INVESTIGATING CADMIUM LEVELS IN U.S. COCOA PRODUCTS AND THE EFFECTS ON THE INDUSTRY

by

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ABSTRACT

Cadmium is a heavy metal that is both abundant and naturally occurring in the environment. It is found in soils and can be taken up by some crops and animals, which eventually accumulates in the food chain. Cocoa products are particularly susceptible to increased exposure to cadmium as they naturally take up more of the nutrients in soils than many other plants. Cadmium toxicity could lead to a variety of negative health effects including renal tubular dysfunction, disruption in calcium metabolism and osteomalacia. For this reason, a Provisional Monthly Tolerable Intake of 25 micrograms/kg body weight (1.75 mg per 70 kg person per month) has been established. To assess the levels of cadmium in cocoa products currently on the U.S. market, 249 samples were tested and analyzed for their average parts per million over several parameters. There was a positive correlation between the percentage of cocoa solids in each product and the amount of cadmium typically found. The highest average amounts of cadmium based upon the form of product were found in the powdered products at 0.842 parts per million. By region, the products from the African region generally had the lowest amounts of cadmium at 0.098 parts per million compared to Latin American sourcing which held the highest averages at 0.695 parts per million. Addition of ingredients like sweeteners, dairy products and flavoring agents to cocoa make the products more palatable and dilute the amount of cadmium in these products by lowering the percent cacao. By creating limits on the maximum levels of cadmium in chocolate products specific to one country or region, the international market detracts from the needs of singular countries because it

impedes fair global trade and favors exclusion of certain areas of the global market. Cadmium levels in cocoa products should be examined with the potential health benefits in mind. By doing such, it is fair to assume that cocoa products are safe in moderation. Human bodies are self-regulating which make them similar to the environment as they both fluctuate with the levels of their nutrients, and only in extreme cases of imbalance are there detrimental effects on their health. This being said, regulating and monitoring these imbalances is extremely important to provide maximal public health protection.

Introduction

Objective

The objective of this study was to assess cadmium levels found in cocoa products currently on the market for sale to consumers in the United States in order to adequately submit recommendations to Codex Alimentarius on comments for proposed maximum allowable limits of cadmium in cocoa products. Codex standards are based on the best available science assisted by independent international risk assessment bodies or ad-hoc consultations organized by the Food and Agriculture Organization of the United Nations and the World Health Organization (Codex 1994). While being recommendations for voluntary application by members, Codex standards serve in many cases as a basis for national legislation for most countries (Codex 1994). Codex's Committee on Contaminants in Foods was informed that a proposal for exposure assessment of cadmium from cocoa and cocoa products was made for inclusion in the priority list of contaminants and naturally occurring toxicants proposed for evaluation by the Joint Expert Committee on Food Additives (Codex 2014). The Committee created an Electronic working group to submit recommendations for a draft to establish maximum limits of cadmium in cocoa-derived products to protect the health of consumers and ensure fair trade. Codex being a body that relies on scientific evidence to back up their suggested practices, made the decision to establish said working group in response to standards being set to go into place by some countries.

Sources

Cadmium is a naturally occurring heavy metal that is found in the majority of the environment. Cadmium is found in small quantities in the Earth's air, water and soil. In pure form, cadmium is a silver-white, soft metal with no definitive taste or odor.

Cadmium and its interactions in soil with plants especially related to the food system have been studied in varying degrees. The research interest of cadmium uptake in plants was sparked based on identifying accumulation of cadmium in soils due to amendments and use of certain fertilizers. In 1968, the Ministry of Health and Wellness in Japan announced that "itai-itai disease" was commonly associated with cadmium toxicity. This announcement came after it was discovered that rice farmers in Japan had been exposed to dangerously high levels of cadmium from industrial waste being used as a soil amendment (Tsuchiya 1969). An accumulation of cadmium in soil can result from fluctuations in the environment due to natural and man-made influences. Studies have focused on grains and rice as they naturally absorb more of the soil components than other plants (Grant 1998). The findings from these studies can be related to cocoa plants, as they are similar in their soil nutrient uptake. Figure 1 illustrates how in general, cadmium level fluctuation occurs in a cycle in our environment.

