dust, tarmac, concrete, or painted surfaces.

5) Where above-ground fermenting and drying is not possible, place containers or loose beans on clean tarps or other clean barriers, not directly on soil.

6) Use of protective covers during fermenting or drying (e.g., a transparent carport roof or some other form of transparent cover) might be a suitable alternative to relocating fermenting or drying areas.

7) In locations where sun-drying cannot be performed in locations free from dust, soil, and other sources of environmental Pb contamination, well-designed and maintained artificial dryers would be an effective (albeit more expensive) alternative.

8) Turn the beans on clean paint-free surfaces during drying and avoid walking on drying beans with soil contaminated footwear and clothing.

Discussion

The Experts generally agree that methods such as relocating all fermentation and drying areas away from roadsides and parking areas and using raised (unpainted) platforms, clean tarps, transparent covers, or other means to control dust and exhaust in these areas have the potential for considerable reduction in the amount of environmental Pb contamination of wet cocoa bean shells. Prevention of Pb contamination on the outer bean shell by any means would theoretically result in considerable reduction of Pb contamination as the beans move forward during processing. However, the Experts agree that there are no studies or empirical data available in the publicly available literature that demonstrate any measured or expected reduction of Pb from the application of these practices in large or small operations in the cocoa industry. Ramtahal (2012) sampled beans during on-farm fermentation and drying; on one farm, bean Pb concentrations remained <5 ppb, while on the other farm, bean Pb concentrations reached more than 1,000 ppb Pb. Thus, the Expert Committee generally agrees that implementation of this strategy would provide a standard level of quality and care at the post- harvest points in the chocolate supply chain that would contribute to the reduction of Pb on the outside of the cocoa bean shell.

Although the prevention methods and the materials needed are already developed and readily available, there are likely to be regional differences in terms of which of these practices can be readily adopted and scaled compared to other areas where scaling would take some effort and time (e.g., in regions where these practices are not commonly practiced by farmers). However, in some cocoa growing regions a number of these practices have been implemented. Anecdotally, the Expert Committee members did observe fermenting and drying on raised platforms in some areas of Ecuador; and in others, beans were spread directly on the ground without tarps or other protective measures. The Expert Committee generally agrees the reduction strategy can be implemented without potential for unintended adverse public health, economic, environmental, and social impacts.

Application: The Expert Committee agrees that this reduction strategy would be most effective for Pb contamination prevention.

Potential magnitude of reduction: Two Experts predict that the level of Pb reduction in chocolate products from implementing this strategy could be greater than 25 percent. Two Experts think the extent of reduction cannot be quantified or is not known.

Time frame for potential reduction: Three Experts think it would take 1 year from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb levels. One Expert predicts it would take 1 to 5 years.

Strength of evidence for reduction: Three Experts think there is no evidence of a reduction, but anticipate one occurring. The fourth Expert thinks the reduction has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: The Experts agree this strategy could be implemented without prohibitive costs to the chocolate industry.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. The fourth Expert thinks the reduction strategy could have positive social impacts.

Scalability of potential reduction: Two Experts think there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa farms and exporters. One Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms and exporters but anticipates scaling is still possible. The fourth thinks the scalability of the proposed reduction strategy is unknown and potentially challenging because of regional differences in resource availability and capacity.

Technological feasibility of method: Two Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective. One Expert thinks the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available.

Confidence: Two Experts have a medium to high degree of confidence that the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believe there is sufficient evidence to support this statement. One Expert has a very high degree of confidence that the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant. The fourth Expert has a medium degree of confidence that the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believes there is sufficient evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 75 percent, a feasibility score of 71 percent, and an overall score of 72 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-19 for the Experts' individual scoring of this strategy.

4.4.1.2 Prevent Pb Contamination of Whole Wet Beans during Transport

Overview of Strategy

The Expert Committee evaluated this strategy as a means to prevent Pb contamination of wet whole beans during on-farm transport and during transportation of wet beans to processing areas and dry beans to buyers. This Pb-BAP would provide cocoa growers with plastic pails (or other similar containers) or clean biodegradable bags to collect beans in the orchard to transport wet beans to the fermentation and drying sites, and clean, disposable (biodegradable) bags in which to transport dry beans to buyers.

Background

During cocoa bean harvesting and on-farm transport of the beans, it is important to use clean plastic pails or clean biodegradable bags in order to avoid potential cross-contamination with previously harvested beans and to encourage clean processes from the start. The Expert Committee concluded in the Root Cause report that bean harvesting is not thought to be a point of appreciable risk for Pb contamination. Nevertheless, protection of the wet beans from direct contact with soil and dust in the orchard is a prevention step easily controlled by using clean harvesting and transporting methods.

Following harvesting, wet beans are transported from the field to a processing area often in bags that are reused numerous times without cleaning or replacement. Methods such as using clean bags or clean plastic containers for transportation have the potential not only to reduce cumulative cross-contamination of clean beans with previously transported "dirty" beans but may also contribute to a reduction of environmental contamination of the beans from airborne dust and other sources prior to reaching the processing areas. However, there are currently no empirical data in the publicly available scientific literature that demonstrate using clean bags for transportation would significantly reduce the amount of environmental contamination on the outer shell of the bean. In part, it is not clear how contaminated the reused bags are; these data could be relatively easy to obtain.

There might also be a benefit from using clean biodegradable bags during the final transportation of dry beans to a storage warehouse and/or where the beans will be inspected and purchased by buyers. Although the dry beans would be less susceptible to airborne dust accumulation during this transportation phase, cross-contamination of Pb from the reuse of dirty bags is easily preventable by providing clean bags for this final transportation step.

Discussion

The Expert Committee generally agrees that this strategy along with the other proposed and evaluated Pb-BAPs would provide a standard level of quality and care at the post-harvest points in the chocolate supply chain that could contribute to the reduction of Pb on the outside of the wet cocoa bean shell. The Expert Committee did observe one facility in Ecuador that provided clean bags to growers as an incentive. However, the Expert Committee believes that in most cocoa growing regions around the world it is likely that beans are transported from one point to another in reused bags (or other reused containers).

The Expert Committee generally agrees that this approach has some potential to reduce Pb levels on wet cocoa beans but there are currently no data to quantify by how much or how important this source of contamination is on the farm or in bean processing areas. The Experts recommend further research to address this data gap (see Section 7.1). The materials and methods needed to implement this reduction strategy are already developed, readily available, and likely already used in some cocoa growing regions. However, distributing bags and other types of containers is of concern especially where the number of cocoa farms is extensive and spread out over a large geographical area. Therefore, there are likely to be regional differences in terms of which of these practices can be readily adopted and scaled to meet the production demands compared to other areas where scaling would take some effort and time. The Expert Committee also acknowledges that once a new reusable container (e.g., a pail) is used, there would be little incentive for a farmer to clean the container especially in regions where clean water sources are not readily available. Furthermore, one Expert believes that use of clean, disposable (biodegradable) bags in which to transport dry beans to buyers is not necessary to reduce Pb concentrations in cocoa. However, it should be noted that the Expert Committee is not aware of any data on the potential for cross-contamination of Pb when reusable bags are used for transport.

The Expert Committee also generally agrees this reduction strategy could be implemented without negative public health, environmental, and social impacts, and may possibly be beneficial to society. The costs associated with implementation of this strategy are generally thought not to be prohibitive or possibly beneficial to the industry over the long-term although one Expert does not think the costs are known or can be quantified at this time.

Application: The Expert Committee agrees that this reduction strategy would be most effective for Pb contamination prevention.

Potential magnitude of reduction: Two Experts think the extent of reduction cannot be quantified or is not known. One Expert predicts that the level of Pb reduction in chocolate products from implementing this strategy could be greater than 25 percent. The fourth Expert thinks the level of Pb reduction could be 10 to 25 percent.

Time frame for potential reduction: Three Experts think it would take 1 year from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb levels. One Expert predicts it would take 1 to 5 years.

Strength of evidence for reduction: Three Experts think there is no evidence of a reduction, but they anticipate one occurring. The fourth Expert thinks there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts).

Potential public health impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: Two Experts gave a rating indicating that this strategy could be implemented without prohibitive costs to the chocolate industry. One Expert thinks the reduction strategy would have economic benefits to the industry and/or the consumer over the long-term. The fourth Expert thinks the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. The fourth Expert thinks the reduction strategy could have positive social impacts.

Scalability of potential reduction: One Expert thinks the scalability of the proposed reduction strategy is unknown and potentially challenging due to the different capacity of each country as it relates to their available resources within the cocoa sector; in growing regions where these practices are not commonly practiced by farmers, assistance might need to be provided through training, incentives, etc. Another Expert thinks the strategy is not scalable because farmers will have little incentive to clean containers once new reusable containers are used. The third Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms. The fourth Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa farms and processing facilities within a coca growing region.

Technological feasibility of method: Two Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective. One Expert thinks the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications.

Confidence: Two Experts have a very high degree of confidence that the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believe the evidence to support this statement is abundant. One Expert has a medium to high degree of confidence that the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement. The fourth Expert has a low degree of confidence that the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products, with a high probability that the reductions might not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 69 percent, a feasibility score of 66 percent, and an overall score of 67 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-20 for the Experts' individual scoring of this strategy.

4.4.2 Agricultural Strategies to Reduce Pb with Medium Combined Confidence Scores

One Pb reduction strategy related to agricultural practices received a medium combined confidence score.

4.4.2.1 Test Painted Surfaces for Pb

Overview of Strategy

This reduction strategy involves testing painted surfaces for Pb in cocoa bean growing and processing areas (e.g., where beans are fermented and dried) and encapsulating or removing all Pb-containing painted surfaces in the fermentation and drying areas in bean origin countries. Independent auditors would perform onsite inspections and Pb testing of bean processing areas and facilities where painted surfaces are proximal processing beans. The Pb test would likely need to be sensitive enough to detect levels of Pb in a small patch of paint in the range of about 1,000 ppm. Simple chemical colorimetric "spot tests" have been effective in identification of Pb paint in housing in the United States and Europe and are relatively inexpensive (see for example https://www.epa.gov/lead/lead-test-kits). If Pb is found to be present, several mitigation options would be proposed and discussed with the local operators. Such mitigation measures might include removal and replacement of Pb-painted surfaces (following environmental guidance), encapsulation of painted surfaces, or relocation of bean fermenting and drying areas away from painted surfaces. Follow-up inspections would occur after a reasonable time for the mitigation measured to be implemented to confirm that the Pb-paint problem has been resolved.

Background

It is likely in many of the cocoa-producing countries and regions that older painted surfaces contain Pb painting; Pb paint was only recently phased out in several countries. During its trip to Ecuador, the Expert Committee observed peeling or eroding paint in some areas of the processing facilities.

Discussion

The Experts generally agree there are no studies or empirical data available in the publicly available literature that demonstrate any measured or expected reduction of Pb in chocolate products from the application of this practice in large or small operations in the cocoa industry, but it is well known that Pb paint is a point source for contamination in several industries and a public health and environmental hazard. Although Pb paint remediation is based on methods and materials already developed and readily available, there are likely to be regional differences in terms of which of these practices could be readily adopted and scaled compared to other areas where scaling could take some effort and time. The Experts agree this strategy could be implemented without adverse public health or environmental impacts assuming proper Pb remediation protocols and personal protective equipment are used, and also generally agree that society would either benefit or not be negatively impacted by the proper removal of Pb paint.

Application: The Expert Committee agrees that this reduction strategy would be most effective for Pb contamination prevention.

Potential magnitude of reduction: Two Experts think the extent of reduction cannot be quantified or is not known. One Expert predicts that the level of Pb reduction in chocolate products from implementing this strategy could be greater than 25 percent. The fourth Expert think the level of Pb reduction could be less than 10 percent.

Time frame for potential reduction: Two Experts predict it would take 1 to 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb levels. One Expert predicts it would take 1 year. One Expert thinks the timing of the reduction is not known.

Strength of evidence for reduction: Two Experts think there is no evidence of a reduction, but anticipate one occurring. One Expert thinks there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts). One Expert cannot be certain a reduction will be realized.

Potential public health impacts: Three Experts think the reduction strategy could be implemented without potential for unintended adverse public health impacts. One Expert thinks the reduction strategy could be implemented without significant potential for unintended adverse public health impacts with proper exposure prevention methods (e.g., using properly fitted PPE during Pb paint removal).

Potential economic impacts: Three Experts gave a rating indicating this strategy could be implemented without prohibitive costs to the chocolate industry. One Expert gave a rating indicating that the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: Three Experts gave a rating indicating the reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks the reduction strategy could have environmental benefits once Pb paint is removed (assuming proper environmental protection and disposal measures have been takes such as using tarps to contain paint debris).

Potential social impacts: Two Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. Two Experts think the reduction strategy could have positive social impacts (once Pb paint is properly remediated).

Scalability of potential reduction: Two Experts think the scalability of the proposed reduction strategy is unknown and potentially challenging due to the different capacity of each country as it relates to their available resources within the cocoa sector. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms and processing facilities within a cocoa growing region. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa farms and processing facilities within a coca growing region.

Technological feasibility of method: Two Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective. One Expert thinks the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available. One Expert thinks the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications.

Confidence: Two Experts have a medium to high degree of confidence that the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believe there is sufficient evidence to support this statement. Two Experts have a low degree of confidence that the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products, with a high probability that the reductions might not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 38 percent, a feasibility score of 63 percent, and an overall score of 58 percent (Table 3). The Expert Committee rated this strategy in the **Medium** category based on the combined confidence score. Refer to Table B-21 for the Experts' individual scoring of this strategy.

5.0 Strategies Related to Manufacturing Practices

This section describes the Cd and Pb reduction strategies that the Expert Committee identified for manufacturing practices. These strategies apply to certain actions that could be taken at facilities that process cocoa beans or manufacture chocolate products. Strategies with the highest confidence scores are presented first (see Section 5.1), followed by those with medium confidence scores (see Section 5.2) and those with low confidence scores (see Section 5.3).

5.1 Highest Rated Manufacturing Strategies

Two reduction strategies related to manufacturing practices received high confidence scores. The following sub-sections describe these strategies and their feasibility considerations.

5.1.1 Blend Beans or Liquor as a Cd Control Measure

Overview of Strategy

The purpose of this strategy is to advise all cocoa and chocolate manufacturers to manage chocolate Cd levels through cocoa bean blending. This would be accomplished by testing cocoa bean lots based on the perceived risk of high Cd due to country of origin and then blending beans to meet regulatory limits. The control of bean blending would be included in the manufacturer's Quality and Food Safety Management System as necessary to manage Cd levels in chocolate products and would be subject to independent verification as part of the site's certification to a Global Food Safety Initiative (GFSI) benchmarked food safety scheme. See Section 6.2.2 for details on GFSI certification.

Background

Presently the only effective approach to reduce Cd in chocolate products is to blend cocoa beans. Cocoa beans of specific origins (e.g., Ecuador, Peru, Venezuela, Columbia, Trinidad, Indonesia, Dominican Republic) have been identified as being at risk for high Cd levels as compared to other origins (e.g., Ivory Coast, Ghana, Nigeria, Cameroon). For details, see the Root Cause Report, Table 3a. There is also variation of Cd levels within at risk origins. By blending beans, manufacturers would be able to produce chocolate products to meet regulatory limits. Beans could be blended by exporters at origin; at the manufacturer's facility; or at a third party location. An alternative to blending cocoa beans would be to process individual bean lots into chocolate liquor and blend semi-finished chocolate liquors prior to producing chocolate products. In either option, cocoa bean lots would need to be tested, identified, and traced to the final blended product. Finished chocolate products would need to be tested at a defined frequency to assure formulation and blending control. Any blending process would need to assure that Pb levels did not inadvertently increase as a result of blending for Cd.

Discussion

The Expert Committee determined in the Root Cause Phase that contaminated, mineralized, or highly acidic soils are one of the major sources of Cd in cocoa beans, which occurs through direct uptake of phytoavailable Cd by the cocoa tree during the pre-harvest stage. The Expert Committee generally agrees that testing and blending cocoa beans and/or semi-finished chocolate liquor would result in measurable Cd reductions within 1 year or less. Some agricultural strategies evaluated in this report that address bean quality have longer-term implementation time frames, with predicted Cd reductions occurring only after 5 years and up to 20 years or more following implementation. The Expert Committee notes the Code of Practice (CODEX, 2020) supports blending as a standard practice with reservations from some cocoa producing countries (Peru). For economic reasons, these countries view this practice as a short-term solution that would result in the loss of origin identity for countries producing fine flavor cocoa.

The technology required to implement this strategy is already in use for Cd, including both cocoa bean and chocolate liquor testing and blending. There is suggestive evidence of a reduction of Cd based on Expert discussions with the industry. However, supporting analytical data and individual company practices are not available to the Expert Committee due to confidentiality and there is no published empirical data in the publicly available scientific literature demonstrating the effectiveness of cocoa bean/liquor blending in reducing Cd levels in chocolate products. In addition, no data are available to demonstrate how bean blending or liquor blending would impact Pb concentrations.

This strategy would have the largest impact on chocolates that are not of single origin, and for which the bean recipe can be changed without impacting the product flavor. For these types of products, this strategy could be expected to have from 10 to 25 percent or perhaps greater reduction in Cd concentrations in chocolate products. This would typically include most mass-marketed confectionery products. For chocolates that are single origin with a signature flavor, this strategy would have a reduced impact because signature flavor profiles could be changed as a result of bean or liquor blending. In addition, the availability of lower Cd concentration beans within a specific origin could limit blending options.

The Expert Committee notes this strategy has potential scalability issues with medium and small processors because of a potential limited capability to blend beans or chocolate liquor within their facilities. The Experts generally agree the implementation of this reduction strategy would not result in negative public health, environmental, or economic impacts. Social impacts are unlikely except for possible reduced marketability of high Cd beans in certain cocoa growing regions.

Application: Three Experts think this strategy applies primarily to Cd reduction. The fourth Expert thinks both Cd and Pb levels could change due to blending beans or liquor.

Potential magnitude of reduction: Two Experts predict the magnitude of reduction could be 10 to 25 percent. One Expert predicts the magnitude of reduction could be greater than 25 percent. The fourth Expert thinks the potential magnitude of reduction is not known or quantifiable.

Time frame for potential reduction: The Experts agree the reduction would be observed in 1 year or less from the implementation date.

Strength of evidence for reduction: Two Experts think the reduction has been reliably demonstrated either by practical implementation on a large farm or manufacturing facility or during large scale field trials and documented in the scientific literature by a reputable organization or by a government agency. Two think there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts).

Potential public health impacts: The Experts agree the reduction strategy could be implemented without considerable potential for unintended adverse public health impacts.

Potential economic impacts: The Experts agree the reduction strategy could be implemented without prohibitive costs (i.e., implementation of strategy would be cost neutral or the cost could be absorbed by the industry and/or the consumer).

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. The fourth Expert thinks the reduction strategy could have unacceptable adverse social impacts because growers in high Cd origins may not be able to market beans due to limitations associated with blending.

Scalability of potential reduction: Two Experts gave a rating indicating there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of manufacturing facilities. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of manufacturing facilities. The fourth Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe of manufacturing facilities but anticipates scaling is still possible.

Technological feasibility of method: Three Experts think the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective.

Confidence: Two Experts have a very high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believe the evidence to support this statement is abundant. One Expert has a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement. The fourth Expert has a low to medium degree of confidence the proposed reduction strategy could result in demonstrable Cd reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions could not be achieved, with some evidence to support this statement. Some manufacturers of fine flavor or specific origin chocolates may not be able to find low Cd beans with these designations to blend with the higher Cd beans known to occur.

Conclusion

This strategy received a combined confidence score of 75 percent, a feasibility score of 79 percent, and an overall score of 78 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-22 for the Experts' individual scoring of this strategy.

5.1.2 Establish Bean Cleaning and Winnowing Quality Assurance Practices for Pb Contamination

Overview of Strategy

The purpose of this strategy is to require all cocoa and chocolate manufacturers to establish bean cleaning and winnowing quality assurance (QA) practices to control Pb levels in chocolate liquor. The implementation of these practices would be included in the manufacturer's Quality and Food Safety Management System as necessary to manage Pb levels in chocolate products and would be subject to independent verification as part of the site's certification to a GFSI benchmarked food safety scheme. See Section 6.2.2 for details on GFSI certification. This would establish a consistent level of quality across all factories from which improvements could be implemented.

Background

The context of this strategy is that the Expert Committee determined in the Root Cause Phase that bean cleaning and shell removal processes play a key role in redistributing soil particles from cocoa bean shells and waste material to nibs. These processes are not presently controlled to manage Pb levels in nibs.

Cocoa bean cleaning processes are operated to remove non-cocoa impurities that can cause wear and damage to subsequent processing equipment. These include stones, pieces of metal, bean clusters, pieces of wood, sand, and dust particles. A typical bean cleaning process will include the removal of course and fine material by sieving and aspiration; the removal of ferrous material with a magnet; and the removal of stones by gravity separation (destoning). In most cocoa processing operations, bean cleaning equipment is operated to protect downstream process equipment. Standard operating conditions may or may not be established and monitored. Preventive maintenance activities may or may not be implemented. The role of fine soil and shell particles in the cocoa bean stream as the primary contributor to nib Pb level is not understood by industry.

The process of shell removal through bean breaking and winnowing is controlled for operational efficiency, product quality, and regulatory compliance. Winnowing is controlled to achieve a shell-in-nib limit of 1.75 percent. This includes routine sampling and analysis for shell-in-nib content and adjustment of breaking and air classification parameters. The role of shell content as a contributor to nib Pb level is generally understood, but not intentionally controlled to control Pb levels in products.

The Expert Committee conducted a study at a major North America cocoa processing plant operated by one of the largest companies in the industry on 17 and 18 August 2020. The study was conducted to understand the impact of cocoa bean cleaning and winnowing processes on the reduction of Pb in cocoa products. One of the learnings from the study is that approximately 70 percent of the Pb in finished nibs can be attributed to contact of nibs at bean breaking with soil particles from cocoa bean shells and waste material. The remaining 30 percent can be attributed to controllable shell at winnower sieves and winnowing system fines used as nibs. Appendix C of this report provides detailed information on the Expert Committee's study. The study's findings indicate the importance of both bean cleaning and winnowing as processes to control Pb in nib.

Table 4 compares current and future state of quality assurance practices that would be required for bean cleaning and winnowing. The future state would establish a consistent level of quality across all factories from which improvements could be implemented.

Table 4. Current and Proposed Future QA Practices for Bean Cleaning and Winnowing

QA Practice	Current	Future
Standard operating conditions and process control	Standard operating conditions for feed rates, air flow, static pressure, breaker speeds, etc. not established. Measurements/checks and adjustment of conditions not consistently performed.	Standard operating conditions established for bean cleaning and winnowing equipment. Routine measurements/checks and adjustments to return equipment to optimal settings.
Preventive maintenance	Bean cleaning and winnowing equipment not consistently included in facility preventive maintenance programs.	Preventive maintenance scheduled for screens (to clean blinded and repair torn screens) and aspiration systems (to assure proper airflow and vacuum).
Instrument calibration	Instruments not calibrated.	Critical instruments identified and calibrated to traceable standards – testing scales, airflow instruments, etc.
Recordkeeping	No records of bean cleaning equipment operation. Winnowing shell-in-nib (SIN) records, but no records of winnower operating parameters.	Operating records for bean cleaning equipment (feed rates, aspiration static pressure, etc.). Winnower SIN records and winnower operating records (breaker speeds, aspiration damper settings, etc.).
SIN testing	Companies have different SIN testing methods. No standardized method.	All companies follow an agreed standard method.
Chocolate liquor Pb testing	No routine chocolate liquor Pb testing.	Routine chocolate liquor Pb testing to verify effectiveness of bean cleaning and winnowing controls.
Training	Operators and supervisors not aware of the impact of cleaning and winnowing on Pb control.	Operators and supervisors trained to understand relationship between bean cleaning and winnowing operations and Pb levels.

Discussion

The Expert Committee generally agrees the implementation of this strategy could result in some level of Pb reduction in chocolate products due to improved process control and can be implemented relatively quickly (about 1 year to at most 5 years). However, the magnitude of reduction is difficult to assess across the industry because it is dependent on the current effectiveness of bean cleaning and winnowing processes in each manufacturing facility. Therefore, the benefit of implementing this strategy is not to achieve further reduction in Pb levels, but to improve control over the process. The Experts generally agree this type of quality assurance should be implemented as a prerequisite for all cocoa and chocolate manufacturers. The Experts also generally agree this strategy is scalable for all size chocolate and cocoa manufacturers. The type of bean cleaning and shell winnowing equipment used by large manufacturers is the same as medium and small manufacturers. The only difference is the size and operating capacity. The Expert Committee agrees there would be no adverse impacts on public heath, society, and the environment from implementing this strategy, and the economics would be cost neutral or absorbed by the industry.

Application: The Expert Committee agrees this reduction strategy would be most effective for Pb contamination prevention.

Potential magnitude of reduction: Two Experts think the extent of reduction cannot be quantified or is not known. One Expert predicts that the level of Pb reduction in chocolate products from implementing this strategy could be greater than 25 percent. The fourth Expert thinks the level of Pb reduction could be less than 10 percent.

Time frame for potential reduction: Two Experts predict it would take 1 to 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb levels. One Expert predicts it would take 1 year or less. One Expert thinks the timing of the reduction is not known.

Strength of evidence for reduction: Two Experts think there is no evidence of a reduction, but anticipate one occurring. One Expert thinks the reduction has been reliably demonstrated by practical implementation in a manufacturing facility and documented in the scientific literature by a reputable organization or by a government agency. The fourth Expert thinks the reduction has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: The Experts agree this strategy could be implemented without prohibitive costs to the chocolate industry.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: The Experts agree this reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa manufacturing facilities. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa manufacturing facilities. The fourth Expert thinks there is demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe of cocoa manufacturing facilities, or if applicable, a smaller subset based on need or practicality.

Technological feasibility of method: Two Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective. One Expert thinks the technology needed to implement this strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available.

Confidence: Two Experts have a medium degree of confidence that the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products, with low probability that the reductions could not be achieved and believe there is sufficient evidence to support this statement. One Expert has a very high degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant. One Expert has a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 69 percent, a feasibility score of 78 percent, and an overall score of 76 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-23 for the Experts' individual scoring of this strategy.

5.2 Medium Rated Manufacturing Strategies

One reduction strategy related to manufacturing practices received a medium combined confidence score. The following sub-section describes this strategy and its feasibility considerations.

5.2.1 Develop and Use New Mechanical Techniques to Clean Beans to Reduce Pb Contamination

Overview of Strategy

Current cocoa bean cleaning processes consist of mechanical equipment to remove foreign materials that contain Pb. This equipment includes aspiration, sieving, destoning, and magnets. This strategy would identify new mechanical cleaning approaches to further remove foreign material beyond what is currently achievable and develop and implement new processing equipment based on the new technology with a specific focus on Pb reduction.

Background

Cocoa bean cleaning processes are operated to remove non-cocoa impurities that can cause wear and damage to subsequent processing equipment. These include stones, pieces of metal, bean clusters, pieces of wood, sand, and dust particles. A typical bean cleaning process will include the removal of coarse and fine material by sieving and aspiration; the removal of ferrous material with a magnet; and the removal of stones by gravity separation (destoning). This approach to cleaning is standard within the cocoa industry. Currently, cocoa bean cleaning processes are operated to remove foreign material and not to reduce Pb. Pb reduction is achieved as an outcome of cleaning and not as an intentional objective.

The Expert Committee conducted a replicated study at a major North America cocoa processing plant operated by one of the largest companies in the industry on 17 and 18 August 2020. The study was conducted to understand the impact of cocoa bean cleaning and shell removal processes on the reduction of Pb in cocoa products. The Expert Committee confirmed that mechanical cleaning removes fine material attached to the outside of the bean and loose in the cocoa bean stream through sieving and aspiration. Table 5 summarizes Pb levels of the uncleaned beans, cleaned beans, and cleaning waste streams measured during the study.

Table 5. Summary of Pb Sampling of Bean Cleaning Process Streams at a Cocoa Bean Processing Facility

Stream	Mean Pb (ppb)	Samples (n)
Whole uncleaned beans	95.2	12
Shells of uncleaned beans	163.3	6
Nibs of uncleaned beans*	15.2	6
Material over 25.0 mm screen – bean clusters	44.5	6
Material through 2.0 mm screen – "dust"	3,130	6
Aspiration dust	2,370	6
Cleaned beans	39.7	6

*Note: One Expert indicated the "usual clean methods" used by analytical laboratories have typically reported Pb nib concentrations <3 ppb.

Based on the available information and personal observations, the Expert Committee postulates that the Pb containing fine material removed by sieving and aspiration is generated during the transport and handling of cocoa beans. This includes soil particles liberated from the shell surface, and shell fragments containing adsorped Pb.

If a new mechanical cleaning technology could be developed, one of the challenges to implementation would be the capital required to install it at every cocoa bean processing facility. To facilitate implementation, consideration could be given to using third party processors to clean the beans between origin and the cocoa facility. This might be able to reduce the total capital required.

Discussion

Based on the results of the Experts' Bean Cleaning and Winnowing Study (Table 5 and Appendix C), the Expert Committee confirmed that existing mechanical cleaning operations at the manufacturing facility does remove fine material attached to the outside of the bean and loose particles in the cocoa bean stream through sieving and aspiration. Based on these results, the Experts proposed a strategy that would require development and installation of an additional step prior to roasting and bean cracking where abrasion technology (e.g., friction from bean-to-bean contact, soda blasting) could further remove Pb bonded to the outside of cocoa beans. However, results from a gentle bean abrasion study (bean-to-bean friction) conducted by the Expert Committee (see Appendix D) demonstrated that greater force is needed to remove Pb from the outer shell. Further research and development would be required to determine whether a controlled bean abrasion step could be designed to remove Pb without breaking the shell.

The Expert Committee generally agrees that the concept of incorporating an additional mechanical cocoa bean cleaning step in the manufacturing process has some merit and could possibly reduce Pb contamination from 10 to 25 percent or greater. However, the technology has not been sufficiently developed to test the hypothesis that a bean abrasion step would work in an experimental setting or in a facility. Development and field testing of such technology could take 5 years or longer and therefore, this should be considered a longer-term solution. The Experts also agree that for a bean abrasion method to be cost-effective, a considerable reduction in Pb contamination in the cocoa nib stream would need to be observed. The Experts generally agree that should an effective mechanical bean cleaning step be developed and inserted into the manufacturing process (either in each facility or in a third party facility), there would be no appreciable negative impacts on public health, the environment (with adequate environmental protection measures), or society due to implementation of this strategy.

Application: The Expert Committee agrees this reduction strategy would be most effective for Pb contamination prevention.

Potential magnitude of reduction: Two Experts think the extent of reduction cannot be quantified or is not known. One Expert predicts the level of Pb reduction in chocolate products from implementing this strategy could be greater than 25 percent. The fourth Expert thinks the level of Pb reduction could be 10 to 15 percent.

Time frame for potential reduction: Two Experts think the timing of the reduction is unknown. One Expert predicts it would take more than 5 years from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb levels. One Expert predicts it would take 1 to 5 years.

Strength of evidence for reduction: One Expert thinks the reduction has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts. One Expert thinks there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts). One Expert thinks there is no evidence of a reduction, but anticipates one occurring. One Expert cannot be certain a reduction will be realized.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse public health impacts.

Potential economic impacts: Two Experts think the extent of economic impact cannot be quantified or is not known. One Expert thinks the reduction strategy could be implemented without prohibitive costs over the long-term (i.e., implementation of strategy is cost neutral or the cost can be absorbed by the industry and/or the consumer). The fourth Expert thinks the reduction strategy cannot be implemented without significant and prohibitive costs that cannot be recovered over the long-term.

Potential environmental impacts: Three Experts think the reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks the reduction strategy might have unintended adverse environmental consequences, which could be avoided with routine environmental monitoring and/or with implementation of proper environmental protection measures.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. The fourth Expert thinks there could be positive social impacts.

Scalability of potential reduction: Two Experts gave a rating indicating they think there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa manufacturing facilities, but anticipate that scaling is still possible. Two Experts think the scalability of the proposed reduction strategy is unknown and potentially challenging because the technology has not been developed for cocoa applications.

Technological feasibility of method: Two Experts gave a rating indicating they think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. Two Experts think the technology needed to implement the reduction strategy has not been developed.

Confidence: Two Experts have a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believe there is sufficient evidence to support this statement. One Experts has a low to medium degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions could not be achieved, with some evidence to support this statement. One Experts has a low degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 44 percent, a feasibility score of 47 percent, and an overall score of 47 percent (Table 3). The Expert Committee rated this strategy in the **Medium** category based on the combined confidence score. Refer to Table B-24 for the Experts' individual scoring of this strategy.

5.3 Lowest Rated Manufacturing Strategies

One reduction strategy related to manufacturing practices received a low confidence score. The following sub-section describes this strategy and its feasibility considerations.

5.3.1 Use Chemical Washing Techniques to Clean Beans to Reduce Pb Contamination

Overview of Strategy

This strategy applies to the development and implementation of a wet cleaning process to remove soil that is adhered to the cocoa bean shell. This would have a primary purpose of reducing Pb levels in cocoa beans.

Background

Wet cleaning equipment would be installed and operated at cocoa bean processing plants or at a third party location. Wet cleaning (washing) is a common practice for the cleaning of fruits and vegetables. This would be a novel technology for cocoa bean cleaning. Current industry practice is to clean cocoa beans mechanically. A typical bean cleaning process includes the removal of coarse and fine material by sieving and aspiration; the removal of ferrous material with a magnet; and the removal of stones by gravity separation (destoning).

The Expert Committee conducted a study at a major North America cocoa processing plant operated by one of the largest companies in the industry on 17 and 18 August 2020. The study was conducted to understand the impact of cocoa bean cleaning and shell removal processes on the reduction of Pb in cocoa products. As part of the study, raw uncleaned beans were washed with detergent and detergent/nitric acid, and compared to the site mechanical cleaning process for Pb reduction. The following is a summary of the Pb levels of the uncleaned beans, mechanically cleaned beans, and wet cleaned beans measured during the study.

Table 6. Summary of Cocoa Bean Pb Contamination by Bean Cleaning Approach

Stream	Mean Pb (ppb)	Variance (ppb^2)	Samples (n)
Uncleaned Beans	95.2	11,500	10
Cleaned Beans - Mechanical	39.7	166	6
Cleaned Beans - Detergent	42.3	81.1	6
Cleaned Beans - Detergent and Nitric Acid	23.2	13.4	6

Wet cleaning and mechanical cleaning both appear to reduce the mean Pb level and the variation between samples of inbound cocoa beans. There does not appear to be a difference between the level of reduction between mechanical cleaning and washing with detergent. However, sequential washing with detergent and nitric acid does appear to reduce the mean Pb level more than detergent washing or mechanical cleaning alone. It also appears to reduce the variation between cleaned bean samples.

The wet cleaning of cocoa beans with detergent and nitric acid would be a novel technology with unassessed quality and food safety risks. A potential process would be to wash the beans with detergent and/or nitric acid, rinse with water, and then dry before shell removal. The following is a list of risks and potential solutions that would have to be evaluated.

Table 7. Assessment of Risks Associated with Wet Cleaning of Cocoa Beans

Issue	Risk	Assessment
Food Safety	*Salmonella* outgrowth in cocoa beans due to non-uniform bean drying and storage.	Likely to occur. Potential solution is uniform drying of beans to avoid pockets of high moisture.
Food Safety	Formation of *Salmonella* niches in processing environments.	Likely to occur. Potential solution is separating wet processing environments from dry raw bean processing environments.
Food Safety	Mycotoxin formation due to mold formation as a result of non-uniform bean drying and storage.	Likely to occur. Potential solution is uniform drying of beans to avoid pockets of high moisture.
Quality	Off flavor due to mold formation as a result of non-uniform bean drying and storage.	Likely to occur. Potential solution is uniform drying of beans to avoid pockets of high moisture.
Quality	Off flavor due to contact with nitric acid.	Impact of nitric acid contact on cocoa bean flavor is unknown.
Quality	Potential degradation of cocoa butter due to contact with nitric acid, though one Expert noted that the conditions tested in the Bean Cleaning and Winnowing Study (Appendix C) would likely not have caused any degradation.	Impact of nitric acid contact on cocoa butter flavor or hardness is unknown.

Discussion

The Expert Committee generally agrees that washing the raw whole cocoa bean with an acidic detergent wash could remove considerable amounts of Pb bound to the outside of the shell, perhaps as much as 75 percent compared to uncleaned beans based on the committee's Bean Cleaning and Winnowing Study results (Table 6). The Experts also generally agree that detergent washing alone appears to have little effect in reducing Pb bound to the outer bean shell compared with traditional cocoa bean processing at commercial facilities. In addition, the Experts agree that the presence of water in the cocoa bean processing step could promote fungal and bacterial (e.g., Salmonella) growth if the beans are not uniformly dried before moving down the cocoa bean processing stream. Table 7 presents some potential challenges associated with implementation of this strategy, many of which would need to be resolved should this strategy be pursued further. Additional considerations such as the need to segregate wet processing environments from dry raw bean processing environments in the manufacturing facility and the cost associated with the design and installation of an efficient drying system to rapidly reduce water content also lower the overall feasibility score for implementing this strategy as is.

The Expert Committee generally agrees the reduction strategy could be implemented without negative social impacts or even with social benefits. However, the Experts' evaluations of the potential impact of implementing this strategy on public health, the environment, and economics varied widely as did the scoring for the availability and effectiveness of the technology and scalability. Despite the wide variation in scoring for many of the feasibility factors, the Experts generally agree that their level of confidence in implementing this strategy at the present time is low.

Application: The Expert Committee agrees this reduction strategy would be most effective for Pb contamination prevention.

Potential magnitude of reduction: Two Experts predict the level of Pb reduction in chocolate products from implementing this strategy could be greater than 25 percent. Two Experts think the extent of reduction cannot be quantified or is not known.

Time frame for potential reduction: One Expert predicts it would take more than 5 years from the time of the decision to implement before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb levels. One Expert predicts it would take 1 to 5 years. One Expert predicts it would take 1 year or less. The fourth Expert thinks the timing of the reduction is unknown.

Strength of evidence for reduction: Two Experts cannot be certain a reduction will be realized. One Expert thinks the reduction has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts. The fourth Expert thinks there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts).

Potential public health impacts: Two Experts think the reduction strategy could have unintended adverse public health consequences secondary to fungal or bacterial growth from improperly dried cocoa beans. One Expert thinks the reduction strategy could be implemented without significant potential for unintended adverse public health impacts. The fourth Expert thinks the reduction strategy could be implemented without significant potential for unintended adverse public health impacts with proper mitigation controls.

Potential economic impacts: Two Experts think the reduction strategy could not be implemented without significant and prohibitive costs that could not be recovered over the long-term due to the development of new technology and installation in manufacturing facilities. One Expert thinks the reduction strategy could be implemented without prohibitive costs (i.e., implementation of strategy is cost neutral or the cost can be absorbed by the industry and/or the consumer) over the long-term. The fourth Expert thinks the economic impact cannot be quantified or is not known.

Potential environmental impacts: Two Experts think the reduction strategy might have unintended adverse environmental consequences, which could be avoided with the implementation of proper environmental protection measures. One Expert thinks the reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks the reduction strategy could have unintended adverse environmental consequences, such as disposal of wastewater and energy consumption from having to dry washed beans.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts and the fourth Expert thinks there could be positive social impacts.

Scalability of potential reduction: Two Experts gave a rating indicating they think the scalability of the proposed reduction strategy is unknown and potentially challenging because the technology has not yet been developed for cocoa. One Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa manufacturing facilities, but anticipates that scaling is still possible. The fourth Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy can readily be scaled to a smaller (defined) subset of cocoa manufacturing facilities.

Technological feasibility of method: Two Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. One Expert thinks the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available. The fourth Expert thinks the technology needed to implement the reduction strategy has not been developed.

Confidence: Three Experts have a low degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products, with a high probability the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time. One Expert has a low to medium degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence the reductions could not be achieved, with some evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 6 percent, a feasibility score of 38 percent, and an overall score of 31 percent (Table 3). The Expert Committee rated this strategy in the **Low** category based on the combined confidence score. Note that the need for this strategy to reduce Pb in chocoates could be avoided by better "on farm" processing to avoid soil and dust contact with fermenting and drying beans (see Section 4.4.1.1). Refer to Table B-25 for the Experts' individual scoring of this strategy.

6.0 Strategies Related to Business Practices

This section describes the Cd and Pb reduction strategies that the Expert Committee identified for business practices. These strategies apply to certain actions that companies in the cocoa industry can take to reduce Cd or Pb concentrations in cocoa beans or chocolate products. Strategies with the highest confidence scores are presented first (see Section 6.1), followed by those with medium confidence scores (see Section 6.2). None of the strategies pertaining to business practices had low confidence scores.

6.1 Highest Rated Business Strategies

Three reduction strategies related to business practices received high combined confidence scores. The following sub-sections describe these strategies and their feasibility considerations.

6.1.1 Incorporate Better Agricultural Practices into Cocoa Sustainability/Certification Programs

Overview of Strategy

The chocolate industry has recognized that improvements must be made to the cocoa supply chain in order to address issues related to child labor, deforestation, farmer income, and cocoa supply. As a result, many of the SDs have implemented cocoa sustainability programs. While the specific details vary, these programs establish requirements to improve farmer livelihoods, environmental impact, and cocoa farm productivity. Most of the SDs have made public commitments to source 100 percent of their cocoa bean supply from either one of the third party cocoa certification schemes or their own sustainability scheme by 2030. This commitment includes financial investment in producing countries to implement requirements and independent verification to provide evidence of implementation. This also includes commitment to improve cocoa traceability in order to provide confidence in the effectiveness of the industry efforts. The purpose of this strategy is to incorporate into industry cocoa sustainability and certification programs recommended Better Agricultural Practices to reduce Pb and Cd in cocoa.

Background

The following SDs have made public statements regarding their commitment to cocoa sustainability. These commitments include plans regarding financial investment; sourcing strategy; and verification methods.

- Mars – “Cocoa for Generations” (Mars, 2020)

  Ensure 100% of our cocoa is responsibly sourced globally and is traceable by 2025. Going beyond the current level of certification standards and practices and committing us to action across three focus areas that put cocoa farmers, communities and the environment at the center of our efforts. Backed by a $1 billion investment over 10 years, Cocoa for Generations has two pillars: Responsible Cocoa Today and Sustainable Cocoa Tomorrow.

- Hershey – “Cocoa for Good” (The Hershey Company, 2020)

  In 2019, 51 percent of food ingredients sourced (by cost) were certified to third-party environmental and/or social standards. Representative standards include: Fair Trade USA, Rainforest Alliance, RSPO, and Bonsucro. We’re investing half a billion dollars by 2030 to nourish children, elevate youth, build prosperous communities and preserve natural ecosystems.

- Nestlé – “Nestlé Cocoa Plan” (Nestle, 2020)

  Nestlé has committed to sourcing 100% of the cocoa it uses for confectionery products worldwide from the Nestlé Cocoa Plan by 2025. The Nestlé Cocoa Plan will achieve sustainable good quality cocoa by building long term loyal customer – farmer group relationships; supply chain traceability to the farmer; and rewarding NCP farmers for certification and good quality.

- Cargill – “Cargill Cocoa Promise” (Cargill, 2020)

We have mapped 151,558 farmers (72%) in our direct supply chain. We have achieved 100% traceability of our direct supply chain in Ghana and 70% in Côte d'Ivoire. 43% of our global cocoa volume is third-party certified as sustainable. Through the Cargill Cocoa Promise program, we are also training farmers in other Good Agricultural Practices (GAPs) to practice efficient, environmentally sound and safe farming. This ultimately allows them to increase the profitability and productivity of their existing land without encroaching into forests.

- Lindt – "Lindt & Sprungli Farming Program" (Lindt, 2020)

  Our goal: 100% traceable and externally verified worldwide cocoa bean supply chain. Within the internal monitoring & performance management system, field staff visit each farmer participating in the Farming Program at least once a year to see if the training content on agricultural, social, environmental and business aspects of farming is applied on the farms. Potential corrective actions are discussed together with the farmer and their implementation monitored. The ultimate aim is to measure the progress the farmers are making towards sustainable cocoa production and environmentally friendly agriculture. The external verification of our Program is an important step towards our overall aim of a sustainable long-term supply chain. We are committed to working towards a 100% verified cocoa bean supply chain by 2020.

- Blommer Chocolate Company – "Sustainable Origins" (Blommer, 2020)

  Improving overall living conditions for farmers which allow cocoa growing communities to flourish while guaranteeing future cocoa supply. Sustainable Origins™ builds upon expanding farming skills to empower farmers; improve market transparency and strengthen farmer associations to ensure fully traceable, high quality products to meet our customers' expectations. As an industry leader, we believe sustainability efforts in cocoa communities provides value at every touch point in the supply chain through improved and more consistent quality and a sustainable future for cocoa farming families.

- Barry Callebaut – "Forever Chocolate" (Barry Callebaut, 2020)

  Barry Callebaut has invested in the development of sustainable cocoa programs for well over a decade. We offer customers sustainable cocoa from the following programs: Cocoa Horizons, Fairtrade, Rainforest Alliance and UTZ. Explore each of these programs and see which products we offer today that contain sustainable cocoa. By 2025, we will have 100% sustainable ingredients in all our products.

- Mondelez – "Cocoa Life" (Mondelez, 2020)

  By 2025, all Mondelēz International's chocolate brands will source their cocoa through Cocoa Life. We focus our efforts on the three areas where we can make the most difference: sustainable cocoa farming businesses; empowered cocoa communities; conserved and restored forests. $400 million USD by 2022 to empower at least 200,000 cocoa farmers and reach one million community members. Supply Chain Verification FLOCERT verifies the flow of cocoa from Cocoa Life communities into our supply chain. It also verifies the benefits cocoa farmers receive, such as premium payments and clear trade terms. Verification drives learning and transparency, and ensures we are sourcing from the farming communities we invest in.

- Guittard Chocolate Company – "Honorable Sourcing" (Guittard, 2020)

  Certified Cocoa is one way we approach empowering farmers and farmer groups to instill best practices—both agricultural and social. Our Fair Trade Certified products for consumers and chefs underline our commitment to supporting farmer organizations and increasing farmer incomes.

The industry has utilized third party certifications as a way to verify cocoa supply chain conformance to child labor, worker safety, environmental, and farm productivity requirements. UTZ, Rainforest Alliance, and Fairtrade are the leading cocoa certification programs working globally in all origins. In 2018, UTZ and Rainforest Alliance merged operating as one organization but with two separate certification schemes. While there is an international standard for sustainable and traceable cocoa (ISO 34101-2:2019), UTZ, Rainforest Alliance, and Fairtrade each maintain their own certification standard that is based on requirements for economic, social, and environmental aspects.

As part of certification and sustainability programs, the industry has implemented auditing programs to verify that requirements have been met. Incorporation of "Better Agricultural Practices" into these certification and sustainability programs allows the existing auditing programs to verify Cd and Pb management practices at the same time. Traceability, accountability, and verification of farming practices are all a necessary part of this certification process in order to implement the Cd and Pb strategies to their fullest intent. This is not an unrealistic extension because cocoa certification programs currently include requirements for Good Agricultural Practices.

- The UTZ Code of Conduct, Cocoa Module, version 1.1, includes certification requirements for postharvest processing. (See: https://utz.org/better-business-hub/strengthening-your-reputation/utz-train-farmers/)
    - CO.B.4 - "Cocoa beans are dried in a way that prevents contamination from smoke, fuel, odors, and other sources that may affect the quality."
- The ISO standard for sustainable and traceable cocoa (ISO 34101-2:2019) includes requirements for post-harvest handling. — Drying (5.3.9) and Post-harvest — Packing and storage of cocoa beans (5.3.10). (See: ISO, 2019)
    - 5.3.9 Post-harvest — Drying, Table 11 — Requirements for drying
        1) Where beans are dried at farm or organization level, the organization shall ensure the competence of agricultural workers in appropriate drying techniques that avoid direct contact with roads and soil.
        2) The organization shall ensure that sun-drying is conducted on a clean and prepared surface.
    - 5.3.10 Post-harvest — Packing and storage of cocoa beans, Table 12 Requirements for packing and storage of cocoa beans

While cocoa certification has been widely adopted by the chocolate industry, there has been criticism regarding its effectiveness in driving improvements. An October 2019 Washington Post investigative report (Whoriskey, 2019) found significant lapses in UTZ compliance reviews that cast doubt on the effectiveness of certification. Even though certification is performed by independent certification bodies, conflict of interest is always a potential concern in any assessment scheme. A study on sustainable cocoa and UTZ certification in Côte d'Ivoire conducted by Wageningen University, NL (Ingram et al., 2017) found marginal differences between certified and non-certified farms on child labor and environmental conditions. However, the same study found that training given to farmers to assure and improve drying as part of Good Agricultural Practices may have contributed to improvements in cocoa quality.

Discussion

This proposal is a better business practices strategy that could enable the implementation of better agricultural practices designed to reduce Cd and Pb levels in cocoa as described in Section 4. The Experts acknowledge the concern that while cocoa certification has been widely adopted by the chocolate industry, there has been criticism regarding its effectiveness in driving improvements. As a standalone strategy, this proposed better business practice is not expected to directly reduce Pb or Cd in chocolate products but rather work in combination with better agricultural practices to improve traceability, accountability, and verification of farming and post-harvest cocoa processing practices. The Experts generally agree the reduction strategy could be implemented in 1 year or less with observable benefits.

The Experts agree there could be no negative impact of implementing this strategy on public health, the environment, or society. The Experts also generally agree the implementation of this strategy could have minimal economic impact on SDs because most have already implemented cocoa sustainability and certification programs. The better agricultural practices described in Section 4 could be complementary and benefit from the establishment of modified, consistent, and enforced cocoa certification practices. Therefore, there would be minimal economic risk to the SDs to adopt this strategy. On the other hand, there is a wide variation in Expert Committee evaluations pertaining to the issue of scalability. This better business practice would be most effective if implemented by a majority of chocolate manufacturers.

Application: The Expert Committee agrees the reduction strategy would be effective for both Cd and Pb contamination prevention.

Potential magnitude of reduction: Two Experts think the extent of reduction cannot be quantified or is not known. One Expert thinks the level of Pb and Cd reduction in chocolate products from implementing this strategy could be 10 to 25 percent. The fourth Expert thinks the level of Pb and Cd reduction could be greater than 25 percent.

Time frame for potential reduction: The Experts agree it would take 1 year or less from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb and Cd levels.

Strength of evidence for reduction: Two Experts think there is no evidence of a reduction but anticipate one occurring. One Expert thinks the reduction has been reliably demonstrated by practical implementation in the manufacturing sector and documented in the scientific literature by a reputable organization or by a government agency. The fourth Expert thinks the reduction has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts.

Potential public health impacts: Three Experts think the reduction strategy could be implemented without significant potential for unintended adverse public health impacts. The fourth Expert thinks the reduction strategy can be implemented without significant potential for unintended adverse public health impacts with proper exposure prevention methods.

Potential economic impacts: The Experts agree the reduction strategy could be implemented without prohibitive costs over the long-term.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: The Experts agree the reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: One Expert gave a rating indicating there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire cocoa manufacturing sector. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of the cocoa manufacturing sector. One Expert thinks there is demonstrated potential the proposed reduction strategy could readily be scaled to the entire cocoa manufacturing sector, or if applicable, a smaller subset based on need or practicality. The fourth Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire cocoa manufacturing sector but anticipates scaling is still possible.

Technological feasibility of method: Two Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective. Two Experts think the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective.

Confidence: Two Experts have a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products, with low probability the reductions could not be achieved and believe there is sufficient evidence to support this statement. One Expert has a very high degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant. The fourth Expert has a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products and believe there is sufficient evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 69 percent, a feasibility score of 76 percent, and an overall score of 74 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-26 for the Experts' individual scoring of this strategy.

6.1.2 Provide Education/Training at the Local Level to Implement Reduction Strategies

Overview of Strategy

This strategy is proposed as a component of the other reduction implementation strategies that would require training in order to facilitate effective implementation. Because this strategy would facilitate the implementation of other strategies, it would only indirectly reduce Cd and Pb in chocolate products by providing widely disseminated education and training locally in cocoa growing regions and facilitating information dissemination and consistency. The Expert Committee will identify specific reduction strategies where education and the "train-the-trainer" (TTT) application would be most effective.

Background

"Train-the-Trainer" (TTT) is an educational model and tool that has been used effectively for decades in the workplace. It is based on Abraham Maslow's analysis of the learning process where he determined that how well students learned depended on the degree of satisfaction both teachers and students took in the learning process. When students and teachers enjoyed the process and felt fulfilled by it, students learned faster and retained the information better (https://www.simplypsychology.org/maslow.html). Under this model, a trainer educates other employees while at the same time training them to teach and train others. Usually, there is also a curriculum that all trainers follow so that the materials and concepts being presented retain consistency of content and quality. TUSDA and the Food and Drug Administration (FDA) implement TTT courses and programs in the agricultural and food safety sectors (see for example: https://www.usda.gov/media/blog/2016/11/15/training-growers-growing-trainers-preparing-new-food-safety-requirements).

By training employees to train others, the pathway for information dissemination, outreach, and education is greatly facilitated (and made consistent) resulting in an effective and efficient means to implement "on-the-ground" programs. The TTT model offers distinct advantages over other training models because information is quickly disseminated, and trainees typically learn faster and retain the information better than in other teaching models. In addition, when participants learn a subject and simultaneously learn how to teach others, it provides personal satisfaction and fulfillment better than other teaching models. Furthermore, when adopting this model of information dissemination and education, new jobs are often created and employees are empowered to take on more skilled positions thereby resulting in societal benefit for the long term.

One educational model to consider is to train agricultural extension officers, who then go into the field and train farmers. Select examples of international agricultural training programs include:[2]

1) The University of the West Indies. This extension program's mission can be summarized as supporting the sustainability of the cocoa sector through management of genetic resources, research, innovation, and outreach by creating a learning environment of global excellence and

[2] Please refer to the end of the References (Section 8) for other examples.

developing an innovation-oriented research program and strong outreach program (https://sta.uwi.edu/cru/training).

2) UTZ Certification Training: According to the website, "training is key to success at the UTZ program. It's through training that farmers learn about sustainable agricultural practices and how to improve yields, protect workers and look after the environment." The UTZ certification programs utilize the TTT approach where field representatives in each country provide training to local non-governmental organizations and technical advisers working for traders and companies in the supply chain. These trainers in turn train farmers, giving them the knowledge and skills that they need to succeed (https://utz.org/better-business-hub/strengthening-your-reputation/utz-train-farmers/).

3) CGIAR (formerly the Consultative Group for International Agricultural Research) is a global partnership that unites international organizations engaged in research about food security. The CGIAR Research Program on Climate Change, Agriculture and Food Security seeks to address the increasing challenge of global warming and declining food security on agricultural practices, policies, and measures through strategic, broad-based global partnerships. This is an example of guidance published by this organization to maintain consistency in education and training for growing cocoa and is used by the master trainers, practitioners, and extension officers with direct contact with cocoa farmers: https://ccafs.cgiar.org/publications/manual-cocoa-extension-ghana#.X5TkdHV7mct.

4) Swiss Contact: The Sustainable Cocoa Production Program facilitates capacity-building measures for 165,000 smallholder cocoa farmers in 57 selected districts across 10 cocoa producing provinces in Indonesia. It is funded by the Swiss State Secretariat for Economic Affairs and collaborates with nine local and multinational cocoa and chocolate companies. The Program facilitates and implements specific activities in the social, economic, and environmental dimensions and employs an integrated and well-established approach that incorporates good agricultural practices, technology transfer systems, community development, and other methods (https://www.swisscontact.org/nc/en/country/indonesia/projects/projects-indonesia/project/-/show/sustainable-cocoa-production-program-scpp.html.)

The list of international organizations committed to provide training and education using TTT and other methods provides ample evidence that such programs are feasible, sustainable, and effective across agricultural sectors and would work for cocoa as well. During its tour of Ecuador, the Expert Committee observed TTT efforts coordinated by at least one company aimed at educating local farmers. One Expert noted that government agencies and private organizations in Trinidad train cocoa farmers on good agricultural practices. Another Expert noted that education and training at the local level is supported within the chocolate industry. For example, SDs have sustainability programs in most countries of origin (some of these are described in the links provided and in Section 6.1.1). These programs address a broad range of topics, like improving crop productivity, ensuring farmers continue to grow cocoa, and addressing child labor issues. This training occurs at "demonstration plots," training centers, and coops.

These existing programs would provide an opportunity for educating farmers on better agricultural practices (for example, keeping beans clean to avoid Pb contamination on the outer shell of wet beans) and could even be a vehicle for training farmers on minimizing Cd contamination. In most cases however, Pb and Cd reduction is not the focus of these programs. In order for this approach to be effective for these purposes, new educational curricula and guidance will need to be developed or old guidance amended with specific attention to reducing Cd and Pb contamination in cocoa beans and processing. There would also be a need to verify that training and education programs are well-funded, properly implemented, and that the information being exchanged is up-to-date and accurate. Verification of better business practices is discussed in Sections 6.1.1 and 6.2.2.

Discussion

This strategy is proposed as a component of the better agricultural practice strategies presented in Section 4, which would require training in order to facilitate effective implementation of those strategies. In other words, this better business practices strategy is designed to enable agricultural practices designed to reduce Cd and Pb in cocoa beans in cocoa-growing regions. As a standalone strategy, this proposed better business practice is not expected to directly reduce Pb or Cd in chocolate products but rather work in combination with better agricultural practices to promote all-way communication, ensure consistency of information exchange, facilitate materials dissemination, provide education and training opportunities in the community, and monitor farming and post-harvest cocoa processing practices.

The Expert Committee generally agrees the implementation of this strategy would not have negative public health, environmental, or social impacts (with potential societal benefits). The Experts also generally think the economic impact would not be prohibitive, although actual costs might not be known or quantifiable at this time. On the other hand, there is a wide variation in Expert Committee responses to the issues of technological feasibility, scalability, and time for implementation of this strategy before benefits are observed.

Application: The Expert Committee agrees the reduction strategy would be most effective for both Cd and Pb contamination prevention.

Potential magnitude of reduction: Two Experts think the level of Pb and Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent. Two Experts think the extent of reduction cannot be quantified or is not known.

Time frame for potential reduction: One Expert predicts it would take 1 year or less from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb and Cd levels. One Expert predicts it would take 1 to 5 years. One Expert predicts it would take more than 5 years. The fourth Expert thinks the timing of the reduction is unknown.

Strength of evidence for reduction: Two Experts think there is no evidence of a reduction but anticipate one occurring. One Expert thinks the reduction has been reliably demonstrated either by practical implementation on a large farm or manufacturing facility and documented in the scientific literature by a reputable organization or by a government agency. The fourth Expert thinks there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts).

Potential public health impacts: The Experts agree the reduction strategy could be implemented without significant potential for unintended adverse public health impacts.

Potential economic impacts: Two Experts think the reduction strategy could be implemented without prohibitive costs over the long-term. One Expert thinks there could be economic benefits to the industry and/or the consumer over the long-term. The fourth Expert thinks the extent of economic impact cannot be quantified or is not known.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: Two Experts think the reduction strategy could be implemented without potential for unacceptable adverse social impacts. Two Experts think the reduction strategy could have positive social impacts.

Scalability of potential reduction: One Expert gave a rating indicating there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms, processors, exporters, etc. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa farms, processors, exporters, etc. One Expert thinks there is no documented or demonstrated potential that the proposed reduction strategy could readily be scaled to the entire universe or a subset of cocoa farms, processors, exporters, etc. but anticipates scaling is still possible. The fourth Expert thinks the scalability of the proposed reduction strategy is unknown.

Technological feasibility of method: One Expert gave a rating indicating the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective. One Expert thinks the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective. Another Expert also thinks the technology needed to implement the reduction strategy has been developed and has been demonstrated to be effective for cocoa applications, but it is not widely available. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications.

Confidence: Two Experts have a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products and believe there is sufficient evidence to support this statement. One Expert has a very high degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products and believe the evidence to support this statement is abundant. The fourth Expert has a low to medium degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions might not be achieved, with some evidence to support this statement.

Conclusion

This strategy received a combined confidence score of 69 percent, a feasibility score of 70 percent, and an overall score of 69 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-27 for the Experts' individual scoring of this strategy.

6.1.3 Test Surfaces of Cocoa Beans for Pb Contamination at Point of Purchase and Reject Beans with Elevated Pb Levels

Overview of Strategy

The purpose of this strategy is to perform an onsite quality inspection of beans prior to purchase for the obvious gross contamination of the outer cocoa bean shell with Pb contaminated soil/dust/residue. The Pb test would likely need to be sensitive enough to detect levels on a representative sampling of bean shells, in the range of about 0.5 to 1 ppm. Standard laboratory tests for Pb have sensitivity in the parts per billion range. However, colorimetric tests are analytically less sensitive. If Pb levels are deemed high enough (that is, are higher than a trigger level to be determined), then the purchaser should reject that lot of beans.

Background

The context of this strategy is that the Expert Committee determined in the Root Cause Phase that the majority of Pb contamination in chocolate products occurs from environmental exposure of the outer shell of wet whole beans during the fermenting/drying processing to Pb contaminated soil and dust. The amount of Pb contamination found on the outer shell appears to be dependent on the concentration of Pb in the soil/dust, the surface area of the shell coming in contact with soil/dust, and possibly the contact duration and the stage of drying (wet beans would tend to accumulate more soil/dust on the shell). Because cocoa bean nibs and shell tested for Pb immediately after harvesting contain only very low levels of Pb, the Expert Committee concludes that improved agricultural practices used to protect the beans from environmental sources of Pb during fermenting and drying when the beans are most likely to contact contaminated soils and dust would theoretically strongly reduce the levels of Pb in the commercial cocoa beans and in final chocolate products. In cocoa growing areas where preventative measures cannot be implemented to their fullest, testing beans for Pb contamination is a management practice that would assist in identifying highly contaminated beans before purchase.

This measure could provide a means to control the amount of Pb entering the chocolate supply chain at the bean origin. There are no studies or empirical data available in the publicly available literature that demonstrate any measured or expected reduction of Pb from the application of this practice in large or small operations. However, the Expert Committee qualitatively believes any practice that reduces the potential for soil, dust, leaded fuel exhaust, and Pb paint contamination of the outer shell of whole beans (especially during fermenting and drying) could result in an appreciable reduction in Pb in chocolate products (see the strategies for Better Agricultural Practices for Pb Reduction).

Technologically, testing a representative sampling of cocoa beans for Pb concentration could be conducted using methods and materials already developed. In locations where laboratories are accessible and that have the capacity to analyze Pb in cocoa beans, this strategy could be implemented immediately and without considerable cost to the buyer. However, the Expert Committee generally believes that in some cocoa growing regions, access to laboratory facilities is limited or difficult. In these situations, the timeframe for testing Pb concentration may be too long to be practical. For this reason, the Expert Committee generally agrees the effectiveness of this method would be considerably improved if a rapid test could be used in the field to determine the degree of Pb contamination in cocoa beans lots. However, whether there is a universal capacity for a quick turnaround of effectively sensitive tests warrants further investigation and analysis. The biggest challenge might be finding a rapid Pb test method with a level of detection low enough to provide reliable results at the Pb levels estimated to be present on the outer bean shell following fermenting and drying. Most rapid tests on the market today were developed for testing Pb paint and Pb contaminated soils in the range of 20 to 500 ppm (Landes et al., 2019; Hutter and Moshman, 1995; Preer and Murchison, 1986; Grohse et al., 1993).

Rapid colorimetric Pb test kits for paint have been evaluated for accuracy and sensitivity and found to be reliable when Pb levels are relatively high in paint (https://www.epa.gov/Pb/Pb-test-kits). Use of these kits on the outer shell of cocoa beans under the circumstances of relatively high amounts of Pb (greater than 5,000 ppm) might prove valid. However, at levels of Pb below 5,000 ppm on the outer shell, this technology would be limited. One possible way to account for the lower Pb levels on cocoa bean shells is to test wipe a relatively large number of beans in order to increase the combined surface test area and increase the amount of Pb contact with the swab. There are also Pb test kits available for soil, leachates, and water that offer greater sensitivity. However, in some cases, the samples must be analyzed in a laboratory (with up to 4 days for turnaround time). In addition to sensitivity and accuracy, Pb test kits for paint using certain types of colorimetric chemical reactions might be impacted by the presence of other chemicals. Barium and red paint color have been shown to interfere with the detection of Pb; neither of these two would be of concern for cocoa bean shells. It should also be noted that x-ray fluorescence technology often used as a rapid Pb test for painted surfaces is even less sensitive than the colorimetric assays and would likely not be a suitable alternative for cocoa beans.

As with several other remediation strategies requiring analysis of environmental or biological contaminants, issues around sampling and traceability are paramount for the analysis of Pb on the outer shell of cocoa beans. In all sampling plans for cocoa beans or other crops, variability among samples will require careful planning. Therefore, in order to implement this strategy to its fullest capability, representative sampling plans must be developed and followed. This is common across the food industry when monitoring for environmental hazards and biological contamination, albeit not necessarily effective. One Expert Committee member noted that “thief samplers” can be used to collect bean samples at various locations within a bulk shipment. (Note: Thief samplers are sampling tools that are routinely used to collect samples of granules and powders.)

Discussion

The Expert Committee generally agrees that steps taken to prevent Pb contamination in cocoa beans before the beans reach the manufacturing facility would be effective in reducing Pb in chocolate products. This strategy proposes an additional check point where cocoa bean lots that are tested and found to be highly contaminated with Pb could be rejected before purchase and export. Existing laboratory methods could be used to analyze Pb levels in cocoa beans in growing regions with sufficient sensitivity to detect even trace levels of Pb. However, the Expert Committee generally agrees that the reliance on a laboratory to conduct the analysis would be time consuming and limit scalability due to laboratory inaccessibility in many cocoa growing regions. Therefore, the Expert Committee generally agrees that the confidence in the effectiveness of this strategy for testing Pb contamination in beans prior to purchase would be considerably improved if a rapid, inexpensive Pb test could be performed in the field. Such test kits are available commercially but the Expert Committee did not conduct pilot studies to validate the effectiveness of these kits. A research recommendation (see Section 7.1) and a sample experimental protocol (see Appendix F) to test the efficacy of available rapid Pb test kits in the field to address this data gap is included in this report. Because of the unknown availability of a rapid Pb test sensitive enough for use in the field, the Experts vary somewhat in their interpretations and ratings for technological and scalability feasibility.

The Expert Committee generally agrees Pb reduction could be observed in 1 year or less following implementation and levels of Pb reduction of greater than 25 percent could be achievable depending on the frequency and extent of bean shell testing at the point of purchase. The Expert Committee also agrees that there would likely be no adverse public health and environmental impacts associated with implementing this strategy.

The Experts generally agree the costs associated with testing are not prohibitive but the impact of rejecting beans could negatively impact some growers and processers where cocoa bean Pb contamination is a persistent problem.

Application: The Expert Committee agrees this reduction strategy would be most effective for Pb contamination prevention.

Potential magnitude of reduction: Three Experts predict the level of Pb reduction in chocolate products from implementing this strategy could be greater than 25 percent. The fourth Expert thinks the extent of reduction cannot be quantified or is not known.

Time frame for potential reduction: Three Experts predict it would take 1 year or less from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb levels. The fourth Expert thinks the timing of the reduction is unknown.

Strength of evidence for reduction: One Expert thinks the reduction has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts. One Expert thinks there is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts). One Expert thinks there is no evidence of a reduction but anticipates one occurring. The fourth Expert cannot be certain a reduction will be realized.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without significant potential for unintended adverse public health impacts.

Potential economic impacts: Two Experts think the reduction strategy could be implemented without prohibitive costs (i.e., implementation of strategy is cost neutral or the cost can be absorbed by the industry and/or the consumer) over the long-term. One Expert thinks the reduction strategy could have economic benefits to the industry and/or the consumer over the long-term. The fourth Expert thinks the economic impact cannot be quantified or is not known.

Potential environmental impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse environmental impacts. The fourth Expert thinks there could be environmental benefits.

Potential social impacts: Three Experts think this reduction strategy could be implemented without potential for unacceptable adverse social impacts. The fourth Expert thinks there could be unacceptable social impacts due to lost income from rejected cocoa beans at the point of purchase.

Scalability of potential reduction: Two Experts gave a rating indicating the scalability of the proposed reduction strategy is unknown and potentially challenging because a rapid Pb testing method has not been verified or developed and verification of representative sampling could be difficult. In addition, most cocoa growing areas are not equiped with commercial laboratory facilities to perform Pb testing at the sensitivity required and at the sample volume required. One Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of cocoa farms, processors, and exporters. The fourth Expert thinks there is demonstrated potential the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms, processors, and exporters, or if applicable, a smaller subset based on need or practicality.

Technological feasibility of method: Two Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available. One Expert thinks the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. The fourth Expert thinks the technological feasibility of this strategy is limited because of the uncertainty around whether a rapid, sensitive Pb test is available to faciliate a commercially viable screening program in the field.

Confidence: Two Experts have a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believe there is sufficient evidence to support this statement. One Expert has a very high degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant. The fourth Expert has a low degree of confidence the proposed reduction strategy could result in demonstrable Pb reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 63 percent, a feasibility score of 57 percent, and an overall score of 58 percent (Table 3). The Expert Committee rated this strategy in the **High** category based on the combined confidence score. Refer to Table B-28 for the Experts' individual scoring of this strategy.

6.2 Medium Rated Business Strategies

Two reduction strategies related to business practices received medium combined confidence scores. The following sub-sections describe these strategies and their feasibility considerations.

6.2.1 Offer Incentives to and Provide Funding for Local Growers

Overview of Strategy

This is a better business practice designed to support the implementation of proposed recommended Cd and Pb reduction measures primarily involving better agricultural practices (see Section 4.1). Therefore, this strategy would be a component of the better agricultural practices to reduce Cd and Pb from cultivation through bean storage and export. As such, this strategy would facilitate the implementation of other strategies thereby only indirectly reducing Cd and Pb in chocolate products.

As proposed, this strategy would encourage the chocolate industry to offer financial assistance through extension programs (see Section 6.1.2) or directly to growers and processors in cocoa producing regions to facilitate the purchase of new materials, to offset additional labor costs, and to promote consistency and sustainability in the implementation of the reduction strategies. Further, the chocolate industry would provide incentives such as the preferential purchase of "clean" (i.e., low Cd and Pb) cocoa beans from local growers and processors to encourage early adoption of better agricultural practices and to sustain implementation over the longer term. In addition, the chocolate industry would set aside funds to support research specifically focused on filling data gaps associated with recommended reduction strategies or to fund research in the development of new strategies.

Background

Other remediation strategies have been proposed and recommended in this report that promote better agricultural practices to reduce Pb and Cd in cocoa beans before they are exported to chocolate manufacturing facilities. More specifically, Pb reduction measures include testing for Pb-contaminated beans at the point of purchase, removing Pb-painted surfaces in processing areas, drying and fermenting beans away from roadways and other dusty areas, and promoting the use of elevated platforms or clean tarps to reduce environmental contamination of wet beans. For Cd reduction, the proposed agricultural practices include soil and bean testing for Cd in growing areas or potential new growing areas, adding soil amendments to reduce Cd phytoavailability, and replacing established cocoa trees with new germplasm selected to accumulate lower amounts of Cd.

For financial assistance to be effective, strategies would need to be assessed on a regional basis to determine the most efficient use of funds and the likelihood for the most significant improvements in reducing Cd or Pb contamination. It is probable that the effectiveness of any one or a combination of better agricultural practices will be dependent on the region and that financial assistance would need to be correlated with the likelihood for the greatest success. In other words, financial assistance should be tailored to get the most out of each dollar spent. Another aspect of financial assistance is whether it is a one-time cost or whether annual renewals would be necessary. These decisions would need to be made on a case-by-case basis following carefully conceived plans and guidance, which would be developed by the industry.

In terms of incentive programs, the Expert Committee discussed one idea at length. The primary purpose of this incentive program would be to encourage buyers to preferentially purchase beans in growing regions where it has been demonstrated that beans are grown, harvested, fermented, and dried following the implementation of better agricultural practices for Cd and/or Pb. As a business plan, this strategy would decrease the risk of purchasing beans high in Cd and/or Pb while also providing incentive to those growers and processors that adopt better agricultural practices as recommended by the industry. One challenge to implementing an incentive program based on the adoption of better agricultural practices and reduced Cd and Pb in cocoa beans would be tracing beans at the point of testing or purchase to the original growing area processing facilities in cocoa producing regions. This is a problem for any strategy that involves assessing high Cd and Pb risk areas in any cacao growing region (see for example, Sections 4.1.1. and 4.1.2). It might be more efficient to closely track the implementation of better agricultural practices at the farm level and in the processing areas and establish early on whether the practices work. By providing financial assistance to maintain these practices and ensure compliance, testing beans for Cd and Pb would be less important with the knowledge that the practices are being implemented and that they work.

A third feature of this better business strategy is for the industry to fund research specifically focused on filling data gaps for existing remediation strategies and for the development of new strategies to reduce Pb and Cd in cocoa beans and chocolate products. In terms of data gaps, the Expert Committee listed and briefly described data gaps and important research areas that would help improve or inform the implementation of the proposed strategies. These research recommendations are documented throughout this report.

The Expert Committee did not conduct an economic analysis of any of these funding proposals. In terms of feasibility from an economic standpoint, it would be incumbent for the industry to assess the costs for implementing these programs and weigh them against the short-term and long-term benefits. The decision to implement funding assistance programs will be dependent on factors that the Expert Committee does not have knowledge of or access to.

Discussion

This strategy is proposed as a component of the better agricultural practice strategies presented in Section 4, which could be facilitated by providing incentives or (and other means of monetary support) primarily to growers in order to facilitate the effective implementation of better agricultural practices for Pb and Cd. In other words, this better business practices strategy is designed to enable agricultural practices designed to reduce Cd and Pb in cocoa growing regions. As a standalone strategy, this proposed better business practice is not expected to directly reduce Pb or Cd in chocolate products. Rather, it would work in combination with the implementation of better agricultural practices to improve compliance and consistency in the use of agricultural methods and prevention practices while reducing the economic impact to the growers when considerable changes in existing practices would need to be made.

The Expert Committee generally agrees the implementation of this strategy would not have negative public health, environmental, or social impacts. The Experts generally agree that the economic impact on the chocolate industry would be dependent on the scope of the program and the ratio of benefit to cost, that is, the benefit being the production of cocoa beans with measurably reduced Cd and Pb. On the other hand, there is a wide variation in Expert Committee responses to the issues of technological feasibility and scalability.

Application: The Expert Committee agrees the reduction strategy would be effective for both Cd and Pb contamination prevention.

Potential magnitude of reduction: Two Experts think the extent of Pb and Cd reduction cannot be quantified or is not known. One Expert thinks the level of Pb and Cd reduction in chocolate products from implementing this strategy could be greater than 25 percent. The fourth Expert thinks the extent of reduction could be 10 to 25 percent.

Time frame for potential reduction: Two Experts think the timing of the reduction is unknown. One Expert predicts it would take 1 year or less from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb and Cd levels. The fourth Expert predicts it would take 1 to 5 years.

Strength of evidence for reduction: One Expert gave a rating indicating the reduction has been reliably demonstrated by practical implementation and documentation in the scientific literature by a reputable organization or by a government agency. One Expert thinks the reduction has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts. One Expert thinks there is no evidence of a reduction but anticipates one occurring. The fourth Expert cannot be certain a reduction will be realized.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without significant potential for unintended adverse public health impacts.

Potential economic impacts: Two Experts think the reduction strategy could be implemented without prohibitive costs over the long-term. Two Experts think the extent of economic impact cannot be quantified or is not known due to some uncertainty regarding scope.

Potential environmental impacts: Three Experts think the reduction strategy could be implemented without potential for unintended adverse environmental impacts. The fourth Expert thinks there could be environmental benefits.

Potential social impacts: Two Experts think the reduction strategy could have positive social impacts. Two Experts think the reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Two Experts think the scalability of the proposed reduction strategy is unknown and potentially challenging because it is not yet known how incentive programs would be structured. One Expert gave a rating indicating there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire universe of cocoa farms. The fourth Expert thinks there is demonstrated potential that the proposed reduction strategy can readily be scaled to the entire universe of cocoa farms, or if applicable, a smaller subset based on need or practicality.

Technological feasibility of method: Two Experts think the technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications. One Expert thinks the technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective. The fourth Expert thinks the technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available.

Confidence: One Expert has a very high degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products and believes the evidence to support this statement is abundant. One Expert has a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement. One Expert has a low to medium degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions could not be achieved, with some evidence to support this statement. The fourth Expert has a low degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products, with a high probability that the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 50 percent, a feasibility score of 63 percent, and an overall score of 60 percent (Table 3). The Expert Committee rated this strategy in the **Medium** category based on the combined confidence score. Refer to Table B-29 for the Experts' individual scoring of this strategy.

6.2.2 Certify Management Systems to GFSI Schemes

Overview of Strategy

The purpose of this strategy is to require all cocoa and chocolate manufacturers to certify their Quality and Food Safety Management Systems to one of the Global Food Safety Initiative (GFSI) benchmarked food processing certification schemes. These certification schemes include FSSC 22000 (FSSC = Food Safety System Certification); BRCGS (Brand Reputation Compliance Global Standards); SQF (Safe Quality Food); and IFS (International Featured Standards). This will provide for accredited independent assessment of quality and food safety practices necessary to assure that cocoa bean and chocolate manufacturing operations are not sources of Cd and Pb into chocolate products. These practices include the hazard assessment and control of ingredients, packaging materials, and equipment product contact materials of construction. They also include the control of processes such as cocoa bean cleaning and shell removal. These processes are discussed further in Section 5.1.2.

Background

The context of this strategy is that the Expert Committee determined in the Root Cause Phase that cocoa bean processing and chocolate manufacturing operations are not a likely source of Cd and Pb in chocolate products beyond the Cd and Pb that was already in raw material shipments of cocoa beans. Quality and Food Safety certification audits assure that controls are in place to avoid the introduction of Cd and Pb through processing water, production equipment, and product packaging. Accredited independent verification that these controls are in place provide evidence to stakeholders that manufacturers are following Good Manufacturing Practices. The Global Food Safety Initiative (GFSI) is a private organization, established and managed by the international trade association, the Consumer Goods Forum in 2000. The GFSI maintains a scheme to benchmark food safety standards for manufacturers. GFSI benchmarked standards have become the global standard for food safety certification, with over 150,000 certificates covering 162 countries. GFSI certification bodies are accredited by national accreditation bodies to assure consistency of assessment.

The Expert Committee determined in the Root Cause Phase that cocoa bean processing and chocolate manufacturing operations are not a likely source of Cd and Pb in chocolate products. All food manufacturers operate a Quality and Food Safety Management System to assure that required expectations are effectively implemented. These include the implementation of Good Manufacturing Practices (GMPs) and the effective operation of manufacturing processes that impact product quality and food safety. The implementation of GMPs provides for the controls necessary to avoid the introduction of Cd and Pb into chocolate products through packaging (e.g., printing inks, packaging material) and equipment product contact surfaces (e.g., lead solder, lead containing brass components). The effective operation of cocoa bean cleaning and shell winnowing processes assures that Cd and Pb present in raw cocoa beans is reduced to the lowest feasible level. This is discussed in Section 5.1.2.

Certification of a manufacturer's Quality and Food Safety System to an internationally recognized standard, such as one of the GFSI benchmarked standards, provides independent verification that necessary controls are in place. This should be viewed as a prerequisite requirement for cocoa processing and chocolate manufacturing operations to manage the risk of Cd and Pb transfer into chocolate products. This also includes verification that regulatory and market requirements are being met, including EU requirements. These could be expanded to include requirements from the Expert Committee. Certification is the current practice for most large cocoa and chocolate manufacturers. The recommended change is to require this as a prerequisite requirement for all manufacturers, large and small. This would assure a consistent baseline for all manufacturers and provide a standard base level of quality on which other reduction measures can be added.

Certification by independent accredited certification bodies is a common approach by the food industry to assure quality and food safety. A perception by many consumers is that self-certification and policing by the industry does not work that well, or at least is not in the best interest of the consumer and general public. A different approach to certification would be better governmental oversight to achieve a consistent base level by all manufacturers.

Discussion

This strategy is a better business practices strategy that would potentially enable strategies designed to improve agricultural and manufacturing practices as described elsewhere in this report. The Experts acknowledge the concern that while cocoa certification has been widely adopted by the chocolate industry, perception by many consumers is that self-certification and policing by the industry does not work that well, or at least is not in the best interest of the consumer and general public. As a standalone strategy, this reduction strategy is not expected to directly reduce Pb or Cd in chocolate products. Rather it would work in combination with better agricultural and manufacturing practices to improve incidence avoidance. The Expert Committee generally agrees that implementing this strategy would help to ensure that minimal or baseline (yet important) control methods are in place across the industry as a standard practice. It should be considered a prerequisite for all cocoa and chocolate manufacturers to establish a standard base level.

The Experts agree there would be no negative impact of implementing this strategy on public health, the environment, or society. The Experts also generally agree that the implementation of this strategy would not be economically prohibitive because this strategy is a foundational prerequisite strategy that most SDs have already implemented. However, the Experts note that the initial and ongoing annual cost of certification could impact cocoa and chocolate manufactures that have not already certified their Quality and Food Safety Management Systems; most likely this would be the smaller manufacturers.

Application: The Expert Committee agrees the reduction strategy would be effective for both Cd and Pb contamination prevention.

Potential magnitude of reduction: Two Experts think the extent of reduction cannot be quantified or is not known. One Expert thinks the level of Pb and Cd reduction in chocolate products from implementing this strategy would be 10 to 25 percent. The fourth Expert thinks the level of Pb and Cd reduction would be less than 10 percent.

Time frame for potential reduction: Two Experts predict it could take 1 year or less from the time of implementation before the effectiveness of this strategy is realized with respect to the production of cocoa with measurable reductions in Pb and Cd levels. One Expert predicts it would take 1 to 5 years. The fourth Expert thinks the timing of the reduction is unknown.

Strength of evidence for reduction: Two Experts cannot be certain a reduction will be realized. One Expert thinks the reduction has been reliably demonstrated by practical implementation and documented in the scientific literature by a reputable organization or by a government agency. The fourth Expert thinks there is no evidence of a reduction but anticipates one occurring.

Potential public health impacts: The Experts agree the reduction strategy could be implemented without significant potential for unintended adverse public health impacts.

Potential economic impacts: The Experts agree the reduction strategy could be implemented without prohibitive costs over the long-term.

Potential environmental impacts: The Experts agree the reduction strategy could be implemented without potential for unintended adverse environmental impacts.

Potential social impacts: The Experts agree the reduction strategy could be implemented without potential for unacceptable adverse social impacts.

Scalability of potential reduction: Three Experts gave a rating indicating there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to a smaller (defined) subset of the cocoa farms manufacturing sector. The fourth Expert thinks there is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy could readily be scaled to the entire cocoa manufacturing sector.

Technological feasibility of method: Three Experts gave a rating indicating the technology needed to implement the reduction strategy has been developed, is currently widely available and in use for cocoa applications and has been demonstrated to be effective. The fourth Expert thinks the technology needed to implement this strategy has been developed but its effectiveness has not been demonstrated for cocoa applications.

Confidence: Two Experts have a medium degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products, with low probability the reductions could not be achieved and believe there is sufficient evidence to support this statement. One Expert has a medium to high degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products and believes there is sufficient evidence to support this statement. One Expert has a low degree of confidence the proposed reduction strategy could result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products, with a high probability the reductions could not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time.

Conclusion

This strategy received a combined confidence score of 44 percent, a feasibility score of 72 percent, and an overall score of 66 percent (Table 3). The Expert Committee rated this strategy in the **Medium** category based on the combined confidence score. Refer to Table B-30 for the Experts' individual scoring of this strategy.

7.0 Research Recommendations

When preparing this report, the Experts identified research recommendations that were expected to provide greater confidence in the various reduction strategies. Each Expert was invited to submit recommendations for further research, and the following list documents every research recommendation received.

As noted earlier in this report, the Expert Committee did not include any members trained or educated in the field of economics and credentialed economists were not consulted during the Committee's deliberations. The Experts note that cost-benefit analyses for the reduction strategies may be needed to ascertain implementation costs. These analyses can also evaluate whether countries of origin have the available resources within the cocoa sector to facilitate strategy implementation.

7.1 Research Recommendations Specific to Pb Reduction Strategies

Research Recommendation: Identify Steps in Post-Harvest Cocoa Bean Processing Leading to Pb Contamination

Section 4.4 describes three agricultural strategies to reduce Pb contamination on the cocoa bean shell. The premise for all three strategies is that preventing post-harvest Pb contamination of the wet, outer shell during processing and transport would be an effective approach to reducing Pb in chocolate products. However, to the Expert Committee's knowledge, no systematic sampling and Pb testing of beans during post-harvest processing and transportation has been conducted to date.

The Expert Committee determined in the Root Cause Phase that the majority of Pb total concentration in chocolate products occurs from environmental exposure of the outer surface (shell) of wet whole beans during the fermenting/drying processing to Pb contaminated soil and dust. The results of a small pilot study conducted by the Expert Committee in Ecuador suggest that the amount of Pb contamination found on the outer shell appears to be dependent on the concentration of Pb in the soil/dust, the surface area of the shell coming in contact with soil/dust, and possibly the contact duration and the stage of drying (i.e., wet beans would tend to accumulate more soil/dust on the shell).

Therefore, the Experts recommend bean sampling and Pb testing be conducted in a systematic and sequential manner from harvesting to fermentation and drying to the final processing steps prior to shipment. This should be conducted in several cocoa growing regions, including representative areas in Africa, South America, and Southeast Asia. Quantitation limits for Pb should be 1 mg/kg for dry soil and 5 ppb for beans and shells. Testing of soils and airborne dust, painted surfaces, and transport vesicles (e.g., pails and bags) for Pb contamination as potential sources of bean contamination should also be included in the sampling and testing plan. Data generated from this practical research approach would be helpful to identify primary and secondary sources of environmental Pb contamination of beans in order to focus and refine the agricultural strategies described in Section 4.4 to develop the most cost-effective and efficient cocoa bean Pb contamination prevention methods to use in the field.

Research Recommendation: Generate Data to Better Understand the Nature of Pb Bonding to Cocoa Outer Shell

Section 5.2.1 describes a Pb reduction strategy to improve existing mechanical cleaning approaches that remove foreign material, and to install new processing equipment (either already existing or not yet developed) with a specific focus on Pb reduction. For example, a potential improvement to the cleaning process might be to add a process step where beans are intentionally contacted by tumbling, mixing, or surface treatment with a food grade abrasive to gently treat bean surfaces to remove adhered soil.

The results of the cocoa manufacturing facility bean cleaning study described in Appendix C confirmed that mechanical cleaning removes a portion of the fine material attached to the outside of the bean and loose in the cocoa bean stream through sieving and aspiration. However, a considerable portion of the Pb contaminating the outer shell of the cocoa bean is not removed by these methods. As individual beans contact each other, shell material and adhered soil particles appear to be removed from the beans due to abrasion but the Pb particles generated during this process are retained in the processing stream (and may be adsorbed on nibs).

Appendix D presents the results of an experiment designed by the Experts to determine the extent of Pb-contaminated shell fines production from a relatively nonaggressive abrasion technique, that is, rolling and shaking beans to promote bean-to-bean contact without breakage. However, Pb dust fines were not generated using this technique. This new research recommendation follows-up on the original shaker/roller experiment with a more aggressive form of abrasion. (Note, one Expert suggested use of sandpaper grit for this experiment; another Expert suggested use of a stiff brush.) Appendix E provides a sample protocol that could be used to design a research study around this concept. If Pb fines are generated using this approach, without damaging the shell, then it would be conceivable that a method using food grade abrasive to gently treat bean surfaces could be an effective means for reducing Pb levels during cocoa processing in a manufacturing facility.