Sources of cadmium contamination by geological means can occur in several ways. Volcanic ash is a big source of cadmium contamination in areas in proximity of a volcano. This is due to cadmium being released into the air as a volcano erupts. The volcanic ash settles onto the land and is added into soils or accumulates in waterways which can be used to irrigate fields and crops (Toxicological Profile for Cadmium, 2002). Another similar example of this is areas affected by forest fires. This natural fluctuation is normally not problematic but in extreme cases where accumulation builds up in waterways, negative effects on human health such as "itai-itai" disease and tubular renal dysfunction can occur. Natural human exposure to cadmium can occur in higher levels based on their diet. Two examples of foods relatively high in cadmium are shellfish and organ meats. Shellfish are bottom feeders, so they have higher exposure to what is in their water and when cadmium is in higher concentrations in the water they live in, they naturally have a higher uptake of cadmium (Toxicological Profile for Cadmium, 2002). Organ meats such as the liver and kidneys of animals also accumulate higher levels of cadmium (Toxicological Profile for Cadmium, 2002).

Cadmium also can be released into the environment by man-made means. The four main sources of this contamination are from burning coal or waste, smoking tobacco related products, mining operations of zinc ores, and phosphate-based fertilizers (Tudoreanu, 2004). When coal or waste is burned, the cadmium in the materials being burned forms free metal complexes and is released into the atmosphere. From this release, the cadmium can settle in soils and waterways just as it does in volcanic eruptions. Because of this, areas surrounding landfills and coal burning plants see elevated levels. Human exposure can also occur by breathing in the air that contains these free metal complexes. The biggest route of human exposure from a non-food source is from smoking tobacco. Just as in the case of burning materials, the smoke being ingested contains free metal cadmium complexes. Cadmium is present in high levels in cigarettes and other tobacco products due to tobacco being another plant well apt at the uptake of nutrients in its soils. Cadmium is also most effectively absorbed into the human body through inhalation as compared to ingestion. This exposure is one of the many adverse health effects that long-term tobacco smokers face. Mining operations of zinc ores also can be means of exposure to the environment as cadmium is always found in concentrations with natural zinc deposits. Zinc and cadmium form complexes that are broken during the mining and smelting process and can be released in water runoff. This runoff can accumulate in waterways that can eventually make its way to crops and fields. The last man-made source of cadmium is the use of phosphate-based fertilizers. The chemistry of the soil can also affect the way cadmium and nutrients are taken up through the plant.

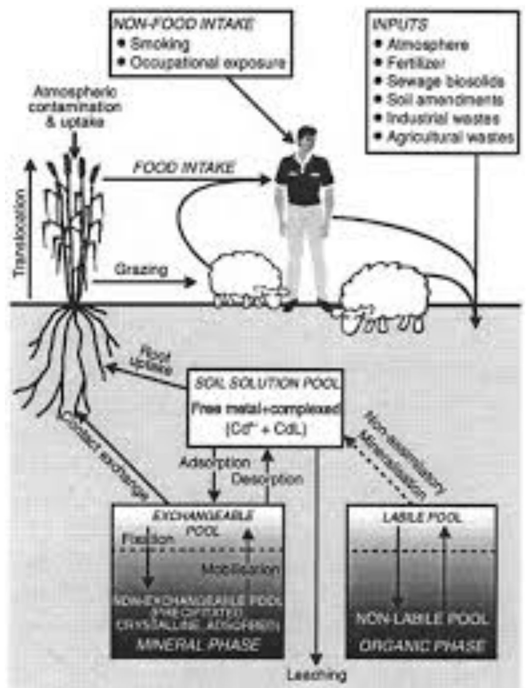


Figure 1 Fluxes of Cadmium in Soils, Plants & the Food System adapted from (McLaughlin, 1999**)**

Toxicity

Prolonged exposure to cadmium is problematic because when humans ingest cadmium, it accumulates in the kidneys. This accumulation is worrisome over time as cadmium has a relatively long half-life of 10-35 years and takes about a month for the body to excrete it. This accumulation can put humans at risk for adverse kidney and liver function since it leads to renal tubular dysfunction. Chronic cadmium exposure can cause a disruption in calcium metabolism that leads to "itai-itai" disease, which presents as lower bone density and fragile bones. The Joint Expert Committee on Food Additives (JECFA), an international committee organized by the World Health Organization and the Food and Agriculture Organization of the United Nations, has set standards on the Provisional Tolerable Monthly Intake (PTMI) of cadmium in humans. This was set to 25 micrograms per kilograms of bodyweight, which reflects the renal endpoint in humans. The renal endpoint reflected in this assessment is the point at which renal tubular dysfunction presents in a patient. JECFA's estimation for dietary exposure to cadmium from cocoa and its related products alone, range from 0.005 to 0.39 microgram per kilogram of body weight per month. Using this estimation of dietary exposure along with the PTMI, the estimation range is about 0.02% to 1.6% of the monthly exposure to cadmium from cocoa products.

Cadmium exposure to humans occurs in two main routes, inhalation of air containing cadmium and ingestion of cadmium containing foods with dermal exposure considered an insignificant route of exposure. In the lungs, anywhere from 10% to 50% of the inhaled dose is absorbed depending on solubility, particle size and duration of exposure to the specific cadmium compound. How much cadmium is absorbed thorough ingestion is also based on secondary factors including gender, age, smoking status and nutritional status. Smoking cigarettes is usually on the higher end of absorption because the particles found in tobacco tend to be very small (). When cadmium is ingested through a food vessel, up to 6% of the cadmium present is absorbed with 2.5% being the average absorption percentage. A diet rich in zinc or chromium also decreases the effectiveness of the gastrointestinal tract absorbing the cadmium. Once absorbed into the body, cadmium is transported by blood bound to metallothionein. Cadmium is found primarily in the kidneys with about 50% of the body's total amount of cadmium being located in the kidneys and liver (Toxicological Profile for Cadmium, 2002). Absorbed cadmium is excreted through the urinary tract over a long period of time. Cadmium ingestion can also have negative effects on zinc absorption as zinc and cadmium follow the same absorption route.

Products

Cocoa products are defined as products containing cocoa liquor, mass, powder or processed chocolate produced from the dried partially fermented fatty seeds of the *Theobroma cacao* tree. The process from cacao harvest to the point where a consumer ingests the product is complex and each step of the process dictates what it becomes and what concentration of each of the components the product contains. The cacao pods are the fruit of the cacao tree and they are harvested by hand and broken open to release a mixture of pulp and cacao seeds. This mixture then undergoes a process of both anaerobic and aerobic fermentation to end up as cocoa beans. These beans then go through a drying process that allows them to be sold to manufacturers. Roasting the beans is the next step, which separates the bean from the kernel and cracks the bean. This cracked bean is now called cocoa nib and is blown from the cocoa shell to separate it. The shell-less nibs are then ground to liquefy the cocoa butter inside the nib to produce chocolate liquor. At this step in the manufacturing process, the cocoa liquor is manipulated by the addition of ingredients depending on the manufacturer's intended final product. This manipulation can either be the extraction of the cocoa butter, or using the remains to produce a cake like form of cocoa. This cake is then broken into small pieces and then pulverized to form cocoa powder. Depending on the manipulation, the product can now be used to create a wide variety of chocolate products such as dark, milk, bakers, and other types. These types of chocolate are then produced in many different forms to become finished products available to consumers such as bars and powders. Chocolate and cocoa related products are available to consumers at almost every level of the production process from pods and seeds to cocoa powders and bars.

Cacao is sourced from many different parts of the world, but mostly in hot and humid climates especially those that are located around the equator. Table 1 shown below depicts the areas throughout the world with the most cocoa production. These are the areas from which most manufacturers source their cocoa to create their chocolate products. The given amounts for each year show that cocoa production is a slightly growing industry globally with large growth in the Americas and a slight decline in Asia and Oceana regions. Looking at the Latin American region specifically, there are 500,000 farms of cocoa most of which are small farms, which employ more than 3,500,000 workers. Many Latin American countries in the past few decades have had a major shift in their economies because of major impacts to their imports and exports. These changes were due to a variety of factors including shifts in trade, and the implementation of new laws to prevent narcotics trade. These detriments had crippled the economies of said countries, which forced them to seek new agricultural alternatives, including an expanding cocoa product market. This shift in cash crops has since started to bring these countries' economies to their formal vitality in a much safer and regulated system.