Research Recommendation: Evaluate Rapid Pb Test Kits for Field Use

Section 6.1.3 describes a Pb reduction strategy to use onsite quality inspections of beans for gross contamination of the outer cocoa bean shell with Pb contaminated soil/dust/residue prior to purchase. In cocoa growing areas where preventative measures cannot be implemented to their fullest, testing beans for Pb contamination is a management practice that would assist in identifying highly contaminated beans before purchase. The purchaser would then have an option to reject bean lots with demonstrably high levels of Pb.

In locations where laboratories that have the capacity to analyze Pb in cocoa beans are accessible, this strategy could be implemented immediately, without considerable cost to the buyer. However, in some cocoa growing regions, access to laboratory facilities is likely to be limited or difficult. Under these circumstances, the timeframe for testing for the presence of Pb on cocoa bean shells may be too long to be practical. For this reason, the Expert Committee generally agrees the effectiveness of this Pb reduction strategy would be considerably improved if a rapid test could be used in the field to determine the degree of Pb contamination in cocoa beans lots.

Rapid colorimetric Pb test kits for paint have been evaluated for accuracy and sensitivity and found to be reliable when Pb levels are relatively high in paint (https://www.epa.gov/Pb/Pb-test-kits). However, these test kits and others designed to detect Pb in leachates and water have not been universally tested for their effectiveness in detecting the presence of Pb on food products such as cocoa bean shells. The Expert Committee therefore recommends that existing, available rapid Pb test kits for solid surfaces (e.g., paint), leachates, and water, be tested for effectiveness in determining the presence of Pb on cocoa bean shells at onsite processing areas. A protocol for evaluating the effectiveness of a variety of Pb test kits is provided in Appendix F.

Research Recommendation: Explore Feasibility of a Rapid Pb Soil Testing Method

All soils have lots of Fe, and variable Pb. A method has been identified that would reliably measure Fe with a rapid inexpensive method, Chaney conceived that a simple reliable rapid method to measure soil Fe oxides would reveal soil contaminated beans. Formation of Prussian Blue (ferro-ferri-cyanide) cannot work because the soil ferric iron is not soluble to react with ferrocyanide.

A possible rapid, inexpensive, safe method could use this approach: Collect a few beans from the shipment; place them in a plastic container such as a plastic urine-analysis cup with screw top or a small paper drinking cup. Add a solution of vinegar plus vitamin C to reduce soil ferric to ferrous; after shaking for several minutes, add a solution of Na-acetate to raise solution pH including the reagent Ferrozine at recommended concentration (Stookey, L.L. 1970. Ferrozine-A new spectrophotometric reagent for iron. Anal. Chem. 42:779-781). If the solution changes to strong blue-purple coloration, it indicates substantial soil contamination. This would need to be tested in a laboratory to assure that "clean beans" did not release enough ferrous to cause formation of the ferrous-ferrozine with blue-purple color (seems very unlikely).

7.2 Research Recommendations Specific to Cd Reduction Strategies

Research Recommendation: Using Soil Amendments to Increase Soil pH

Section 4.1.3 describes a strategy that uses soil amendments to increase soil pH to mitigate Cd phytoavailability and reduce uptake. Both greenhouse and field studies have shown that raising soil pH can reduce Cd accumulation by cocoa seedlings and trees. In cocoa orchards, although liming products can be spread under the trees at reasonable cost, leaching of the alkalinity to neutralize subsurface soil is slow. The products do not raise the pH of the main rooting zone (0-15 cm) for many years because of soil chemistry.

In order to help cocoa agronomists understand this slow leaching problem with surface-applied liming products, greenhouse tests with surface-applied liming materials should be conducted. Such tests are done most effectively by using replicated (3 or 4 per treatment) test columns of strongly acidic cocoa orchard soils (using 10 cm diameter Plexiglas or Polypropylene columns with 60 cm depth of soil; 15 cm of “topsoil” and 45 cm of “subsoil”) with surface application of the products and using daily rainwater or deionized water additions at average rainfall rates for cocoa orchards. Soils should be collected from topsoil and subsoil of a strongly acidic cocoa orchard, and each “separate layer of soil” mixed thoroughly. At the end of the leaching phase, the columns would be frozen, then sawed to obtain 2.5 cm layer increments of soil depth. Each layer is then mixed well and analyzed for pH, exchangeable ions including Al^{3+}, and phytoavailable Cd and Zn (using methods such as Mehlich-3, DTPA, or 0.01 M $CaCl_2$). The remaining lime-requirement of each soil layer would also be measured chemically.

Such tests should include local commercial limestone products (calcitic and dolomitic) and hydrated lime [$Ca(OH)_2$] products available to farmers, a known leachable alkaline amendment (such as Wollastonite, $CaSiO_3$), and limestone plus biodegradable organic matter such as farmer-made composts (e.g., mixing the liming product with the compost, say 25 ton/hectare dry compost, before application). The outcomes of such an experiment will clarify the effectiveness of limestone leaching in a highly controlled lab experiment to help in design, conduct, and interpretation of field tests of the need for deeper penetration in the orchard, and methods that might work.

Replicate columns could also be used to grow cocoa seedlings to evaluate uptake. Such experiments would support recommendations for field limestone practice as limited by the natural soil chemistry limits on leaching in established cocoa orchards to use in teaching growers about liming needs and methods. Another treatment should be included in which the test limestone products are mixed well with the 15 cm topsoil layer before placing in the column.

Because raising soil pH usually reduces the phytoavailability of soil Zn, it can indirectly increase Cd accumulation by trees in the field. Thus, phytoavailable Zn should also be measured in the column experiments. This phenomenon was identified by Argüello et al. (2020). If liming reduces Zn phytoavailability enough to increase Cd uptake, liming cocoa orchard soils may require Zn fertilizer along with liming products. In the columns testing with seedlings, the usual plant macro- and micro-nutrients in seedlings should be measured plus Cd and Pb.

Another significant limitation on using liming to both increase soil fertility and reduce Cd accumulation by cocoa is that liming can reduce Zn and Mn phytoavailability to cocoa trees. Are there methods to spread the liming agents under cocoa trees, or ways to partially incorporate the lime products into the 0-15 cm rooting depth that protects roots from injury and achieves goals of limestone application to raise root zone pH and reduce Cd uptake? The above experiments will help establish effective and cost-effective methods to limit Cd uptake by cocoa. Will Zn fertilizers be needed to increase Zn phytoavailability in the limed soils?

The Experts also note that the practicality and logistics of how these amendments are applied and incorporated into the soils in the cocoa orchards should be assessed.

Research Recommendation: Use Zinc Sulfate Soil Amendments to Reduce Cd Uptake and Translocation from Soils

- Field evaluations are required in cocoa to further validate the effectiveness of Zn amendments. Dos Santos et al (2020) clearly showed that Zn amendment strongly inhibited Cd uptake and translocation in cocoa. Effective logistics regarding its application in the field need to be verified.

- Can injection of dissolved $ZnSO_4$ solution or slurry into the topsoil layer achieve needed reduction in crop Cd compared to surface application of $ZnSO_4$ powder or solution? Leaching tests could be conducted in the laboratory using columns of soil studied for less than one year as noted above.

- Need to clarify the interactions of Zn with Cd in translocation to shoots, translocation to fruits, and translocation to shells and nibs.

Research Recommendation: Genetic Improvement Strategies (General)

All genetic options depend on finding natural low Cd uptake or translocation genetic sources among natural cocoa genotypes, or making low Cd genotypes using biochemical processes.

- Some genetic variation has been reported, but the research methods used and related studies showed variance levels which raise doubts about current evidence.

- Several researchers had reported that the ratio of bean Cd to leaf Cd varies during the year, as does the Cd levels in leaves. These sources of variation need to be understood in order to learn how to interpret field collected data on tissue Cd concentration.

- Does the ratio of shell-Cd to nib-Cd vary genetically, and does the ratio change during the season of fruit formation and bean filling or fermentation? This needs to be understood in order to be able interpret whole bean analyses across the whole year of sampling. Does soil pH or Zn level affect the shell-Cd/nib-Cd ratio? Or the leaf-Cd:nib-Cd ratio?

- Although breeding activities are a continuing process, the investment to develop the molecular methods to determine if a specific gene is present, and to alter expression of genes using non-GMO methods is very important in developing genetic practical solutions.

Research Recommendation: Use Scion Grafts to Reduce Cd Uptake from Soils

Research needs to be conducted to identify cocoa scion germplasm which has the “fine flavor,” disease resistance, and yield required for economic cocoa production, but also has reduced Cd translocation of Cd to fruits or to nibs unrelated to rootstock used.

Research Recommendation: Develop and Plant Cocoa Rootstocks That Accumulate Less Cd from Soils

- Research needs to be conducted to identify low Cd accumulating cocoa rootstock genotypes for grafting. Cocoa germplasm for use as rootstock does not need to have the “fine flavor”, disease resistance and yield required for economic cocoa production, but might have low Cd accumulation by roots or translocation to shoots. It will likely take many years to find and prove the value of selected rootstock genotype germplasm for this use, but once proven can be used with improved scions with high yields and high quality, lower Cd beans.

- Technological feasibility: Further research needs to be conducted to identify the low Cd accumulating cocoa cultivar rootstock to be used in grafting.

Research Recommendation: Use Molecular Breeding Techniques to Develop Cocoa Genotypes That Accumulate Less Cd

The cocoa genes for transporters which actually absorb soil Cd at levels in common cocoa soils (ZIP1 or NRAMP5), store Cd in root or shoot vacuoles (HMA3) and translocate Cd from roots to cocoa shoots (HMA2) need to be identified, so that genetic screening using DNA sequences can be used to evaluate possible breeding lines which have expression of genes to increase Cd storage in roots, reduce Cd transport to shoots or Cd transport to nibs. Gene probes are required to assess existence and activity of these genes in Cd uptake and other biochemical aspects of Cd uptake and transfer to beans. Can HMA3 expression or overexpression in roots (or shoots) be increased by non-GMO methods to keep Cd from shoots or fruits and nibs? A wide range of additional research is needed in order to rapidly and efficiently breed improved cultivars with strong production characters but low Cd due to expression of known genes or newly identified key genes.

Research Recommendation: Use Amendments Recommended by CODEX but Not Included in Other Strategies

Section 4.3.1 describes different amendments including sugarcane by-products, organic-rich materials, clay minerals, and other inorganic minerals identified by the CODEX Code of Practice that may have the potential to reduce Cd uptake from soils and minimize its transfer into cocoa beans. Though this strategy received a combined low confidence rating from the Expert Committee due to the lack of empirical evidence for its use in cocoa, the Experts believe that some of these amendments compared to the others may hold more promise as a Cd reduction strategy.

Not only do sugarcane by-products (vinasse and cachaza) and other organic-rich materials (compost, animal manures, humus, and vermicompost) have chemical properties that have been shown to reduce Cd uptake, they may offer farmers a cheaper alternative to other chemical amendments if viable as a mitigation strategy.

Therefore, with further research through well-designed field trials at cocoa farms, the effectiveness of the above-mentioned amendments to mitigate Cd uptake should be validated. The Experts also note that the practicality and logistics of how these amendments are applied in the field should be assessed.

Research Recommendation: Use Zinc Sulfate Foliar Sprays to Reduce Cd Levels in Cocoa Beans

Section 4.3.3 describes a strategy to reduce the transfer of Cd into cocoa beans through the application of foliar $ZnSO_4$. The literature reports that this method has been used to mitigate Cd levels in other crops (e.g., wheat, rice) and thus has potential to work for cocoa trees, particularly for those that are grown in Zn-deficient soils. Though it received a low confidence rating from the Expert Committee due to a lack of empirical evidence for its application in cocoa, some Experts believe that it may hold promise as a Cd reduction strategy and should be evaluated.

Therefore, multi-season field evaluations of foliar $ZnSO_4$ are required in cocoa to further validate the effectiveness of this strategy. Note, because foliar sprays are used for other cocoa management needs (e.g., disease control), most farms have the equipment needed to implement this strategy.

Research Recommendation: Clarify Geologic Sources of High Cd and High Cd:Zn Ratio Soils in Colombia, Peru, Ecuador, and Other Nations

Section 4.1.2 describes a strategy that recommends that farmers stop planting new cocoa orchards in regions with high Cd phytoavailability. In some nations, natural processes have led to soils with high Cd and high Cd:Zn ratio (Albarrcín et al., 2019). One type of high Cd:Zn ratio Cd source for soils is shale parent materials, while other high Cd soils with normal Cd:Zn (~1:100 by weight) ratios may have received Cd and Zn from dispersal of wastes of historic mining of Zn-Pb-Ag-Cu in these countries. When cocoa is grown on some soils with high Cd:Zn ratios, bean Cd has been as high as 20 mg Cd/kg, so even a small amount of such very high Cd cocoa beans would cause high Cd levels in bean mixtures at collection points.

The geology and soil formation processes that cause the unique high Cd and especially the high Cd:Zn problem soils in South America and the Caribbean need to be clarified for farmer and national decisions about where cocoa can be safely grown so the beans will meet EU and California Cd limits. With fuller knowledge of where and why such soils occur, validated soil association and soil series maps of predicted excessive phytoavailable Cd in such soils can be prepared to advise growers so that soils may be modified to limit Cd transfer or avoided for cocoa production.

Research Recommendation: Clarify the Role of Fermentation on Cd Levels in Cocoa Beans and Nibs Before Drying and Determine if Fermentation Can Be Managed to Reduce Cd in Cocoa Nibs

A paper by Vanderschueren et al. (2020) reported that fermentation could reduce Cd concentration in finished beans. Many theses from South American countries reported that using specific yeasts added to fermentation, draining of the mucilage before fermentation, adding non-yeast microbes and other approaches they reported to achieve an appreciable reduction in bean or nib Cd concentration. On the other hand, Ramtahal (2012) found that bean Cd concentration increased during fermentation. Logically, unless the fermentation liquid is removed (washed off) the beans, the metabolism during fermentation uses some of the energy substrates and mass of stored energy, so the Cd concentration should increase. Many of the reported studies used study methods that raise concerns about measurements; and the mass balance of Cd during fermentation was not evaluated. Or whether some of the Cd is removed from the shell, or would Cd also migrate from the nibs as well? Lee et al. (2019) developed laboratory controlled fermentation vessels to study changes in polyphenols; this equipment could be applied to metal balances as well. So, until a number of studies are conducted with full mass and Cd and Zn balance attained, under well-controlled conditions, the ability to change Cd levels in cocoa beans or nibs during fermentation remains unsettled.

Research Recommendation: Test Use of Zn Chelates of a Known Cd-selective Chelating Agent Application to Leach Topsoil Cd to Deeper in the Soil Profile and Reduce Cd Phytoavailability to Cocoa

At least one commercial chelating agent (EGTA; Ethylene-bis(oxyethylenenitrilo)tetraacetic acid or Ethylene glycol-bis(2-aminoethylether)-N,N,N,N'-tetraacetic acid or ethyleneglycol-tetraacetic acid) is known to bind Cd much more strongly than Zn in contrast with well-known chelators used in agriculture such as EDTA, DTPA, and EDDHA; these common agricultural chelators bind Cd and Zn approximately equally and are unlikely to reduce Cd uptake by cocoa other than by Zn released during degradation of the agent in soil. The addition of EGTA or ZnEGTA to soils, followed by rainfall/irrigation, would leach Cd-EGTA down the soil profile. Because the feeder roots of cocoa are shallow, reducing phytoavailable Cd in the active feeder root zone would effectively reduce Cd accumulation by shallow-rooted plant species. A series of laboratory soil extraction tests, soil column tests of Zn-EGTA addition with measurement of Cd and Zn leaching, greenhouse tests with cocoa plants, and eventually field tests of such a method would show whether it would be effective and cost-effective. Because the compound is biodegradable, and only low concentrations would need to be applied, it should be safe and effective. It is likely that adding the Zn-EGTA to the surface of the soil (powder or solution) during the rainy season would leach the agent into the topsoil where the Zn would exchange for Cd; the increased phytoavailable Zn would further reduce Cd uptake by cocoa. Although a sequence of tests in noted above, as soon as the proof of principle is demonstrated in the lab-scale testing, greenhouse and field studies could begin. This possible technology was conceived by R.L. Chaney independent of his work on the Committee. Discussion of using various chelating agents to control metals in nutrient solutions and other media by Parker, Chaney, and Norvell (1995) discusses the chemistry involved.

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International Agricultural Training Programs and Documents Links

West Indies: https://sta.uwi.edu/cru/training.

Ecuador/Olam: https://www.farming-program.com/sites/default/files/publication-files/LT_FS_FarmingProgram_Ecuador_A4_190612.pdf.

Ecuador: https://www.we.org/en-CA/we-stories/global-development/cacao-farm-ecuador-rainforest-agricultural-training.

Rainforest Alliance (New York): https://www.rainforest-alliance.org/sites/default/files/2017-04/toward-sustainable-cocoa-sector.pdf.

Feed the Future (Florida):
https://www.agrilinks.org/sites/default/files/resource/files/MEAS%20CS%20Ecuador%20-%20Cacao%20-%20What%20Does%20It%20Mean%20to%20be%20Socially%20Responsible%20-%20Blare%20and%20Useche%20-%20July%202014.pdf

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APPENDIX A. Reductions Strategies Scoring Scheme

The Expert Committee used the following scoring scheme to evaluate the candidate Cd and Pb reduction strategies. The Experts developed multiple versions of the scoring scheme throughout the project, and what follows is the final version (November 9, 2020) that was used to evaluate the reduction strategies.

Maximum Score = 36

Characteristics of Cd/Pb Concentration Reductions

1. Applies to… [No Ranking]
    a. Primarily Cd
    b. Primarily Pb
    c. Both Cd and Pb

2. Magnitude of reduction [No Ranking]
    a. Expected to result in >25% reduction in Cd or Pb concentrations in either cocoa beans or chocolate products
    b. Expected to result in 10% to 25% reduction
    c. Expected to result in less than 10% reduction
    d. The extent of the reduction cannot be quantified or is not known

3. Time frame of reduction [No Ranking]
    a. Immediate, reduction will be observed in less than 1 year from the implementation date
    b. Intermediate, reduction will be observed between 1 and 5 years from the implementation date
    c. Longer term, reduction will not be observed until at least 5 years after the implementation date
    d. The timing of the reduction is not known

4. Evidence for reduction [Max Score = 4]
    a. The reduction has been reliably demonstrated either by practical implementation on a large farm or manufacturing facility or during large scale field trials and documented in the scientific literature by a reputable organization or by a government agency [4]
    b. The reduction has been reliably demonstrated in an experimental setting in peer-reviewed publications, government documents, or other empirical data that are available to the Experts [3]
    c. There is suggestive evidence of a reduction (e.g., anecdotal accounts, findings in unrefereed publications, data that are not available to the Experts) [2]
    d. There is inconsistent evidence of a reduction [1]
    e. There is no evidence of a reduction, but the Experts anticipate one occurring [1]
    f. The Experts cannot be certain a reduction will be realized [0]

Feasibility

5. Public health [Max Score = 4]
    a. Reduction strategy can be implemented without significant potential for unintended adverse public health impacts [4]
    b. Reduction strategy can be implemented without significant potential for unintended adverse public health impacts with proper exposure prevention methods (e.g., PPE) [3]
    c. Reduction strategy may have unintended adverse public health consequences, such as: _____. *[Note: Concerns listed in response to this question and their implications on feasibility will be discussed in a future call.]* [0]

6. Economic[3] [Max Score = 4]
    a. Reduction strategy is expected to have economic benefits to the industry and/or the consumer over the long-term [4]
    b. Reduction strategy can be implemented without prohibitive costs (i.e., implementation of strategy is cost neutral or the cost can be absorbed by the industry and/or the consumer) [3]
    c. Reduction strategy cannot be implemented without significant and prohibitive costs that cannot be recovered over the long-term, for example: _____. *[Note: provide a brief description of the potential cost and its origin and implications on feasibility, to be discussed in a future call.]* [0]
    d. The extent of economic impact cannot be quantified or is not known [0]

7. Environmental[4] [Max Score = 4]
    a. Reduction strategy is expected to have environmental benefits [4]
    b. Reduction strategy can be implemented without potential for unintended adverse environmental impacts [3]
    c. Reduction strategy may have unintended adverse environmental consequences, such as: _____. *[Note: Concerns listed in response to this question and their implications on feasibility will be discussed in a future call.]* [0]

8. Social[5] [Max Score = 4]
    a. Reduction strategy is expected to have positive social impacts [4]
    b. Reduction strategy can be implemented without potential for unacceptable adverse social impacts [3]
    c. Reduction strategy may have unacceptable adverse social impacts, such as: _____. *[Note: Concerns listed in response to this question and their implications on feasibility will be discussed during a future call.]* [0]

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[3] Note: For the purposes of this report, the Expert Committee has limited its definition of economic feasibility to the potential cost of implementing the recommended reduction strategy to the chocolate industry and ultimately the consumer, factoring in any long-term economic benefits. Economic impacts such as lost wages and jobs are factored into the Committee's definition and evaluation of social impact.

[4] The Expert Committee needs to seek clarification from SDs/AYS on the intended definition of "environmental feasibility" as stated in the Consent Agreement before continuing its evaluation of the strategies.

[5] Note: The Consent Judgment does not define social impacts. It will be up to the Experts to define social impacts when rating reduction strategies. These could include impacts on quality of life, reliance on child labor, etc.

9. Scalability [Max Score = 4]
    a. There is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy can readily be scaled to the entire universe of cocoa farms, exporters, manufacturing facilities, etc. [4]
    b. There is documented implementation or strong empirical evidence that demonstrates the proposed reduction strategy can readily be scaled to a smaller (defined) subset of cocoa farms, exporters, manufacturing facilities, etc. [3]
    c. There is demonstrated potential that the proposed reduction strategy can readily be scaled to the entire universe of cocoa farms, exporters, manufacturing facilities, etc., or if applicable, a smaller subset based on need or practicality [2]
    d. There is no documented or demonstrated potential that the proposed reduction strategy can readily be scaled to the entire universe or a subset of cocoa farms, exporters, manufacturing facilities, etc., but the Experts anticipate that scaling is still possible. [1]
    e. The scalability of the proposed reduction strategy is unknown and potentially challenging because of: _____. *[Note: Concerns listed in response to this question and their implications on feasibility will be discussed during a future call.]* [0]

10. Availability of underlying technology [Max Score = 4]
    a. The technology needed to implement the reduction strategy has been developed, is currently widely available ***and in use for cocoa applications***, and has been demonstrated to be effective [4]
    b. The technology needed to implement the reduction strategy has been developed for cocoa applications, is currently widely available, and has been demonstrated to be effective [3]
    c. The technology needed to implement the reduction strategy has been developed, has been demonstrated to be effective for cocoa applications, but it is not widely available [2]
    d. The technology needed to implement the reduction strategy has been developed but its effectiveness has not been demonstrated for cocoa applications [1]
    e. The technology needed to implement the reduction strategy has not been developed [0]

Overall Confidence Rating

11. Overall confidence [Max Score = 8]
    a. High - There is a ***very high degree of confidence*** that the proposed reduction strategy will result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products over the time frame indicated in response to Question 3 and the evidence to support this statement is abundant [8]
    b. Medium-High There is a ***medium to high degree of confidence*** that the proposed reduction strategy will result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products over the time frame indicated in response to Question 3 and there is sufficient evidence to support this statement [6]
    c. Medium - There is a ***medium degree of confidence*** that the proposed reduction strategy will result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products, with low probability that the reductions will not be achieved, and there is sufficient evidence to support this statement [4]
    d. Low-Medium - There is a ***low to medium degree of confidence*** that the proposed reduction strategy will result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products, with an equally low-medium degree of confidence that the reductions will not be achieved, with some evidence to support this statement [2]

e. Low - There is ***low degree of confidence*** that the proposed reduction strategy will result in demonstrable Cd/Pb reductions in cocoa beans or chocolate products, with high probability that the reductions will not be achieved and/or there is insufficient evidence to support drawing a conclusion at this time [0]

APPENDIX B. Experts' Ratings of the Reduction Strategies

This appendix presents the Experts' individual ratings of the reduction strategies that they evaluated. Ratings were assigned using the "Reductions Strategies Scoring Scheme" in Appendix A. The strategies are presented in the same order as they appear in the main body of this report. The ratings have been anonymized. Refer to Section 3 of this report for further information on the scoring scheme, how composite scores were calculated, and how the scores are presented in the following tables.

It should be noted that the results of the evaluations presented in this appendix are "blinded," meaning the names of the Experts have been removed and replaced with the generic Expert 1, Expert 2, etc. In addition, the order in which the results for each Expert are presented has been randomized from one strategy to another, such that any observable patterns in scoring from one strategy to another are purely coincidental.

Table B-1. Ratings on "Exporters to Stop Purchasing Beans from Regions with High Cd Phytoavailability" (see Section 4.1.1)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	>25%	>25%	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1 yr	1 yr	1-5 yrs	1-5 yrs	N/A	N/A
4. Evidence for reduction	3	3	3	3	12	75
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	4	0	3	10	63
7. Feasibility - environmental	3	3	2	2	10	63
8. Feasibility - social	0	0	0	0	0	0
9. Feasibility - scalability	2	4	4	2	12	75
10. Feasibility - technological	3	4	4	3	14	88
11. Overall confidence	8	8	8	6	30	94
				Total Score	104	
				Percent Max	72	
				Tier	**High**	**High**

Table B-2. Ratings on "Farmers to Stop Planting New Orchards in Regions with High Cd Phytoavailability" (see Section 4.1.2)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	> 25%	> 25%	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	> 5 yrs	1-5 yrs	> 5 yrs	> 5 yrs	N/A	N/A
4. Evidence for reduction	3	3	2	3	11	69
5. Feasibility - public health	4	4	3	4	15	94
6. Feasibility - economic	0	3	3	3	9	56
7. Feasibility - environmental	2	4	3	2	11	69
8. Feasibility - social	3	4	3	3	13	81
9. Feasibility - scalability	2	2	2	2	8	50
10. Feasibility - technological	2	4	2	4	12	75
11. Overall confidence	6	6	6	8	26	81
				Total Score	105	
				Percent Max	73	
				Tier	**High**	**High**

Table B-3. Ratings on "Use Soil Amendments to Increase Soil pH" (see Section 4.1.3)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	10-25 %	> 25%	10-25 %	> 25%	N/A	N/A
3. Time frame of reduction	1-5 yrs	1 yr	1 yr	1-5 yrs	N/A	N/A
4. Evidence for reduction	3	3	3	3	12	75.0
5. Feasibility - public health	3	4	3	3	13	81.3
6. Feasibility - economic	0	3	0	3	6	38
7. Feasibility - environmental	2	3	3	3	11	69
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	1	3	0	0	4	25
10. Feasibility - technological	2	3	2	2	9	56
11. Overall confidence	6	8	4	6	24	75
				Total Score	91	
				Percent Max	63	
				Tier	**High**	**High**

Table B-4. Ratings on "Use Zinc Sulfate Soil Amendments to Reduce Cd Uptake from Soils" (see Section 4.1.4)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	10-25 %	10-25 %	Unknown or not quantifiable	> 25%	N/A	N/A
3. Time frame of reduction	1-5 yrs	1 yr	1-5 yrs	1-5 yrs	N/A	N/A
4. Evidence for reduction	3	2	2	3	10	63
5. Feasibility - public health	4	3	3	4	14	88
6. Feasibility - economic	3	0	0	3	6	38
7. Feasibility - environmental	3	3	2	3	11	69
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	0	1	1	3	5	31
10. Feasibility - technological	1	1	2	3	7	44
11. Overall confidence	6	4	4	8	22	69
				Total Score	87	
				Percent Max	60	
				Tier	**High**	**High**

Table B-5. Ratings on "Use Scion Grafts to Reduce Cd Uptake from Soils" (see Section 4.1.5)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	> 25%	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1-5 yrs	1-5 yrs	Unknown	Unknown	N/A	N/A
4. Evidence for reduction	1	4	1	1	7	44
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	3	3	0	9	56
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	4	3	1	1	9	56
10. Feasibility - technological	1	4	1	1	7	44
11. Overall confidence	6	8	4	4	22	69
				Total Score	94	
				Percent Max	65	
				Tier	**High**	**High**

Table B-6. Ratings on "Develop and Plant Rootstocks That Accumulate Less Cd from Soils" (see Section 4.1.6)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	> 25%	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1-5 yrs	> 5 yrs	Unknown	Unknown	N/A	N/A
4. Evidence for reduction	4	1	1	1	7	44
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	3	0	3	9	56
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	3	4	1	1	9	56
10. Feasibility - technological	4	1	1	1	7	44
11. Overall confidence	8	6	4	4	22	69
				Total Score	94	
				Percent Max	65	
				Tier	**High**	**High**

Table B-7. Ratings on "Use Self-Rooted Cocoa to Reduce Cd Uptake from Soils" (see Section 4.1.7)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	> 25%	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	Unknown	> 5 yrs	Unknown	> 5 yrs	N/A	N/A
4. Evidence for reduction	1	1	1	4	7	44
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	0	3	3	4	10	63
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	1	4	1	4	10	63
10. Feasibility - technological	1	1	1	4	7	44
11. Overall confidence	4	6	4	6	20	63
				Total Score	94	
				Percent Max	65	
				Tier	**High**	**High**

Table B-8. Ratings on "Use Molecular Breeding Techniques to Identify Cocoa Genotypes That Accumulate Less Cd" (see Section 4.1.8)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	> 25%	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1-5 yrs	Unknown	> 5 yrs	Unknown	N/A	N/A
4. Evidence for reduction	1	1	3	1	6	38
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	3	4	0	10	63
7. Feasibility - environmental	3	3	2	2	10	63
8. Feasibility - social	3	3	3	0	9	56
9. Feasibility - scalability	4	1	2	1	8	50
10. Feasibility - technological	1	1	4	1	7	44
11. Overall confidence	8	4	4	4	20	63
				Total Score	86	
				Percent Max	60	
				Tier	**High**	**High**

Table B-9. Ratings on "Test Water from Irrigation Sources and Use Alternate Water Sources, if Needed" (see Section 4.2.1)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	10-15%	N/A	N/A
3. Time frame of reduction	Unknown	Unknown	> 5 yrs	1-5 yrs	N/A	N/A
4. Evidence for reduction	1	0	2	2	5	31
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	0	3	3	9	56
7. Feasibility - environmental	4	3	4	3	14	88
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	0	0	1	4	5	31
10. Feasibility - technological	1	1	3	3	8	50
11. Overall confidence	2	0	4	4	10	31
				Total Score	79	
				Percent Max	55	
				Tier	**Med**	**Med**

Table B-10. Ratings on "Use Amendments Recommended by CODEX but Not Included in Other Strategies" (see Section 4.1.10)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	> 25%	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1-5 yrs	Unknown	1-5 yrs	Unknown	N/A	N/A
4. Evidence for reduction	2	0	0	2	4	25
5. Feasibility - public health	4	4	4	3	15	94
6. Feasibility - economic	3	0	0	0	3	19
7. Feasibility - environmental	2	2	0	3	7	44
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	2	1	0	0	3	19
10. Feasibility - technological	2	0	1	1	4	25
11. Overall confidence	2	0	2	2	6	19
				Total Score	54	
				Percent Max	37	
				Tier	**Low**	**Low**

Table B-11. Ratings on "Use Mineral Soil Amendments" (see Section 4.3.2)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	Unknown	Unknown	Unknown	1-5 yrs	N/A	N/A
4. Evidence for reduction	0	1	1	0	2	13
5. Feasibility - public health	4	3	4	3	14	88
6. Feasibility - economic	0	0	0	0	0	0
7. Feasibility - environmental	3	3	3	2	11	69
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	0	0	1	1	2	13
10. Feasibility - technological	1	1	1	1	4	25
11. Overall confidence	2	2	0	0	4	13
				Total Score	49	
				Percent Max	34	
				Tier	**Low**	**Low**

Table B-12. Ratings on "Use Zinc Sulfate Foliar Sprays to Reduce Cd Levels in Cocoa Beans" (see Section 4.3.3)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	Unknown	1 yr	Unknown	1-5 yrs	N/A	N/A
4. Evidence for reduction	0	1	2	2	5	31
5. Feasibility - public health	4	4	3	3	14	88
6. Feasibility - economic	0	0	0	0	0	0
7. Feasibility - environmental	3	3	2	2	10	63
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	0	1	2	2	5	31
10. Feasibility - technological	1	0	1	1	3	19
11. Overall confidence	0	0	4	2	6	19
				Total Score	55	
				Percent Max	38	
				Tier	**Low**	**Low**

Table B-13. Ratings on "Use Foliar Sprays Rick in Iron and Manganese" (see Section 4.3.4)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	Unknown	Unknown	Unknown	Unknown	N/A	N/A
4. Evidence for reduction	0	0	0	0	0	0
5. Feasibility - public health	4	3	4	3	14	88
6. Feasibility - economic	0	0	0	0	0	0
7. Feasibility - environmental	3	2	3	3	11	69
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	1	2	0	1	4	25
10. Feasibility - technological	0	1	0	1	2	13
11. Overall confidence	0	0	0	2	2	6
				Total Score	45	
				Percent Max	31	
				Tier	**Low**	**Low**

Table B-14. Ratings on "Phytoextract Cd from Soils Using Hyperaccumulators" (see Section 4.3.5)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	> 25%	Unknown or not quantifiable	10-25%	> 25%	N/A	N/A
3. Time frame of reduction	> 5 yrs	Unknown	> 5 yrs	Unknown	N/A	N/A
4. Evidence for reduction	3	2	2	0	7	44
5. Feasibility - public health	2	0	2	2	6	38
6. Feasibility - economic	3	0	0	0	3	19
7. Feasibility - environmental	2	0	3	2	7	44
8. Feasibility - social	0	3	3	3	9	56
9. Feasibility - scalability	1	1	0	0	2	13
10. Feasibility - technological	1	1	1	0	3	19
11. Overall confidence	4	0	0	0	4	13
				Total Score	41	
				Percent Max	28	
				Tier	**Low**	**Low**

Table B-15. Ratings on "Use Fertilizers Rich in Certain Elements" (see Section 4.3.6)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd & Pb	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1-5 yrs	Unknown	1-5 yrs	1-5 yrs	N/A	N/A
4. Evidence for reduction	1	0	1	0	2	13
5. Feasibility - public health	4	3	3	4	14	88
6. Feasibility - economic	3	0	0	0	3	19
7. Feasibility - environmental	3	3	2	3	11	69
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	1	0	1	0	2	13
10. Feasibility - technological	0	1	1	1	3	19
11. Overall confidence	0	2	0	2	4	13
				Total Score	51	
				Percent Max	35	
				Tier	**Low**	**Low**

Table B-16. Ratings on “Adopt Agroforestry or Monoculture Techniques” (see Section 4.3.7)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	Unknown	Unknown	Unknown	> 5 yrs	N/A	N/A
4. Evidence for reduction	0	0	0	2	2	13
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	0	0	0	0	0	0
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	3	0	9	56
9. Feasibility - scalability	1	0	1	1	3	19
10. Feasibility - technological	3	0	1	1	5	31
11. Overall confidence	0	0	0	2	2	6
				Total Score	49	
				Percent Max	34	
				Tier	**Low**	**Low**

Table B-17. Ratings on "Manage Fermentation Practices to Reduce Cd in Beans" (see Section 4.3.8)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1 yr	Unknown	Unknown	1-5 yrs	N/A	N/A
4. Evidence for reduction	1	1	0	1	3	19
5. Feasibility - public health	4	4	3	4	15	94
6. Feasibility - economic	3	0	3	0	6	38
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	0	1	0	1	2	13
10. Feasibility - technological	1	0	1	1	3	19
11. Overall confidence	0	0	0	2	2	6
				Total Score	55	
				Percent Max	38	
				Tier	Low	Low

Table B-18. Ratings on "Use Microbial Inoculation Techniques" (see Section 4.3.9)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	Unknown	Unknown	Unknown	Unknown	N/A	N/A
4. Evidence for reduction	0	1	0	0	1	6
5. Feasibility - public health	3	3	4	4	14	88
6. Feasibility - economic	0	0	3	0	3	19
7. Feasibility - environmental	3	2	3	3	11	69
8. Feasibility - social	3	3	4	3	13	81
9. Feasibility - scalability	1	1	0	0	2	13
10. Feasibility - technological	1	1	0	0	2	13
11. Overall confidence	0	0	0	0	0	0
				Total Score	46	
				Percent Max	32	
				Tier	**Low**	**Low**

Table B-19. Ratings on "Prevent Pb Contamination of Beans during Fermenting and Drying" (see Section 4.4.1.1)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Pb	Pb	Pb	Pb	N/A	N/A
2. Magnitude of reduction	> 25%	Unknown or not quantifiable	> 25%	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1 yr	1 yr	1 yr	1-5 yrs	N/A	N/A
4. Evidence for reduction	3	1	1	1	6	38
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	3	3	3	12	75
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	4	3	3	3	13	81
9. Feasibility - scalability	3	0	3	1	7	44
10. Feasibility - technological	4	4	3	2	13	81
11. Overall confidence	8	6	6	4	24	75
				Total Score	103	
				Percent Max	72	
				Tier	**High**	**High**

Table B-20. Ratings on "Prevent Pb Contamination of Whole Wet Beans during Transport" (see Section 4.4.1.2)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Pb	Pb	Pb	Pb	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	10-25%	> 25%	N/A	N/A
3. Time frame of reduction	1 yr	1-5 yrs	1 yr	1 yr	N/A	N/A
4. Evidence for reduction	1	1	2	1	5	31
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	0	3	4	10	63
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	4	3	13	81
9. Feasibility - scalability	0	0	3	4	7	44
10. Feasibility - technological	4	2	4	1	11	69
11. Overall confidence	6	0	8	8	22	69
				Total Score	96	
				Percent Max	67	
				Tier	**High**	**High**

Table B-21. Ratings on "Test Painted Surfaces for Pb" (see Section 4.4.2.1)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Pb	Pb	Pb	Pb	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	> 25%	< 10%	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	Unknown	1-5 yrs	1-5 yrs	1 yr	N/A	N/A
4. Evidence for reduction	0	1	2	1	4	25
5. Feasibility - public health	4	4	3	4	15	94
6. Feasibility - economic	0	3	3	3	9	56
7. Feasibility - environmental	3	3	4	3	13	81
8. Feasibility - social	3	3	4	4	14	88
9. Feasibility - scalability	0	3	4	0	7	44
10. Feasibility - technological	1	3	3	2	9	56
11. Overall confidence	0	6	6	0	12	38
				Total Score	83	
				Percent Max	58	
				Tier	**Med**	**Med**

Table B-22. Ratings on "Blend Beans or Liquor as a Cd Control Measure" (see Section 5.1.1)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd & Pb	Cd	Cd	Cd	N/A	N/A
2. Magnitude of reduction	10-25%	10-25%	> 25%	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1 yr	1 yr	1 yr	1 yr	N/A	N/A
4. Evidence for reduction	2	4	2	4	12	75
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	3	3	3	12	75
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	3	0	9	56
9. Feasibility - scalability	3	4	1	4	12	75
10. Feasibility - technological	4	4	3	4	15	94
11. Overall confidence	2	8	8	6	24	75
				Total Score	112	
				Percent Max	78	
				Tier	**High**	**High**

Table B-23. Ratings on "Establish Bean Cleaning and Winnowing Quality Assurance Practices for Pb Contamination" (see Section 5.1.2)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Pb	Pb	Pb	Pb	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	> 25%	< 10%	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1 yr	1-5 yrs	1-5 yrs	Unknown	N/A	N/A
4. Evidence for reduction	1	3	4	1	9	56
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	3	3	3	12	75
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	4	4	3	2	13	81
10. Feasibility - technological	4	2	4	3	13	81
11. Overall confidence	4	8	4	6	22	69
				Total Score	109	
				Percent Max	76	
				Tier	**High**	**High**

Table B-24. Ratings on “Develop and Use New Mechanical Techniques to Clean Beans” (see Section 5.2.1)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Pb	Pb	Pb	Pb	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	> 25%	10-25%	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	Unknown	> 5 yrs	1-5 yrs	Unknown	N/A	N/A
4. Evidence for reduction	1	2	3	0	6	38
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	0	0	3	0	3	19
7. Feasibility - environmental	3	2	3	3	11	69
8. Feasibility - social	3	4	3	3	13	81
9. Feasibility - scalability	0	1	1	0	2	13
10. Feasibility - technological	0	1	1	0	2	13
11. Overall confidence	2	6	6	0	14	44
				Total Score	67	
				Percent Max	47	
				Tier	**Med**	**Med**

Table B-25. Ratings on "Use Chemical Washing Techniques to Clean Beans" (see Section 5.3.1)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Pb	Pb	Pb	Pb	N/A	N/A
2. Magnitude of reduction	> 25%	> 25%	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1 yr	> 5 yrs	1-5 yrs	Unknown	N/A	N/A
4. Evidence for reduction	3	2	0	0	5	31
5. Feasibility - public health	4	3	0	0	7	44
6. Feasibility - economic	3	0	0	0	3	19
7. Feasibility - environmental	3	2	0	2	7	44
8. Feasibility - social	3	4	3	3	13	81
9. Feasibility - scalability	3	1	0	0	4	25
10. Feasibility - technological	2	1	1	0	4	25
11. Overall confidence	0	2	0	0	2	6
				Total Score	45	
				Percent Max	31	
				Tier	**Low**	**Low**

Table B-26. Ratings on "Incorporate Better Agricultural Practices into Cocoa Sustainability/Certification Programs" (see Section 6.1.1)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd & Pb	Cd & Pb	Cd & Pb	Cd & Pb	N/A	N/A
2. Magnitude of reduction	10-25%	> 25%	Unknown or not quantifiable	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	1 yr	1 yr	1 yr	1 yr	N/A	N/A
4. Evidence for reduction	3	4	1	1	9	56
5. Feasibility - public health	3	4	4	4	15	94
6. Feasibility - economic	4	3	3	3	13	81
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	4	3	1	2	10	63
10. Feasibility - technological	4	4	3	3	14	88
11. Overall confidence	6	8	4	4	22	69
				Total Score	107	
				Percent Max	74	
				Tier	**High**	**High**

Table B-27. Ratings on "Provide Education/Training at the Local Level to Implement Reduction Strategies" (see Section 6.1.2)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd & Pb	Cd & Pb	Cd & Pb	Cd & Pb	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	> 25%	> 25%	N/A	N/A
3. Time frame of reduction	Unknown	> 5yrs	1-5 yrs	1 yr	N/A	N/A
4. Evidence for reduction	1	1	2	4	8	50
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	0	4	3	10	63
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	4	3	3	4	14	88
9. Feasibility - scalability	0	1	3	4	8	50
10. Feasibility - technological	2	1	3	4	10	63
11. Overall confidence	6	2	6	8	22	69
				Total Score	100	
				Percent Max	69	
				Tier	**High**	**High**

Table B-28. Ratings on "Test Surfaces of Cocoa Beans for Pb Contamination at Point of Purchase and Reject Beans with Elevated Pb Levels" (see Section 6.1.3)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Pb	Pb	Pb	Pb	N/A	N/A
2. Magnitude of reduction	> 25%	Unknown or not quantifiable	> 25%	> 25%	N/A	N/A
3. Time frame of reduction	1 yr	Unknown	1 yr	1 yr	N/A	N/A
4. Evidence for reduction	2	0	1	3	6	38
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	3	0	3	4	10	63
7. Feasibility - environmental	4	3	3	3	13	81
8. Feasibility - social	3	3	0	3	9	56
9. Feasibility - scalability	3	0	0	2	5	31
10. Feasibility - technological	2	0	2	1	5	31
11. Overall confidence	6	0	8	6	20	63
				Total Score	84	
				Percent Max	58	
				Tier	**Med**	**High**

Table B-29. Ratings on "Offer Incentives to and Provide Funding for Local Growers" (see Section 6.2.1)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd & Pb	Cd & Pb	Cd & Pb	Cd & Pb	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	10-25%	> 25%	Unknown or not quantifiable	N/A	N/A
3. Time frame of reduction	Unknown	1-5 yrs	1 yr	Unknown	N/A	N/A
4. Evidence for reduction	0	3	4	1	8	50
5. Feasibility - public health	4	4	4	4	16	100
6. Feasibility - economic	0	3	3	0	6	38
7. Feasibility - environmental	3	3	3	4	13	81
8. Feasibility - social	3	3	4	4	14	88
9. Feasibility - scalability	0	2	4	0	6	38
10. Feasibility - technological	1	2	3	1	7	44
11. Overall confidence	0	6	8	2	16	50
				Total Score	86	
				Percent Max	60	
				Tier	**High**	**Med**

Table B-30. Ratings on "Certify Management Systems to GFSI Schemes" (see Section 6.2.2)

Rating Category	Expert 1	Expert 2	Expert 3	Expert 4	Combined Score	Percent Maximum
1. Applies to:	Cd & Pb	Cd & Pb	Cd & Pb	Cd & Pb	N/A	N/A
2. Magnitude of reduction	Unknown or not quantifiable	Unknown or not quantifiable	< 10%	10-25%	N/A	N/A
3. Time frame of reduction	Unknown	1 yr	1-5 yrs	1 yr	N/A	N/A
4. Evidence for reduction	0	0	4	1	5	31.3
5. Feasibility - public health	4	4	4	4	16	100.0
6. Feasibility - economic	3	3	3	3	12	75
7. Feasibility - environmental	3	3	3	3	12	75
8. Feasibility - social	3	3	3	3	12	75
9. Feasibility - scalability	1	4	3	3	11	69
10. Feasibility - technological	1	4	4	4	13	81
11. Overall confidence	4	0	6	4	14	44
				Total Score	95	
				Percent Max	66	
				Tier	**High**	**Med**

APPENDIX C. Summary of Bean Cleaning and Winnowing Study

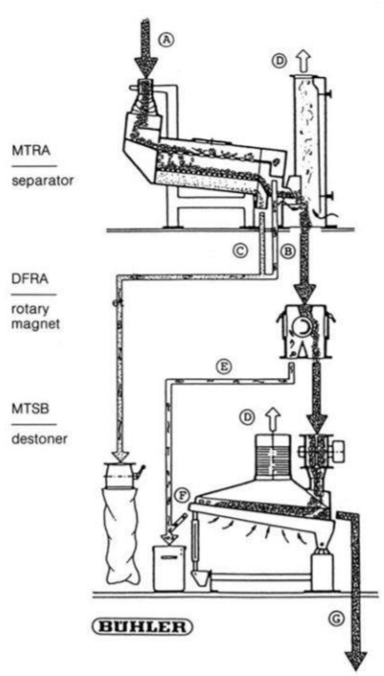
Overview

A Bean Cleaning and Winnowing Study was conducted at a major North America cocoa processing plant operated by one of the largest companies in the industry over the period 17-19 August 2020. The purpose of the study was to measure the level of Pb in cocoa bean cleaning and shell winnowing process streams and to assess the impact of these processes on reducing Pb in cocoa nibs. Received and cleaned cocoa beans; cocoa bean cleaning waste streams; and winnower shell and nib streams were sampled and analyzed for Pb. In addition, selected samples were analyzed for iron (Fe), cadmium (Cd), and aluminum (Al) for informational purposes. The study was conducted on a 100 metric ton lot of Ivory Coast cocoa beans. Sampling occurred during five different production batches (or "replicates") from this lot. A copy of the study protocol is included at the end of this appendix. All four Experts approved the final sampling plan, and one Expert was present throughout the sampling event.