Region	Thousands of Tons (Percent of total)		
	2012-2013	2013-2014 (Estimated)	2014-2015 (Estimated)
Africa	2836 (71.9%)	3197 (73.3%)	2984 (71.6%)
Americas	622 (15.8%)	708 (16.2%)	729 (17.5%)
Asia & Oceana	487 (12.3%)	454 (10.4%)	455 (10.9%)

Table 1 Regions of Cocoa Production around the globe. (Codex, 2014)

Cocoa and cocoa based products have a wide variety of nutritional compositions based on the type of cocoa used, the concentrations of cocoa in their products and the components of the products themselves. Various studies have concluded that many health benefits are associated with moderate consumption of cocoa products such as antioxidant, cardiovascular benefits, influence of insulin resistance, positive effects on immune function and carcinogenesis, central nervous system protection, benefits with skin and finally against obesity. The various cocoa products that are available to consumers have varying nutritional compositions.

Whole cocoa beans are the most basic and minimally processed product available to consumers as they are in the early stage of cocoa production but are not a commonly product bought. Cocoa butter is commercially available for use in the beginning stage of chocolate product formulation, but also available in raw forms to consumers. Cocoa nibs are also used in commercial formulation of cocoa products and are rarely seen in product available to the consumer other than in whole form. Cocoa powder is seen widely at both the consumer and manufacturer levels. Cocoa powders for manufacturers are used in the formulation of other cocoa products whereas the cocoa powder at the consumer level is a final product either intended to add to another product (such as chocolate cakes or brownies) or as a ready to use product in products such as drinks. Cocoa bars are the most widely seen product to the consumer as a finished product that is ready to eat and mostly used in manufacturing other cocoa derived products. Each of these products has a certain percent cacao, whether indicated on the label or not, that indicates the total amount of cocoa used in the product. This percentage can be broken up into the percentage related to cocoa from fat solids and cocoa from non-fat solids, which sum up to the total amount of cocoa solids.

Many products on the market are the byproduct of the blending of cocoa and cocoa products in different formulations to create a final product. This blending can be from blending cacao derived from different regions of the world, blending the types of products used in the makeup of the final product, blending the amounts of each product and a combination of such. A general trend of major cocoa manufacturer's is to source cocoa from many different areas of the world and blend them together to make a more homogenous product. By keeping the percentages of cocoa from each region, manufacturers ensure a better chance of always producing the same product flavor.

Many countries have started to set standards of maximum allowable limits on cadmium that are varying in both their scientific basis and categories of products subject to these limits. One group specifically is the European Union (EU) who has set standards to go into effect January 1st of 2019 and are listed in Table 2. The standards set have four categories and are all based on parts per million of cadmium in their respective categories' products. The EU standards' categories are at various levels of the production process and target specific groups.

Type of Chocolate product	**Parts per Million (ppm)**
Milk Chocolate with <30% cocoa solids	0.1
Chocolate with <50% total dry cocoa solid; Milk Chocolate with ≥30% total dry cocoa solids	0.3
Chocolate with >50% cocoa solids	0.8
Cocoa Powder	0.6

Table 2 European Union's Maximum Allowable Limits for Cadmium in Cocoa Products.

The objectives of my study were to test not only the EU standards against the products on the U.S. market but also to quantify standards in a scientific based manner. Prior to the study, many questions could be asked as to why the EU standards were set to the limits they were and what the basis for this was. If there was a difference in found levels, what should be used as to what levels are safe? How do the EU limits compare to those proposed by the Codex electronic working group? Why would there be a difference between what is available to the EU and what is available to the U.S.? If there were harmful levels found, how could the U.S. ensure safe products for consumers? If cadmium was found to be at dangerous levels and cannot be adequately removed from products in a realistic manner, is there other means of finding a way to reduce levels? If levels of cadmium in cocoa products currently available to consumers on the U.S. market are higher than the EU or other proposed standards, then global standards should be set to reflect safe levels to the consumer because authorities have a responsibility of ensuring safe products while ensuring fair and equal trade.

Methods

The products used for experimentation were sourced from a variety of outlets, but were all available to consumers in the U.S. Purchases were made in store, online from retailers and samples were sourced from major U.S. companies. The products ranged from low end to high-end price wise, specialty to common types of products, and they were chosen to cover major types of products and categories of products. Once sufficient amounts of samples were collected, the samples were coded in an alphanumeric system. This system was used then to accurately identify relevant information for each specific product. The forms the product included bar, powder, nib, bean, and pieces. The type of category it fell into included milk, dark, baking, semi-sweet baking, cacao and "not listed." The percentages were recorded in the ranges of the percent of cocoa that the product fell into including 0%-19%, 20%-34%, 35%-49%, 50%-64%, 65%-79%, 80%-94%, 95%-100%, and "not listed." The country of origin was recorded as which country the product specified its origin as with secondary sources also recorded. The region in which they fell were based on categories of global cocoa sourcing. Regions included in the study included as Africa, Asia and Oceana and the Americas. Another response recorded was whether the product claimed to hold an organic status. Finally, products that claimed to have some other factor to them were also recorded, which could include being alkalized, being raw, types of sweeteners, fair and other trade alliances, and other related categories.

Once all of the relevant information was compiled, the coded samples were individually weighed out and bagged into coded bags. Samples were weighed to include 100 grams in each sample bag and were broken apart to remove any identifying marks, which made each sample indistinguishable. This weight was chosen to have a manageable amount of sample for the testing lab and to give uniformity to the sample population as a whole. The samples were packed and shipped to an outside facility for testing. The analysis of the cacao products was performed according to the AOAC method 986.15. This process uses solvent extraction to remove the cadmium from the sample and then Inductively Coupled Plasma with Mass Spectrometry (ICP-MS) to quantify the amount that was initially extracted. This analysis was used to determine the amount of cadmium contained in the product in the form of parts per million. In total 249 samples were tested to a limit of detection of 0.001 micrograms per liter. Once the data was received, it was compiled into the master spreadsheet for data analysis. The results were analyzed by several factors including, region of origin type of product, form it is received by the consumer, percent cacao in the product, organic status, and several other claims from the product label. These product parameters were used to differentiate the products from each other in non-identifying ways to allow for analysis of target areas. These parameters were also used to target more specific areas of interest beyond individual comparisons to find correlations between several specific product parameters. The data was analyzed using Microsoft Excel to find basic statistical information for all of the product groups including their mean, minimum, maximum and standard deviation.

Results

Table 2 shows the total statistical analysis of all the samples studied and is separated by their percent cocoa solids percentage. For each of the ranges of percent cocoa solids, the standard deviation shows how widespread the data occurred in that range. For the products with less than 50% cocoa, they each had a very small standard deviation, which illustrates the low range of values that fell within those groups around the mean. For the 65%-79% range, there was an increase in variation with the 95% to 100% range having the greatest amount of variation.

	20%-34%	35%-49%	50%-64%	65%-79%	80%-94%	95%-100%
N	19	34	26	46	8	92
Average ppm	0.092	0.095	0.197	0.262	0.254	0.619
Minimum ppm	0.01	0.01	0.04	0.01	0.07	0.040
Maximum ppm	0.14	0.2	0.8	2.2	0.58	2.990
Standard Deviation	±0.054	±0.049	±0.186	±0.362	±0.154	±0.590

Table 3 Tables of values of cadmium of all samples and statistical analysis of products by % cacao