Process Sampling - Results and Discussion

The cocoa bean cleaning process at the facility where the study was conducted consists of screening to remove course and fine material; aspiration to remove light material; destoning to remove stones; and a rotary magnet to remove ferrous objects. Figure C-1 presents a flow diagram for a typical cocoa bean cleaning process. Cocoa beans were sampled as received into the facility (Received Beans) and at the exit of the cleaning process (Cleaned Beans). Samples were also collected from two waste streams: the "Overs" stream (25.0 mm screen size) and the "Unders" waste stream (2.0 mm screen size). The amount of material collected in these two waste streams was also recorded. Light material removed during aspiration was also sampled and the amount collected recorded. The results are listed in Table C-1.

Figure C-1. Flow Diagram of a Typical Cocoa Bean Cleaning Process (Source: Beckett, 2009)



The cocoa bean cleaning process was found to reduce the Pb concentration of cocoa beans by physically removing fine and light material that contains a Pb concentration that is approximately two orders of magnitude higher than that of cleaned beans. The difference in the mean Pb concentration of Received Beans versus Cleaned Beans was found to be statistically significant using a one-sided two-sample t-test. These results demonstrate the importance of bean cleaning in the removal of high Pb concentration waste material prior to bean breaking and winnowing to reduce contact with exposed nib surfaces.

Table C-1. Summary of Bean Cleaning Pb Measurements

Material	Mean Pb Concentration (ppb)	Highest Pb Concentration (ppb)	Number of Samples	Amount (% of Received Beans)
Received Beans – Whole Beans	95.2	370	12	100.0
Shells Only	163.0	270	6	N/A
Nibs Only	15.2	32	6	N/A
Cleaned Beans	39.7	64	6	99.5
Waste – Overs (25.0 mm)	44.5	56	6	0.1
Waste – Unders (2.0 mm)	3,130	4,500	6	0.3
Waste – Aspiration dust	2,370	4,400	6	0.1

The host facility’s cocoa bean shell removal process consists of infrared heat treatment of cleaned beans to loosen shells; bean breaking; and two-stage nib and shell separation. The two stages are the Prewinnower and Winnower. Figure C-2 is a photograph of a typical winnowing operation at a cocoa bean processing facility. Beans are crushed in the bean breaking process to loosen shells from nibs. The shells are removed from the nibs in the Prewinnower and Winnower. The Prewinnower is a single channel shell/nib separator, with one nib screen. The Winnower is a multiple channel shell/nib separator, with five nib screens of progressively smaller sizes. The Prewinnower and Winnower nib outputs are combined and conveyed to another process area for milling into chocolate liquor. Shell removal is controlled at the Prewinnower and Winnower by adjusting air flow at each screen to achieve a less than 1.75% shell-in-nib (SIN) level in the combined nib stream. Nibs were sampled at each screen and the contribution of each screened fraction to the overall over nib output was measured. The results are listed in Table C-2.

Figure C-2. Photograph of Cocoa Bean Winnower (Source: https://www.buhlergroup.com/content/buhlergroup/global/fr/products/barth_winnower.html)

The SIN of the combined nib output from the Prewinnower and Winnower was measured for the “cleaned beans” in each test replicate. Shells were sampled for Pb concentration from the combined output of the Prewinnower and Winnower. The results are listed in Table C-3.

The Prewinnower nib mean Pb concentration was found to be 28.9 ppb. The Winnower nib mean Pb concentration (from all channels) was found to be 33.0 ppb. Based on the flow contribution of each to the total nib output, this would calculate to an overall nib Pb concentration of 31.8 ppb. This is consistent with the Pb concentration reported by the SDs for Ivory Coast liquor (mean = 39.8 ppb, interquartile range = 21.7 ppb), as shown in Table 6b of the Root Cause Report. SIN content of the combined nib output stream was found to be controlled below the 1.75% level. At an overall study SIN content of 1.63% and shell Pb concentration of 363 ppb, shell can be calculated to contribute 6.3 ppb to the overall nib Pb concentration of 31.8 ppb. During this study, the process was configured such that the winnowing system fines (Winnower Channel 6 material) were combined with the nib stream before further processing. This is currently the routine practice. At an overall study mean Pb concentration of 143 ppb and an overall nib contribution level of 2.4%, fines can be calculated to contribute 3.4 ppb to the overall nib Pb concentration of 31.8 ppb. This suggests that the nib obtains approximately 70% of its Pb concentration (22.1 ppb) through contact with Pb containing material (i.e., shell, soil, light and fine material) during bean breaking and winnowing.

Table C-2. Summary of Winnower Pb Measurements

Sampling Location	Screen Size (mm)	Pb Concentrations (ppb)		SIN (%) Mean	Flow Contribution (%)
		Mean	Highest		
Prewinnower	6.00	28.9	39.3	2.24	28.4
Winnower Data					
Nib Channel 1	5.16	19.9	21.2	N/A	1.8
Nib Channel 2	4.04	15.2	43.7	0.69	18.4
Nib Channel 3	3.04	32.0	67.3	1.08	22.6
Nib Channel 4	2.24	41.7	64.0	1.74	16.4
Nib Channel 5	1.00	77.7	112.5	2.40	10.0
Nib Channel 6 (Fines)	< 1.00	143.0	160.0	N/A	2.4
All Nib Channels	N/A	33.0	40.7	N/A	71.6

Notes: Five samples were collected at each sampling location shown in the table.
The flow contribution (100%) is separated into the prewinnower (28.4%) and the winnower (71.6%). The winnower contribution is further separated into the individual winnower channels.

Table C-3. SIN and Shell Pb Concentrations, by Replicate

Replicate	SIN (%)	Pb Shell Concentrations (ppb)		Number of Samples
		Mean	Highest	
1	1.54	491	1,600	6
2	1.72	303	410	8
3	1.67	313	340	6
4	1.66	407	940	7
5	1.54	304	480	5
Overall Study	1.63	363	1,600	32

Nib Pb concentration was found to increase with a decrease in nib particle size. The mean Pb concentration of nibs sampled at each Winnower screen increased as the screen size decreased. Using a non-parametric trend test, the increase in mean Pb concentration across the Winnower channels with decreasing screen sizes was found to be statistically significant. The nib Pb concentrations reported in Table C-2 are sample measurements, not values adjusted for shell content. However, if the nib Pb concentrations were adjusted based on the SIN levels for each nib fraction, the same increasing nib Pb concentration trend would be observed.

The relationship between nib Pb concentration and particle size can be explained by the increase in surface area to volume ratio of particles as particles decrease in size. Using a cube as a model for a nib, and assuming that the winnowing screen size is the nib (cube) edge dimension, surface area to volume (SA:V) ratios can be calculated for each winnowing nib fraction. The mean Pb concentration and mean Al concentration measured for each winnowing screen is listed with the corresponding SA:V ratio in Table C-4. Mean Pb concentration is plotted against SA:V ratio in Figure C-3. A similar plot was created for mean Al concentration in Figure C-4. Al was plotted in addition to Pb because the presence of Al in nib would also be a result of contact with shell, soil, and other fine material. Plotting Al in addition to Pb allows the relationship between particle size and metal concentration to be assessed using a second metal. (Note: Al can be used as a proxy for soil contamination. Clean nibs have very low levels of Al, and dirty nibs have high levels of Al.) Both plots indicate a similar linear relationship. The increase in nib Pb concentration with increasing nib SA:V ratios suggests that nibs are contacting Pb containing material (i.e., shell, soil, light and fine material) during bean breaking and winnowing. As nib particles get smaller, the nib SA:V ratio increases, resulting in more nib surfaces available to contact Pb containing material. Bean breaking should be operated to maximize the production of larger nib fractions.

Table C-4. Estimated Surface Area to Volume Ratio and Pb and Al Concentrations, by Winnowing Screen

Nib Winnowing Fraction	Winnowing Screen Size (mm)	Estimated Nib SA:V Ratio (mm^{-1})	Mean Pb Concentration (ppb)	Mean Al Concentration (ppm)
Prewinnower	6.00	1.00	28.9	51.1
Winnower Channel 1	5.16	1.16	19.9	39.7
Winnower Channel 2	4.04	1.49	15.2	25.7
Winnower Channel 3	3.04	1.97	32.0	42.7
Winnower Channel 4	2.24	2.68	41.7	70.6
Winnower Channel 5	1.00	6.00	77.7	132.4

Figure C-3. Relationship between Winnower Nib Pb Concentration and Nib Dimensions

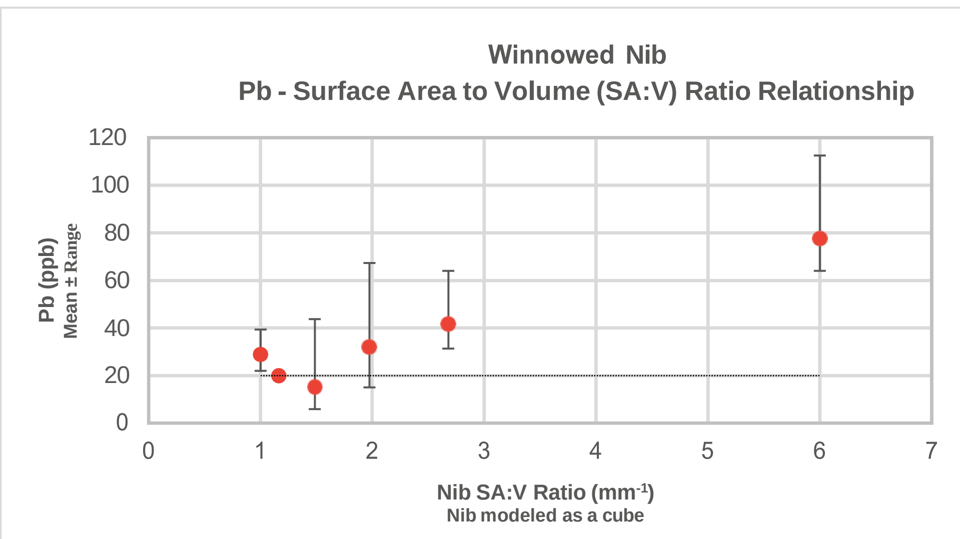
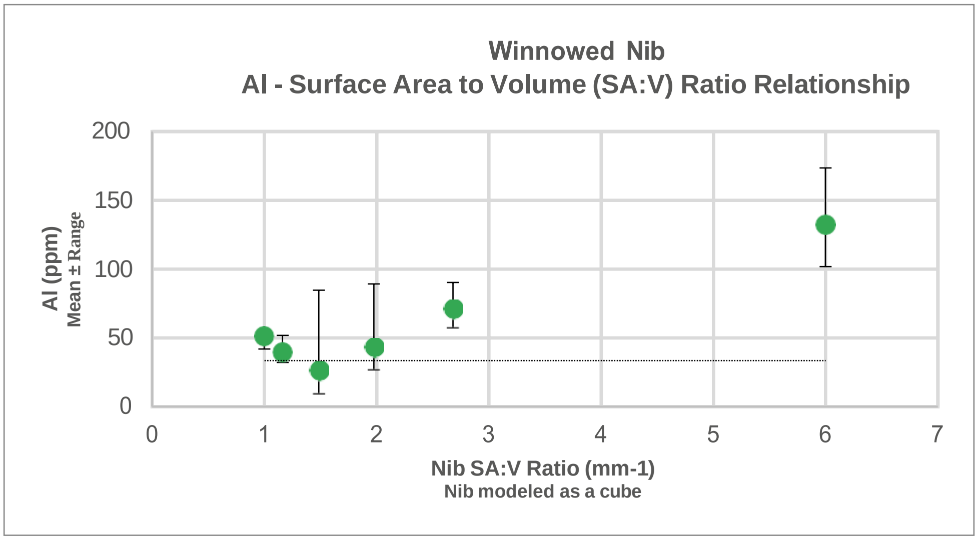


Figure C-4. Relationship between Winnower Nib Al Concentration and Nib Dimensions



Assessment of Bean Cleaning Approaches

To better understand the nature of cocoa bean Pb concentration, received beans were subjected to two laboratory washing methods: (1) detergent washing and (2) detergent washing followed by acid washing (methods commonly used to reduce soil contamination of plant samples). An 0.1% sodium lauryl sulfate solution was used as the detergent, and a 1.0 M nitric acid solution was used for the acid. The washing procedures are further described in the study protocol, included at the end of this appendix. The Experts compared the Pb concentrations across the following categories of beans: as received, mechanically cleaned (i.e., using the processes at the host facility), detergent washed, and detergent and acid washed. The results are listed in Table C-5.

The mean Pb concentration of cocoa beans after the detergent washing process and the mean Pb concentration of cocoa beans after the mechanical cleaning process were not statistically different, based on a one-sided two-sample t-test. However, both processes led to statistically significant reductions in the mean Pb concentration as compared to the mean Pb concentration of received beans. Both mechanical cleaning and detergent washing appear to remove Pb containing material included in the bulk bean stream and physically adhered to the cocoa bean surface.

The mean Pb concentration of cocoa beans after the detergent and acid washing process was found to be significantly different as compared to the mean Pb concentration of received beans, cocoa beans after mechanical cleaning, and cocoa beans after the detergent washing. Statistical significance was again assessed using a one-sided two-sample t-test. Acid washing cocoa beans after detergent washing appears to further reduce the mean Pb concentration of cocoa beans by removing Pb chemically adsorbed on the shell surface. This indicates that adsorption is most likely a mechanism contributing to post-harvest cocoa bean Pb contamination.

Table C-5. Assessment of Effectiveness of Different Bean Cleaning and Washing Methods

Material	Cleaning Process	Pb (ppb) Mean	Variance (ppb^2)	Comment
Received Beans	Uncleaned	95.2	11,500	None
Mechanically Cleaned	Host facility	39.7	166	Mean Pb levels for mechanically cleaned and detergent washed materials are not significantly different. Both are significantly different than received beans.
Detergent Washed	Lab method: water and lauryl sulfate	42.3	81.1	
Detergent & Acid Washed	Lab method: water and lauryl sulfate and nitric acid	23.2	13.4	Mean Pb level significantly different than received beans, mechanically cleaned, and detergent washed materials.

Note: Based on 12 "received bean" samples and 6 samples each for the different cleaning and washing techniques.

Bean Cleaning and Winnowing Study – Final Protocol

Last revised by Tim Ahn following site visit on June 29, 2020

Note: This protocol describes the sampling and analysis methodologies that the Experts planned to implement for the Bean Cleaning and Winnowing Study. Some deviations from protocol (e.g., fewer samples collected than planned) occurred in the field, due to unforeseen circumstances.

Purpose

The purpose of this Bean Cleaning and Winnowing Study is to understand the impact of cocoa bean cleaning and shell removal (winnowing) processes on the reduction of lead (Pb) in cocoa products. The study will also provide information on the level of lead (Pb) in cocoa bean waste streams. This is an important piece of information that is presently missing in the literature. Cadmium (Cd) levels will also be measured in various process streams for informational purposes.

Study Overview

This study will monitor the cleaning and winnowing of five 20 MT lots of cocoa beans at a cocoa bean processing facility over the period 17-19 August 2020. Samples will be taken of cocoa beans, waste materials, nibs, and shells at various points in the process to assess lead (Pb) levels as beans are cleaned and winnowed to produce nibs for processing into chocolate liquor. Samples will be analyzed for metal content and physical characteristics. The host facility's bean cleaning and winnowing process is detailed in "Figure 1 – Process Flow Diagram."

Bean Receiving

The host facility will select approximately 200 MT of West African cocoa beans (Ivory Coast or Ghana) that will be used to supply the five (5) 20 MT replicates. Facility contacts will sample the 200 MT bean lot for Pb and Cd concentrations and other parameters before the 20 MT sub-lots arrive at the facility. The study will have access to the host facility's bean testing results. The receiving and unloading system will be run as empty as possible between 20 MT lots to ensure breaks between each replicate. It is estimated that it will take approximately 20 minutes to empty a 20 MT bulk bean truck. Each 20 MT delivery will be sampled at the beginning, middle, and end of the truck unloading to create a composite sample of the delivered lot. Two composite samples will be created for each replicate. One sample will be analyzed by the host facility for physical parameters. The other will be analyzed by Eurofins for heavy metals.

Cleaning

Received beans will be processed through the bean cleaning process. The bean cleaning process consists of screening, aspiration, destoner, and a magnet. Waste streams from screening, aspiration, and destoning will be weighed and sampled for each run (replicate). The only exception to this is the Aspiration Fines collection. In order to weight Aspiration Fines between each replicate, the dust collection system would have to be shut down between each replicate. Since this would cause a significant process interruption, the Aspiration Fines waste barrels will be sampled and weighed at the end of the entire 5 replicate trial. The bean silo will be run at a 2 tonne level to reduce the amount of mixing between lots. It is estimated that it will take approximately 90 minutes to clean a specific lot.

Winnowing

Cleaned beans will be processed through the IR Heating Drum to evaporate moisture and loosen the shell for removal. After heating, the beans will be conveyed to the bean breakers to create nibs and shells. Shells and nibs at the facility are separated using a two-stage process of a Prewinnower and a Winnower. Both pieces of equipment work on the same principle. Shells and nibs are passed over screens of progressively smaller sizes. Material on the screen is aspirated to remove shells with the remaining material discharging to the nib stream. Material passing through the screen is screened over a smaller screen. This process continues over multiple stages. Samples will be taken at each stage (channel) and at the final nib and shell points as detailed in "Table 1 – Sample Table."

Sampling

Samples will be taken at various points during each production run. For statistical purposes, each production run is to be considered as a study replicate. The study will consist of 5 replicates. Each replicate is a production run of 20 MT of cocoa beans. Inbound cocoa beans and cleaning streams will be subsampled during the production run and composited for a representative sample of the run (replicate). Winnowing streams (nibs, shells) will be sampled with individual samples tested, not composites, representing the entire run (replicate). This is to allow the analysis of process variation. Sampling details are listed in "Table 1 – Sample Table."

Testing

Physical characteristics testing will be performed by the host facility's internal laboratory following their standard protocols for cocoa bean evaluation and shell-in-nib testing. These are typical of industry practices. Metals testing of cocoa beans, nibs, shells, and various cleaning waste streams will be performed by Eurofins meeting requirements established by the Expert Committee. Of importance is the protocol for the analysis of cocoa beans and the hygienic separation of shell and nibs to determine nib lead (Pb) level prior to processing. Testing will also measure concentrations of cadmium (Cd), iron (Fe), and aluminum (Al) to provide additional information. The external laboratory will separate shells and nibs as follows:

- Weigh sample material.
- Put cocoa beans in a liquid nitrogen bath.
- Let liquid nitrogen evaporate (~30-45 mins).
- Use tweezers to separate shells and nibs.
- Sieve nibs to remove any remaining shells.

Samples of inbound cocoa beans ("uncleaned") and IR discharge cocoa beans ("cleaned") will be wet washed at the external laboratory to assess the nature of lead (Pb) and cadmium (Cd) on the external surface of the bean. Cocoa beans will be detergent washed using 0.1% sodium lauryl sulfate and acid washed using 1.0 M HCl. The detergent washing procedure should remove weakly adhered soil particles and mucilage residue. The acid washing procedure should remove chemically adsorbed elements. The washing procedures should provide insight as to the nature of Pb contamination during post-harvest handling. The washing protocol is attached in Appendix 1.

Table 1 – Sample Table

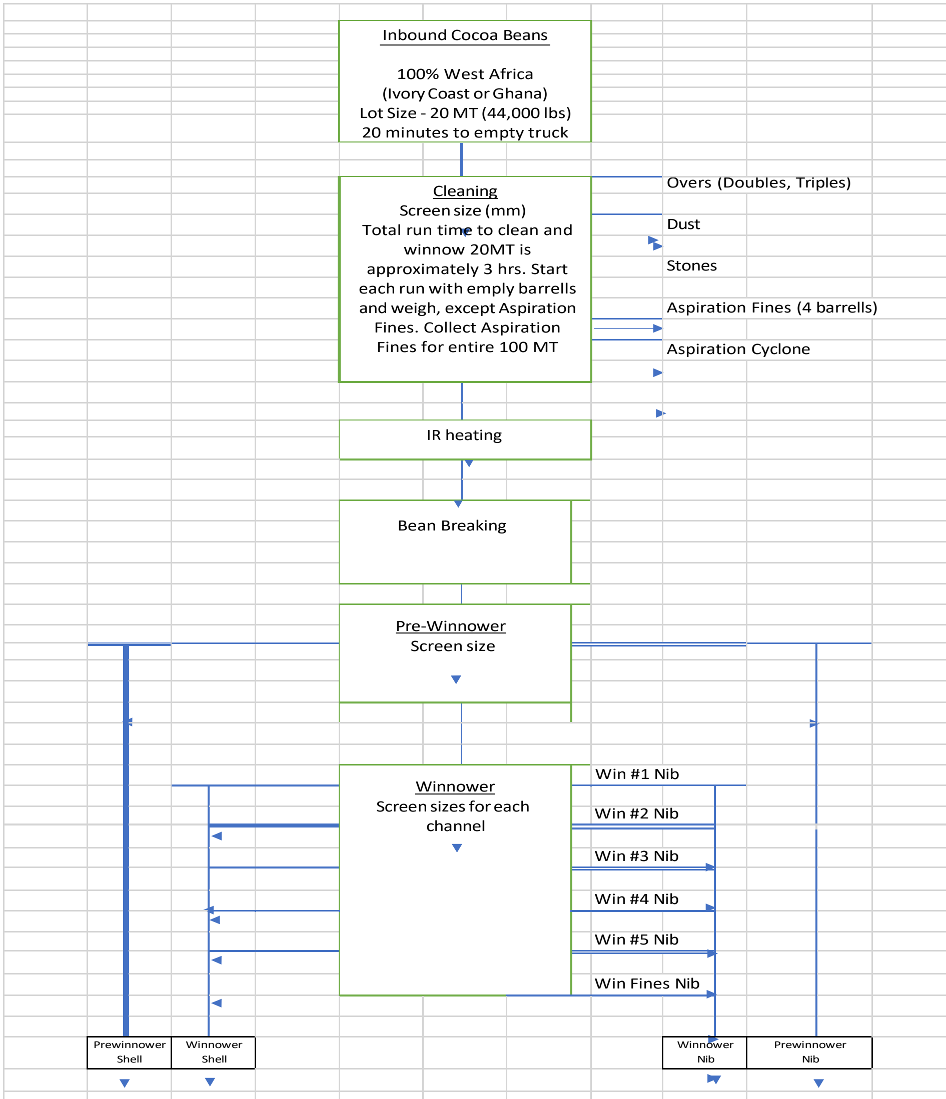
Location	Material	Analysis	Laboratory	Method	Sampling
Inbound Receiving	Cocoa Beans "200 MT Lot"	Brokens (%) Clusters (%) Flats (%) Foreign Material (%) Residue (%) Sieving (%) Pb, Cd	Host facility	Host facility method	One sample will be analyzed per standard facility protocol for "200 MT Lot" of cocoa beans from which 5 "20 MT Lot" deliveries will be made. This is one representative sample of the cocoa beans used for the entire study.
	Cocoa Beans "20 MT Lot"	Brokens (%) Clusters (%) Flats (%) Foreign Material (%) Residue (%) Sieving (%)	Host facility	Host facility method	1 composite sample for each replicate (20 MT bean lot). Sample to be taken at receival of bulk bean trucks. Composite sample made from beginning/middle/end of truck unloading. Sample size: 2kg (one 50oz. VWR bag)
	• Cocoa Beans • Separated Nib • Separated Shell • Detergent Washed Beans • Acid Washed Beans	Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified Special bean detergent/acid washing protocol Special protocol for nib/shell separation	1 composite sample for each replicate (20 MT bean lot). Sample to be taken at receival of bulk bean trucks. Composite sample made from beginning/middle/end of truck unloading. Sample size: 2kg (one 50oz. VWR bag) All samples below to be tested for Pb/Cd/Al/Fe per replicate. 1) 1 whole bean sample tested per replicate 2) 1 detergent washed bean sample tested per replicate, per protocol 3) 1 acid washed bean sample tested per replicate, per protocol 4) 1 separated nib/shell sample per replicate a. Nib sample tested b. Shell sample tested 5 Pb/Cd/Al/Fe samples per replicate *DUPLICATE SAMPLE LOCATION* • *1 replicate – complete set* • *Every replicate – cocoa beans only (no wash, no separation)*
Cleaning	Aspiration Cyclone	Amount (kg/run)	Host facility	Weighing	Total amount weighed for replicate
		Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified	1 composite sample for each replicate (run) from collected material. Subsampling to be determined during trial to ensure representative composite. Sample size: one 50oz. VWR bag 1 Pb/Cd/Al/Fe sample per replicate *DUPLICATE SAMPLE LOCATION* • *1 replicate*

Location	Material	Analysis	Laboratory	Method	Sampling
	Aspiration Fines – Barrels 1, 2, 3, and 4	Amount (kg/run)	Host facility	Weighing	Total amount collected for all 4 Barrels combined weighed for entire 5 replicate run.
	Aspiration Fines • Barrell 1 • Barrell 2 • Barrell 3 • Barrell 4	Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified	1 composite sample for each barrel for entire 5 replicate run. 4 Pb/Cd/Al/Fe samples per entire run Sample size: one 50oz. VWR bag *DUPLICATE SAMPLE LOCATION* • *1 barrel for 1 replicate*
	Overs	Amount (kg/run)	Host facility	Weighing	Total amount weighed for replicate
		Pb, Cd, Al, Fe	Host facility	Analytical method to be specified	1 composite sample for each replicate from collected material. Subsampling to be determined during trial to ensure representative composite. 1 Pb/Cd/Al/Fe sample per replicate Sample size: one 50oz. VWR bag *DUPLICATE SAMPLE LOCATION* • *1 replicate*
	Stones	Amount (kg/run)	Host facility	Weighing	Total amount weighed for replicate
		TBD	TBD	TBD	1 sample of stones collected from 1 replicate. Hold for potential testing at later date. Sample size: one 32oz.container
	Unders – "Dust"	Amount (kg/run)	Host facility	Weighing	Total amount weighed for replicate
		Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified	1 composite sample for each replicate from collected material. Subsampling to be determined during trial to ensure representative composite. 1 Pb/Cd/Al/Fe sample per replicate Sample size: one 50oz. VWR bag *DUPLICATE SAMPLE LOCATION* • *1 replicate*
	"Cleaned" Cocoa Beans	Brokens (%) Clusters (%) Flats (%) Foreign Material (%) Residue (%) Sieving (%)	Host facility	Host facility method	1 composite sample for each replicate. Subsamples to be pulled 2 times during 90-minute production run to ensure representative composite. Sample size: one 50oz. VWR bag
		Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified Special bean detergent/acid washing protocol	1 composite sample for each replicate. Subsamples to be pulled 2 times during 90-minute production run to ensure representative composite. Sample size: one 50oz. VWR bag 1) bean sample tested per replicate 2) 1 detergent washed bean sample tested per replicate, per protocol 3) 1 acid washed bean sample tested per replicate, per protocol 3 Pb/Cd/Al/Fe samples per replicate *DUPLICATE SAMPLE LOCATION*

Location	Material	Analysis	Laboratory	Method	Sampling
					• *1 replicate – complete set*
Prewinnower	Prewinnower Nib	Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified	3 samples pulled from nib stream every 30 minutes. Each sample tested individually. Sample size: one 50oz. VWR bag 3 Pb/Cd/Al/Fe samples per replicate
		Shell-in-Nib (SIN)	Host facility	Host facility method	1 sample pulled from nib stream for each replicate. Sample size: one 50oz. VWR bag
	Prewinnower Shell	Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified	1 sample pulled from shell stream every 30 minutes. Each sample tested individually. Sample size: one 50oz. VWR bag 3 Pb/Cd/Al/Fe samples per replicate
Winnower	Winnower Channel #1 Nib	Pb, Cd	Eurofins	Analytical method to be specified	1 sample pulled from nib stream every 30 minutes. Each sample tested individually. Sample size: one 50oz. VWR bag 3 Pb/Cd samples per replicate
	Winnower Channel #2 Nib	Pb, Cd	Eurofins	Analytical method to be specified	1 sample pulled from nib stream every 30 minutes. Each sample tested individually. Sample size: one 50oz. VWR bag 3 Pb/Cd samples per replicate
	Winnower Channel #3 Nib	Pb, Cd	Eurofins	Analytical method to be specified	1 sample pulled from nib stream every 30 minutes. Each sample tested individually. Sample size: one 32oz.container 3 Pb/Cd samples per replicate
	Winnower Channel #4 Nib	Pb, Cd	Eurofins	Analytical method to be specified	1 sample pulled from nib stream every 30 minutes. Each sample tested individually. Sample size: one 32oz.container 3 Pb/Cd samples per replicate
	Winnower Channel #5 Nib	Pb, Cd	Eurofins	Analytical method to be specified	1 sample pulled from nib stream every 30 minutes. Each sample tested individually. Sample size: one 32oz.container 3 Pb/Cd samples per replicate
	Winnower Fines Nib	Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified	1 sample pulled from nib stream every 30 min. Each sample tested individually. Sample size: one 32oz.container 3 Pb/Cd/Al/Fe samples per replicate *DUPLICATE SAMPLE LOCATION* • *1 30 min sample for 1 replicate*
	Winnower Nib	Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified	1 sample pulled from nib stream every 30 minutes. Each sample tested individually. Sample size: one 50oz. VWR bag 3 Pb/Cd/Al/Fe samples per replicate *DUPLICATE SAMPLE LOCATION* • *1 30 min sample for 1 replicate*
		Shell-in-Nib (SIN)	Host facility	Host facility method	1 sample pulled from nib stream for each replicate.

Location	Material	Analysis	Laboratory	Method	Sampling
					Sample size: one 50oz. VWR bag
	Winnower Shell	Pb, Cd, Al, Fe	Eurofins	Analytical method to be specified	1 sample pulled from shell stream every 30 minutes. Each sample tested individually. Sample size: one 50oz. VWR bag 3 Pb/Cd/Al/Fe samples per replicate *DUPLICATE SAMPLE LOCATION* • *1 hourly sample for 1 replicate*

Figure 1 - Process Flow Diagram



Appendix 1 of Bean Cleaning and Winnowing Study

Testing detergent and acid removable Pb and Cd of whole cocoa beans; Rufus L. Chaney, June 1, 2020

1. There are 5 replicate samples of "input" or "uncleaned" initial beans, and 5 more of "cleaned (Pre-IR treatment)" cocoa beans following current commercial "cleaning" procedures.

2. Each sample or "lot" of beans will be subjected to two laboratory cleaning procedures which should remove weakly bound particles, mucilage residue and soil particles (detergent washing) or chemically adsorbed elements (acid washing).

3. Detergent washing test: Each "lot" of cocoa beans will first be subjected to a "washing" test using detergent solution. Acid washed polyethylene bottles (or equivalent) of approximately 250 mL capacity will be prepared and labeled with sample number. 100 g of air dry beans will be placed into the bottle. 100 mL of 0.1% sodium lauryl sulfate (a laboratory pure chemical detergent) will be added. The bottle is then either 1) shaken mildly by hand for 5 min.; or 2) placed on a roller table for 5 min. The slurry of beans and extractant are then poured into an acid washed plastic colander or other non-contaminating sieving device (e.g., acid washed 2 mm soil sieve) to collect the cocoa beans from the detergent wash slurry. Rinse the "washed" beans on the collection device with 100 mL of deionized water. Label by Replicate Number and "Detergent Washed Beans."

4. Acid washing of detergent washed beans: The intent of this assessment is to estimate the amount of Pb which is chemically adsorbed to the chemical binding sites of the shells. Although no proof of Pb adsorption to cocoa shells has been reported, experiments were reported in which Pb chemical solutions were shaken with ground cocoa shells wastes and found to be capable of removing much of the dissolved Pb in the test solution. [Many wastes and byproducts (peanut hulls; rice hulls; urban leaf compost; coconut production wastes, etc.) have been tested in this way to see if the byproduct could be useful in treating industrial metal contaminated solutions (but the results have not been applied to industry because such wastes are often messy].

   Each "lot" of "detergent washed cocoa beans" (prepared above) will be roughly split, half for analysis as whole detergent washed beans; and the other half to be subjected to acid washing. Acid washed polyethylene bottles of approximately 250 mL capacity will be prepared and labeled with sample number. Approximately half (exact amount irrelevant) of the detergent washed beans will be prepared for digestion and analysis. The other half of the detergent washed beans sample will be subjected to an acidic washing procedure to release Pb and Cd which are chemically adsorbed to the shell surfaces. 100 mL of 1.0 M HCl will be added and the bottle is then either (1) shaken mildly by hand for 5 minutes; or (2) placed on a roller table for 5 min. The slurry of beans and extractant will then be poured into an acid washed plastic colander or other sieving device to collect the washed cocoa beans from the acid wash slurry and rinsed with 100 mL of deionized water. (Note: Laboratory has indicated that enough deionized water will be used during rinsing such that the water solution has a pH>5.) Label by Replicate Number and "Acid Washed Beans". These beans will be dried and processed for chemical analysis.

5. Preparation and analysis of Cd and Pb in samples from washing test: Each sample will be oven dried and prepared for analysis. Do not separate shells from nibs for these samples as the focus is on surface Pb removal. Pb in nibs is normally <3 ng Pb/g dry cocoa beans, and typically 1 ng/g. But contaminated whole beans have been analyzed with 3000 ng Pb/g dry weight.

   Use the analytical lab's method for total Pb and Cd in dried whole cocoa beans. Grind the whole sample to appropriate particle size for acid digestion to be used. Use at least 1 g of each material as the analytical sample (after mixing the ground sample well) in the acid digestion. Either "hot block" or "microwave" digestion may be used with HNO_3 and H_2O_2. When the sample is digested, filter and dilute to volume as needed for analysis by ICP-MS.

   Use ICP-MS conditions appropriate for the Pb and Cd concentrations expected in the cocoa bean samples. NIST Standard Reference Materials appropriate for the samples being analyzed and digestion blanks will also be tested. Five peach leaf samples and five “Montana II soil samples” will be tested during the program.

During the ICP-MS analysis, use the method of internal standardization to improve the reliability of the measurements of metals concentrations. Use appropriate reference element added to all samples and standards, or pump by a second pump into all samples by constant feed pump. The FDA (Abt et al., 2018) used a multi-element stock internal standard solution containing rhodium (10 mg/L, Rh) for Cd, and bismuth (5 mg/L, Bi) for Pb to conduct the Internal Standardization.

Approximately 1 out of every 10 samples will be sent to the laboratory in duplicate as a QA/QC procedure.

Report 3 significant figures for measured analytes as appropriate.

APPENDIX D. Summary of Bean Abrasion Study

The Expert Committee planned a "Bean Abrasion Study" to build on the findings of the "Bean Cleaning Study" (see Appendix C). The "Bean Cleaning Study" studied the fate of Cd and Pb during bean cleaning and winnowing operations at a cocoa bean processing facility. That study found that Pb was primarily in the bean shell fractions or in fine particles of shell with adsorbed Pb. The literature has shown that nibs sampled under clean laboratory conditions contain 1-5 ppb Pb, while some commercial cocoa beans have been reported to contain over 1,000 ppb Pb.

The Expert Committee hypothesized that abrasion between whole beans would release fine particles with higher Pb concentration than the whole beans—an observation that, if proven, could be used to reduce the amount of Pb entering cocoa bean processing facilities. The Expert Committee planned and conducted its "Bean Abrasion Study," which was an experiment to clarify the nature of the Pb on whole beans that enter cocoa processing facilities. The "Bean Abrasion Study" used the same lot of cocoa beans that were used in the "Bean Cleaning Study." A copy of the study protocol is included at the end of this appendix.

The Expert Committee arranged for laboratory tests to be conducted by Eurofins. Experts hypothesized that abrasion among beans could release fine particles, if present. Three laboratory methods were used to simulate cocoa bean abrasion. First, Eurofins simulated bean abrasion using a roller bed extraction device that contained 200 g of dry whole cocoa beans in a 500 mL plastic bottle. The bottle was rolled for 1 hour, but no fines were obtained upon sieving with a 2 mm sieve; and a small amount of broken shells were generated. Second, Eurofins simulated bean abrasion using a reciprocal shaker-type device, and this experiment had a similar outcome. Finally, concerned that the first two methods may not have had sufficiently strong abrasion, the Experts had a Eurofins laboratory technician use very strong shaking, short of breaking a high fraction of the beans. However, the more vigorous shaking did not generate fine particles upon sieving the shaken mass.

Based on these tests, the Expert Committee interprets the findings as showing that the Pb in cocoa bean samples is strongly bound to the shell of beans; and the Pb could be chemically adsorbed on the shells or trapped by the dried mucilage on the shells. Thus, preventing Pb contamination during fermentation, sun drying, or other pre-processing is the best available method to minimize Pb contamination on the surfaces of cocoa beans, and eventually in chocolate products.

Bean Abrasion Study – Final Protocol

Last revised by Rufus Chaney on October 19, 2020

Note: This protocol describes the sampling and analysis methodologies that the Experts planned to implement for the Bean Abrasion Study. Some deviations from protocol occurred in the laboratory, due to unforeseen circumstances.

The Expert Committee's Bean Cleaning and Winnowing Study showed that a significant fraction of the external Pb could be released by detergent washing or by processing in the usual manner at the facility. Committee discussion raised the question "What fraction of the Pb in the incoming beans is loose or adhering dust particles (including fine soil particles) which could be released by abrasion among beans?" Such abrasion might occur during processing before shipping, during shipping, preparation of bean mixtures to attain chocolate liquor Cd or Pb goals, etc. Thus, a protocol to conduct such an abrasion test was discussed.

Whole beans from the incoming shipment will be used in the experiment. It is hypothesized that mechanical abrasion might release dust particles (mucilage residues, soil particles, some shell) that would not be released without specific abrasion treatment in a factory. Considerable abrasion does occur during bean processing as beans are elevated, shaken, etc., before being "cracked" and winnowed where considerable fine particles containing Pb, Cd, and the soil indicator elements Fe and Al.

A simple abrasion experiment design:

A subsample of about 1.5 kg of "incoming beans before any factory processing" will be prepared, and mixed gently before use in the experiment. Four 100 g samples of the "incoming beans" will be collected for analysis. A weighed amount of 200 g of field moist commercial cocoa beans will be placed in a 500 mL polyethylene bottle (acid washed, rinsed, and dried) and the lid closed. The bottles will be placed on a "roller table" often used in soil extractions and other sample processing (or a mechanical shaker used for similar processing of soil or other samples). The rolling/shaking will continue for 30 minutes at a rate representative of strong shaking if conducted by a human. After the rolling treatment, the beans will be quantitatively poured into a stainless steel or polypropylene soil sieve with 2 mm holes; the bottle will be banged on the sieve 5 times to improve dust release from the bottle. The sieve will then be shaken side-to-side for 1 minute, and banged on the bottom, to allow the "dust particles released by abrasion" to fall thru the sieve onto a clean plastic surface or into the pan attachment available for soil sieves.

All equipment to be used which will contact the samples used in the abrasion test, and in separation of beans from "dust particles released by abrasion" will have been acid washed and deionized water rinsed and dried before use.

The weight of the sieved material will be measured. The collected particles for each replication will be mixed well and aliquots taken to be analyzed for total Pb, Cd, Fe and Al after acid digestion.

Both the beans "cleaned by" the abrasion treatment and beans from the original lot from which the processed beans were obtained will be acid digested and analyzed for Pb, Cd, Fe and Al. Each bean sample should be ground so that the "whole lot of beans or abrasion-processed beans" will be sub-sampled for the analysis, not just a few beans from each lot. It is believed that individual beans vary substantially in Pb concentration, and removable Pb fraction.

4 replications of the test will be conducted.

Samples to be analyzed:

4 starting beans

4 abraded beans

4 fine "dust" sieved from the abraded beans

Detection limits will be the same as used in the main experiment.

APPENDIX E. Suggested Protocol for Conducting an Experiment on Dry Abrasive Removal of Lead (Pb) Bound to Whole Bean Shell

Purpose:

To determine the degree that a moderately abrasive technique removes lead bound to the outer shell of cocoa beans. This experiment follows the initial experiment using shaking and rolling techniques described in Appendix D of the report.