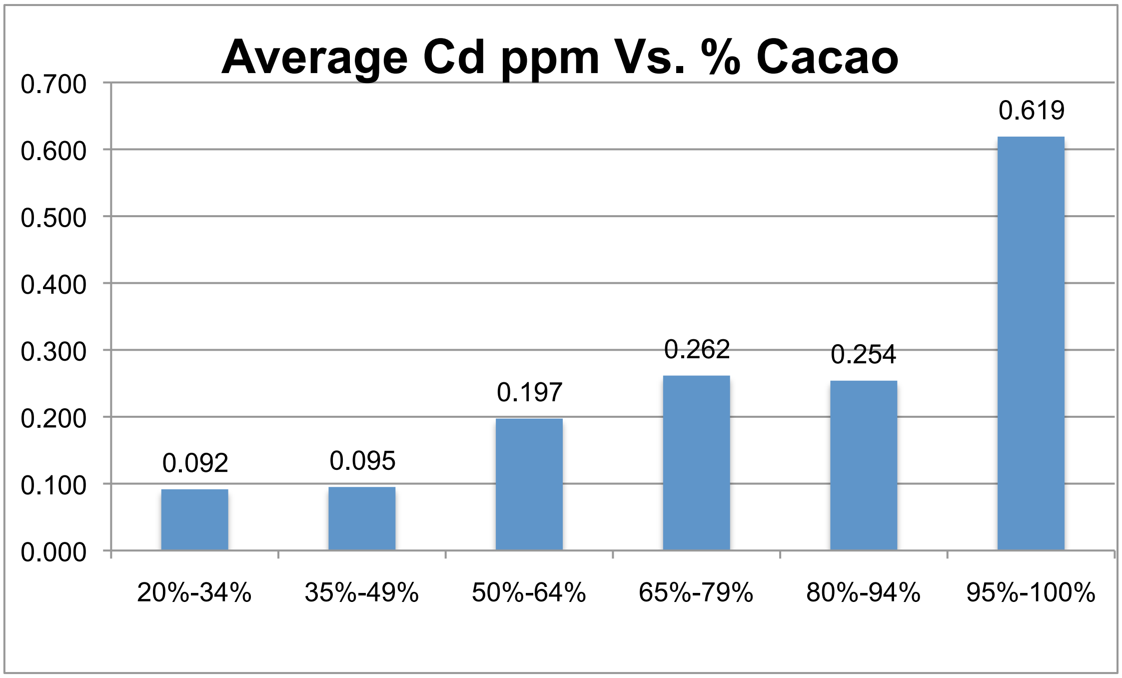


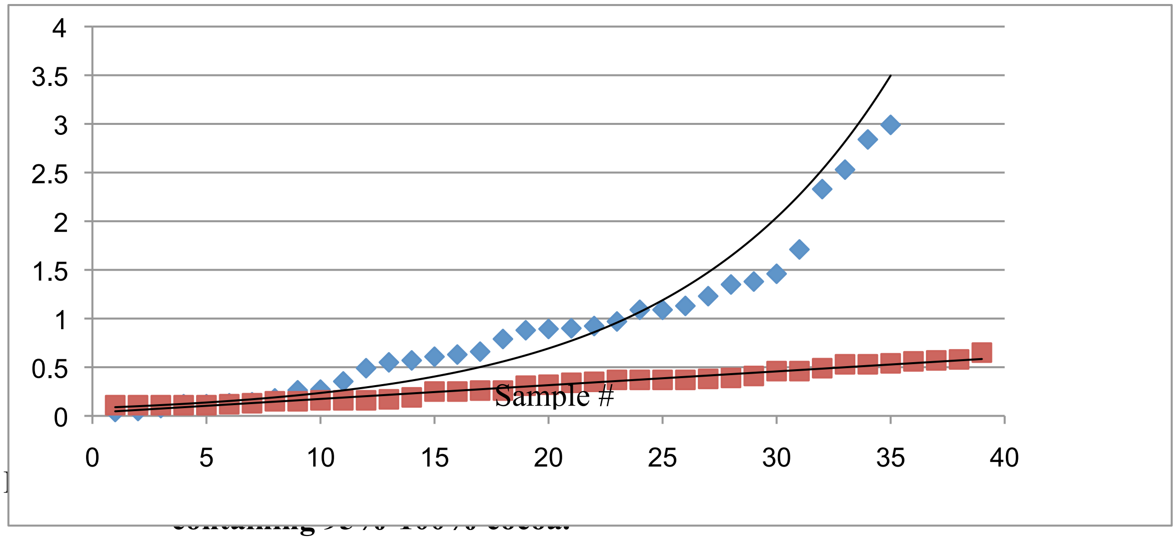
Figure 2 Comparing the average cadmium parts per million by the percentage of cacao in product.

Figure 2 is a graph depicting the average parts per million of cadmium found in each sample based on the percent cacao within each range which includes every sample tested. In this graph we see a positive correlation with an increase in cadmium parts per million with an increase in the percentage range. The major outlier in the grouping is the 95%-100% range that has more than double the average parts per million of cadmium than the next lowest range. With this major outlier, other factors such as one of the other recorded parameters is probably the cause for the difference in the trend of increasing cadmium on a linear scale based upon percentage of cocoa. The 80% to 94% range does not follow this correlation completely as this range's average is less than the average of the 65% to 79% range and can be due to the limited sample size of eight samples in this range compared to the forty-six samples in the 65% to 79% range.