Objectives:

1. Measure Pb concentrations in dust removed from the outer shell of cocoa beans using sandpaper with varying grits and compare to whole bean levels.
2. Generate data that helps describe the nature of the Pb bonding to the outer cocoa shell.
3. Compare the effectiveness of a dry abrasive technique relative to the water-based (acid) method for removing Pb bound to the outside of cocoa bean shells.
4. Determine whether a simple dry abrasive technique (for example, soda blasting) might be useful on a larger scale as an early remediation step to reduce Pb contamination during chocolate manufacturing.

Experimental Methods:

1. Obtain whole cocoa beans, preferably from a region known to have consistently high Pb contamination of the cocoa shell.
2. Purchase Pb-free sandpaper: course (40-60 grit), medium course (80-100), and fine (120-240). Minimum of three different grits, one from each category up to a maximum of six different grits (two from each category).
3. Cut sandpaper into small squares; probably 2”x2” would suffice.
4. In a controlled laboratory environment (without a fan, etc.) and using gloved hands, rub a single bean onto the small square of sandpaper such that the entire surface of the bean has been abraded. Keep the fines and dust on the sandpaper as a combined sample.
5. Brush any remaining loose dust from the abraded bean onto the sandpaper.
6. Place the abraded bean into a properly labeled Pb-free (food grade) plastic bag.
7. Place the corresponding sandpaper and dust/fines into an acid-washed glass jar with a corresponding label.
8. Perform this identically five times with each sandpaper grit for individual cocoa beans.

Samples (minimum of 41 analyses up to a maximum of 77):

1. Control beans. Submit five individual beans for Pb analysis.
2. Control sandpaper. Submit two unused 2”x2” squares of each grit for Pb analysis.
3. Experimental bean samples. Submit five abraded beans plus corresponding five sandpaper/dust/fines to lab for Pb analysis for each grit.

Resources Needed:

1. Source of whole beans.
2. Purchase of sandpaper and brushes (cheap artist paint brushes would work).
3. Labor costs to conduct experiment.
4. Laboratory analysis using standard and EPA approved Pb testing analytical methods and practices.

APPENDIX F. Suggested Protocol for Conducting an Experiment on Colorimetric Determination of Lead on Whole Bean Shell

Purpose:

To determine the sensitivity of commercially available colorimetric assays for detecting Pb bound to the outer shell of cocoa beans.

Objectives:

1. Analyze the presence of Pb on the outer shell of cocoa beans using commercially available Pb colorimetric kits.

2. Compare the accuracy and sensitivity of these colorimetric kits in measuring Pb on outer shell with laboratory analysis of whole beans from the same lot.

3. Determine whether a simple colorimetric test kit would be useful (e.g., sufficiently sensitive enough) in the field for detecting outer shell Pb contamination at the point of purchase in origin countries.

Experimental Methods:

1. Obtain whole cocoa beans, preferably from the Ivory Coast. In order to do this experiment with four test kits and have enough bean sample for each laboratory analysis, approximately 1,000 grams (1 kilogram) of whole beans may be needed.

2. Purchase Pb assay kits from online manufacturers' web sites or hardware, paint, or specialty retailers. Consider purchasing the following kits, all of which may be available from Amazon:

    a. First Alert Premium Lead Test: https://www.firstalert.com/product/premium-lead-test-kit/. Note that this kit allows for direct wiping of surfaces as well as leaching surface using presumably an acid wash. Therefore, for this test kit, there are two different tests that can be conducted. Would need to purchase two of these kits, one for the wipe test and one kit for the leachate test. There are four tests per box.

    b. 3M Lead Check Test Kit: https://www.3m.com/3M/en_US/company-us/all-3m-products/~/All-3M-Products/Consumer/Home-Improvement/LeadCheck-Swabs/?N=5002385+8709316+8711017+8740610+8753945+3294857497&rt=r3.

    c. Scitus Lead Test Kit: https://www.amazon.com/Testing-Results-Seconds-Suitable-Surfaces/dp/B07NBH7KJJ.

    d. Possibly the Health Metric Heavy Metals Test for water: https://www.health-metric.com/pages/heavy-metals. Wash outside of beans with an acid wash and then use the test kit to determine the presence of Pb in the leachate. For three runs, three kits need to be purchased, because each kit only contains one Pb test.

3. Weigh approximately 50 grams of whole beans (15-20 beans) and save them in a Pb-free (food grade) plastic bag and label them as controls. These would be the general control beans for all test kits.

4. In a controlled laboratory environment using gloved hands, follow the directions of the test kit and test whole beans for the presence of Pb on the outer shell.

    a. Step 1: For each test using a "wipe" method, 20 beans should be wiped (one swab for all beans) or until there is a clear color change indicating the presence of Pb. In other words, if a color change is seen after only five beans, stop wiping the bean and save them in a Pb-free (food grade) plastic bag following Step 2. Repeat test until all beans have been wiped. If there is no color change, then all 20 beans would be wiped with one applicator. For duplicate samples (3 per test kit), test a different batch of 20 beans with a different applicator or until the color changes. It may be necessary to do this step for more than three separate batches of beans per test kit.

   b. Step 2: For each wipe test performed, photograph the applicator placed on top of the color chart (included in the test kit) for Pb testing. Save each individual applicator in a Pb-free (food grade) plastic bag and label them corresponding to the test kit and trial run. The labels on the photograph and the actual swab should match.

   c. Step 3: For test kits that require leachate or liquid samples, follow the directions and apply the testing to 20 beans. For duplicate sampling (3), perform the test three times on 20 different beans.

   d. Step 4: Place the 20 tested beans for each test per kit (wipe-tested or leachate tested) in Pb-free (food grade) plastic bags and label them as controls corresponding to the test kit and test performed.

5. Laboratory analyses

   a. Control beans should be homogenized and replicate samples (2) analyzed for Pb.

   b. Tested beans should be homogenized per test performed and replicate samples (2) analyzed for Pb.

   c. If a maximum of three tests per kit is run and analyzed Pb concentration on replicate samples, then 30 samples should be available for analysis plus two controls replicates for a total of 32 Pb tests.

Resources Needed:

1. Source of whole beans.

2. Purchase of Pb testing kits. A quick search indicates that readily available Pb test kits range in price from about $20 – $140 per kit.

3. Labor costs to conduct experiment.

4. Laboratory analysis using standard and EPA approved Pb testing analytical methods and practices.

Attachment 3: Warning Triggers Report

Version 1 of the Experts' Warning Triggers Report was submitted to AYS and the SDs on November 15, 2021.

When preparing this final report, an Expert identified errors in his entries in Table 2. The erroneous entries were corrected, and the Warning Triggers Report in this attachment is referred to as Version 2.0 and is dated March 2022.

Clarifications and additional text were included in the following paragraphs:

- An Expert added a sentence to the end of his Pb conclusion in Section 3.2.
- An Expert made three text revisions to his Cd conclusion in Section 4.2.

The final paragraph in Section 2.4 was revised to explain the difference between the report versions and to remove the reference to the report being a "draft." Additionally, Appendix B of this report was removed, because the bios now appear in the front matter of this final report. Finally, all headers were changed from "Version 1" to "Version 2.0."

Expert Investigation Related to Cocoa and Chocolate Products:

Warning Triggers Report

Submitted to:

As You Sow and the Settling Defendants

Submitted by:

Timothy Ahn

Rufus Chaney, PhD

Michael DiBartolomeis, PhD, DABT

Gideon Ramtahal, PhD

Note: All authors contributed equally to the development of this report. The authors' names are listed alphabetically.

March 2022

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List of Abbreviations

AAS	atomic absorption spectroscopy
ANOVA	analysis of variance
AYS	As You Sow
CCCF	CODEX Committee on Contaminants in Food
Cd	cadmium
CODEX	Short for Codex Alimentarius, a collection of food safety standards, guidelines, and codes
DTPA	diethylenetriaminepentaacetic acid
EU	European Union
FDA	U.S. Food and Drug Administration
Fe	iron
GEMS	Global Environment Monitoring System
ICP-AES	inductively coupled plasma atomic emission spectroscopy
ICP-MS	inductively coupled plasma mass spectrometry
LAC	Latin America and Caribbean
LOD	limit of detection
MADL	Maximum Allowable Dose Levels under Proposition 65
ML	maximum limit
P65	Proposition 65
Pb	lead
QA	quality assurance
QC	quality control
SDs	Settling Defendants
US	United States
Zn	zinc

1.0 Executive Summary

In this third report, the Expert Committee was charged with recommending whether and when concentrations of lead (Pb) and cadmium (Cd) in chocolate products shall be modified from "drop-down" Proposition 65 trigger levels included in the Consent Judgment. The Experts were instructed to base their findings on the lowest Pb and Cd levels that can be feasibly achieved, considering the Pb and Cd reduction strategies identified and evaluated in Phase Two of this project. Feasible, as defined in the Consent Judgment, means "capable of being accomplished in a successful manner within a reasonable period of time, taking into account public health, and economic, environmental, social, and technological factors." Evaluations of 30 potential Cd and Pb reduction strategies using these criteria were developed and reported in the Phase Two report. The Experts based their assessments on their Phase One and Phase Two findings, sampling data provided by As You Sow (AYS) and the Settling Defendants (SDs), a review of relevant scientific literature, consultation with subject matter experts, and their professional judgment.

During a series of videoconferences, the Experts discussed feasible drop-down levels for Pb and Cd. While the Experts agreed on certain findings, described below, consensus was not reached on the lowest Pb and Cd drop-down levels (concentrations) that industry can feasibly achieve for chocolate products sold in California. The Experts agreed that, even with further discussion, they would not be able to converge on the same concentrations for drop-down levels. In short, they "agreed to disagree" on the lowest Pb and Cd concentrations that can be feasibly achieved.

As a result, the Expert Committee agreed that this Phase Three report would present each Expert's individual assessment of the lowest drop-down levels that can be feasibly achieved, and each Expert was charged with proposing drop-down levels and justifying how they were derived. Sections 3 and 4 of this report present the Experts' individual assessments and derivations of Pb and Cd drop-down levels, respectively. A summary of their findings follows:

- **Pb drop-down levels.** Table 1 summarizes the Experts' findings on Pb Proposition 65 drop-down (i.e., trigger) levels. Consensus was reached that it is feasible for the industry to meet all drop-down levels referenced in Section 6.2.1 of the Consent Judgement. However, there is no consensus as to what conditions (e.g., implementation of new Pb reduction strategies versus no new actions) are required to meet these drop down levels. In addition, consensus was reached that further reductions in Pb to lower drop-down levels are feasible. However, there is no consensus as to the lower level of reduction that can be feasibly achieved. The entries in Table 1 show the range of Pb drop-down levels that the Experts recommended.

- **Cd drop-down levels.** Table 2 summarizes the Experts' findings on Cd Proposition 65 drop-down levels. There is no consensus as to whether it is feasible for the industry to meet the current limits, the proposed drop-down limits, or further reductions.

The Experts' conclusions are based on the information available to the Expert Committee as of September 1, 2021.

Table 1. Experts' Findings Regarding Pb Drop-Down Levels

Chocolate Products with up to 65% Cacao Content (Section 6.2.1.a*)			
Expert	Can the Following Pb Drop-Down Levels be Feasibly Achieved?		
	0.100 ppm	0.065 ppm	<0.065 ppm**
Tim Ahn	Yes	Yes	Yes (0.060 ppm)
Rufus Chaney	Yes	Yes	Yes (0.050 ppm)
Michael DiBartolomeis	Yes	Yes	Yes (0.015 ppm)
Gideon Ramtahal	Yes	Yes	Yes (0.060 ppm)
Chocolate Products with Greater Than 65% and up to 95% Cacao Content (Section 6.2.1.b*)			
Expert	**Can the Following Pb Drop-Down Levels be Feasibly Achieved?**		
	0.150 ppm	**0.100 ppm**	**<0.100 ppm****
Tim Ahn	Yes	Yes	Yes (0.090 ppm)
Rufus Chaney	Yes	Yes	Yes (0.075 ppm)
Michael DiBartolomeis	Yes	Yes	Yes (0.020 ppm)
Gideon Ramtahal	Yes	Yes	Yes (0.090 ppm)
Chocolate Products with Greater Than 95% Cacao Content (Section 6.2.1.c*)			
Expert	**Can the Following Pb Drop-Down Levels be Feasibly Achieved?**		
	0.225 ppm	**0.200 ppm**	**<0.200 ppm****
Tim Ahn	Yes	Yes	Yes (0.180 ppm)
Rufus Chaney	Yes	Yes	Yes (0.100 ppm)
Michael DiBartolomeis	Yes	Yes	Yes (0.040 ppm)
Gideon Ramtahal	Yes	Yes	Yes (0.180 ppm)

* These section numbers refer to text in the Consent Judgment.
** Concentrations in the final column are the lowest Pb drop-down levels that the Experts identified as being feasibly achievable.

Table 2. Experts' Findings Regarding Cd Drop-Down Levels

Chocolate Products with up to 65% Cacao Content (Section 6.2.2.a*)			
Expert	**Can the Following Cd Drop-Down Levels be Feasibly Achieved?**		
	0.400 ppm	**0.320 ppm**	**<0.320 ppm****
Tim Ahn	No	No	No
Rufus Chaney	Yes	No	No
Michael DiBartolomeis	Yes	Yes	Yes (0.120 ppm)
Gideon Ramtahal	Yes	No	No
Chocolate Products with Greater Than 65% and up to 95% Cacao Content (Section 6.2.2.b*)			
Expert	**Can the Following Cd Drop-Down Levels be Feasibly Achieved?**		
	0.450 ppm	**0.400 ppm**	**<0.400 ppm****
Tim Ahn	No	No	No
Rufus Chaney	Yes	No	No
Michael DiBartolomeis	Yes	Yes	Yes (0.175 ppm)
Gideon Ramtahal	Yes	No	No
Chocolate Products with Greater Than 95% Cacao Content (Section 6.2.2.c*)			
Expert	**Can the Following Cd Drop-Down Levels be Feasibly Achieved?**		
	0.960 ppm	**0.800 ppm**	**<0.800 ppm****
Tim Ahn	No	No	No
Rufus Chaney	Yes	Yes	No
Michael DiBartolomeis	Yes	Yes	Yes (0.400 ppm)
Gideon Ramtahal	Yes	No	No

* These section numbers refer to text in the Consent Judgment.
** Concentrations in the final column are the lowest Cd drop-down levels that the Experts identified as being Feasibly achievable.

2.0 Background

This section presents background information on the Expert Committee and describes how the Experts developed the Warning Trigger Phase report. This section does not present the Experts' technical findings. Those are included in this report's Executive Summary and discussed in Section 3 and 4.

2.1 Formation and Operation of the Expert Committee

The initiating event for this project was discovery of Cd and Pb in chocolate products purchased in California at levels that triggered Notices of Violation under the state's Proposition 65. The party that discovered these contamination levels (As You Sow [AYS]) and several companies in the chocolate industry (the settling defendants [SDs]) entered into the Consent Judgment that formed the Expert Committee and directed the Experts to prepare this report.

As stipulated by the Consent Judgment, AYS appointed one Expert Committee member; the SDs appointed another; and AYS and the SDs jointly agreed upon and appointed the remaining two. The names of the four Expert Committee members appear on the title page of this report. AYS and the SDs also mutually identified and jointly appointed a Project Manager, who provided administrative and logistical support to the Expert Committee, facilitated discussions during Expert Committee meetings, ensured that the Expert Committee completed its work according to the budget and schedule, and provided word processing and editorial support for this report. Mr. John Wilhelmi of Eastern Research Group, Inc. (ERG) served as the Project Manager.

The Expert Committee members and the Project Manager performed their work under "consulting and confidentiality agreements" with AYS and the SDs, as joint contracting parties. The agreements required Expert Committee members to treat as strictly confidential and not disclose any non-public information provided by the SDs. The Expert Committee abided by these requirements. They thoroughly considered all information received, including non-public information. This report's findings are based on all information that the Expert Committee obtained and reviewed, even though this report is not allowed to present confidential information.

The Consent Judgment defines the Expert Committee's scope of work. It requires the Expert Committee to prepare four reports over a two-year time frame. In March 2020, the Expert Committee completed the first report (the Root Cause Phase report), which identified the sources of Cd and Pb in chocolate products. In April 2021, the Expert Committee completed the second report (the Reductions Recommendations report), which identified feasible means for reducing Cd and Pb levels in chocolate products. In this third report (the Warning Triggers report), the Expert Committee provides its comments on the Proposition 65 warning levels for Cd and Pb. The fourth and final report will present a summary of the Expert Committee's overall findings and recommendations.

Section 3.3.1 of the Consent Judgment sets the following scope for this (third) project phase:

> Evaluating and making recommendations as to whether, and, if so, when, the lead and cadmium concentration levels in Chocolate Products that trigger Proposition 65 warnings shall be modified from the "drop down" levels described in Sections 6.2.1 and 6.2.2 of this Consent Judgment based on Feasible means to reduce lead and cadmium levels over time.

The remainder of this document focuses exclusively on the Expert Committee's comments on the Proposition 65 warning trigger levels as defined in the Consent Judgement.

2.2 Lines of Evidence Considered by the Expert Committee

The Expert Committee considered these lines of evidence when preparing the Warning Triggers Phase report:

- **AYS/SD sampling data.** The Experts reviewed chocolate product sampling data provided by AYS and the SDs. Specifically, AYS's complete chocolate product sampling data was made available to the Experts; and Section 3.3 of this report provides details on those data and how the Experts processed them. The Experts also reviewed relevant records from the data set that the SDs originally provided; Section 3 of the Root Cause Phase report describes those data and how the Experts processed them.

- **Publications.** The Expert Committee considered findings from scientific publications, largely relying on peer-reviewed literature. Graduate theses and unrefereed sources were also reviewed, as appropriate.

To date, the Expert Committee compiled an inventory of more than 400 scientific publications. (Note: A spreadsheet of the Expert Committee's document inventory is available upon request.)

- **Consultation with SMEs.** To inform their Warning Triggers Phase analyses, some Expert Committee members contacted outside SMEs. The Experts made these contacts individually and informed the Project Manager of all contacts made. During the Warning Triggers Phase, the Experts made more than 60 such contacts. Documentation of these is found in the quarterly reports that the Project Manager submitted to AYS and the SDs.

- **Direct observations.** The Expert Committee also considered their own observations from two field trips completed during the Root Cause Phase. The first field trip included tours of three U.S. industrial facilities that either processed cocoa beans or manufactured chocolate products. The second field trip was of supply chain activity in Ecuador. That trip included visits to cocoa farms, bean collection facilities where drying and fermenting occurred, and bean exporter facilities where pre-export bean cleaning and packaging occurred. Additionally, the Experts considered results from an experiment conducted at a chocolate liquor production factory where all material streams were sampled and analyzed by inductively coupled plasma mass spectrometry (ICP-MS) to examine what happened to Pb on the surface of incoming cocoa beans. Descriptions, analyses, and conclusions drawn from these direct observations were included in the Phase One and Phase Two reports; no additional field trips or experiments were conducted by the Expert Committee after the submission of the Phase Two report.

- **Professional judgment.** The Expert Committee members bring decades of experience in relevant scientific disciplines. Their professional judgment also factored into the Warning Triggers Phase conclusions.

2.3 Background on Product Warning Triggers

Section 6.2.1 of the Consent Judgement defines the Proposition 65 chocolate product warning triggers for Pb as follows:

> 6.2.1. Product Warning Triggers Based on Lead Concentration Levels.
>
> (a) For Covered Products with up to 65% cacao content: Product Warnings are required if the Covered Product's associated lead concentration level exceeds 0.100 ppm, provided, however, that as of the sixth anniversary of the Compliance Date, the foregoing lead concentration level shall be deemed to have been reduced to 0.065 ppm unless (i) the Committee has recommended that the 0.100 ppm lead concentration level be continued, a lead concentration level between 0.100 and 0.065 ppm be instituted, or that a lead concentration level less than 0.065 ppm replace the 0.065 ppm level, and (ii) a modification of this Consent Judgment has been entered which reflects the level that shall supersede the drop down to 0.065 ppm.
>
> (b) For Covered Products with greater than 65% and up to 95% cacao content: Product Warnings are required if the Covered Product's associated lead concentration level exceeds 0.150 ppm, provided, however, that as of the sixth anniversary of the Compliance Date, the foregoing lead concentration level shall be deemed to have been reduced to 0.100 ppm unless (i) the Committee has recommended that the 0.150 ppm lead concentration level be continued, a lead concentration level between 0.150 and 0.100 ppm be instituted, or that a lead concentration level less than 0.100 ppm replace the 0.100 ppm level, and (ii) a modification of this Consent Judgment has been entered which reflects the level that shall supersede the drop down to 0.100 ppm.
>
> (c) For Covered Products with greater than 95% cacao content: Product Warnings are required if the Covered Product's associated lead concentration level exceeds 0.225 ppm, provided, however, that as of the sixth anniversary of the Compliance Date, the foregoing lead concentration level shall be deemed to have been reduced to 0.200 ppm unless (i) the Committee has recommended that the 0.225 ppm lead concentration level be continued, a lead concentration level between 0.225 and 0.200 ppm be instituted, or that a lead concentration less than 0.200 ppm replace the 0.200 ppm level, and (ii) a modification of this Consent Judgment has been entered which reflects the level that shall supersede the drop down to 0.200 ppm.

Section 6.2.2 of the Consent Judgement defines the Proposition 65 chocolate product warning triggers for Cd as follows:

> 6.2.2. Product Warning Triggers Based on Cadmium Concentration Levels.
>
> (a) For Covered Products with up to 65% cacao content: Product Warnings are required if the Covered Product's associated cadmium concentration level exceeds 0.400 ppm, provided, however, that as of the sixth anniversary of the Compliance Date, the foregoing cadmium concentration level shall be deemed to have been reduced to 0.320 ppm unless (i) the Committee has recommended that the 0.400 ppm cadmium concentration level be continued, a cadmium concentration level between 0.400 and 0.320 ppm be instituted, or that a cadmium concentration level less than 0.320 ppm replace the 0.320 ppm level, and (ii) a modification of this Consent Judgment has been entered which reflects the level that shall supersede the drop down to 0.320 ppm.
>
> (b) For Covered Products with greater than 65% and up to 95% cacao content: Product Warnings are required if the Covered Product's associated cadmium concentration level exceeds 0.450 ppm, provided, however, that as of the sixth anniversary of the Compliance Date, the foregoing cadmium concentration level shall be deemed to have been reduced to 0.400 ppm unless (i) the Committee has recommended that the 0.450 ppm lead concentration level be continued, a cadmium concentration level between 0.450 and 0.400 ppm be instituted, or that a cadmium concentration level less than 0.400 ppm replace the 0.400 ppm level, and (ii) a modification of this Consent Judgment has been entered which reflects the level that shall supersede the drop down to 0.400 ppm.
>
> (c) For Covered Products with greater than 95% cacao content: Product Warnings are required if the Covered Product's associated cadmium concentration level exceeds 0.960 ppm, provided, however, that as of the sixth anniversary of the Compliance Date, the foregoing cadmium concentration level shall be deemed to have been reduced to 0.800 ppm unless (i) the Committee has recommended that the 0.960 ppm cadmium concentration level be continued, a cadmium concentration level between 0.960 and 0.800 ppm be instituted, or that a cadmium concentration level less than 0.800 ppm replace the 0.800 ppm level, and (ii) a modification of this Consent Judgment has been entered which reflects the level that shall supersede the drop down to 0.800 ppm.

2.4 Process for Developing the Warning Triggers Phase Report

The Expert Committee started working on the Warning Triggers Phase report in April 2021. Their work began with the Experts and the Project Manager identifying questions about the scope of work. On May 4, 2021, the Project Manager held a videoconference with AYS and the SDs to discuss these questions, and the Project Manager documented the agreed-upon answers provided by AYS and the SDs. The complete list of questions and answers are included in Appendix A of this report. The Project Manager shared the list with the Experts and discussed the scope during the first Expert Committee videoconference on May 5, 2021. It was emphasized that the Experts' findings for Phase Three are to be based on Feasibility, as opposed to other factors. The Project Manager noted that "Feasible" has a specific definition in the Consent Judgment:

> "Feasible" means capable of being accomplished in a successful manner within a reasonable period of time, taking into account public health, and economic, environmental, social, and technological factors. In considering whether an action or performance level is Feasible, consideration shall be given, among other things, to scaling as to the size and resources of the potential implementing enterprise involved, the implementing enterprise's place and role within the chain of commerce, the prior demonstration of the viability of the concept or technology at issue at both the research and actual commercial scale, and the nature of the issue being addressed.

The Project Manager scheduled a series of videoconferences in which the Experts discussed their assessment of Feasible drop-down levels. The Experts first discussed Pb drop-down levels, and then Cd drop-down levels. During the initial discussions, the Experts shared their initial assessments, with the charge being identifying the lowest drop-down levels that can be Feasibly achieved. While the Experts agreed on some findings (e.g., that it was Feasible to meet the current and proposed drop-down levels for Pb for the three categories of chocolate products in the Consent Judgment), the Experts ultimately could not agree on specific Pb and Cd concentrations that industry can Feasibly achieve. The Experts agreed that, even with further discussion, they would not be able to converge on the same concentrations for drop-down levels. In short, they "agreed to disagree" on the lowest Pb and Cd concentrations that can be Feasibly achieved. As a result, a decision was made for this report to present each Expert's individual assessment of the lowest drop-down levels that can be Feasibly achieved; and each Expert was charged with proposing drop-down levels and justifying how they were derived. Sections 3 and 4 of this report present the Experts' individual assessments and derivations of Pb and Cd drop-down levels.

Once the Experts drafted their individual assessments, the Project Manager circulated those assessments to the entire committee and offered to convene further videoconferences regarding the drop-down levels. The Project Manager then circulated five drafts of this report to the Experts for review and comment. The Experts were asked to consider input from other Experts on their individual assessments, but Experts were not required to revise their text based on other Experts' feedback. All four Experts authorized the Project Manager to submit this version of the Warning Trigger Phase report to AYS and the SDs, with no dissenting opinions.

This Warning Trigger Phase report reflects information that was available to the Expert Committee as of September 1, 2021. Recognizing that scientists continue to investigate strategies for reducing Cd and Pb in cocoa beans and chocolate products, the Expert Committee originally presented this report as "Version 1." The current document is "Version 2.0" and accounts for corrections that an Expert made to his entries in Table 2.

2.5 Organization of the Warning Triggers Phase Report

The remainder of this report is organized as follows:

- Section 3 presents the Experts' individual assessments of Pb drop-down levels.
- Section 4 presents the Experts' individual assessments of Cd drop-down levels.
- Section 5 presents references for all citations in the report.
- Appendix A lists questions that the Experts and the Project Manager asked about the Phase Three scope of work and the responses provided by AYS and the SDs.

3.0 Experts' Findings on Pb Warning Triggers

The Experts were charged with identifying the lowest Pb drop-down levels that can be Feasibly achieved. The Experts agreed that it is Feasible for the industry to manufacture chocolate products with Pb concentrations below all of the drop-down levels listed in Section 6.2.1 of the Consent Judgment. The Experts further agreed that they were not going to be able reach consensus on the magnitude of the lowest drop-down levels that can be Feasibly achieved. The Experts agreed to present their individual assessments of the lowest Feasible Pb drop-down levels, which are included in this section. The remainder of this section presents the four Experts' individual assessments of the Pb drop-down levels. Refer to Table 1 for a summary of the Experts' Pb findings.

3.1 Tim Ahn's Findings on Pb Warning Triggers

The following Pb Product Warning Triggers can be feasibly achieved. These levels are lower than the 6th anniversary of the Compliance Date "drop-down" levels described in Section 6.2.1 of the Consent Judgment.

- For products up to a 65% cacao content: 0.060 ppm
- For products greater than 65% cacao content and up to a 95% cacao content: 0.090 ppm
- For products greater than 95% cacao content: 0.180 ppm

A review of SD data for chocolate liquor, which is the ingredient that determines Pb concentration in chocolate products, suggests that the industry is generally capable of meeting the proposed reduced drop-down levels through improving current cocoa bean cleaning practices. This improvement can be realized by implementing Bean Cleaning/Winnowing Quality Assurance (QA) Practices for Pb Contamination, Recommendation 5.1.2 in the Phase 2 report across all regions. Drop-down levels lower than those stated above will only be achieved through Better Agricultural Practices related to reducing cocoa bean soil contact during fermentation and drying. As stated in the Phase 2 report, there is no consensus as to the level of reduction that can be achieved, or the timing required to implement these practices. Therefore, lower levels of Pb in Chocolate Products below the reduced drop-down levels listed above cannot be feasibly established.

Discussion

In order to assess the impact of the Consent Judgment drop-down levels, a description of the product and the expected level of chocolate liquor and added cocoa butter included in the product were reviewed. The following is a description of typical products include in the Consent Judgment chocolate product categories.

- Up to 65% cacao
  - Typically, everyday mass merchandised chocolate, including milk chocolate
  - Typical percentage of added cocoa butter: 15%
  - Recommended drop-down level: 0.060 ppm
- Greater than 65% and up to 95% cacao
  - Typically, high chocolate liquor content, single origin, fine flavor chocolate
  - Typical percentage of added cocoa butter: 0 to 5%
  - Recommended drop-down level: 0.090 ppm
- Greater than 95% cacao
  - Cocoa powder, cocoa nibs, 100% chocolate liquor
  - Cocoa butter is not typically added to these products

- Recommended drop-down level: 0.180 ppm

The ability of the chocolate industry to meet the Consent Judgment triggers is based on the capability of cocoa processors to produce chocolate liquor that allows the Pb drop-down levels specified above for each of the product categories to be achieved. Because the Consent Judgment does not specify chocolate liquor Pb concentrations, the chocolate liquor Pb concentrations necessary to meet the Consent Judgment drop-down levels have been estimated with following simplifying assumptions.

- For each product category, because chocolate recipes are not known, all cacao is assumed to be chocolate liquor. Added cocoa butter is ignored.
- For the 95%+ category, the product is based on cocoa powder. In this category, cocoa powder has the highest percentage of non-fat cocoa solids. Pb is present in non-fat cocoa solids, not in the cocoa butter fraction.
- Cocoa powder is assumed to be 22% fat and pressed from 54% fat chocolate liquor. This results in a chocolate liquor to cocoa powder conversion ratio of 1.91 to 1.

With these assumptions, the following are the chocolate liquor Pb concentrations necessary to meet the recommended drop-down levels for the highest cacao percentage for each chocolate product category.

- Up to 65% cacao: 0.092 ppm
- Greater than 65% and up to 95% cacao: 0.095 ppm
- Greater than 95% cacao (cocoa powder): 0.094 ppm

The SD data set was reviewed with respect of the capability to produce 0.094 ppm chocolate liquor. The following observations were made.

- Many chocolate liquor producing countries are capable of producing 0.094 ppm Pb chocolate liquor. Using the SD data for the United States (n = 298 samples), as an example of a producing country that processes cocoa beans from all key global origins (West Africa, Ecuador, Indonesia, etc.), 0.094 ppm Pb chocolate liquor can be produced using existing bean cleaning practices (see Phase 2 report, Table 7b).
- Two key processing countries, Brazil and Indonesia, do not demonstrate chocolate liquor Pb performance at the same capability as other countries, including the United States (see Phase 2 report, Table 7b). This observation is also supported by a review of Brazilian cocoa powder data (see Phase 2 report, Table 4b). Brazilian cocoa powder has a higher concentration of Pb as compared to other origins. A review of whole bean Pb data for Brazil and Indonesia do not indicate a higher level of Pb in the whole beans as compared to other countries (see Phase 2 report, Table 3b). One can only conclude that existing bean cleaning practices are not as effective in reducing Pb as are existing practices in other countries. Improvements such as those recommended in Bean Cleaning/Winnowing QA Practices for Pb Contamination, Recommendation 5.1.2 in the Phase 2 Report will need to be implemented in these key processing regions.

3.2 Rufus Chaney's Findings on Pb Warning Triggers

In our earlier reports of the Committee, we summarized many research reports on Pb levels in chocolates and cocoa beans. We have cited the SD and AYS data on both Cd and Pb, the CODEX data on Cd only, the U.S. Food and Drug Administration (FDA) data on Cd and Pb, and the data from the general literature. The evidence for Pb in cocoa beans shows that levels of 0.002-0.005 mg/kg dry weight (ppm) are the "natural" levels at the moment of harvest, and that levels above that range are the result of human actions adding Pb post-harvest. We identified that source – allowing wet cocoa beans to contact fine soil particles during fermentation and sun-drying of the beans on the farm or during processing at the first stage purchasers of farmers' beans. There are no contradictions of this conclusion in the literature. And our experiment supported this knowledge (ignoring the higher Pb in EuroFins lab-separated nibs where the separation method after cracking the shells with liquid nitrogen and some kind of sieving to separate the nibs from the shell debris allowed redistribution of fine soil particles which had adhered to the shells before the treatment with nitrogen, and transfer of shell Pb to the nibs in our experiment). The world literature strongly supports this understanding of the source of Pb in cocoa nibs and chocolate products.

I also note that FDA advises that any **candy** containing over 0.100 ppm of Pb would be a source of concern to FDA, and regulatory actions have already occurred related to Pb in chocolate products. However, FDA does not relate Pb limits to the %-cocoa solids in a product. Further, all food analyses are made on the "fresh weight" basis, not the dry weight basis which may avoid substantial variation among chocolate products with varied moisture content.

For these reasons I suggested using 0.100 ppm as the limit for >95% cocoa and proportionally lower Pb levels for the other classes; I suggested 0.075 ppm and 0.050 ppm.

This **"proportional" approach** is being used by CODEX, and is at the heart of the Consent Decree numbers. I think the relative proportions of 1.0, 0.75, and 0.50 for the specific cocoa solids ranges are rational and appropriate. Yes, it will require changes by the cocoa bean processing industry to reliably attain even these limits based on recent journal publications reporting the Pb levels in cocoa beans and chocolate products. This is the real world at the present. The higher levels of bean Pb can be prevented by manufacturers and growers to reach my suggested limits using existing equipment and knowledge of the Pb transfer and contamination processes which need to be avoided to limit Pb in chocolates.

I looked again at the two FDA papers on chocolates authored by Abt et al. (2018 and 2020) and another recent paper (de Oliveira et al., 2021). The Abt and Robin review (2020) noted that one Brazilian product contained 0.760 mg Pb/kg, but the commercial cocoa nibs they analyzed were all <0.005 mg Pb/kg. The de Oliveira et al. (2021) study obtained beans and products from 6 regions of cocoa bean production (both South America and Africa). They found quite higher Pb levels in some commercial chocolates than we have seen in most of the rest of the data available. This indicates that some international bean markets are going to need enforcement, or the bean cleaning and separation of nibs at chocolate factories will have to adjust to our experimental findings soon to avoid fines in California. But we know the science about the source. So I still support the Pb limits I listed above.

Thus, although extreme attention to removing contaminating soil particles from incoming cocoa beans can assure meeting the limits I indicated, attaining substantially lower Pb levels would cause appreciable disruption in the chocolate industry. In 5 or 10 years the suggested levels might be lowered to 0.060 ppm, 0.045 ppm and 0.030 ppm, but for the time being, even with our Recommendations, the industry will have to do a lot "in-country" to resolve the post-harvest bean Pb contamination issues.

Our clear recommendation to achieve lower Pb in beans and chocolates, made to all levels of the cocoa industry, is to conduct fermentation and drying on **clean** surfaces, free of soil and dust, and thereby Pb-free surfaces (wooden or plastic). And to assure that painted surfaces do not contain Pb paint which could powder or flake and contaminate beans.

Thus the limits I report as being "Feasible" at the time of this Report are 0.100 ppm Pb for chocolates containing >95% cocoa solids; 0.075 ppm Pb for chocolates containing 65-95% cocoa solids, and 0.050 ppm Pb for chocolates containing <65% cocoa solids.

There are several technical issues which complicate the identification of "feasible limits for Pb in chocolate products." One glaring issue with international (CODEX) and FDA approaches to limiting Pb in chocolates is the localization of all cocoa nib Pb with the non-fat solids. Fat comprises 45-60% of cocoa beans, and chocolate products contain quite variable fractions of cocoa non-fat solids. Because the cocoa bean Pb (and Cd) moves only with the non-fat portion of beans, I suggest that any scientifically based rule about "Pb in chocolates" should be based on the "non-fat cocoa solids." In addition, the moisture content of chocolate products vary somewhat, and current regulations are on the "fresh-weight" or "as is" basis rather than cocoa non-fat solids. Making the change to "non-fat cocoa solids dry weight" basis for regulating Cd and Pb in chocolate products would provide a uniform regulation across chocolate products that are related to the fundamental source of the Pb and Cd.

During our work on Pb in chocolates, we agreed that nearly all Pb in/on farmer or commercial cocoa beans is actually fine soil particles stuck on the outside of the shell. Although the equipment we observed, and tested the performance of during our factory experiment, was able to remove most of the shell and fine dust, some fine particles containing Pb were redistributed to the nibs during the process. For companies to use this knowledge to reduce Pb in chocolate liquor will require evaluation and testing at each factory. Their operations may be similar, but not identical. And small producers do not have such complicated equipment to remove shells and separate nibs, so are more likely to have excessive Pb in chocolate liquor. The alternative we discussed was finding a method to do a quick estimation of soil contamination of a "lot" of beans offered for sale which would identify "dirty" beans which would necessarily have higher Pb levels and might cause higher than allowed Pb in chocolate liquor (see below).

In the future, two activities in the cocoa industry should change after our report. First, it seems likely that some of the methods we suggested the industry could use to train and support farmers in avoiding soil contact of wet cocoa beans could remove nearly all of that Pb source. If market cocoa beans are low in Pb, chocolate manufacturers should readily achieve lower Pb levels in separated nibs, and in the cocoa solids. The Pb will still remain with the non-fat portion of the nibs into the chocolate liquor. It is not reasonable to speculate how much lower than my recommended limits (above) might be attained with improved practices described in our full Reduction Recommendations Report. Given 5-10 years of training farmers in how to avoid Pb contamination of their cocoa beans, and of enforcement by the chocolate industry buyers of cocoa beans, lower Pb levels are expected to be attained. But it will be difficult until bean producers use these clean procedures.

Analysis of cocoa beans and products for the "natural" level of nib Pb (<0.005 mg Pb/kg) is difficult and expensive, requiring inductively coupled plasma mass spectrometry (ICP-MS) analysis. Alternative methods to detect soil contamination of cocoa beans offered for sale are needed to support enforcement of the "clean bean processing" practices noted above and provide negative feedback to the bean producer. We had reviewed the potential use of hand-held X-Ray Fluorescence Analyzers to check beans for Pb but found that the detection limit was too high (radiation exposures and cost were also issues on this use of XRF). Other quick inexpensive methods to identify surface particles with Pb on beans were not found. Since that text was prepared, I considered other possible inexpensive, rapid, and simple methods to show the presence of much soil on beans by measuring a major constituent of soil, iron. The possible formation of Prussian Blue by reacting ferrocyanide with soils Fe^{3+} oxides does not work because the soil Fe^{3+} are not free ions. Alternatively, several ferrous color reagents could be added to a suspension of cocoa beans first treated with an acidic reductant (vitamin C or dithionite) and then obtain a strong color reaction when the solution is partially neutralized (pH) with the addition of a color reagent solution (ferrozine) (Stookey, 1970). A strong purple color would show high levels of Fe on the beans, and infer a high level of soil with surface-bound Pb on the beans and provide a basis to teach the grower of the need to prevent soil contact of his beans during fermentation and sun drying. Because soil is the predominant source of Pb in marketed cocoa beans, this inexpensive rapid method may help solve the bean Pb problem at the source by showing the farmer an immediate evidence of his errors in preparing his crop for sale. The grower could wash his dirty beans and dry them on a clean surface, achieving the needed lower Pb concentration.

3.3 Michael DiBartolomeis' Findings on Pb Warning Triggers

I recommend Proposition 65 trigger levels for Pb of **0.015 ppm** (15 ppb), **0.020 ppm** (20 ppb), and **0.040 ppm** (40 ppb), for chocolate products categorized into Cacao Group 1 (up to and including 65 percent cacao), Group 2 (more than 65 percent up to and including 95 percent cacao), and Group 3 (greater than 95 percent cacao), respectively. These recommendations for Pb are supported by the following findings:

1. The Expert Committee concluded in the Phase One Report that most if not all the Pb contamination in chocolate products originates from environmental contamination of cocoa beans during post-harvest processing. Therefore, it is theoretically possible that Pb contamination of chocolate products can be reduced to negligible levels by fully implementing effective environmental contamination prevention strategies such as those described in the Phase Two Report.
2. Based on the Expert Committee's findings in the Phase Two Report, 15 reduction strategies were rated as feasible to reduce Cd and Pb contamination in chocolate products with "high" feasibility confidence; 6 of which were specific to Pb reduction:

- The six "high" feasibility confidence Pb reduction strategies offer different approaches to changing agricultural practices around processing cocoa and each could provide from 10 percent to 25 percent to greater than 25 percent reduction in Pb levels in chocolate products.
- Combining these "high" feasibility confidence reduction strategies could achieve Pb reductions of at least 50 percent to higher than 70 or 80 percent.

3. Based on the Expert Committee's evaluation of the high feasibility confidence Pb reduction strategies in the Phase Two Report, Pb reduction strategies can be implemented within a range of time starting at less than one year to about five years. This timeframe aligns with the Consent Judgment.
4. Over 15 percent of the AYS tested chocolate products had Pb concentrations at or below 5 ppb and 27 percent were at or below 10 ppb under *status quo* conditions. These data suggest that in areas where environmental Pb contamination is relatively low or the post-harvesting processes are clean, Pb levels can be negligible in chocolate products.
5. The mean levels of Pb in the AYS analyzed chocolate products categorized into Group 1 (up to 65 percent cacao solids) decreased by more than 50 percent from 2014 to 2019. There is also a downward trend in mean Pb values over the same five years. This is evidence that under *status quo* conditions, Pb levels with 65 percent or less cacao can be significantly reduced using currently available Pb reduction measures.
6. For all products in Cacao Groups 1, 2, and 3, the results of the AYS testing demonstrate greater than 95 percent compliance with the Consent Judgment triggers under *status quo* conditions. In other words, almost all chocolate products on the market in California (as represented by the AYS test results) are already compliant with the Pb trigger levels defined in the Consent Judgment.
7. Under *status quo* conditions, nearly 90 percent compliance of chocolate products can be achieved without any further Pb reduction efforts with Proposition 65 triggers set at 0.030 ppm for Group 1, 0.050 ppm for Group 2, and 0.100 ppm for Group 3, which should be the highest triggers considered for Pb under *status quo* conditions.
8. The Consent Judgment Pb trigger levels for products in Group 1 are 4.6 to 7.1 times higher than the estimated Proposition 65 MADL-Equivalent trigger levels for Pb (MADL = Maximum Allowable Dose Levels under Proposition 65). For Group 2, the Consent Judgment triggers are 7.1 to 10.7 times higher and for Group 3, the Consent Judgment triggers are 5 to 5.6 times higher than the estimated MADL-Equivalent trigger levels for Pb.
9. Under *status quo* conditions, 56, 20, and 42 percent of the chocolate products in Cacao Groups 1, 2, and 3 are already compliant with the MADL-Equivalent triggers for Pb, respectively.
10. Under *status quo* conditions, chocolate products in Cacao Groups 1, 2, and 3 are already 57, 35, and 42 percent compliant, respectively, with my recommended Proposition 65 triggers for Pb.
11. Premium or specialty chocolate products labeled as "certified organic" or "single origin" do not appear to contain significantly different levels of Pb contamination than those that are sold as blended and conventionally grown (i.e., "bulk" chocolates). This is consistent with the source of Pb contamination being from environmental sources during processing rather than from the agricultural methods used or the lack of blending of beans from different growing regions. These results provide a compelling argument that no matter where and how cocoa is grown, additional measures must be taken to reduce the environmental contamination of beans with Pb using methods such as what the committee reviewed and evaluated in the Phase Two report.
12. With a 50 percent reduction in Pb from the implementation of Phase Two Pb reduction strategies, greater than 75 percent of the products in all three cacao groups would be compliant with my recommended triggers. It is conceivable that more than 95 percent of chocolate products available in California could meet my recommended trigger levels with a 60 to 75 percent reduction efficiency after fully implementing the Phase Two Pb reduction strategies.
13. In the future, as more analytical data on chocolate products are collected, the analysis of appropriate trigger levels should be revisited. I recommend that individual manufacturers routinely test their own products for both Pb and Cd as part of a routine surveillance plan to identify patterns of contamination in chocolate products and to assist in determining specific sources of contamination for further remediation.

I also recommend that an independent third-party laboratory continue to test chocolate products in California for Pb and Cd levels to build on the existing databases and to track changes in contamination levels as remediation measures are implemented. Furthermore, I recommend that California-specific sales and consumption data for chocolate products in Cacao Groups 1, 2, and 3 be compiled and compared to the AYS testing data representation of products in these groups. The compliance percentages and the trigger levels can then be adjusted if necessary.

General Approach

1. Effective implementation of Pb and Cd reduction strategies for cocoa beans should follow an approach that is based on three guiding principles: surveillance, intervention, and education:

    a. Surveillance in this context would include measuring post-harvest Pb and Cd levels in whole beans and processed beans and products and at various stages before shipping and then inside the chocolate manufacturing facility during processing. Furthermore, environmental monitoring of soil levels for both Pb and Cd would also be helpful to "map" areas where levels of these two metals in the soil are most problematic (i.e., "hot spots"). Although understanding Pb and Cd levels in the final products will be necessary to implement Proposition 65 negotiated triggers, monitoring in the field (e.g., wet beans, fermenting beans, drying beans, and the final product ready for shipping) and in the facility (e.g., pre-winnowing, post-winnowing, liquor, powder) would provide a better understanding of the effectiveness of implemented reduction measures. In essence, surveillance is the key to better understanding Pb and Cd contamination of the raw cocoa bean and manufactured chocolate products in terms of variability, sources of contamination, regional-specific hot spots, trends in reduction or increased contamination, and effectiveness of mitigation measures.

    b. Intervention would be the implementation of better agricultural, manufacturing, and business strategies for Pb and Cd reduction described and evaluated in the Phase 2 report. The Expert Committee identified 15 strategies that when applied individually or in combination with others offer a high degree of confidence in feasibility and effectiveness that Pb and Cd reductions in chocolate products would be observed. There were also five other strategies that offer a medium degree of confidence.

    c. Education would include proper training, communication, and oversight of implementation activities along with ensuring that all people involved in the growing, processing, and handling of beans understand the reasons their actions are important.

2. The application of a precautionary approach to estimate and recommend public health-based trigger levels for warning consumers under Proposition 65 is also warranted for chocolate products. In this context, the reduction of Pb and Cd to the lowest levels feasible in chocolate products is essential to protect any consumer from harm, which is a fundamental intent of the law. This is especially important considering there is no age limit for the consumption of chocolate products; exposure to chemicals in chocolate products begins *in utero* and extends the full lifespan of an individual. Furthermore, a precautionary approach encourages decision-making based on the data and information on hand, thereby avoiding "paralysis by analysis." As more data are collected, earlier decisions can be revisited and modified as appropriate in the future.

3. According to California legislation, those products for which public health protective levels cannot be met are required to carry an appropriately worded Proposition 65 notification warning consumers and users of these products about potential exposures to toxic chemicals in those products. It does not mean these products cannot be sold in California or consumed. This information is intended to educate consumers by providing science and risk-based information to assist them in making decisions regarding their purchase and how they use the product. However, in the event public health trigger levels cannot be met in a smaller percentage of products, the manufacturers would have the option of notifying consumers with a warning, reformulating their product to remove (or reduce levels of) the chemical of concern, or removing noncomplying products from the California marketplace (this third option would be unusual and difficult to do). Manufacturing chocolate products that contain single origin sourced cocoa beans and/or high content cacao solids is a business decision. It should be noted that the statutory language exempts companies with fewer than 10 employees.

4. Proposition 65 does not prescribe a specific percentage of population that must be considered when enforcing consumer protection measures, although the intent of the law is to protect any individual from exposure to toxic substances in consumer products. Proposition 65 also does not prescribe a specific percentage of products under a specific category (e.g., chocolate products), which must be compliant with Proposition 65 enforcement triggers. In other words, there is no prescriptive target (e.g., 50 percent of products) under a specific category that must be compliant with Proposition 65. It is reasonable to assume that most products (e.g., 75 percent) should be compliant and those that are not would require warning notifications or further enforcement action. However, it is also reasonable to assume that achieving nearly 100 percent compliance with a Proposition 65 trigger is probably not feasible, especially when the levels of a toxic chemical contaminant vary widely within a category of product. The Phase One Report provides an in-depth analysis of the Pb and Cd contamination levels in cocoa beans and manufactured products (such as liquor, cocoa powder, cocoa butter) and the results clearly demonstrate a wide variation in contaminant levels within a cocoa producing country and as well as variation between countries. The AYS chocolate product data demonstrates a wide variation in Pb or Cd levels between products, but the data are not helpful to analyze Pb or Cd variation in a single chocolate product produced by the same manufacturer.

5. Proposition 65 Safe Harbor Levels (e.g., MADLs) are developed using results from scientific experimental or epidemiologic studies researching the potential or probability of adverse health effects in humans following exposure to a chemical. Safe Harbor Levels also include additional "safety" factors to address variability in human conditions and responses to chemical exposure and to account for differences between animals and humans, among other factors. This practice ensures that the Safe Harbor Levels are exclusively health-based and not modified by technical feasibility or economic factors. Therefore, any trigger levels adopted for chocolate products that are solely based on the MADL would, by definition, be health-based triggers. Trigger levels above the "MADL Equivalent" would be defined as modified health-based target levels and therefore would be less protective of human health under Proposition 65.

6. I determined and I recommend that the sampling and analytical data collected by AYS for Pb and Cd in chocolate products purchased in California should be used as the primary source of data representing the range of Pb and Cd concentrations consumers could be exposed to from the use of these chocolate products. It is these types of products that would be subject to Proposition 65 warnings. Although the AYS data are limited by a finite number of products sampled and number of analyses conducted, the AYS testing from 2014-2020 provides a robust and technically clean dataset to inform the Expert Committee in the Phase 3 discussions. There are other datasets such as the SD data analyzed and summarized in the Phase One report, but these data are less directly relevant compared to the AYS data and the considerable technical limitations of those data complicate interpretation (see Phase One Report, Section 3 for a complete description of these limitations). Furthermore, data collected by the SDs and provided to the Expert Committee were "blinded" in such a way that it would be impossible for the committee to trace whole bean, chocolate liquor, and cocoa powder lots to California. Although the Expert Committee inquired, the SDs did not provide any additional data on Pb and Cd levels in chocolate products (in California or elsewhere) after the initial submission of analytical data to the Expert Committee for Phase One. Therefore, the only data available to the Expert Committee on Pb and Cd concentrations in chocolate products sold in California are from AYS.

7. The SDs did not provide the Expert Committee with data on the sale of chocolate products in California in general or specific to the cacao content groups prescribed in the Consent Judgment. These data are likely proprietary and not available to the public. I searched the Internet for information that could assist in the analysis of relative sales of products in the three cacao content groups, but I found no useful data. These data would be necessary to understand and compare the percentages of chocolate products in the three cacao content groups sold and presumably consumed in California. Without specific sales data, the AYS product testing data must be used as a surrogate for actual relative sales and consumption data, which is not likely to represent the actual relative consumption of these products since it appears the AYS product selection was based on convenience and representation and not on sales data.

8. The Consent Judgment provides the Expert Committee a timeline to consider in recommending new Proposition 65 trigger levels. The new trigger levels would be applicable six years after the "compliance date," which is one year after the "effective date" of the Consent Judgment, which is the date the document was entered by the Court (February 15, 2018). Roughly estimating, this means the new triggers would be effective starting sometime after February 15, 2025. However, due to delays experienced by the Expert

Committee in delivering the reports, the anniversary of the compliance date might change. Regardless, for the purposes of my analysis and report, I am assuming that the reduction measures implemented beyond existing agricultural, manufacturing, and business practices would need to be developed within a four-year period, which started when the Expert Committee delivered the Phase Two Report on April 12, 2021. Those promising Pb or Cd reduction measures with longer implementation periods would potentially allow for lower trigger levels to be adopted later.

9. In the future, as more analytical data on chocolate products are collected, the analysis of appropriate trigger levels should be revisited.

Methodology

Data Relied On:

1. Initially, I downloaded the AYS product testing data from the organization's website: https://www.asyousow.org/environmental-health/toxic-enforcement/toxic-chocolate and converted the data into an Excel spreadsheet. The initial database includes samples collected between 2014 and 2018. Later, I learned that AYS had accumulated additional data from further sampling between 2018 to 2020. I was able to obtain the complete chocolate product testing and analytical results spreadsheet from AYS. This file contains records for product sampling between 2014 and 2020. There are analytical data for Pb and Cd concentrations for an estimated 587 independent chocolate products in the database. I understand that AYS sampling and testing is ongoing and more data might become available in the future.
2. I manually checked the data between both databases (the original and the expanded databases) for duplicates and missing information. Once "cleaned" and verified I used these data for my analyses and to inform my decisions and recommendations. In addition, I referred to the SD analyses I conducted in the Phase One Report for additional information on Pb and Cd concentrations in cocoa beans at various stages of processing.
3. The expanded AYS database contains the following information: product company and brand names, dates purchased and analyzed, serving size information from the packaging when available, laboratory name and method used, results for cadmium and lead (ppm), and reporting limits. In addition, I obtained the analytical limits of detection (LOD) for the laboratories for Cd and Pb. The LODs varied between laboratories and among the products tested but the differences were negligible for the purposes of analyzing the data based on percentiles and using descriptive statistics such as calculation of a mean. Therefore, I used the LODs for Pb and Cd from the primary laboratory used by AYS and divided those LODs by the square root of 2 (see Phase One Report, Section 3.3.2 for explanation) and inserted those values in the place of "non- detects."
4. If available on the packaging, AYS listed the percent cacao for each chocolate product tested. However, in many cases this information was missing. Therefore, I searched online for individual products for cacao content as reported by the company. The information, if found, was sometimes provided on the company's website or on websites selling the chocolate products. I found the information on cacao content was most reliably provided for "premium" or "high-end" chocolate products where cacao content reportedly exceeds 65 percent. For products in the Group 1 category ("up to 65 percent cacao"), the specific cacao content was often not reported anywhere. These products are generally of lower cacao content (50 percent or less) typically seen for mass produced milk chocolates, lower-end dark chocolates, and other products with multiple ingredients other than cacao solids. In those cases where no cacao content could be confirmed, I designated the cacao content as <65 percent and folded them into Group 1 for Pb and Cd. I also acknowledge the assistance of committee member Mr. Tim Ahn who reviewed my work and identified some discrepancies, which I corrected.
5. The AYS product testing data is roughly broken down as follows: 40 percent of the products tested fall into Cacao Group 1 (up to and including 65 percent cacao), 48 percent in Group 2 (more than 65 percent up to and including 95 percent cacao), and 12 percent in Group 3 (greater than 95 percent cacao). As noted above in the General Approach section, it is unlikely these data represent the actual relative sales and consumption of these products in California.
6. I also relied exclusively on the Pb and Cd reduction strategies described and evaluated by the Expert Committee in the Phase Two Report. I relied on the conclusions of the committee from this report "as is,"

without any further interpretation or revision. Any deviation from those consensus findings at this juncture would be detrimental to the process and could jeopardize the validity of the investigation.

Calculation of MADL-Equivalent Triggers for Pb:

1. Section 6.2 of the Consent Judgment includes proposed Proposition 65 trigger levels (in ppm) for both Pb and Cd under three categories of chocolate products based on cacao content (these Consent Judgment triggers are presented in Tables 3A and 3B). The three prescribed groupings are "up to 65 percent cacao" (Group 1), "greater than 65 percent and up to 95 percent cacao" (Group 2), and "greater than 95 percent cacao" (Group 3). The trigger levels were presented at two levels, a "high" trigger, and a slightly "lower" trigger (Trigger 1 and Trigger 2, respectively). There are three "high" trigger levels for both Pb and Cd and three "lower" trigger levels for both Pb and Cd for a total of 12 Consent Judgment triggers. There is no information in the Consent Judgment explaining how these trigger levels were calculated or the original basis for the trigger levels.
2. It does not appear that the Consent Judgment includes trigger levels estimated based on the health-based MADL for Pb (0.5 µg/day). The Expert Committee was charged with evaluating the feasibility of meeting the trigger levels listed in the Consent Judgment, or any trigger levels lower than the six trigger levels for Pb. Therefore, it is important to calculate a "MADL-equivalent" trigger level to estimate the lower bound health-based trigger levels required under Proposition 65 for Pb in chocolate products.
3. To calculate trigger levels based on the health-based MADL, an estimate of serving size is required. Serving sizes for many of the chocolate products in the AYS database appear to be based on information on the packaging. To verify the accuracy of the serving sizes provided and to obtain missing information, I researched approximately 80 percent of the chocolate products by searching online for nutrition labels. In several cases, especially for products in the greater than 65 percent cacao groupings, the information on the packaging was inconsistent with information provided on the company's website. Serving sizes were corrected based on the best source available.
4. From the serving size data for the chocolate products tested, I calculated the mean serving sizes for products in Group 1, Group 2, and Group 3 as 37 grams, 37 grams, and 12.6 grams, respectively. These estimates are generally in agreement with the results reported from consumption surveys in the US, albeit the available surveys are at least about 30 years old or older (https://www.ars.usda.gov/ARSUserFiles/80400530/pdf/portion.pdf).
5. Using the formula:

   MADL Trigger (µg/g or ppm) = MADL (µg/day) / serving size (g/day)

   I calculated the MADL Equivalent triggers for Pb to be 0.014, 0.014, and 0.040 ppm for Groups 1, 2, and 3, respectively (Table 7C).

Data Analysis:

1. The Consent Judgment Section 5.4 provides a definition of "outlier" pertaining to analytical results from product testing that were deemed outside the working range for the purposes of determining Proposition 65 compliance. The definition is "any single test result obtained that exceeds 0.300 ppm of lead for a product with less than 95 percent cacao content or 0.450 ppm of lead for a product with 95 percent or greater cacao content; or 0.900 ppm of cadmium for a product with less than 95 percent cacao content or 1.92 ppm of cadmium for a product with 95 percent or greater cacao content shall be deemed a potential 'Outlier'." Using this definition of outlier, no outliers were identified for Pb in the AYS chocolate product testing database.
2. After sorting the data for Cacao Groups 1, 2, and 3 for both Pb and Cd, I performed a variety of basic statistical analyses to determine central tendency (e.g., mean and median), the degree the data conform to a normal distribution of the data, range of values, variance, etc. In addition, I evaluated the data based on percentile distributions from 50 percent to 95 percent to better understand the distribution of the data. The results of this basic statistical descriptive analysis indicated the results to be considerably skewed to the lower range of contamination levels and the overall distribution of test results could not be considered normally distributed (see Phase One Report, Section 3.3.1 for explanation). Therefore, I made the decision

to rely primarily on the percentile distribution of the data values, using the median as the central tendency (that is, the 50th percentile) rather than the mean (or average).

3. Most of my remaining analysis of the AYS data focused on comparing the test results for Pb with the three levels of Proposition 65 triggers (Trigger 1, Trigger 2, and the MADL Equivalent trigger) to determine the percent reduction needed to comply with these levels. Using the formula:

   Percent Reduction = [conc 1 (ppm)] – [trigger value (ppm)] / [conc 1 (ppm)] x 100

   I calculated the percent reduction for all AYS data for all Pb trigger levels. In addition, I calculated the percent reduction needed for compliance for different groupings of data based on percentile of distribution (e.g., 50 percent, 75 percent, 90 percent, 95 percent). Positive numbers (in red font) represent the percent reduction needed to reach the trigger level whereas negative (black font) numbers mean the product concentration is below the trigger level (Table 3A-C).

4. In addition to the analysis of Pb in products in Cacao Groups 1, 2, and 3, I evaluated the data for upward or downward trends in Pb levels in the AYS chocolate products sampled from 2014 to 2019 (Figure 1). The results indicate a potential downward trend in Pb levels for Cacao Content Group 1. I also analyzed the differences between 2014 and 2019 in Group 1 using the Excel t-test application and confirmed the respective mean values for 2019 were significantly ($p \leq 0.05$) lower (by 56 percent) than for 2014. Evaluating trends in Cd or Pb reductions would be a more effective and informative tool when selecting for a specific company, and/or a specific product, and/or a specific bean origin, for example.

Table 3. Summary of Reduction Percentages to Reach Pb Trigger Levels for all AYS Tested Chocolate Products

A. Up to 65% Cacao				
Percentile	**Pb Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to P65 Trigger**
50th	0.012	-733	-442	-17
75th	0.022	-355	-195	36
90th	0.032	-213	-103	56
95th	0.040	-150	-63	65
B. >65% and ≤95% Cacao				
Percentile	**Pb Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to P65 Trigger**
50th	0.028	-436	-257	50
75th	0.039	-285	-156	64
90th	0.052	-188	-92	73
95th	0.074	-103	-35	81
C. >95% Cacao				
Percentile	**Pb Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to P65 Trigger**
50th	0.050	-350	-300	20
75th	0.080	-181	-150	50
90th	0.110	-105	-82	64
95th	0.140	-61	-43	71

5. I also calculated whether there were statistically significant differences in Pb levels in the AYS chocolate products from one year to another. It should be noted that for the most part, the AYS analytical test results data were not normally distributed within a sample year. This could reduce the validity of basic statistical analyses. Nevertheless, I applied an analysis of variance (ANOVA) for a single variable for each Cacao Content Group to gain more understanding of the nature of the sampling data. The results of the ANOVA tests indicate the mean levels from year to year were not statistically different except for the mean values

for Pb concentrations in Cacao Content Group 1 (*p≤0.05*). Small sample sizes for some of the years along with high levels of variance (and large standard deviations around the mean) likely contribute to the lack of statistically significant differences from year to year.

6. I also conducted an analysis of “single origin” cocoa bean chocolate products. Chocolate manufacturers that market products as using only “single origin” cocoa beans assert that their product only uses cocoa beans from one source of beans grown in a particular cacao growing country, and in some cases the beans used are specified to a specific cultivar (or variety). These single origin chocolate products do not use a blend of beans from more than one origin. I searched all products in the database that were labeled or reported to be “single origin.” After sorting the data for “blended” versus “single origin,” I calculated the percent reduction needed for compliance to meet the various trigger levels. The results are summarized in Table 4A-C. Although there are some small observable differences between single origin and blended products among the percentiles and the reduction levels needed to meet trigger levels in all Cacao Groups 1 and 2, these are not statistically different using Excel’s t-test application. However, For Cacao Group 3, there is a statistically significant lower mean Pb concentration ($p<0.05$) in chocolate products with single origin beans compared to products made with blended beans. In addition, in Cacao Group 3, single origin chocolate products generally appear to have lower reduction levels needed to meet the three trigger levels. Single origin chocolate products represent about 3 percent of the total products in Cacao Group 1 analyzed for Pb by AYS. For Groups 2 and 3, single origin products represent about 36 percent and 31 percent of the total products in those groups, respectively. Overall, single origin chocolates represent about 22 percent of all the products analyzed for Pb by AYS.

7. I also conducted an analysis of Pb concentrations in chocolate products manufactured from “certified organic” cocoa beans and compared the results to chocolate products made from conventionally grown cocoa beans. I searched all products in the database that were labeled or reported to be “certified organic” and verified the results against the information provided on the manufacturers’ websites. After sorting the data for conventional versus organic, I calculated the percent reduction needed for compliance to meet the various trigger levels. The results are summarized in Table 5A-C. Although there are small observable differences between organic bean and conventional bean products among the reduction levels needed to meet trigger levels in all three cacao content groups, these differences are not statistically significant based on the comparison of mean Pb levels using the t-test. Certified organic chocolate products represent about 20 percent of the total products in Cacao Group 1 analyzed for Pb by AYS. For Groups 2 and 3, certified products represent about 30 percent and 54 percent of the total products in those groups, respectively. Overall, certified organic chocolates represent about 29 percent of all the products analyzed for Pb by AYS.

8. Finally, I analyzed Pb concentrations in chocolate manufactured from combining results from “certified organic” and/or “single origin” cocoa bean tested products and compared those results with the results of chocolate products made from unblended, conventionally grown cocoa beans. After sorting the data for conventional blended versus organic and/or single origin, I calculated the percent reduction needed for compliance to meet the various trigger levels. The results are summarized in Table 6A-C. Although there are small observable differences between combined organic and/or single origin bean and conventional blended bean products among the reduction levels needed to meet trigger levels in all three cacao content groups, these differences are not statistically significant based on the comparison of mean Pb levels using the t-test. The combination of certified organic and single origin chocolate products represents about 21 percent of the total products in Cacao Group 1 analyzed for Pb by AYS. For Groups 2 and 3, the combination of certified organic and single origin chocolate products represents about 54 percent and 61 percent of the total products in those groups, respectively. Overall, the combination of certified organic and single origin chocolate products represents about 42 percent of all the products analyzed for Pb by AYS.

Figure 1. AYS Chocolate Samples: Mean Pb Concentrations Sampling Years 2014 to 2019

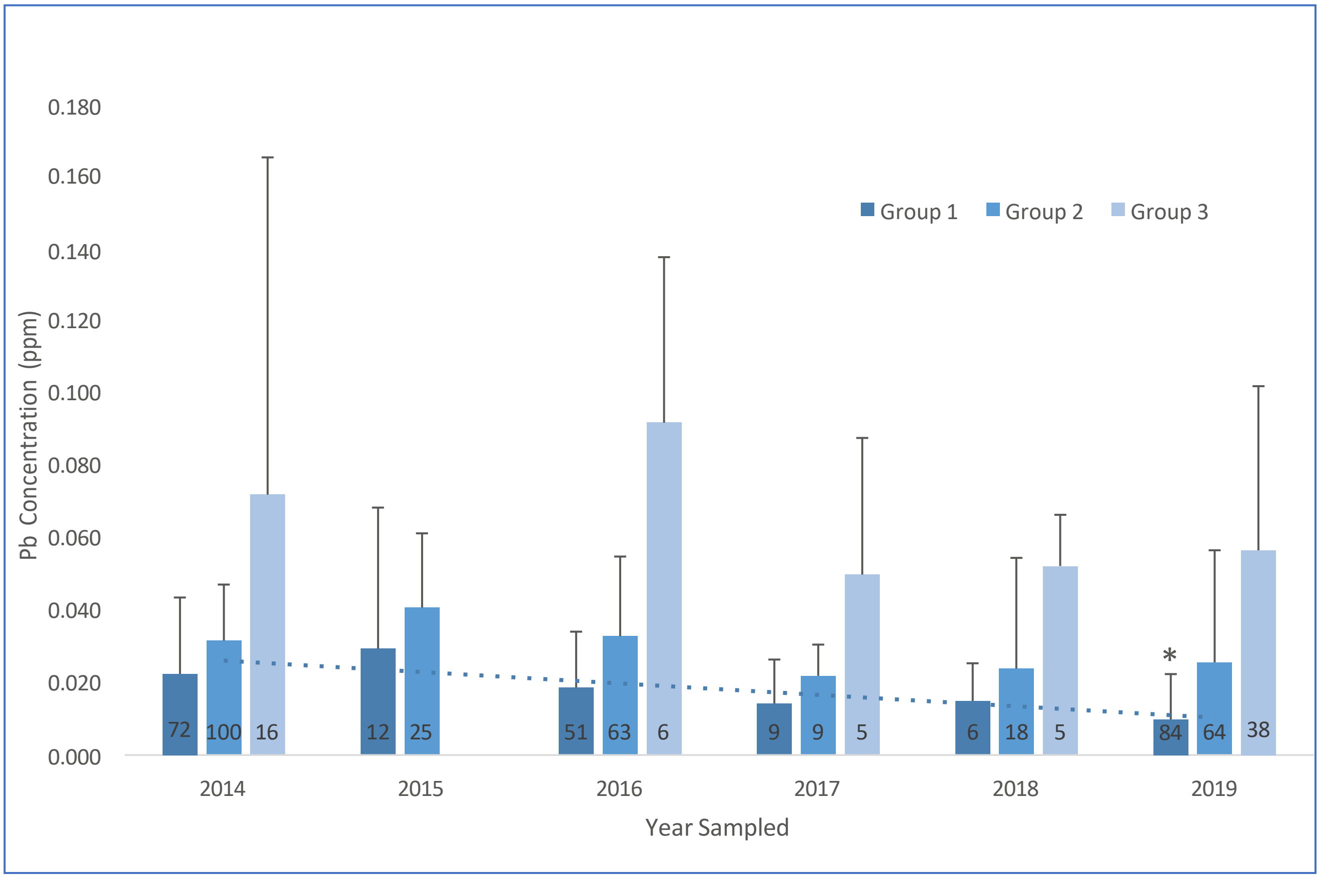


Figure 1 Legend: Values denoted at the base of each bar are the number of samples. Error bars denote the standard deviation around the mean. Dotted line is the estimated trend for Cacao Group 1 calculated using Excel's trend analysis formula. *p<0.05, t-test.

9. Table 5 shows the feasibility (as a percentage of compliance) of cocoa growing, processing, manufacturing, and business practices to meet the three trigger levels based on the concentrations of Pb in chocolate products analyzed by AYS. This table presents the compliance percentage for the products in each cacao content group (1, 2, and 3). The percentage of total products already in compliance with the three levels of triggers (without any further mitigation measures) is shown in the first color-coded "Compliance" column in Tables 5A-C. These results are discussed in more detail below. The second color-coded "Compliance" column in Tables 5A-C shows the percent compliance for all products assuming feasible levels of reduction for Pb following the implementation of Phase Two reduction strategies recommended by the Expert Committee. These calculations are discussed in more detail below.

10. In addition to the three aforementioned trigger levels, I calculated a fourth set of triggers (Table 7D). I propose this fourth set of triggers as the triggers to be adopted in 2025 over the proposed trigger levels in the Consent Judgment. I calculated these triggers based on a compliance percentage for all products of 75 percent or greater assuming the implementation of Phase Two strategies meet feasible reduction amounts for Pb following the application of only those strategies the Expert Committee agreed would have a high level of confidence that the reductions could be met in the given time frames (Phase Two Report). These calculations are discussed in more detail below.

Table 4. Summary of Percent Reduction Needed to Reach Pb Trigger Levels: Single Origin vs. Blended Beans

A. Up to 65% Cacao				
Data for Blended Beans				
Percentile	**Pb Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.011	-809	-491	-27
75th	0.021	-376	-210	33
90th	0.032	-213	-103	56
95th	0.040	-150	-63	65
Data for Single Origin Beans				
Percentile	**Pb Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.021	-376	-210	33
75th	0.021	-376	-210	33
90th	0.026	-285	-150	46
95th	0.040	-150	-63	65
B. >65% and ≤95% Cacao				
Data for Blended Beans				
Percentile	**Pb Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.030	-400	-233	53
75th	0.038	-295	-163	63
90th	0.050	-200	-100	72
95th	0.059	-154	-69	76
Data for Single Origin Beans				
Percentile	**Pb Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.032	-369	-213	56
75th	0.040	-275	-150	65
90th	0.072	-108	-39	81
95th	0.080	-88	-25	83
C. >95% Cacao				
Data for Blended Beans				
Percentile	**Pb Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.060	-275	-233	33
75th	0.097	-131	-105	59
90th	0.130	-73	-54	69
95th	0.175	-29	-14	77
Data for Single Origin Beans				
Percentile	**Pb Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.035	-543	-471	-14
75th	0.050	-350	-300	20
90th	0.074	-206	-172	46
95th	0.099	-128	-103	59

Table 5. Summary of Percent Reduction Needed to Reach Pb Trigger Levels: Certified Organic vs. Conventional Beans

A. Up to 65% Cacao				
Data for Conventional Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.011	-809	-491	-27
75th	0.021	-376	-210	33
90th	0.030	-233	-117	53
95th	0.034	-194	-91	59
Data for Certified Organic Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.014	-614	-364	0
75th	0.023	-335	-183	39
90th	0.046	-117	-41	70
95th	0.069	-45	6	80
B. > 65% ≤ 95% Cacao				
Data for Conventional Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.020	-650	-400	30
75th	0.030	-400	-233	53
95th	0.083	-81	-20	83
90th	0.048	-213	-108	71
Data for Certified Organic Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.030	-400	-233	53
75th	0.040	-275	-150	65
95th	0.071	-111	-41	80
90th	0.053	-183	-89	74
C. > 95% Cacao				
Data for Conventional Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.056	-302	-257	29
75th	0.080	-181	-150	50
90th	0.110	-105	-82	64
95th	0.122	-84	-64	67
Data for Certified Organic Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.050	-350	-300	20
75th	0.072	-213	-178	44
90th	0.112	-101	-79	64
95th	0.138	-63	-45	71

Table 6. Summary of Percent Reduction Needed to Reach Pb Trigger Levels: Combined Certified Organic and Single Origin Vs. Conventional Blended Beans

A. Up to 65% Cacao				
Data for Conventional Blended Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.011	-809	-491	-27
75th	0.020	-400	-225	30
90th	0.030	-233	-117	53
95th	0.035	-190	-88	59
Data for Organic and/or Single Source Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.015	-567	-333	7
75th	0.024	-321	-174	41
90th	0.042	-139	-55	67
95th	0.067	-50	2	79
B. > 65% ≤ 95% Cacao				
Data for Conventional Blended Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.028	-436	-257	50
75th	0.038	-295	-163	63
90th	0.050	-200	-100	72
95th	0.055	-173	-82	75
Data for Organic and/or Single Source Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.027	-456	-270	48
75th	0.039	-285	-156	64
90th	0.059	-153	-69	76
95th	0.084	-78	-18	83
C. > 95% Cacao				
Data for Conventional Blended Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.056	-302	-257	29
75th	0.080	-181	-150	50
90th	0.110	-105	-82	64
95th	0.122	-84	-64	67
Data for Organic and/or Single Source Beans				
Percentile	**Lead (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.050	-350	-300	20
75th	0.070	-221	-186	43
90th	0.110	-105	-82	64
95th	0.130	-74	-54	69

11. Table 7 shows the feasibility (as a percentage of compliance) of cocoa growing, processing, manufacturing, and business practices to meet the three trigger levels based on the concentrations of Pb in chocolate products analyzed for Pb by AYS. This table presents the compliance percentage for the products in each cacao content group (1, 2, and 3). The percentage of total products already in compliance with the three levels of triggers (without any further mitigation measures) is shown in the first color-coded "Compliance" column in Tables 7A-C. These results are discussed in more detail below. The second color-coded "Compliance" column in Tables 7A-C shows the percent compliance for all products assuming feasible levels of reduction for Pb following the implementation of Phase Two reduction strategies recommended by the Expert Committee. These calculations are discussed in more detail below.

12. In addition to the three aforementioned trigger levels, I calculated a fourth set of triggers (Table 7D). I propose this fourth set of triggers as the triggers to be adopted in 2025 instead of the proposed trigger levels proposed in the Consent Judgment. I calculated these triggers based on a compliance percentage for all products of 75 percent or greater assuming the implementation of Phase Two strategies meet feasible reduction amounts for Pb following the application of only those strategies for which the Expert Committee has a high level of confidence that the reductions could be met in the given time frames (Phase Two Report). These calculations are discussed in more detail below.

Table 7. Compliance Percentage of AYS Tested Products with Various Pb Triggers

Table 7A. Proposition 65 Compliance Under Consent Judgment Trigger 1			
Cacao Content	**Trigger 1 (ppm)**	**Compliance***	**Compliance****
≤65%	0.100	98%	100%
>65 to 95%	0.150	99%	100%
>95%	0.225	97%	100%

Table 7B. Proposition 65 Compliance Under Consent Judgment Trigger 2			
Cacao Content	**Trigger 2 (ppm)**	**Compliance***	**Compliance****
≤65%	0.065	98%	99%
>65 to 95%	0.100	100%	100%
>95%	0.200	96%	100%

Table 7C: Proposition 65 Compliance Under Calculated MADL Equivalent Triggers			
Cacao Content	**MADL Trigger (ppm)**	**Compliance***	**Compliance****
≤65%	0.014	56%	85%
>65 to 95%	0.014	20%	52%
>95%	0.040	42%	75%

Table 7D: Proposition 65 Compliance Under DiBartolomeis Proposed Triggers			
Cacao Content	**MJD Trigger (ppm)**	**Compliance***	**Compliance****
≤65%	0.015	57%	88%
>65 to 95%	0.020	35%	81%
>95%	0.040	42%	75%

* Percent product compliance without implementation of any additional recommended strategies (*status quo*).
** Percent compliance with an estimated 50 percent reduction in Pb and Cd following recommended strategy implementation.

≥75th percentile	<50th percentile
≥50th percentile and <75th percentile	

Results and Discussion: Pb Trigger Levels

1. The Expert Committee concluded in the Phase One Report that most if not all the Pb contamination in chocolate products originated from environmental contamination of cocoa beans during post-harvest processing. Therefore, contaminating Pb levels in cocoa beans above the background nib concentrations (ranging from <1 to about 5 ppb) could be completely avoided by implementing effective methods that protect harvested beans from the Pb contaminated soil and dust. Therefore, it is theoretically possible that Pb contamination of chocolate products can be reduced by nearly 100 percent by fully implementing effective mitigation strategies (alone or in combination) such as those described and evaluated in the Phase Two Report.

2. In practice, it is not likely that the Pb reduction strategies could reduce Pb levels in chocolate to "background" levels for all chocolate products. However, based on the analysis of the AYS chocolate product database, the industry can already achieve analytical "non-detect" levels (less than 1 ppb) of Pb in chocolate products, especially for those with lower cacao content, without doing any further mitigation. For the 587 chocolate products in the AYS database with a test result reported for Pb, over 15 percent of the products were measured at or below 5 ppb and 27 percent were at or below 10 ppb. It is of note that the percentage of chocolate products in Groups 2 and 3 with Pb levels at or below 10 ppb for "single origin" (21 percent) is about double the corresponding percentage (11 percent) of "blended" chocolate products. These results support the theoretical possibility that preventing environmental dust/soil contamination of post-harvested cocoa beans during fermentation, drying, and transport, and ensuring only the highest standard of quality assurance/quality control (QA/QC) within manufacturing facilities could reduce Pb levels in chocolate products to below the Proposition 65 MADL-Equivalent triggers. However, I should also emphasize that Pb contamination has not been a focus to date for the chocolate industry, or at least the effort to investigate sources of Pb and reduce Pb levels has been less than the effort expended for Cd. Therefore, there is little information to verify or refute the effectiveness of the proposed Pb reduction strategies presented in the Phase Two Report.

3. Whole bean Pb and Cd monitoring data collected by the SDs and submitted to the Expert Committee were compiled, analyzed, and reported in the Phase One Report. These data have no specificity for the production of chocolate products sold in California. Figure 4B in the Phase One Report shows whole bean Pb concentrations from the countries of origin. Although statistical comparisons among countries was not feasible due to data and reporting limitations, the results do visually support a trend that certain cocoa growing countries have more of a whole bean (i.e., outer shell) Pb contamination problem than others. In particular, the African countries of Nigeria and Tanzania and possibly Ivory Coast and Cameroon appear to have higher median levels than the other countries of origin reported, including for Ghana, another African country. For US manufacturing facilities, the Pb levels in chocolate liquor tend to mirror the whole bean Pb contamination profile (Figure 10B, Phase One Report) for African bean origins. I should note that from these data, blending beans also appears to impact Pb concentrations in chocolate liquor, which is a necessary consideration when relying on bean blending to lower Cd levels.

4. Two better agricultural practice reduction strategies for Pb reduction received high feasibility confidence scores from the Expert Committee (Table 1, Phase Two Report). In addition, three better business practices and one better manufacturing practice, which address Pb reduction issues, also received high feasibility confidence scores from the Expert Committee. Other strategies to reduce Pb contamination fell into the medium feasibility confidence category (Table 1, Phase Two Report).

5. Based on the Expert Committee's evaluation of the high feasibility confidence Pb reduction strategies in the Phase Two Report, Pb reduction strategies can be implemented within a range of time starting at less than one year to about five years (Tables B-19, B-20, B-23, B-26, B-27, and B-28, Phase Two Report). For some strategies, the longer time estimate is due to the possibility that it might take some additional time for the industry (including growers and processors) to match implementation strategies with the growing regions as well as some time to conduct further focused monitoring to better determine where the Pb contamination "hot spots" are. In those identified hot spots, a more rigorous effort might be required to reduce Pb contamination. Uncertainty notwithstanding, I deduce within a reasonable degree of scientific certainty that within one to four years after the start of the implementation period, measurable reduction in Pb will be observed following the implementation of these Pb reduction strategies individually and most effectively, in combination. This timeframe aligns with the Consent Judgment.

6. The six, high feasibility confidence Pb reduction strategies offer different approaches to changing agricultural practices around processing cocoa and each could provide from 10 percent to 25 percent to greater than 25 percent reduction in Pb levels in chocolate products (Tables B-19, B-20, B-23, B-26, B-27, and B-28, Phase Two Report). Combining these reduction strategies could achieve Pb reductions of 50 to 80 percent in chocolate products in a relatively short timeframe once implemented. Because the magnitude of Pb contamination issues vary among cocoa growing countries and probably growing regions within a country, it would be most efficient to first "map" hot spots in these regions and then implement strategies as appropriate. Furthermore, facility operation in the US and other countries might also have different QA/QC measures and capabilities with respect to effectiveness of producing cleaner intermediate products reflected by the Pb levels in the final products. Standardizing QA/QC methods across the industry to ensure that only the highest standards are met should raise the bar for lagging countries and facilities and reduce Pb contamination in associated chocolate products.

7. For all products in Cacao Groups 1, 2 and 3 (based on cacao content as prescribed in the Consent Judgment), the results of the AYS testing demonstrate nearly 100 percent compliance with the two Pb Proposition 65 triggers defined in the Consent Judgment (Tables 7A and 7B) without any further mitigation being taken (i.e., *status quo*). In other words, almost all (96 percent or greater) chocolate products on the market in California are already compliant with the Pb trigger levels defined in the Consent Judgment.

8. In addition, I calculated the percent compliance of products with Pb below the Consent Judgment Proposition 65 triggers for all three Cacao Content Groups (1, 2, and 3) without considering any additional Pb reduction strategies (i.e., *status quo*). About 90 percent compliance of chocolate products can be achieved without any further Pb reduction efforts (as described and evaluated in the Phase Two Report) with triggers set at 0.030 ppm for Group 1, 0.050 ppm for Group 2, and 0.100 ppm for Group 3. These should be the highest Proposition 65 triggers for Pb considered moving forward.

9. However, the charge to the Expert Committee was to evaluate reduction strategies (in the Phase Two Report) that could feasibly reduce Pb in chocolate products below existing levels. The Expert Committee should apply this knowledge to evaluate Proposition 65 trigger levels in Phase Three based on the adoption and implementation of the more feasible reduction strategies. Therefore, any recommendations for triggers above the calculated trigger levels in paragraph number 8 (above) by the Expert Committee is not, in my opinion, fulfilling the charge of the committee as set out in the Consent Judgment. The experts identified 15 "high confidence," feasible reduction measures for both Cd and Pb in the Phase Two Report. Therefore, it is clear from the charge in the Consent Judgment that the experts must recommend lower trigger levels where feasible alternatives to the *status quo* were identified. Therefore, since the Consent Judgment Proposition 65 triggers for Pb can already be achieved at compliance levels of greater than 95 percent (Tables 7A and 7B), lower trigger levels must be considered in conjunction with feasible Pb reduction strategies.

10. The Consent Judgment Pb trigger levels for products in Cacao Group 1 are 4.6 to 7.1 times higher than the estimated Proposition 65 MADL-Equivalent trigger levels for Pb (Table 7C). For Cacao Group 2, the Consent Judgment triggers are 7.1 to 10.7 times higher than the estimated MADL-Equivalent trigger levels for Pb. For Cacao Group 3, the Consent Judgment triggers are 5 to 5.6 times higher than the estimated MADL-Equivalent trigger levels for Pb. As I mentioned previously, there is no information in the Consent Judgment as to how the prescribed triggers were developed; however, they appear not to be health-based triggers. Therefore, I investigated the effort required to ensure that most chocolate products would comply with the Proposition 65 MADL-Equivalent triggers for Pb.

11. As with the Consent Judgment triggers, many chocolate products in all three Cacao Groups are already compliant with the estimated MADL-Equivalent triggers for Pb (Table 7C) without implementing any new Pb reduction strategies. For Cacao Group 1, 56 percent of the products are already compliant with the MADL-Equivalent trigger. For Cacao Groups 2 and 3, the compliance percentages are 20 and 42 percent, respectively.

12. For the estimated MADL-Equivalent triggers to be met for 95 percent of chocolate products, reductions of Pb by as much as 81 percent in the final chocolate products would be required, depending on cacao content (Table 3). For example, to achieve compliance in 75 percent of the Cacao Group 1 products, a 36 percent reduction in Pb would be needed and to achieve 95 percent compliance, a reduction of 65 percent would be required (Table 3A). For Cacao Groups 2 and 3, Pb reductions 71 to 81 percent would be needed for 95

percent compliance with the MADL-Equivalent triggers whereas about a 50 to 60 percent reduction in Pb would be needed to achieve 75 percent compliance (Table 3B and 3C).

13. From the evaluations of the Pb reduction strategies and the estimated effort required to fully implement these strategies, I deduce that on the low end, a 50 percent reduction in Pb levels can be achieved in chocolate products with the implementation of Pb reduction strategies evaluated as high feasibility confidence by the Expert Committee in the Phase Two Report. Assuming a reduction percentage of at least 50 percent, I calculated Pb trigger levels that would be as health protective as possible but would achieve at least 75 to 80 percent compliance among all products in all three Cacao Content Groups (Table 7D).

14. There are two subcategories of chocolate products sold as "specialty" or "premium" chocolate products based on the origin of the cocoa beans and the methods (certified organic) used in growing the beans. For Pb contamination, the AYS test data for single origin bean chocolate products does not indicate that the business decision to not blend beans from different origins significantly impacts the final Pb concentrations. Likewise, the method of growing (i.e., certified organic vs. conventional methods) does not appear to have any impact on the final Pb concentrations in the chocolate products tested. This is consistent with the Expert Committee's conclusion that Pb contamination in chocolate products is from environmental contamination of harvested beans during processing (i.e., fermenting, drying, transporting) rather than contamination during growing. Because of the likely health benefits of certified grown agriculture due to the nonuse of conventional chemical pesticides and fertilizers, the expectation would be that organic certified cocoa beans might be "cleaner" (i.e., lower Pb contamination) than conventionally grown beans. Based on the AYS test data, however, this appears not to be the case probably because of the widespread practice of exposing unprotected wet beans to the environment during fermentation and drying. These results provide a compelling argument that no matter where and how cocoa is grown, additional measures must be taken to further reduce the environmental contamination of the wet beans by adopting the feasible "high confidence" Pb reduction strategies, which the Expert Committee described in the Phase Two report.

15. Based on my analyses of the AYS data, and consideration of the SD data and the Phase Two recommended Pb reduction mitigation measures, I recommend a trigger level of **0.015 ppm** (15 ppb) to be used for all chocolate products in Cacao Groups 1, which is approximately equal to the estimated MADL-Equivalent trigger of 0.014 ppm. For products in Cacao Group 2, I recommend a trigger level of **0.020 ppm** (20 ppb), which is 1.4 times higher than the estimated MADL-Equivalent trigger. For products in Cacao Group 3, I recommend a trigger level of **0.04 ppm** (40 ppb), which equals the estimated MADL-Equivalent trigger.