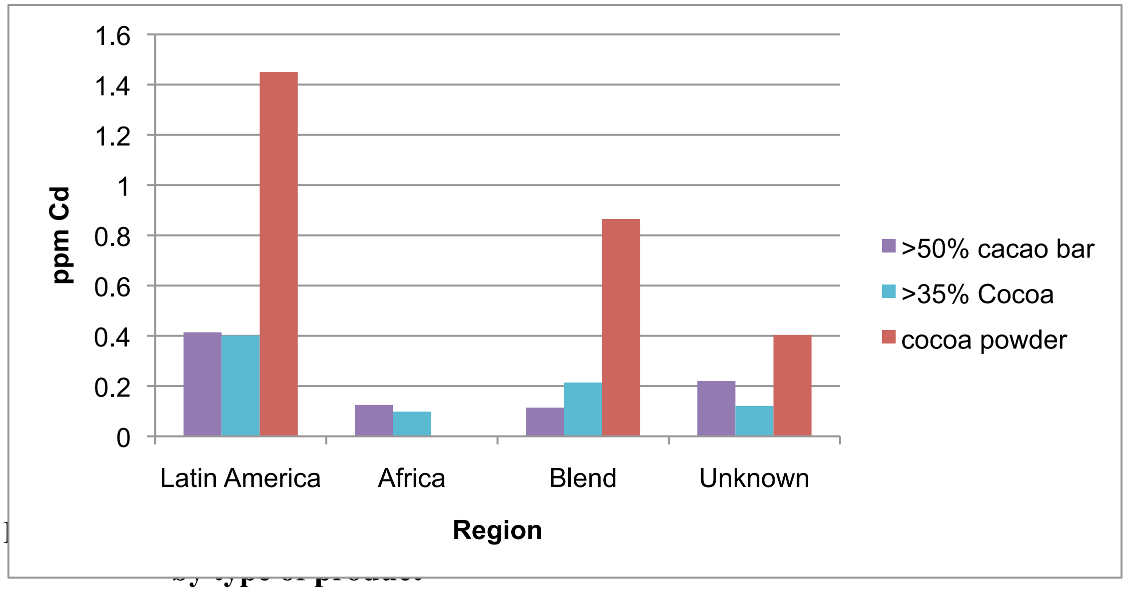
	Powder	>50% Bar	>35% Bar
N=	47	118	152
Average ppm	0.918	0.267	0.228
Minimum ppm	0.05	0.010	0.010
Maximum ppm	2.99	2.200	2.200
Standard deviation	±0.688	±0.264	±0.244
Coefficient of Variation	0.749	0.989	1.069

Table 4 Comparison of products containing greater than 50% cocoa in bar and powder form and bars containing greater than 35% cacao

Tables 4. shows the comparison of bars and powders and their statistical analysis for both greater than 35% cocoa solids and greater than 50% cocoa solids respectively. These tables show evidence that the difference in product type be associated with the amount of cadmium on average in a sample. The greater than 50% bars show about one fourth the amount of cadmium on average than the powder samples and in the bars with greater than 35%, there is about one fifth less the amount of cadmium than the powder samples. This agrees with the data as a whole that shows the positive correlation with the percent cacao and the amount of cadmium in a sample.



The correlation between type of product and the amount of cadmium is also evident in Figure 3, which shows the trend in the amount of cadmium in samples based on product type from minimum to maximum in the 95% to 100% ranges. The comparison shows the large difference the type of product made within the same percentage range. Referring back to Figure 2, the outlying difference in the 80% to 94% range and 95% to 100% range is caused by the powdered samples in the higher range. The red points indicate the bar samples while the blue points indicate the powdered samples.



Breaking down these comparisons further, Figure 4 illustrates the differences in how geographic region influences the amount of cadmium in a sample. In each of the three groups of products, the amount of cadmium is significantly higher in the Latin American countries than in Africa or in either of the non-disclosed geographic groups. Looking at the groups for the African cocoa products a very minimal amount of cadmium is seen in their products especially when compared to the Latin American products. This disparity indicates a geographic correlation between higher cadmium levels in Latin America as compared to Africa.

Discussion

The goal of the study was to adequately assess the levels of cadmium in cocoa products available in the U.S. and evaluate if they were a cause for concern while comparing found levels to the maximum limits set out by the EU. The levels found in the products we tested overall were not a cause for concern. The levels were higher than the standards set in place by the European Union while still maintaining levels that are safe. These findings should require reevaluation by the EU of what levels of cadmium are reasonable for manufacturers while ensuring the safety of consumers and the promotion of fair trade. Each of the main objectives were successfully completed by our analysis and allowed for the findings of this study to be used in suggesting limits to been established for the recommendations to the Codex committee. Because the European Union has set limits on various products at many different times through out the production process and because the cause for concern would be to the consumer at the time of consumption, the electronic working group has set their limits on products that would be available to the consumer and fit broader categories rather than categories that may be confusing. For cocoa powders the limit was suggested to be 4.0 parts per million and for cocoa liquors, essentially all other cocoa products available to the consumer, to be 3.0 parts per million. These limits were set because they were just above the highest parts per million of cadmium found in the study, but well below the line of concern for the public health as a whole.