16. Without any effort to implement any new Pb reduction strategies (i.e., *status quo*), products in Cacao Groups 1, 2, and 3 are already 57 percent, 35 percent, and 42 percent compliant, respectively, with my recommended triggers (Table 5D). With a 50 percent reduction in Pb from the implementation of Pb reduction strategies, greater than 75 percent of the products in all three cacao groups would be compliant with my recommended triggers. My recommended trigger levels are therefore already feasible to achieve and with a 50 percent reduction of Pb, nearly all chocolate products available in California would be compliant. The percent compliance would be greater with a greater reduction percentage from implementing Pb reduction strategies. It is conceivable that more than 95 percent of chocolate products available in California could meet my recommended trigger levels with a 60 to 75 percent reduction efficiency after fully implementing the Phase Two Pb reduction strategies.

17. As noted previously, the AYS product testing data are unlikely to accurately represent the actual relative sales and consumption of chocolate products in California as grouped by cacao content prescribed in the Consent Judgment. If the AYS testing data underrepresent the sales and consumption of chocolate products in Cacao Group 1, unmitigated (*status quo*) or mitigated compliance with the MADL-Equivalent Proposition 65 trigger or my recommend trigger for Pb for all chocolates consumed in California would be higher. Likewise, if the AYS testing data overrepresent the sales and consumption of chocolate products in Cacao Groups 2 or 3, compliance with the MADL trigger or my recommend trigger for Pb for all chocolates consumed in California would be higher. Conversely, if the AYS testing data underrepresent the sales and consumption of chocolate products in Cacao Groups 2 or 3, compliance with the MADL Proposition 65 trigger or my recommend trigger for Pb for all chocolates consumed in California would be lower.

3.4 Gideon Ramtahal's Findings on Pb Warning Triggers

Observations: Chocolate, cocoa products, and cocoa bean data provided by AYS, SDs, and CODEX

(a) For Covered Products with up to 65% cacao content:

Trigger level 0.100 ppm or 0.065 ppm

- Chocolate data provided by AYS: more than 98% of the samples met both trigger levels
- Chocolate liquor and bean data provided by the SDs: more than 70% of the countries tested had samples that will meet both trigger levels

(b) For Covered Products with greater than 65% and up to 95% cacao content:

Trigger level 0.150 ppm or 0.100 ppm

- Chocolate data provided by AYS: more than 99% of the samples met both trigger levels
- Chocolate liquor and bean data provided by the SDs: more than 75% of the countries tested had samples that will meet both trigger levels

(c) For Covered Products with greater than 95% cacao content

Trigger level 0.225 ppm or 0.200 ppm

- Chocolate data provided by AYS: more than 95% of samples met both trigger levels
- Chocolate liquor and bean data provided by the SDs: with the exception of one country, all other countries had samples that will meet both trigger levels

Comments on data

The majority of the sample data provided by AYS and SDs can meet both the current and proposed triggers specified from the Consent Judgment for Pb. For samples/products that may have difficulty meeting these limits, there is a possibility that our Phase II Pb reduction recommendations could be effective if implemented, particularly those specific to the post-harvest process of cocoa beans in affected countries of origin as it represents the first stage of Pb contamination.

Comments on potential solutions

The bean cleaning study that the expert committee performed as part of our Phase two reduction recommendations demonstrated that levels could be effectively reduced to approximately 0.05 ppm Pb in processing plants using their normal cleaning procedures. However, this bean cleaning result may not be representative for all chocolate manufacturing companies as they all vary in size with quite possibly different equipment for processing beans. This cleaning process will need to be streamlined and optimized to realize a reduction throughout all applicable bean cleaning practices available.

On the other hand, the reality is that for some of the more Pb-affected countries of origin, implementation of these post-harvest reduction strategies will not be a short-term process. A number of the small shareholder farmers who make up the majority of the industry within these countries do not have a proper support system to adapt to these changes easily. Additionally, enacting this level of change will require further investigation to fully understand a country's post-harvest practices, so as to provide the necessary indicators, investment, infrastructural support, and training to name a few steps. I foresee this to be a much more long-term activity going beyond 2024 to get affected countries/farmers exports to meet bean Pb-compliance. Nevertheless, I do believe Pb reduction is possible, but will definitely be incremental to align with affected countries' capabilities.

Position on Proposition 65 Warning Triggers

In order to make my assessment on feasible drop-down Pb levels for the different product categories, I examined the cocoa powder (>95 cocoa product category) data from both AYS and the SDs. This is because cocoa powder should account for the highest Pb concentration of all the cocoa products sampled and analyzed (worst case scenario) due to the fact that it has the lowest cocoa butter contribution which is known to have negligible metal contamination. I then looked at the percentage of samples from this dataset that were not likely to meet the proposed trigger limit (0.200 ppm) and selected an achievable average for them based on the general difficulty of an affected country to implement and reduce Pb contamination of their beans.

Review of 95% cocoa solids data (Feasible drop-down level <0.200 ppm):

AYS' >95% cocoa solids data statistically analyzed by Michael and subsequently separated by cocoa powder:

- Though it represents what is available in the Californian market, I do not believe it paints a clear picture of Pb levels due to its limited dataset and analyses (n=37 cocoa powder samples). Additionally, there was no traceability data by country.

SDs' cocoa powder data (Table 5b, Batch 1 Cocoa Powder Pb Sampling Data, by Producing Country, Root Cause Phase report):

- Firstly I believe that this data is a lot more robust (n=1267) and provides a clearer picture of potential Pb levels that may enter the Californian chocolate product market and identifies countries of origin which is a lot more important for reduction recommendation measures.

- The majority of these samples from the different countries can meet the proposed 0.200 ppm trigger limit, with the exception of Brazil and Indonesia. However, it is important that we consider all other countries that also have the potential to exceed this 0.200 ppm threshold.

- As such, upon further review, the combined data from the different countries shows us that 25% of the samples will exceed a 75th quantile Pb concentration value of 0.180 ppm which is close to 0.200 ppm threshold. Based on my view that Pb reduction for beans from affected countries will be much more long-term and on an incremental basis, a feasible target value of 0.180 ppm appears to be much more appropriate as it represents a current realistic average. It is not too drastic and is achievable on a smaller scale until further impactful changes could be made within those affected countries to reduce Pb contamination of beans and their eventual corresponding products.

- The feasible Pb drop-down levels for the other categories of chocolate products were proportionally adapted from 0.180 ppm based on the Consent Judgement's proposed trigger limits. Chocolate products with up to 65% cacao content (0.090 ppm) and chocolate products with >65% and <95% cacao content (0.060 ppm).

4.0 Experts' Findings on Cd Warning Triggers

The Experts were charged with identifying the lowest Cd drop-down levels that can be Feasibly achieved. The Experts agreed that they were not going to be able to reach consensus on the magnitude of the lowest drop-down levels; and their individual recommendations (Table 2) exhibited a greater range for Cd drop-down levels when compared to the Pb drop-down levels. The Experts agreed to present their individual assessments of the lowest Feasible Cd drop-down levels, which are included in this section. The remainder of this section presents the four Experts' individual assessments of the Pb drop-down levels. Refer to Table 2 for a summary of the Experts' Cd findings.

4.1 Tim Ahn's Findings on Cd Warning Triggers

The Cd Product Warning Trigger levels described in Section 6.2.2 of the Consent Judgment cannot be feasibly achieved. The cocoa market consists of two categories of products based on the type of cocoa beans used: "fine flavor" and "bulk or common." Fine flavor cocoa beans are used in premium chocolate products due to their distinctive taste and color. While fine flavor cocoa beans account for approximately 10 to 15% of world exports, South America and the Caribbean region accounts for approximately 90% of their production. A review of SD data for cocoa bean Cd concentration indicates that cocoa beans from the South American and Caribbean geographic region that includes Peru, Ecuador, Colombia, Venezuela, and Trinidad are on average approximately 10 times higher in Cd than cocoa beans from the West African geographic region. Cocoa beans from the West African geographic region are of the bulk or common type. This is further supported by a review of SD chocolate liquor data, which is the ingredient that determines Cd concentration in chocolate products, and CODEX cocoa powder Cd concentration data. The Consent Judgment does not differentiate between bulk and fine flavor cacao products.

While blending and formulation are effective methods to feasibly achieve the drop-down levels for bulk or common cacao products, they are not effective methods for Cd control for the production of fine flavor cacao products using cocoa beans from the South American and Caribbean region. Bulk or common cacao products can be formulated to use less of a high Cd region and more of a low Cd region. For fine flavor cacao products, at the current trigger levels, approximately 60% of the chocolate liquor from the region exceeds the trigger. At the drop-down levels, this will increase to approximately 70%. At these high levels of chocolate liquor exceeding the triggers, it is difficult to effectively use blending and formulation as a reduction strategy. While the Expert Committee has identified six High Confidence Reduction Strategies to address the root cause of Cd uptake in the Phase 2 report, there is no consensus as to the level of reduction that can be achieved, or the timing required to effectively implement these strategies. For fine flavor cacao products, there are no currently identified feasible reduction methods that would enable the implementation of the drop-down triggers stated in Section 6.2.2 of the Consent Judgment.

Discussion

In order to assess the impact of the Consent Judgment drop-down levels, a description of the product and the expected level of chocolate liquor and added cocoa butter included in the product were reviewed. The following is a description of typical products include in the Consent Judgment chocolate product categories.

- Up to 65% cacao
    - Typically, everyday mass merchandised chocolate, including milk chocolate
    - Typical percentage of added cocoa butter: 15%
    - Current trigger: 0.400 ppm
    - Drop-down trigger: 0.320 ppm
- Greater than 65% and up to 95% cacao
    - Typically, high chocolate liquor content, single origin, fine flavor chocolate

    - Current trigger: 0.450 ppm
    - Drop-down trigger: 0.400 ppm
    - Typically, percentage of added cocoa butter: 0 to 5%
- Greater than 95% cacao
    - Cocoa powder, cocoa nibs, 100% chocolate liquor
    - Current trigger: 0.960 ppm
    - Drop-down trigger: 0.800 ppm
    - Typically, no added cocoa butter

The ability of the chocolate industry to meet the Consent Judgment triggers is based on the capability of cocoa processors to produce chocolate liquor that allows the Cd drop-down levels specified above for each of the product categories to be achieved. Because the Consent Judgment does not specify chocolate liquor Cd concentrations, the chocolate liquor Cd concentrations necessary to meet the Consent Judgment drop-down levels have been calculated with following simplifying assumptions.

- For each product category, because chocolate recipes are not known, all cacao is assumed to be chocolate liquor. Added cocoa butter is ignored.
- For the 95%+ category, the product is based on cocoa powder. In this category, cocoa powder has the highest percentage of non-fat cocoa solids. Cd is present in non-fat cocoa solids, not in the cocoa butter fraction.
- Cocoa powder is assumed to be 22% fat and pressed from 54% fat chocolate liquor. This results in a chocolate liquor to cocoa powder conversion ratio of 1.91 to 1.

With these assumptions, the following are the chocolate liquor Cd concentrations necessary to meet the current triggers and drop-down levels for the highest cacao percentage for each chocolate product category.

- Up to 65% cacao: 0.615 ppm (current); 0.492 ppm (drop-down)
- Greater than 65% and up to 95% cacao: 0.474 ppm (current); 0.421 ppm (drop-down)
- Greater than 95% cacao (cocoa powder): 0.502 ppm (current); 0.419 ppm (drop-down)

The SD, AYS, and CODEX data sets were reviewed with respect of the capability to produce 0.530 ppm chocolate liquor (current trigger) and 0.444 ppm chocolate liquor (drop-down level). These are the average chocolate liquor Cd concentrations necessary across all three product categories. The following observations were made.

- Phase 2 report, Tables 3a, 6a, and 7a demonstrate the Cd levels of South American and Caribbean cocoa beans and chocolate liquor as compared to West African cocoa beans and chocolate liquor. The Cd concentration of South American and Caribbean cocoa beans and chocolate liquor are approximately 10 times higher than West African cocoa beans and chocolate liquor.
- A review of chocolate liquor Cd concentrations for SD data from 2015 to 2018 for Ecuador, Peru, and Venezuela indicates the current trigger would result in approximately 60% of the chocolate liquor exceeding the trigger. The drop-down trigger would result in approximately 70% of the chocolate liquor exceeding the trigger.
- The CODEX data for cocoa powder Cd concentration indicates the Latin America Caribbean (LAC) region is 8.7 higher than the Africa region. The LAC region includes Brazil, which based on SD data, does not appear to be a high Cd country. This means that the Cd levels are most likely higher for the Peru, Ecuador, Colombia, Venezuela, and Trinidad subregion of LAC. CODEX estimates that at a maximum

limit (ML) of 0.8 ppm, approximately 57.8% of the cocoa powder will exceed the ML. This is also consistent with observation made from the SD data.

4.2 Rufus Chaney's Findings on Cd Warning Triggers

The levels of Cd in different cocoa products vary widely due to manufacturing processes and cocoa bean sources. I think we have a technical responsibility to discuss the scientific basis for cocoa Cd limits. When essentially all the Cd is associated with the nonfat cocoa solids, but current limits are based on "total cocoa solids," the basis for Cd concentration in chocolates in the regulation is faulty. It is simply wrong science to set limits on "total cocoa solids" when that fails to be related to the fundamental reason Cd might be present in the product. Some products contain fat and nonfat proportions similar to that of whole beans (which also vary somewhat among genotypes, production years, locations, designs).

Even the discussion of cocoa products at CODEX-CCCF (Codex Committee on Contaminants in Food) shows the confusion of labels on samples analyses submitted by different nations to CODEX-CCCF to be part of the official Global Environmental Monitoring System (GEMS) dataset of cocoa composition. In addition, some cocoa products may have some water content, but the use of reported data (wet weight basis for the chocolate products) by the CODEX committee ignores any information related to water content of a product. Some discussion at the Joint FAO/WHO Expert Committee on Food Additives (JECFA) noted "dry weight basis," but not at CODEX-CCCF. JECFA had great difficulty in evaluating "cocoa powder" product analyses because the composition of the analyzed materials did not specify that it was 100% cocoa solids, or if non-cocoa (such as sugar, cocoa butter, oils, etc.) ingredients in some "cocoa powder" were present in the product/sample analyzed and reported by countries.

I recommend that Proposition 65 limits should be based on "nonfat cocoa solids" content of products, the portion of cocoa that carries Cd into products. Companies know this factor and could report it on their products instead of the presently reported "cocoa content."

We should also be considering the completed and planned activities regarding Cd in cocoa products at CODEX-CCCF in 2021. In the 2021 "pre-meeting" document on this topic, the CODEX-CCCF committee is trying to follow a "proportional" pattern in setting limits on Cd in cocoa products. That means that the ratio of Cd to cocoa solids should remain approximately equal among products with wide variation in "total cocoa solids dry matter basis." The second principle for setting CODEX-CCCF Cd limits is minimization of the rejection of cocoa products in the CODEX-CCCF database. The workgroup is considering a database of cocoa analyses submitted with many nations' cocoa containing products, recognizing that the data may not be of equal quality nor describe the same cocoa products. Although their goal is to not exceed rejection of greater than 5% of the cocoa crop from any "production region," because the LAC region produces most of the cocoa beans containing higher levels of Cd, greater than 5% of the LAC crop would be rejected with some of the limits considered at CCCF. Table 8 shows the CCCF, JECFA (Joint Expert Committee on Food Additives and Contaminants), and Codex Alimentarius Commission (CAC) existing limits for Cd in cocoa products and the results of the 2021 CCCF meeting which will be considered at the November 2021 CAC meeting.

Table 8. Listing of CCCF and Codex Alimentarius Commission (CAC) actions on Cd in Chocolate Products

Cd Actions	Cd Concentration Limits (ppb) by CODEX % cocoa subset				
	≤30%	30-50%	50-70%	>70%	Powder
CAC already Adopted	--	--	**0.8**	**0.9**	--
CCCF Proposed 2020 [1]	0.300	0.6 – 0.7	--	--	2.0 – 3.0
CCCF Proposed 2021 [2]	0.3 – 0.4	0.500	--	--	--
JECFA, 2021 Recco's [3]	0.300	0.500	--	--	1.500
CCCF → CAC in 2021 [4]	0.300	0.700	--	--	Delayed
EU Established Limits	0.1	0.3	--	--	--

[1] From CX/CF 20/16 (2020); there were no actions to adopt these limits due to COVID.
[2] From CX/CF 21/14/6 (2021).
[3] JECFA, 2021.
[4] Whitworth, 2021.
[Limits in Pb in cocoa products were delayed to 2022 for more data and discussion.]

Table 9. Our Committee is evaluating revision of the present listed Proposition 65 concentration limits for Cd in cocoa containing products sold in CA. Three ranges in "%-cocoa content" of individual cocoa containing products are listed. Recommended limits are based on the "proportional" approach.

Drop-Down Levels	Product cocoa content <65%	Product cocoa content 65-95%	Product cocoa content >95%
	Cd Concentrations (ppb, "as is weight")		
Initial	0.400	0.450	0.960
"Drop-Down"	0.320	0.400	0.800
Corresponding CODEX	0.700	0.800	0.900
Chaney Recommendation	**0.400**	**0.600**	**0.800**

The CCCF approach is based on the statistical distribution of Cd measured in cocoa products from many nations. The US, European Union (EU), and Japan have the strongest ability to do the appropriate analysis of Cd in cocoa products, but do not produce cocoa beans. The CCCF team decided to aggregate all cocoa product analyses sent into CCCF from several parts of the world if the analytical methods appeared reliable. The data were entered in a GEMS database used by the CCCF committee working on Cd in cocoa products.

Their approach has been based on their usual intent that for the selected Cd limit, no more than 5% of the crop from any cocoa producing region can be declared unacceptable. But because of the nature of soils (and cocoa products) in "Latin America and the Caribbean" cocoa production region (LAC), the Cd concentrations in cocoa products from LAC are much higher than the other CCCF regions. The bean Cd comes from natural soil Cd in cocoa orchards. In addition, the LAC region submitted a large number of analyses of many kinds of cocoa products which raised the number of analyses of the higher Cd products in the GEMS database, which may influence any limit set based on not cutting off more than 5% of any region's cocoa product sales.

The CCCF approach also considers the daily Cd ingestion in cocoa products of each group of products based on the total cocoa fraction (not the nonfat cocoa fraction which carries essentially all the Cd in cocoa products). They discussed at length the fallibility of the reported compositions, especially of cocoa powder.

The 2021 CCCF pre-Meeting Document [CX/CF 21/14/6 (March 2021), "Maximum levels for cadmium in chocolates and cocoa-derived products (at Step 4)"], is a report to CCCF. The CCCF proposes recommended limits to the CAC which formally sets food metal limits.

Separately, at their 2013 Meeting, the JECFA Committee again reviewed Cd in cocoa and cocoa products in detail, using the revised "Cluster Diets." And further evaluated Cd from cocoa and cocoa products in their 2021 Meeting. They identified the Cluster Diets with the highest intakes of cocoa and cocoa products and the calculated daily Cd ingestion associated with those diets.

"The estimates of mean population dietary exposure to cadmium from products containing cocoa and its derivatives for the 17 new Global Environmental Monitoring System – Food Contamination Monitoring and Assessment Programme (GEMS/Food) Cluster Diets (see Annex 3) ranged from 0.005 to 0.39 µg/kg body weight (BW)/month, which equated to 0.002-1.6% of the provisional tolerable monthly intake (PTMI) of 25 µg/kg BW/month. Similar mean population cadmium dietary exposures for individual cocoa products were estimated from national data, ranging from 0.001-0.46 µg/kg BW/month (0.004-1.8% of the PTMI)."

The highest potential dietary exposures (95th percentile) to cadmium for high "one day" consumers of products containing cocoa and its derivatives in addition to cadmium derived from other foods were estimated to be 30-69% of the PTMI for adults and 96% of the PTMI for children 0.5-12 years of age. **The JECFA Committee noted that this estimated total cadmium dietary exposure for high consumers of cocoa and cocoa products was likely to be overestimated and did not consider it to be of concern.**

Considerations relevant to setting limits on and timing of establishing Cd limits for cocoa beans and chocolate products:

In the last two years, our Committee has sorted out the "Root Causes" of high levels of Pb and Cd in cocoa beans and chocolate products. Our work identified the difficulty in reducing Cd in cocoa beans in LAC where "natural" Cd in soils causes higher "natural" accumulation of Cd in cocoa beans. In our study of "Reduction Recommendations," many possible methods are under consideration to reduce Cd in cocoa beans. But these bean Cd-reduction methods are not simple methods, and not inexpensive or easily achieved.

Currently, chocolate producers have the choice of purchasing beans from West Africa which reliably contain low levels of Cd in order to dilute the Cd in "fine flavor" beans from the LAC Region in making chocolate products.

To be sure, most major cocoa industry companies are obtaining cocoa beans with low enough Cd to make the products they work to produce. They obtain proper trace analyses of proper samples of 20 t lots of beans in shipping containers offered for sale. That approach appears to work well enough to deal with Proposition 65 for general chocolates producers. But for producers of fine flavor chocolates, finding enough low Cd beans is a much more difficult and expensive situation.

Appropriate analysis of Cd in a sample of cocoa beans from a single farmer sample or a shipping container are equally expensive. Until the composition of beans in relation to soils where they are produced becomes settled knowledge, and methods to prevent mixing of high Cd beans with low Cd beans are developed, beans with 27 ppm Cd (from Santander, Colombia) may be mixed with beans from western Africa with 0.2 ppm Cd, causing excessive Cd in the mixed bean source lot.

In our evaluation of methods to reduce Cd in beans, we found several promising ways that bean Cd could be reduced **if 5-20 years were available before limits on Cd in cocoa products had to be met.** Otherwise, the bean producers would be shut out of selling cocoa beans (ignoring cheating). Amending soils with limestone and Zn (and possibly organic matter such as manure or compost) can increase soil pH to reduce soil Cd phytoavailability; and increased soil zinc (Zn) can inhibit Cd uptake by the cocoa roots. But no method to mix these amendments within the topsoil has been demonstrated to be effective in field testing without harming the cocoa tree's root systems, partly because this species has shallow roots (95% of roots in the top 0-15 cm) when grown in rain forest areas where it is adapted. One test showed that liming the top layer of the topsoil (as would occur with the surface applied limestone) reduced Cd uptake from that layer, but increased Cd uptake from deeper soil in the profile. So the limestone and zinc fertilizers need to either be mixed into the topsoil, or be leached into the topsoil over many years. Technology for inexpensive mixing of limestone, Zn, and other amendments into the topsoil of standing cocoa orchards has been identified by Ramtahal et al. (2022; in press) using a backpack powered fluid injection device. Because other amendments can reduce Zn phytoavailability, it will be important to include Zn fertilizer with any liming or organic matter amendments used in injection.

Plant breeding can conceivably reduce Cd in commercial cocoa beans by several approaches as we discussed. But even if successful "natural" or "bioengineering" methods were used to reduce Cd in cocoa germplasm, it would take decades to achieve combining lower Cd with other the desired properties of the cocoa cultivars produced because yield, disease resistance, fine flavor, and other properties are also needed in new cultivars to win commercial acceptance. And when improved genetically low Cd cocoa cultivars (with needed market properties) are developed, new seedlings must replace current trees which will also take 2-5 years before the lower Cd beans can be harvested. There is insufficient appreciation of the time needed to achieve identification of genetic resources which might give low Cd cocoa beans, and the time needed to transfer that genetic trait to the desired cocoa quality and yields in several growing regions. This is discussed in the Reductions Recommendations Report. Perhaps confidential research we have not been able to obtain has found such fundamental germplasm. But it is not likely an exceptionally low Cd cocoa germplasm will be in a modern high yielding, fine flavor, and disease resistant genotype will be "on farms" for 25 years. Because many scion genotypes with varied disease resistance, fine flavor, etc. are commonly grafted to strong rootstocks, the fastest way to obtain consistently low Cd cocoa beans is to develop a rootstock with over-expression of HMA3 to pump Cd into root cell vacuoles and greatly diminish shoot/bean Cd.

Because of the high cost of ICP-MS analysis of Cd in plant tissue or soil samples is higher than most labs in LAC can afford, it will be a slow and difficult process to achieve validated field agronomic improvements, or plant breeding improvements to substantially reduce Cd in cocoa beans.

Fortunately, flame atomic absorption spectrometry (AAS) or inductively coupled plasma atomic emission spectroscopy (ICP-AES) analysis of **"phytoavailable Cd"** in soils can be low cost and accurate (using diethylenetriaminepentaacetic acid [DTPA] or Mehlich-3 methods commonly used in agriculture), but the collection and proper analysis of samples, and development of validated farm and regional soil Cd, Zn and pH maps is expensive and difficult. Even within a 2-hectare cocoa orchard, soil Cd, Zn and pH can vary significantly; all of these are relevant to cocoa Cd accumulation. Any farm or regional surveys should include at least soil pH, phytoavailable Cd, and phytoavailable Zn. The ratio of soil to solution in those traditional soil fertility extracts is 10 g/20 mL giving low detection limits, and the matrix of the extract does not cause errors in the analysis of Cd by AAS or ICP-AES. However, total soil Cd measurements using strong acid digestion dissolves iron (Fe) and other elements which cause significant error in measurement for low normal soil Cd levels by AAS or ICP-AES. In addition total soil digests are usually diluted 1 g/100 mL, so soil total Cd measurements either would be too expensive (need ICP-MS) or would not be reliable in mapping areas where low Cd crops can be obtained. Although the extremely Cd rich (>10 mg Cd/kg dry soil) Cd-mineralized soils in part of Colombia and other Cd-mineralized soils elsewhere would be easy to characterize with traditional soil analysis methods and prohibit cocoa production for sale.

We have agreed that Companies have the right and the power to selectively purchase low Cd beans if they can find them. And Government Agencies and Companies can teach growers how to manage cocoa production to limit Cd in beans at market. Several nations are creating maps of soil and bean Cd levels and may be using that information to inform Companies where they can find beans with low enough Cd concentration to meet the purchaser's demands. These data could also be used to inform Cocoa Cooperatives on where and how to achieve needed bean Cd levels. But remediation of soil pH and phytoavailable Zn in the cocoa rooting zone will take a long time because the amendments cannot be tilled into the rooting depth of soil.

But because of the small farms involved in most cocoa production (∼2 hectare), analyses of beans or soil are not a tolerable crop production cost for individual cocoa farmers. And the specific local management of each farm affects soil pH, and Cd and Zn phytoavailability, which strongly affect bean Cd levels. At best, regional or soil association mapping, combined with pH measurements of each farm (inexpensive) can help in selecting beans for purchase to meet US and EU limits on Cd in chocolates. Liming has been shown to be both effective and greatly needed on many cocoa farms which produce beans with higher levels of Cd. But as noted above, surface application of limestone in established orchards only very slowly increases the pH of the main rooting zone soils for cocoa. Surface applications of liming materials or organic matter should include Zn fertilizer because these amendments reduce the phytoavailability of soil Zn which would promote Cd uptake.

But even if we assume the wisest application of the knowledge we have assembled in our reports, changing bean production practices to achieve lower Cd in beans will be a slow and difficult change in LAC society. Even the fields of one grower are variable both in phytoavailable Cd and Zn and soil pH. And both local plant genetics and soil management contribute to actual bean Cd levels.

Cocoa growing “Cooperatives” do exist, and can work with government and cocoa industry assistance to help their member/growers achieve lower Cd in beans they produce. Because these Cooperatives usually involve farms within a relatively small area, the similarity of soils and production practices in a Cooperative may allow more rapid reduction of bean Cd levels. We have not seen information on the fraction of all growers or land area involved with cocoa production that are participants in cooperatives. But one bean or soil sample per farm is not enough to assure bean Cd concentrations.

Reducing levels of Cd allowed in chocolate products sold in California will cause huge dislocation in the cocoa industry, and harm large numbers of growers in developing countries. **The needed changes in soil pH and phytoavailable Cd are not practically possible in the short term.** Companies can refuse purchase of beans with higher levels of Cd, but will lose much of the “fine flavor” beans from LAC due to excessive soil Cd naturally present in these uncontaminated soils. Given enough time, breeding of low Cd cocoa genotypes may allow change of the cultivars in cocoa orchards so no high Cd beans are brought to market. That will be difficult and even slower.

Information about soil-plant relationships of Cd in cocoa, distribution of soil Cd concentrations, soil Cd phytoavailability, and potential methods to achieve lower Cd concentrations in farmers’ beans offered for sale are provided in the “Reductions Recommendations Report.”

4.3 Michael DiBartolomeis’ Findings on Cd Warning Triggers

I recommend Proposition 65 trigger levels for Cd of **0.120 ppm** (120 ppb), **0.175 ppm** (175 ppb), and **0.400 ppm** (400 ppb) for chocolate products categorized into Cacao Group 1 (up to and including 65 percent cacao), Group 2 (more than 65 percent up to and including 95 percent cacao), and Group 3 (greater than 95 percent cacao), respectively. These recommendations are supported by the following findings:

1. Based on the Expert Committee’s findings in the Phase Two Report, 15 reduction strategies were rated as feasible to reduce Cd and Pb contamination in chocolate products with “high” confidence; 11 of which were specific to Cd reduction.
2. It is reasonable to deduce that a 50 percent reduction of Cd in chocolate products could be achieved following the implementation of these strategies individually or in combination over a four-year period:
   - Among the 11 “high” feasibility confidence Cd reduction strategies, four better agricultural strategies offer different approaches to changing agricultural practices around growing cacao and each could provide greater than 25 percent reduction in Cd levels in chocolate products.
   - Another four genetic-based strategies were also rated “high” feasibility confidence, but the experts were less sure of the reduction magnitude potential for these strategies, which still require much development before implementation.
   - One “high” feasibility confidence better manufacturing practice (bean or liquor blending) could also reduce Cd concentrations in chocolate products by more than 25 percent.
   - Two better business strategies, also rated “high” in feasibility confidence, could each reduce Cd levels in chocolate products from 10 percent to greater than 25 percent.
3. Cd reduction strategies could be implemented within a range of time starting at less than one year to five years, and possibly longer for the genetic-based solutions. This timeframe aligns with the Consent Judgment.
4. For Cacao Groups 1 and 2, the results of the AYS testing demonstrate that 93 percent or greater of the chocolate products in this category already have Cd concentrations below the Consent Judgment triggers without the need for implementing any new “Phase Two” reduction strategies (i.e., *status quo*). For Group 3, 81 percent or more of the products already meet both Consent Judgment triggers.
5. The mean levels of Cd in the AYS analyzed chocolate products categorized into Group 1 (up to 65 percent cacao) decreased by 37 percent from 2014 to 2019. There is also a downward trend in mean Cd values over

the same five years. This is evidence that under *status quo* conditions, Cd levels with 65 percent or less cacao can be significantly reduced using currently available Cd reduction measures.

6. For US produced cocoa powder as reported to the Expert Committee by the SDs more than 93 percent are compliant with the Consent Judgment Cd triggers for Group 3 under the *status quo*.
7. 90 percent compliance of chocolate products can be achieved under the *status quo* with Cd triggers set at 0.190 ppm for Group 1 and 0.350 ppm for Group 2, which should be the highest Cd trigger levels considered under *status quo* (i.e., unmitigated) conditions.
8. Calculated health-based MADL-Equivalent triggers for Cd are 0.111, 0.111, and 0.325 ppm for chocolate products in Groups 1, 2, and 3, respectively.
9. The Consent Judgment Cd trigger levels for products in Group 1 are 2.9 to 3.6 times higher than the estimated MADL-Equivalent trigger levels for Cd. For Group 2, the Consent Judgment triggers are 3.6 to 4 times higher and for Group 3, the Consent Judgment triggers are 2.5 to 2.9 times higher than the estimated MADL-Equivalent trigger levels for Cd.
10. Under *status quo* conditions, chocolate products in Groups 1, 2, and 3 are already 69, 43, and 25 percent, compliant with the MADL-Equivalent triggers, respectively.
11. Under *status quo* conditions, chocolate products in Groups 1, 2, and 3 are already 73, 57, and 42 percent compliant, respectively, with my recommended triggers.
12. With an assumed and feasible 50 percent reduction in Cd from the implementation of Phase Two Cd reduction strategies, more than 80 percent of the products in all three Cacao Groups 1, 2 and 3 would be compliant with my recommended triggers.
13. Based on my analysis of the AYS test data for chocolate products, the mean Cd levels in "specialty" products (i.e., single origin beans and/or using certified organic agricultural methods) are significantly higher compared to mean Cd levels in "bulk" chocolate products (i.e., blended beans from various origins using conventional agricultural methods). Based on the AYS data, lower Proposition 65 trigger levels for the three cacao content groups (such as the values I recommend) can already be met for a large percentage of bulk chocolate products, within a reasonable degree of scientific probability, under *status quo* conditions. With the implementation of Cd reduction strategies as described and evaluated by the Expert Committee in the Phase Two report, nearly 100 percent compliance with my recommended trigger levels can be met for bulk chocolate products.
14. The "single origin factor" for increased Cd levels in some products might be explained by the limitations of only using beans possibly from a specific high Cd growing region or cultivar and not blending with other beans from lower Cd growing regions. On the other hand, explaining the "organic factor" is more difficult. The increased Cd levels in beans grown using organic methods of agriculture might rely more on compost as fertilizer made from plant debris high in Cd; thereby recycling the contaminant into the soil over many seasons. Both the single origin and the organic factors need further investigation and development of reduction measures specifically focused on addressing this problem.
15. There might be concern among some chocolate manufacturers that my proposed trigger levels are too low for some "specialty" chocolate products. Although Cd levels in beans from single origin chocolate sources and/or certified organic beans might be more difficult to control (this remains to be seen), achieving compliance with my proposed trigger levels is still feasible within a reasonable degree of scientific probability for many of these products. Furthermore, in my expert opinion, manufacturing and marketing chocolate products using specific cocoa beans is a business decision and the Proposition 65 triggers should only be dependent on statistical compliance of all chocolate products, or better yet for "bulk" chocolates, not for specific specialty subgroups.
16. In the future, as more analytical data on chocolate products are collected, the analysis of appropriate trigger levels should be revisited. I recommend that individual manufacturers routinely test their own products for both Pb and Cd as part of a routine surveillance plan to identify patterns of contamination in chocolate products and to assist in determining specific sources of contamination for further remediation. I also recommend that an independent third-party laboratory continue to test chocolate products in California (and elsewhere if necessary) for Pb and Cd levels to build on the existing databases and to track

changes in contamination levels as remediation measures are implemented. Furthermore, I recommend that California-specific sales and consumption data for chocolate products in Cacao Groups 1, 2, and 3 be compiled and compared to the AYS testing data representation of products in these groups. The compliance percentages and the trigger levels can then be adjusted if necessary.

General Approach

1. My general approach for Cd analysis and development of recommendations is the same as for Pb. Please see Section 3.3 under "General Approach" for details.

Methodology

Data Relied On:

1. Initially, I downloaded the AYS product testing data from the organization's website: https://www.asyousow.org/environmental-health/toxic-enforcement/toxic-chocolate and converted the data into an Excel spreadsheet. The initial database includes samples collected between 2014 and 2018. Later, I learned that AYS had accumulated additional data from further sampling between 2018 to 2020. I was able to obtain the complete chocolate product testing and analytical results spreadsheet from AYS. This file contains records for product sampling between 2014 and 2020. There are analytical data for Pb and Cd concentrations for an estimated 587 independent chocolate products in the database. I understand that AYS sampling and testing is ongoing, and more data might become available in the future.
2. I manually checked the data between both databases (the original and the expanded databases) for duplicates and missing information. Once "cleaned" and verified I used these data for my analyses and to inform my decisions and recommendations. In addition, I referred to the SD analyses I conducted in the Phase One Report for additional information on Pb and Cd concentrations in cocoa beans at various stages of processing.
3. The expanded AYS database contains the following information: product company and brand names, dates purchased and analyzed, serving size information from the packaging when available, laboratory name and method used, results for cadmium and lead (ppm), and reporting limits. In addition, I obtained the analytical limits of detection (LOD) for the laboratories for Cd and Pb. The LODs varied between laboratories and among the products tested but the differences were negligible for the purposes of analyzing the data based on percentiles (as opposed to other descriptive statistics such as calculation of a mean). Therefore, I used the LODs for Pb and Cd from the primary laboratory used by AYS and divided those LODs by the square root of 2 (see Phase One Report, Section 3.3.2 for explanation) and inserted those values in the place of "non-detects."
4. If available on the packaging, AYS listed the percent cacao for each chocolate product tested. However, in many cases this information was missing. Therefore, I searched online for individual products for cacao content as reported by the company. The information, if found, was sometimes provided on the company's website or on websites selling the chocolate products. I found the information on cacao content was most reliably provided for "premium" or "high-end" chocolate products where cacao content reportedly exceeds 65 percent. For products in the Group 1 category ("up to 65 percent cacao"), the specific cacao content was often not reported anywhere. These products are generally of lower cacao content (50 percent or less) typically seen for mass produced milk chocolates, lower-end dark chocolates, and other products with multiple ingredients other than cacao solids. In those cases where no cacao content could be confirmed, I designated the cacao content as <65 percent and folded them into Group 1 for Pb and Cd. I also acknowledge the assistance of committee member Mr. Tim Ahn who reviewed my work and identified some discrepancies, which I corrected.
5. The AYS product testing data is roughly broken down as follows: 40 percent of the products tested fall into Cacao Group 1 (up to and including 65 percent cacao), 48 percent in Group 2 (more than 65 percent up to and including 95 percent cacao), and 12 percent in Group 3 (greater than 95 percent cacao). As noted above in the General Approach section, it is unlikely these data represent the actual relative sales and consumption of these products in California.
6. I also relied exclusively on the Pb and Cd reduction strategies described and evaluated by the Expert Committee in the Phase Two Report. I relied on the conclusions of the committee from this report "as is,"

without any further interpretation or revision. Any deviation from those consensus findings at this juncture would be detrimental to the process and could jeopardize the validity of the investigation.

Calculation of MADL-Equivalent Triggers:

1. Section 6.2 of the Consent Judgment includes proposed Proposition 65 trigger levels (in ppm) for both Pb and Cd under three categories of chocolate products based on cacao content (these Consent Judgment triggers are presented in Tables 10A and 10B). The three prescribed groupings are "up to 65 percent cacao" (Group 1), "greater than 65 percent and up to 95 percent cacao" (Group 2), and "greater than 95 percent cacao" (Group 3). The trigger levels were presented at two levels, a "high" trigger, and a slightly "lower" trigger (Trigger 1 and Trigger 2, respectively). There are three "high" trigger levels for both Pb and Cd and three "lower" trigger levels for both Pb and Cd for a total of 12 Consent Judgment triggers. There is no information in the Consent Judgment explaining how these trigger levels were calculated or the original basis for the trigger levels.
2. It does not appear that the Consent Judgment includes trigger levels estimated based on the health-based MADL for Cd (4.1 µg/day). The Expert Committee was charged with evaluating the feasibility of meeting the trigger levels listed in the Consent Judgment, or any trigger levels lower than these six Cd trigger levels. Therefore, it is important to calculate a "MADL-equivalent" trigger level to estimate the lower bound health-based trigger levels required under Proposition 65 for Cd in chocolate products.
3. To calculate trigger levels based on the health-based MADL, an estimate of serving size is required. Serving sizes for many of the chocolate products in the AYS database appear to be based on information on the packaging. To verify the accuracy of the serving sizes provided and to obtain missing information, I researched approximately 80 percent of the chocolate products by searching online for nutrition labels. In several cases, especially for products in the greater than 65 percent cacao groupings, the information on the packaging was inconsistent with information provided on the company's website. Serving sizes were corrected based on the best source available.
4. From the serving size data for the chocolate products tested, I calculated the mean serving sizes for products in Group 1, Group 2, and Group 3 as 37 grams, 37 grams, and 12.6 grams, respectively. These estimates are generally in agreement with the results reported from consumption surveys in the US, albeit the available surveys are at least about 30 years old or older (https://www.ars.usda.gov/ARSUserFiles/80400530/pdf/portion.pdf).
5. Using the formula:

   MADL Trigger (µg/g or ppm) = MADL (µg/day) / serving size (g/day)

   I calculated the MADL Equivalent triggers for Cd to be 0.111, 0.111, and 0.325 ppm for Groups 1, 2, and 3, respectively (Table 14C).

Data Analysis:

1. The Consent Judgment Section 5.4 provides a definition of "outlier" pertaining to analytical results from product testing that were deemed outside the working range for the purposes of determining Proposition 65 compliance. The definition is "any single test result obtained that exceeds 0.300 ppm of lead for a product with less than 95 percent cacao content or 0.450 ppm of lead for a product with 95 percent or greater cacao content; or 0.900 ppm of cadmium for a product with less than 95 percent cacao content or 1.92 ppm of cadmium for a product with 95 percent or greater cacao content shall be deemed a potential 'Outlier'." Using this definition of outlier, I identified three analytical results for Cd that met this definition. For the purposes of my analysis, I eliminated these three test results from further analysis.
2. After sorting the data for Cacao Groups 1, 2, and 3 for both Pb and Cd, I performed a variety of basic statistical analyses to determine central tendency (e.g., mean and median), the degree the data conform to a normal distribution of the data, range of values, variance, etc. In addition, I evaluated the data based on percentile distributions in increments from 50 percent to 95 percent to better understand the distribution of the data. The results of this basic statistical descriptive analysis indicated the results to be considerably skewed to the lower range of contamination levels and the overall distribution of test results could not be considered normally distributed (see Phase One Report, Section 3.3.1 for explanation).

Therefore, I made the decision to rely primarily on the percentile distribution of the data values, using the median as the central tendency (that is, the 50th percentile) rather than the mean (or average).

Table 10. Summary of Reduction Percentages to Reach Cd Trigger Levels

A. Up to 65% Cacao				
Percentile	**Cd Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.051	-684	-527	-118
75th	0.130	-208	-146	15
90th	0.218	-83	-47	49
95th	0.289	-38	-11	62
B. >65% and ≤95% Cacao				
Percentile	**Cd Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.148	-204	-170	25
75th	0.248	-81	-61	55
90th	0.350	-29	-14	68
95th	0.490	8	18	77
C. >95% Cacao				
Percentile	**Cd Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.430	-123	-86	24
75th	0.620	-55	-29	48
90th	1.200	20	33	73
95th	1.418	32	44	77

3. Most of my remaining analysis of the AYS data focused on comparing the test results for Cd with the three levels of Proposition 65 triggers (Trigger 1, Trigger 2, and the MADL Equivalent trigger) to determine the percent reduction needed to comply with these levels. Using the formula:

   Percent Reduction = [conc 1 (ppm)] – [trigger value (ppm)] / [conc 1 (ppm)] x 100

   I calculated the percent reduction for all AYS data for all Cd trigger levels. In addition, I calculated the percent reduction needed for compliance for different groupings of data based on percentile of distribution (e.g., 50 percent, 75 percent, 90 percent, 95 percent). Positive numbers (in red font) represent the percent reduction needed to reach the trigger level whereas negative (black font) numbers mean the product concentration is below the trigger level (Table 10A-C).

4. In addition to the analysis of Cd in products in Cacao Groups 1, 2, and 3, I evaluated the data for upward or downward trends in Cd levels in the AYS chocolate products sampled from 2014 to 2019 (Figure 2). The results indicate a potential downward trend in Cd levels for Cacao Content Group 1. I also analyzed the differences between 2014 and 2019 in Group 1 using a paired t-test and confirmed the respective mean values for 2019 were significantly ($p \leq 0.05$) lower (by 37 percent) than for 2014. Evaluating trends in Cd or Pb reductions would be a more effective and informative tool when selecting for a specific company, and/or a specific product, and/or a specific bean origin, for example.

5. I also calculated whether there were statistically significant differences in Cd levels in the AYS chocolate products from one year to another. It should be noted that for the most part, the AYS analytical test results data were not normally distributed within a sample year. This reduces the validity of basic statistical analyses. Nevertheless, I applied an ANOVA test (for a single variable) for each Cacao Content Group to gain more understanding of the nature of the sampling data. The results of the ANOVA tests for Cd indicate the mean levels from year to year were not statistically different. Small sample sizes for some of the years along with high levels of variance (and large standard deviations around the mean) likely contribute to the lack of statistically significant differences from year to year.

Figure 2. AYS Chocolate Samples: Mean Cd Concentrations Over Time

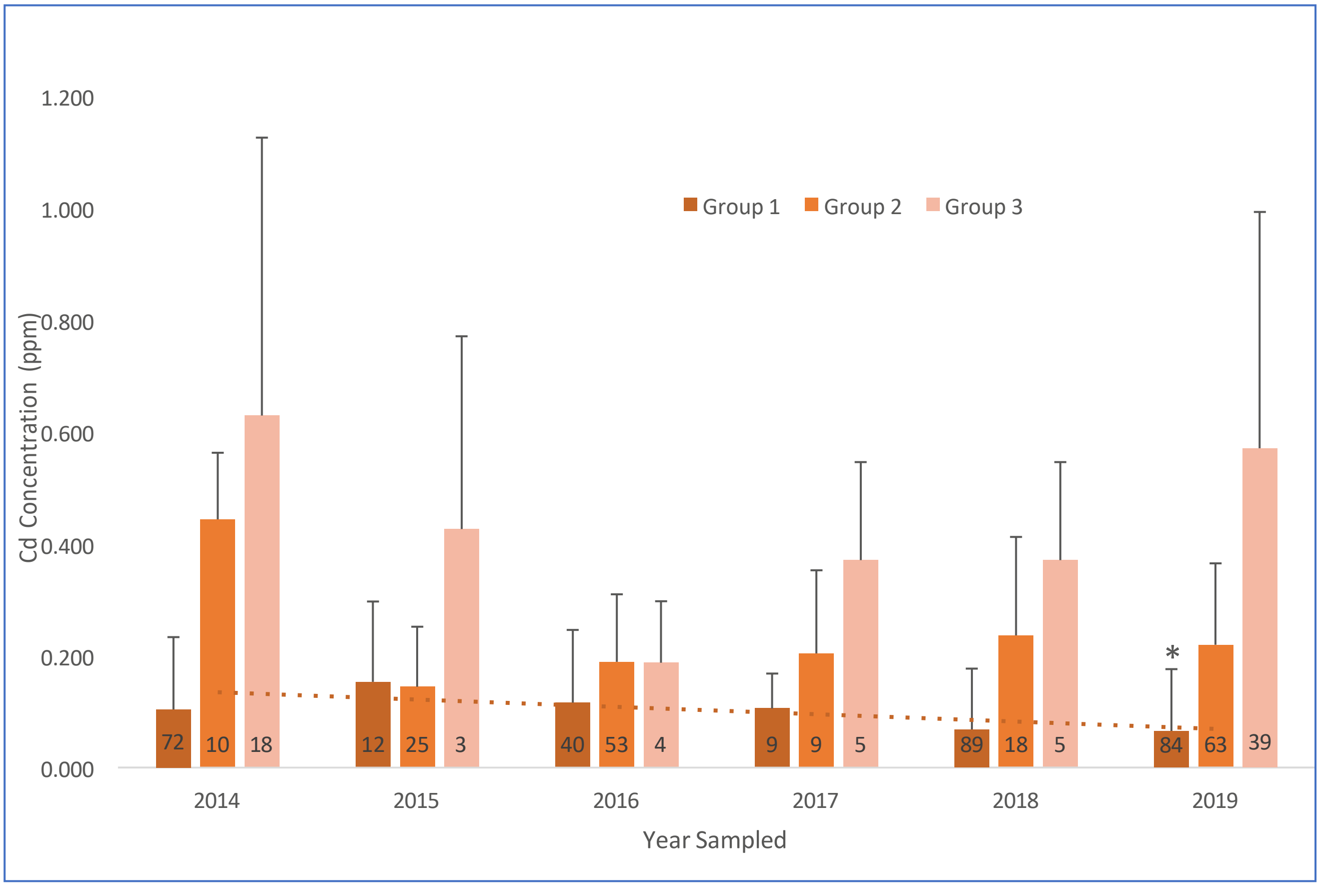


Figure 2 Legend: Values denoted at the base of each bar are the number of samples. Error bars denote the standard deviation around the mean. Dotted line is the estimated trend for Cacao Group 1 calculated using Excel's trend analysis formula. * p<0.05.

6. I also conducted an analysis of "single origin" cocoa bean chocolate products. Chocolate manufacturers that market products as using only "single origin" cocoa beans assert that their product only uses cocoa beans from one source of beans grown in a particular cacao growing country, and in some cases the beans used are specified to a specific cultivar (or variety). These single origin chocolate products do not use a blend of beans from more than one origin. I searched all products in the database that were labeled or reported to be "single origin." After sorting the data for "blended" versus "single origin," I calculated the percent reduction needed for compliance to meet the various Cd trigger levels. The results are summarized in Table 11A-C. For all three cacao content groups, there are large observable differences between Cd levels (based on percentiles) and reduction levels needed to meet trigger levels in single origin versus blended chocolate products. The mean Cd levels in all three cacao content groups for blended bean chocolate products are statistically significantly lower ($p<0.05$) than mean Cd levels in single origin chocolates, although the differences are much greater for chocolate products in Cacao Groups 1 and 2. Single origin chocolate products represent about 3 percent of the total products in Cacao Content Group 1 analyzed for Cd by AYS. For Groups 2 and 3, single origin products represent about 36 percent and 32 percent of the total products in those groups, respectively. Overall, single origin chocolates represent about 22 percent of all the products analyzed for Cd by AYS.

7. I also conducted an analysis of Cd concentrations in chocolate products manufactured from "certified organic" cocoa beans and compared the results to chocolate products made from conventionally grown cocoa beans. I searched all products in the database that were labeled or reported to be "certified organic" and verified the results against the information provided on the manufacturers' websites. After sorting the

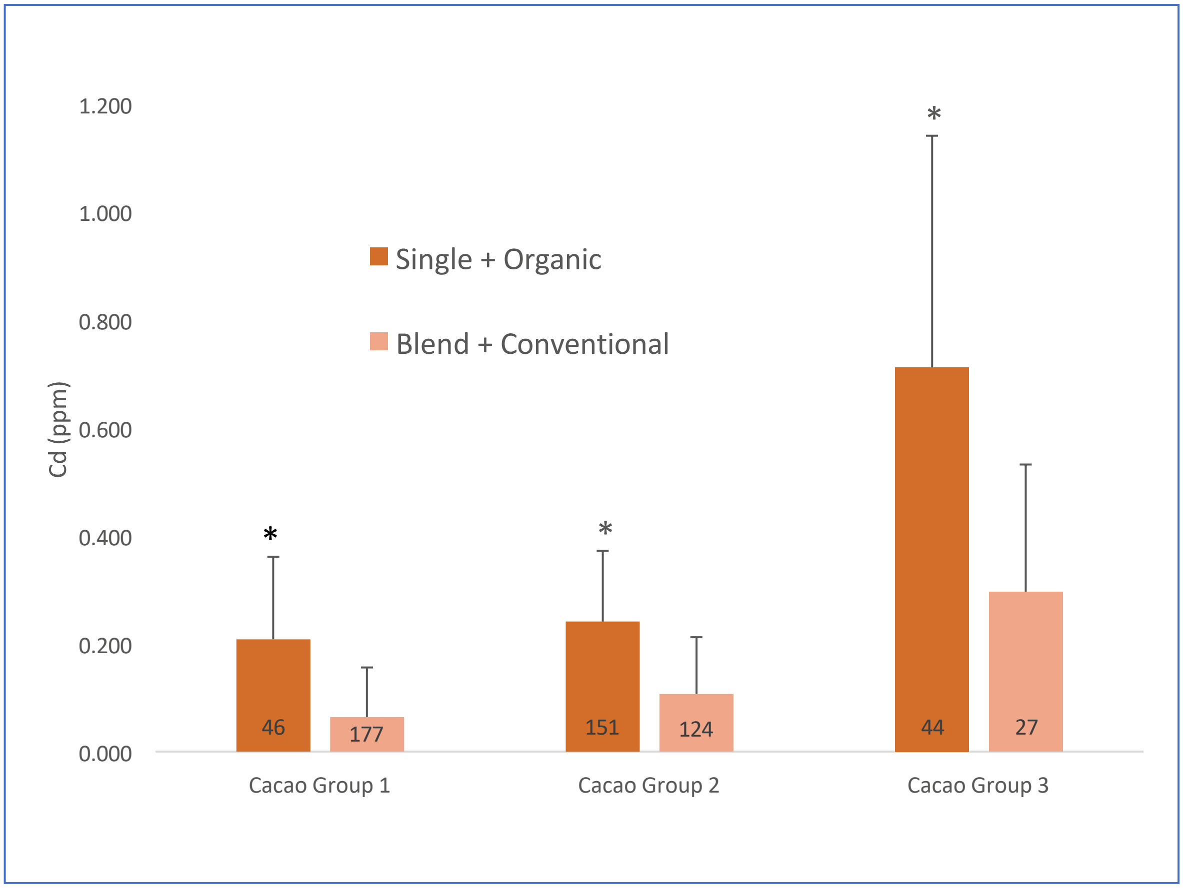
data for conventional versus organic, I calculated the percent reduction needed for compliance to meet the various trigger levels. The results are summarized in Table 12A-C. For all three cacao content groups, there appear to be large observable differences between chocolate products made with organic beans compared to conventional beans among the reduction levels needed to meet trigger levels. The mean Cd levels for conventionally grown bean chocolate products are highly statistically significantly lower ($p<0.001$, t-test) than mean Cd levels in certified organic chocolates in all three cacao content groups. Certified organic chocolate products represent about 19 percent of the total products in Cacao Group 1 analyzed for Cd by AYS. For Groups 2 and 3, certified products represent about 29 percent and 58 percent of the total products in those groups, respectively. Overall, certified organic chocolates represent about 29 percent of all the products analyzed for Cd by AYS.

8. Finally, I analyzed Cd concentrations in chocolate manufactured from combining results from “certified organic” and/or “single origin” cocoa bean tested products and compared those results with the results of chocolate products made from blended, conventionally grown cocoa beans. After sorting the data for conventional blended versus organic and/or single origin, I calculated the percent reduction needed for compliance to meet the various trigger levels. The results are summarized in Table 13A-C. For all three cacao content groups, there are large observable differences between Cd levels (based on percentiles) and reduction levels needed to meet trigger in combined organic and/or single origin bean and conventional blended bean products. Mean Cd levels in conventional blended bean products are highly statistically significantly lower ($p<0.001$) than mean Cd levels in chocolate products made with combined organic and/or single origin beans (Figure 3). The combination of certified organic and single origin chocolate products represents about 21 percent of the total products in Cacao Group 1 analyzed for Cd by AYS. For Groups 2 and 3, the combination of certified organic and single origin chocolate products represents about 54 percent and 62 percent of the total products in those groups, respectively. Overall, the combination of certified organic and single origin chocolate products represents about 42 percent of all the products analyzed for Cd by AYS.

9. Table 14 shows the feasibility (as a percentage of compliance) of cocoa growing, processing, manufacturing, and business practices to meet the three trigger levels based on the concentrations of Cd in chocolate products analyzed by AYS. This table presents the compliance percentage for the products in each cacao content group (1, 2, and 3). The percentage of total products already in compliance with the three levels of triggers (without any further mitigation measures) is shown in the first color-coded “Compliance” column in Tables 14A-C. These results are discussed in more detail below. The second color-coded “Compliance” column in Tables 14A-C shows the percent compliance for all products assuming feasible levels of reduction for Cd following the implementation of “high” confidence Phase Two reduction strategies recommended by the Expert Committee. These calculations are discussed in more detail below.

10. In addition to the three aforementioned trigger levels, I calculated a fourth set of triggers (Table 14D). I propose this fourth set of triggers as the triggers to be adopted in 2025 over the proposed trigger levels prescribed in the Consent Judgment. I calculated these triggers based on a compliance percentage for all products in the three cacao content groups of 80 percent or greater assuming the implementation of Phase Two strategies meet feasible reduction amounts for Cd following the application of only those strategies for which the Expert Committee has a high level of confidence that the reductions could be met in the given time frames (Phase Two Report). A greater compliance percentage would be achieved by considering “specialty” chocolate products separately from “bulk” chocolate products. These calculations are discussed in more detail below.

Figure 3. AYS Chocolate Samples: Mean Cd Concentrations for Single Origin/Organic versus Blended/Conventional



13. Figure 3 Legend: Values denoted at the base of each bar are the number of samples. Error bars denote the standard deviation around the mean. * p<0.001.

Table 11. Summary of Percent Reduction Needed to Reach Cd Trigger Levels: Single Origin vs. Blended Beans

A. Up to 65% Cacao				
Data for Blended Beans				
Percentile	**Cd Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.050	-700	-540	-122
75th	0.128	-213	-150	13
90th	0.180	-122	-78	38
95th	0.295	-36	-8	62
Data for Single Origin Beans				
Percentile	**Cd Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.260	-54	-23	57
75th	0.265	-51	-21	58
90th	0.274	-46	-17	59
95th	0.277	-44	-16	60
B. >65% and ≤95% Cacao				
Data for Blended Beans				
Percentile	**Cd Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.105	-329	-281	-6
75th	0.220	-105	-82	50
90th	0.340	-32	-18	67
95th	0.437	-3	8	75
Data for Single Origin Beans				
Percentile	**Cd Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.221	-104	-81	50
75th	0.280	-61	-43	60
90th	0.364	-24	-10	70
95th	0.506	11	21	78
C. >95% Cacao				
Data for Blended Beans				
Percentile	**Cd Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.380	-153	-111	14
75th	0.570	-68	-40	43
90th	0.848	-13	6	62
95th	1.421	32	44	77
Data for Single Origin Beans				
Percentile	**Cd Conc. (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.595	-61	-34	45
75th	0.990	3	19	67
90th	1.200	20	33	73
95th	1.362	29	41	76

Table 12. Summary of Percent Reduction Needed to Reach Cd Trigger Levels: Certified Organic vs. Conventional Beans

A. Up to 65% Cacao				
Data for Conventional Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.041	-876	-680	-171
75th	0.100	-300	-220	-11
90th	0.140	-186	-129	21
95th	0.170	-135	-88	35
Data for Certified Organic Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.180	-122	-78	38
75th	0.248	-61	-29	55
90th	0.398	-1	20	72
95th	0.561	29	43	80
B. > 65% ≤ 95% Cacao				
Data for Conventional Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.100	-350	-300	-11
75th	0.180	-150	-122	38
95th	0.376	-20	-6	70
90th	0.280	-61	-43	60
Data for Certified Organic Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.248	-81	-61	55
75th	0.340	-32	-18	67
90th	0.438	-3	9	75
95th	0.502	10	20	78
C. > 95% Cacao				
Data for Conventional Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.290	-231	-176	-12
75th	0.415	-131	-93	22
90th	0.573	-68	-40	43
95th	0.700	-37	-14	54
Data for Certified Organic Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.580	-66	-38	44
75th	1.030	7	22	68
90th	1.430	33	44	77
95th	1.460	34	45	78

Table 13. Summary of Percent Reduction Needed to Reach Cd Trigger Levels: Combined Certified Organic and Single Origin Vs. Conventional Blended Beans

A. Up to 65% Cacao				
Data for Conventional Blended Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.040	-900	-700	-178
75th	0.097	-312	-230	-14
90th	0.130	-208	-146	15
95th	0.160	-150	-100	31
Data for Organic and/or Single Source Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.180	-122	-78	38
75th	0.260	-54	-23	57
90th	0.390	-3	18	72
95th	0.528	24	39	79
B. > 65% ≤ 95% Cacao				
Data for Conventional Blended Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.064	-607	-528	-74
75th	0.123	-267	-227	9
90th	0.220	-105	-82	50
95th	0.296	-52	-35	62
Data for Organic and/or Single Source Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.220	-105	-82	50
75th	0.300	-50	-33	63
90th	0.437	-3	8	75
95th	0.510	12	22	78
C. > 95% Cacao				
Data for Conventional Blended Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.290	-231	-176	-12
75th	0.415	-131	-93	22
90th	0.582	-65	-37	44
95th	0.740	-30	-8	56
Data for Organic and/or Single Source Beans				
Percentile	**Cadmium (ppm)**	**Percent Reduction to Trigger 1**	**Percent Reduction to Trigger 2**	**Percent Reduction to MADL Trigger**
50th	0.565	-70	-42	42
75th	0.910	-5	12	64
90th	1.421	32	44	77
95th	1.457	34	45	78

Table 14. Compliance Percentage of AYS Tested Products with Various Cd Triggers

Table 14A. Proposition 65 Compliance Under Consent Judgment Trigger 1			
Cacao Content	**Trigger 1 (ppm)**	**Compliance***	**Compliance****
≤65%	0.400	98%	100%
>65 to 95%	0.450	94%	100%
>95%	0.960	86%	100%

Table 14B. Proposition 65 Compliance Under Consent Judgment Trigger 2			
Cacao Content	**Trigger 2 (ppm)**	**Compliance***	**Compliance****
≤65%	0.320	95%	99%
>65 to 95%	0.400	93%	100%
>95%	0.800	81%	99%

Table 14C: Proposition 65 Compliance Under Calculated MADL Equivalent Triggers			
Cacao Content	**MADL Trigger (ppm)**	**Compliance***	**Compliance****
≤65%	0.111	69%	91%
>65 to 95%	0.111	43%	69%
>95%	0.325	25%	77%

Table 14D: Proposition 65 Compliance Under DiBartolomeis Proposed Triggers			
Cacao Content	**MJD Trigger (ppm)**	**Compliance***	**Compliance****
≤65%	0.120	73%	93%
>65 to 95%	0.175	57%	91%
>95%	0.400	42%	81%

* Percent product compliance without implementation of any additional recommended strategies (*status quo*). ** Percent compliance with an estimated 50 percent reduction in Pb and Cd following recommended strategy implementation.	
≥75th percentile	<50th percentile
≥50th percentile and <75th percentile	

Results and Discussion: Cd Trigger Levels

1. The Expert Committee concluded in its first report that Cd is accumulated in the cocoa nib from the uptake of Cd from the soil into the cacao plant. In addition to soil concentrations of Cd, the amount of Cd uptake in the plant is also dependent on soil conditions such as pH and the presence or absence of other soil constituents such as Zn. Unlike mitigation measured for Pb, which are predominantly focused on the prevention of environmental contamination of Pb on the outer cocoa shell, there is a greater variety of options for reducing Cd levels in the cocoa nib, but most are not as straightforward.

2. Based on our evaluations of the Cd reduction strategies in the Phase Two Report, Cd reduction strategies can be implemented within a range of time starting at less than one year to more than five years, and possibly longer for genetic-based solutions. Therefore, determining what levels of Cd reductions can be achieved in a four-year time frame is more complicated for Cd than for Pb because the Cd strategies require different effort levels to initiate.

3. It might take some additional time for the industry (including growers and processors) to match implementation strategies with the growing regions as well as some time to conduct further focused monitoring to better determine where the "hot spots" are. In those identified hot spots, a more rigorous effort might be required to reduce Cd contamination, especially for specific "fine flavor" cultivars. Uncertainty notwithstanding, I deduce within a reasonable degree of scientific certainty that within four

years after the start of the implementation period, measurable reduction in Cd will be observed with the magnitude of reduction dependent on the combination of strategies used. This timeframe aligns with the Consent Judgment.

4. Four better agricultural strategies (See Tables B-1, B-2, B-3, and B-4 in the Phase Two Report) were given a cumulative rating of “high” feasibility confidence by the Expert Committee to effectively reduce Cd in chocolate products if implemented. These strategies offer different approaches to changing agricultural practices around growing cacao and each could provide greater than 25 percent reduction in Cd levels in chocolate products. The four genetic-based strategies were also rated “high” feasibility confidence, but the experts were less sure of the reduction magnitude potential for these strategies, which still require much development before implementation. In addition, one “high” feasibility confidence better manufacturing practice (Bean or Liquor Blending, Table B-22) could also reduce Cd concentrations in chocolate products by more than 25 percent. Furthermore, two better business strategies (Tables B-26 and B-27, Phase Two Report) rated high in feasibility confidence and if implemented could each also reduce Cd levels in chocolate products by 10-25 percent or greater than 25 percent.

5. Based on these estimated magnitudes for Cd reduction percent for individual strategies, I deduce within a reasonable degree of scientific certainty that a 50 percent reduction of Cd in chocolate products could be observed following implementation of these strategies (individually or in combination) within the next four years. The actual magnitude of reduction could be lower or higher depending on the extent of implementation of these strategies and monitoring and enforcement. Furthermore, following the development of other reduction measures such as the genetics-based strategies, the reduction potential could be even greater in four or more years.

6. For Cacao Groups 1 and 2, the results of the AYS testing demonstrate that most products (93 percent or greater) already have Cd concentrations below the two triggers defined in the Consent Judgment (Table 14A, 14B) without the need for implementing any new “Phase Two” reduction strategies. For Group 3 (>95 percent cacao), 81 percent or more of the products already meet Trigger 1 and 2 levels (Table 14A, 14B). For US produced cocoa powder as reported to the Expert Committee by the SDs (see Phase One Report, Table 5a), more than 93 percent are compliant with the Consent Judgment Cd triggers for Group 3 (> 95 percent cacao) without considering any additional Cd reduction strategies (i.e., *status quo*). These results are remarkably consistent and indicate that most chocolate products on the market in California (and perhaps in the US) are already compliant with the Cd trigger levels defined in the Consent Judgment.

7. Moreover, I calculated the percent compliance of optional Cd Proposition 65 triggers below the Consent Judgment triggers for Cacao Content Groups 1 and 2 without considering any additional Cd reduction strategies (i.e., *status quo*) (calculations not shown). It appears that about 90 percent compliance of chocolate products can be achieved without any further Cd reduction efforts (as described and evaluated in the Phase Two Report) with Cd triggers set at 0.190 ppm for Group 1 and 0.350 ppm for Group 2. The Consent Judgment Trigger 2 of 0.800 ppm for Group 3 is at 81 percent compliance under *status quo* conditions. As noted above, Cd levels in cocoa powder produced by the US (as reported by the SDs) is 93 percent compliant with a Proposition 65 trigger of 0.8 ppm and are more than 82 percent compliant with a lower trigger level of 0.6 ppm under *status quo* conditions. These should be the highest Proposition 65 triggers for Cd considered moving forward.

8. However, the charge to the Expert Committee was to evaluate reduction strategies (in the Phase Two Report) that could feasibly reduce Cd in chocolate products below existing (i.e., *status quo*) levels. The Expert Committee should apply this knowledge to evaluate Proposition 65 trigger levels in Phase Three based on the adoption and implementation of the more feasible reduction strategies. The experts identified 15 high feasibility confidence reduction measures for both Cd and Pb in the Phase Two Report. Therefore, it is clear from the charge in the Consent Judgment that the experts must recommend lower trigger levels where feasible alternatives to the *status quo* were identified. Since the Consent Judgment Proposition 65 triggers for Cd can already be achieved at compliance levels of greater than 80 percent (Table 14), lower trigger levels must be considered in conjunction with feasible Cd reduction strategies.

9. The Consent Judgment Cd trigger levels for products in Cacao Group 1 are 2.9 to 3.6 times higher than the estimated health-based MADL-Equivalent trigger levels for Cd (Table 14C). For Cacao Group 2, the Consent Judgment triggers are 3.6 to 4 times higher than the estimated MADL-Equivalent trigger levels for Cd. For Cacao Group 3, the Consent Judgment triggers are 2.5 to 2.9 times higher than the estimated MADL-

Equivalent trigger levels for Cd. As I mentioned previously, there is no information in the Consent Judgment as to how the prescribed triggers were developed; however, they do not appear to be health-based triggers. For this reason, I investigated the effort required to ensure that most chocolate products would comply with the Proposition 65 health-based MADL-Equivalent triggers for Cd.

10. As with the Consent Judgment triggers, chocolate products in all three Cacao Groups are already compliant with the estimated health-based MADL-Equivalent triggers (Table 14C) without implementing any new reduction strategies. For Cacao Group 1, 69 percent of the products are already compliant with the MADL-Equivalent trigger. For Cacao Groups 2 and 3, the compliance percentages are 43 and 25 percent, respectively.

11. For the estimated health-based MADL-Equivalent triggers to be met for 95 percent of chocolate products, reductions of Cd by as much as 77 percent in the final chocolate products would be required, depending on cacao content (Table 10). For example, to achieve compliance with the MADL-Equivalent trigger in 75 percent of the Cacao Group 1 products, a 15 percent reduction in Cd would be needed and to achieve 90 percent compliance, a reduction of 49 percent would be required (Table 10A). For Cacao Groups 2 and 3, Cd reduction of about 70 percent would be needed to achieve 90 percent compliance with the MADL-Equivalent triggers whereas about a 50 percent reduction in Cd would be needed to achieve 75 percent compliance (Tables 10B, 10C).

12. Although I estimate, within a reasonable degree of scientific certainty that reductions of more than 50 percent Cd levels can be achieved with the implementation of the Cd reduction strategies described and evaluated by the Expert Committee in the Phase Two report, it might take longer than four years to accomplish full implementation (see for example the Genetic-based Cd reduction strategies in the Phase Two Report). For this reason, I have set near-term expectations at 50 percent Cd reduction with the future holding more promise for reductions of greater than 50 percent as the longer-term strategies are fully implemented. Assuming a reduction percentage of 50 percent, I calculated trigger levels that would be as health protective as possible but would achieve at least 80 percent compliance among all products in all three cacao groups (Table 14D).

13. I recommend a trigger level of **0.120 ppm** (120 ppb) to be used for all chocolate products in Cacao Groups 1, which is comparable to the estimated MADL-Equivalent trigger of 0.111 ppm. For products in Cacao Group 2, I recommend a trigger level of **0.175 ppm** (175 ppb), which is about 1.6 times higher than the estimated MADL-Equivalent trigger. For products in Cacao Group 3, I recommend a trigger level of **0.400 ppm** (400 ppb), which is about 1.2 times higher than the estimated MADL-Equivalent trigger. Although my recommended trigger levels are above the MADL-Equivalent triggers, they are considerably lower than the prescribed non-health-based Consent Judgment triggers and could be lowered in the future as a more refined estimate of reduction magnitude following implementation strategies is developed.

14. Without any further effort to implement any new Cd "high confidence" feasible reduction strategies from the Phase Two Report, products in Cacao Groups 1, 2, and 3 are already 73 percent, 57 percent, and 57 percent compliant, respectively, with my recommended triggers. With a 50 percent reduction in Cd from the implementation of Cd reduction strategies, more than 80 percent of the products in all three cacao groups would be compliant with my recommended triggers (Table 14D). These trigger levels are therefore already feasible to achieve and with a 50 percent reduction in Cd, I conclude within a reasonable degree of scientific certainty that 80 percent or more of all chocolate products would be compliant.

15. There are two subcategories of chocolate products sold as "specialty" or "premium" chocolate products based on the origin of the cocoa beans (i.e., single origin) and the methods (i.e., certified organic) used in growing the beans. For Cd contamination, the AYS test data for single origin bean chocolate products clearly indicates that the business decision to not blend beans from different origins significantly raises the risk for increased Cd concentrations in the single origin specialty products compared to chocolate products produced by blending beans from different origins ("bulk") (Table 12). Likewise, the method of growing (i.e., certified organic vs. conventional methods) also appears to result in statistically significant increased Cd levels in the final products made from organically grown beans when compared to products made conventionally grown beans. As expected, when combining specialty products (single origin plus organic) and comparing Cd levels in those with chocolate products made from conventional grown, blended beans, significantly higher Cd levels were reported for the specialty products (Table 13).

16. To further investigate these differences, I calculated compliance percentages of combined certified organic with single origin marketed chocolate products (i.e., "specialty" chocolates) and compared them to conventionally grown, blended chocolate products ("bulk" chocolates) in Cacao Groups 1 through 3. The results are shown in Table 15. Chocolate products in the "bulk" category for Cacao Groups 1 and 2 are already more than 80 percent compliant with my recommended trigger levels without further mitigation (i.e., *status quo*) whereas the compliance percentage for Cacao Group 3 is estimated to be 67 percent. Following implementation of the Phase Two "high" confidence feasible Cd reduction measures with a 50 percent efficacy, I project that the compliant rates for bulk chocolates in all three cacao content groups would be over 95 percent. These results clearly indicate that Proposition 65 compliance is achievable for bulk chocolates products in any of the three cacao content groups at trigger levels lower than the non-health-based Consent Judgment triggers. Furthermore, I conclude within a reasonable degree of scientific certainty that my recommended Proposition 65 trigger levels can also be met for specialty products. Although products in the combined specialty groups are only 25 to 34 percent compliant under the *status quo* for the three cacao content groups, with implementation of the Cd reduction strategies from the Phase Two report, compliance rates could increase to 70 percent or higher. However, it might be more difficult for manufacturers of specialty products to meet the lower Proposition 65 trigger levels without implementing Cd reduction measures to their fullest extent.

17. The "single origin factor" for increased Cd levels in some products might be explained by the limitations of only using beans possibly from a specific high Cd growing region or cultivar and not blending with other beans from lower Cd growing regions. On the other hand, explaining the "organic factor" is more difficult. The increased Cd levels in beans grown using organic methods of agriculture might rely more on compost as fertilizer made from plant debris high in Cd; thereby recycling the contaminant into the soil over many seasons. Both the single origin and the organic factors need further investigation and the probable development of reduction measures specifically focused on addressing these specific problems.

18. As noted previously, the AYS product testing data are unlikely to accurately represent the actual relative sales and consumption of chocolate products in California as grouped by cacao content prescribed in the Consent Judgment. If the AYS testing data underrepresent the sales and consumption of chocolate products in Cacao Group 1, unmitigated (*status quo*) or mitigated compliance with the MADL-Equivalent Proposition 65 trigger or my recommend trigger for Cd for all chocolates consumed in California would be higher. Likewise, if the AYS testing data overrepresent the sales and consumption of chocolate products in Cacao Groups 2 or 3, compliance with the MADL trigger or my recommend trigger for Cd for all chocolates consumed in California would be higher. Conversely, if the AYS testing data underrepresent the sales and consumption of chocolate products in Cacao Groups 2 or 3, compliance with the MADL Proposition 65 trigger or my recommend trigger for Cd for all chocolates consumed in California would be lower.

Table 15. Impact of Specialty Products vs. Bulk Products on Compliance Percentage with MJD Cd Triggers:

Cacao Content	MJD Cd Triggers (ppm)	Compliance*	Compliance**
A. Compliance for All AYS Cd Tested Products Combined			
≤ 65%	0.120	73%	93%
> 65 to 95%	0.175	57%	91%
> 95%	0.400	42%	81%
B. Compliance for AYS Cd Tested Products Conventionally Grown/Blended ("Bulk")			
≤ 65%	0.120	84%	98%
> 65 to 95%	0.175	83%	97%
> 95%	0.400	67%	96%
C. Compliance for All Cd AYS Tested Products Certified Organic/Single Origin ("Specialty")			
≤ 65%	0.120	26%	70%
> 65 to 95%	0.175	34%	85%
> 95%	0.400	25%	70%
* Percent product compliance without implementation of any additional recommended strategies (*status quo*)			
**Percent compliance with an estimated 50 percent reduction in Cd following recommended strategy implementation			
≥ 75th percentile			
≥ 50th percentile < 75th percentile			
< 50th percentile			

4.4 Gideon Ramtahal's Findings on Cd Warning Triggers

Observations: Chocolate, cocoa products, and cocoa bean data provided by AYS, SDs, and CODEX

(a) For Covered Products with up to 65% cacao content:

Trigger level 0.400 ppm or 0.320 ppm (2024)

- *Chocolate data provided by AYS*: More than 95% met both 0.400 ppm and 0.320 ppm Cd trigger levels. Less than 5% exceeded warning limits and most of these were organic dark chocolates (54-65% cocoa solids).
- *Chocolate liquor data provided by the SDs:* With the exception of Ecuador and Haiti, products made from chocolate liquor and cocoa beans from all other sampled countries should be able to meet both 0.400 ppm and 0.320 ppm Cd trigger levels for each product category.
- *Cocoa bean data provided by the SDs*: Products made from cocoa beans from the LAC countries, Indonesia, and Papua New Guinea would exceed both 0.400 ppm and 0.320 ppm Cd trigger levels.
- *Chocolate data provided by CODEX:* More than 95% of these samples from different cocoa-growing regions throughout the world met both 0.400 ppm and 0.320 ppm Cd trigger levels.

(b) For Covered Products with greater than 65% and up to 95% cacao content

Trigger level 0.450 ppm or 0.400 ppm (2024)

- *Chocolate data provided by AYS:* More than 92% met both 0.450 ppm and 0.400 ppm Cd trigger levels. Less than 8% exceeded warning limits and most of these were dark chocolates

- *Chocolate liquor data provided by the SDs:* With the exception of Ecuador and Haiti, products made from chocolate liquor and cocoa beans from all other sampled countries should be able to meet both 0.450 ppm and 0.400 ppm Cd trigger levels for each product category.
- *Cocoa bean data provided by the SDs*: Products made from cocoa beans from LAC countries, Indonesia, and Papua New Guinea are likely to exceed both 0.450 ppm and 0.400 ppm Cd trigger levels for this product category.
- *Chocolate data provided by CODEX*: No data for this category (under reevaluation)

(c) For Covered Products with greater than 95% cacao content

Trigger level 0.960 ppm or 0.800 ppm (2024)

- *Chocolate data provided by AYS*: 17% and 21% of samples analyzed exceeded trigger levels 0.960 ppm and 0.800 ppm respectively. These comprised mainly of cocoa powder and some cocoa bean samples.
- *Chocolate liquor data provided by the SDs:* With the exception of Ecuador and Haiti, products made from chocolate liquor and cocoa beans from all other sampled countries should be able to meet both 0.960 ppm and 0.800 ppm Cd trigger levels for each product category.
- *Cocoa bean data provided by the SDs:* Products made from cocoa beans from LAC countries, Indonesia, and Papua New Guinea are likely to exceed both 0.960 ppm and 0.800 ppm Cd trigger levels for this product category.
- *Chocolate data provided by CODEX:* More than 80% of the samples from different cocoa-growing regions throughout the world met both 0.960 ppm and 0.800 ppm Cd trigger levels with the exception of those from the LAC region.

Comments on data

- The data provided by AYS, SDs, and CODEX demonstrated that majority of the chocolate samples from different chocolate manufacturers and cocoa-growing regions throughout the world can meet the trigger levels for Cd in the three (3) different categories of covered products with their respective % cacao contents.
- However, for the other samples that were unable to meet these trigger levels, it was clear that most came from the LAC region and to a lesser extent the Asian and Oceanic regions. The LAC region also represents approximately 80% of the world's fine or flavor cocoa supply. Majority of these beans are channeled into a niche market where typically a higher cacao content is used to manufacture up-market products (single origin dark chocolates/powders/nibs) which are in high demand and have been growing rapidly over the years. Thus, if these LAC cocoa beans are high in Cd, the greater the likelihood that products in the fine or flavor niche market made from these beans will not be able to meet the warning triggers.
- The Cd levels in the cocoa bean data provided by the SDs could have been overestimated since the "whole bean" was used inclusive of shell. The shell is known to have up to twice the amount of Cd in it than the nib and may be even more depending on cocoa variety and thus should not be included in the Cd analysis. Additionally, approximately 95% of the shell is discarded in the chocolate manufacturing process which should reduce overall Cd concentrations in the eventual liquor and should not be an issue of major contribution to contamination there.

Comments on potential solutions

- Our findings from the Root Cause Phase report revealed that the source of Cd in cocoa beans from affected regions are from natural origins as the cocoa tree accumulates it directly from the soil (cultivation phase). For this phase, short-term reductions are not feasible as the timeline for most of the Phase II Reduction Recommendations such as soil ameliorants and genetic strategies are 1-5 years or > 5 years with no clear magnitude of reduction. Countries should be given additional time to conduct further research into feasible strategies.

- There are some post-harvest short-term solutions that could be implemented to reduce overall bean Cd levels and its products. As indicated in our Reductions Recommendations report, this includes blending of beans and not buying beans from affected high Cd export countries/farms.
- Even though blending of Cd beans will favor some covered products through dilution, it is not feasible for high cocoa content specialty dark chocolates and other related products that depend on fine or flavor characteristics from single origin cocoa beans. A number of boutique shops and industries in this niche market that carry these products will therefore be challenged by these warning limits. On the other hand, rejection of beans from a country/farm level has significant implications on their revenue and livelihoods.

Position on Prop 65 Warning Triggers

Majority of the products from different chocolate manufacturers can meet the current Prop 65 warning limits, however, it is concerning that fine or flavor products that are produced from majority of the beans from the LAC region may be faced with some difficult challenges.

There are some short-term solutions like blending and the rejection of beans that could favor reduction of Cd levels in some cocoa and chocolate products from affected countries, however, this would not augur well for niche market fine or flavor products. Additionally, the other recommended reduction mitigation strategies to deal with this contamination which occurs through a naturally occurring process, are still in their development stages and will require a lot more time to bring into fruition. Thus, until there is much more progress in this area, I believe that the original Cd warning triggers for each respective category of covered products should not be modified particularly for the chocolate products with higher cacao content (>65%). They should remain at 0.400 ppm for products up to 65%, 0.450 ppm for products greater than 65% cacao content and up to a 95% cacao content, and 0.960 ppm for products greater than 95% cacao content.

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APPENDIX A. Clarifications on the Experts' Scope of Work

Before the Experts began their Phase Three work, they first clarified the scope of work with AYS and the SDs. The Experts prepared written questions for the two parties, and the Project Manager asked these questions (and some additional questions that he prepared) before the Phase Three work began. The following list includes the questions that were asked and the answers that were provided by AYS and the ISDs. These questions and answers were shared with the Experts and discussed during a videoconference meeting before the Experts began their Phase Three work.

1. The Proposition 65 Maximum Allowable Dose Levels (MADLs) for Cd and Pb are 4.1 µg/day and 0.5 µg/day, respectively. Please confirm that the Expert Committee is not charged with assessing these levels. In other words, please confirm that the Experts are not being asked whether they think the Proposition 65 MADLs should be higher or lower.

   Response:
   The derivation of the MADLs and perceptions of their protectiveness is outside of the scope of work.

2. At the beginning of the project, As You Sow shared calculations showing how action levels of Cd or Pb in chocolate products (expressed in units of ppm) could be calculated from Proposition 65 MADLs (expressed in units of µg/day). If memory serves, this calculation assumed a serving size of chocolate products. The Experts have requested that this calculation be provided again. Please confirm whether any part of the calculation is adjusted for percent nonfat cocoa solids in the chocolate products.

   Response:
   AYS and SDs do not agree on details of the calculation. Nonetheless, the Experts are not being asked to comment on the calculation and its underlying assumptions. The Experts are being asked to evaluate whether the negotiated drop-down levels (trigger levels) in Section 6.2 of the Consent Judgment can be Feasibly achieved or reduced.

3. Sections 6.2.1 and 6.2.2 of the Consent Judgment present three tiers of action levels for Pb and Cd, respectively, and refer to a date of "the sixth anniversary of the Compliance Date." Please confirm the calendar date of this anniversary.

   Response:
   The sixth anniversary of the Compliance Date is February 14, 2025. The Experts must express opinions on what is Feasible as of the Compliance Date; but they are not limited to providing opinions within this time frame.

4. Sections 6.2.1 and 6.2.2 of the Consent Judgment present three tiers of action levels for Pb and Cd, respectively. These action levels are expressed as concentrations. Please explain how these levels were derived and what they represent. For instance, are they based on the Proposition 65 limits, the EU limits, the FDA limits, or something else entirely? And how were the levels calculated? Were different serving sizes assumed for the different cacao content of chocolate products? The Experts have noted that they must understand exactly how these numbers were derived before they can proceed with their Phase Three work.

   Response:
   The Experts' charge is to determine which negotiated drop-down levels in Section 6.2 can be Feasibly achieved or reduced by 2025 or at a later date. Their charge is not to evaluate how the negotiated drop-down levels were derived.

   For context, the grouping of chocolate products in Section 6.2 of the Consent Judgment was based on categories of commercially available chocolate products. The >95% cacao content category generally captures cocoa powder and unsweetened baking chocolate; the 65-95% cacao content category generally captures dark chocolates; and the <65% category captures mass market chocolates. The Experts should evaluate these categories as is. The Experts have the option to comment on whether different cacao content thresholds should be used when assessing Feasibility.

5. Is the Expert Committee being asked to review and comment on various other standards beyond Proposition 65 (e.g., EU, FDA)? Or are their evaluations limited to the negotiated drop-down levels listed in Sections 6.2.1 and 6.2.2 of the Consent Judgment?

   Response:
   No to the first question; yes to the second question.

6. Are the action levels in Sections 6.2.1 and 6.2.2 of the Consent Judgment adjusted for percent of cocoa solids? Or adjusted for percent of nonfat cocoa solids?

   Response:
   No to both questions. The negotiated drop-down levels were not set with reference to the type of cocoa solids.

7. Please confirm the Expert Committee's basic charge with respect to the action levels in Sections 6.2.1 and 6.2.2 of the Consent Judgment. Are the Experts being asked to advise on <u>what the action levels should be</u> based on exposure assessment and/or risk assessment arguments? Or are the Experts being asked to advise on <u>what action levels can be Feasibly achieved and by when</u>?

   Response:
   The Experts' charge is to advise on what drop-down levels can be Feasibly achieved or reduced and by when. Their charge is not to advise on what levels should be set based on exposure assessment or risk assessment arguments.

8. Some of the action levels in Sections 6.2.1 and 6.2.2 of the Consent Judgment are expressed as concentration ranges. If Experts decide a concentration range can be Feasibly achieved, are they being further asked to specify a concentration within that range that can be Feasibly achieved?

   Response:
   For each category of chocolate products, the Experts are asked to recommend the lowest specific drop-down level(s) (i.e., a concentration) that can be Feasibly achieved—and this limit(s) must apply to the full range of cacao covered by the category. No level can be higher than the respective 2018 limit. The Experts can recommend different limits for different cacao percentages of chocolate products within a given category.

9. Are Experts basing their judgments for this report on the SDs' ability to meet action levels? Or are they to base their judgments on all chocolate manufacturers' (including the "boutique" manufacturers) ability to meet the action levels?

   Response:
   No to the first question. The Experts can assess Feasibility based on different types of chocolate companies.

10. The Expert Committee's Phase Two report identified "reduction strategies" that have the potential to reduce Cd or Pb levels in chocolate products. Please confirm that the recommendations made in the Phase Two report (i.e., the identified reduction strategies) should form the basis for the Phase Three conclusions.

    Response:
    The Phase Two report is finished. The reduction strategies in Phase Two should inform the Phase Three conclusions.

11. If the Experts are unsure of the Pb and/or Cd reductions that can be Feasibly achieved, would it be acceptable for the Experts to propose new research/studies to gather more information, leave the action levels unchanged for now, and reevaluate the action levels in the future (perhaps as long as 5-7 years from now) after more data are collected?

    Response:
    The Experts are charged with making an informed judgment on the drop-down levels that can be Feasibly achieved.

12. What level of consensus is expected for Phase Three? Would it be acceptable, for instance, if the Experts agreed to what action levels can be Feasibly met and by when but have different opinions on the "pathways" that can be taken to meet the action levels?

    Response:
    High-level consensus on drop-down levels that can be Feasibly achieved or reduced is the goal. The Experts may have a range of opinions on how to achieve those reductions. The Experts are encouraged to provide information to support their decisions, but the Experts' proposed "pathways" for achieving reductions will not be prescriptive.

13. Do the parties have any guidelines or expectations for the length and level of detail for the Phase Three report?

    Response:
    This is within the Committee's discretion.

14. To inform their deliberations, will the Experts have access to new testing data (e.g., for chocolate products and possibly for other process streams) that have been generated by AYS and the SDs since the project began 2 years ago?

    Response:
    The Consent Judgment does not contemplate any automatic provision of further testing information to the Committee but it states that the Committee may reasonably request additional testing information and, if it exists, the SDs will make a good faith effort to promptly provide it within 30 days on a blinded basis. (Any such requests should therefore be as specific and tailored as possible as gathering information within and amongst companies can be time consuming and it will likely take more than a month to gather and get blinded.)

15. Is commenting on bioavailability of Cd and Pb in chocolate products within the scope of work for Phase Three?

    Response:
    No.