The limits set forth by both the EU and the recommendations for Codex are extremely different. If the European standards go into place, a vast amount of products tested just by this study would be ineligible for purchase by consumers.

Their categories specifically leave large gaps in products because they target specific parts of the production process. The major flaw in this approach is that many times products are sold as ingredients and not as finalized products. Under the EU guidelines, cocoa power that has 2 parts per million of cadmium would not be able to be sold to a manufacturer that may have intended to use it in a blend that could be diluted down to below the limit by the time it is sold to the consumer. The cocoa powders specifically are formed from earlier stages of the cocoa processing steps rather than other chocolate products that contain greater 50 percent cocoa solids. This disparity could be confusing to manufacturers because as this study shows, there is a positive correlation with the extent of processing; with greater processing correlating to a decreased amount of cadmium in the product. Confusion also could lie in what defines a chocolate product with greater than 50 percent cocoa solids and cocoa powders as the majority of the cocoa powders in this study have fallen in both categories.

There are several limitations of the study and several aspects that were beyond the scope of this study. None of the powders tested claimed outright that they were from the African region. This limits the power of the argument for Latin American powders, as there is not information in this study to directly compare them to other regions other than inferences from the other categories of data including the blended and unknown origin products. The regions used in this study were also extremely broad. This limits the arguments for specific countries of origin as the increased levels could be from a more focused point than just a continent. The sample sizes for some of the parameters studied were not as large of sample populations as other groups. By increasing the sample size of some of the populations, a greater degree of confidence could be assumed. The parameters taken from the labels of the products were not uniform for every product. Some of the products listed vague regions or areas while others were much more specific in their information. Further studies targeting each of these drawbacks from the study could greater increase the precision and confidence of the study.

The largest disproportion is the difference in Latin American powder samples compared to the other regions. The levels in the samples from every other region were on average a fraction of the cadmium levels of the Latin American samples. Cadmium levels in this region of the world could be caused by many external natural occurrences of cadmium in the environment. Geographic buildup over time could be the cause of the elevated amounts due to the large concentration of volcanic land located in those regions as compared to the African region. The Latin American region is part of what is called "the Ring of Fire" which holds the majority of the world's volcanoes, something the African countries are not a part of (Ring of Fire, 2015). Another geographic buildup could be from the many zinc deposits in the Latin American countries as compared to the African region (USGS, 2013).

Setting limits on a contaminant in foods requires many considerations including the health implications, the limits on each category of product, and the international market as a whole. Cadmium in cocoa products has realistically low health implications Using JECFA's daily exposure estimate range of 0.005 to 0.39 micrograms per kilogram of body weight, the typical exposure ranges from 0.02 to 1.6% of the PTMI. Using the PTMI of 0.25mg/kg, the average adult weighing 70 kilograms would have to eat 44 bars of 20 grams to exceed the PTMI (Bellinger, 1992). From our findings, Table 5 indicates the amount of 20g servings an average adult weighing 70 kg would have to ingest during a one month time period to reach JECFA's PTMI for cadmium. These numbers are based on 20g servings, but not every cocoa product holds this serving size. Specifically many of the powdered products had serving sizes that were significantly less at 2.5 grams per serving. The products with the higher % cocoa contain more cadmium, but less added ingredients such as sugar or milk solids. With the less added ingredients, the less palatable the product is to a consumer so the expectation is that consumption of products with a high percent of cacao (and therefore a higher amount of cadmium) would be lower. In contrast, products with lower levels of cadmium that may be consumed in higher amounts because they contain additives that may have other health risks associated with them that would have detrimental effect much more quickly than the prolonged exposure to cadmium. The American Heart Association recommends limiting the amount of added sugars you consume to no more than half of your daily discretionary calorie allowance. For women this is no more than 100 calories per day, and for men, no more than 150 calories per day (Sugar 101, 2014). The USDA reports a regular milk chocolate bar to have 77.4 grams of added sugar per serving (Sugar 101, 2014). This means by consumers eating about either one and one third of a milk chocolate bar or two milk chocolate bars, depending on gender, a consumer would exceeding those standards for added sugar in their diet.

% Range	Average Cadmium (ppm)	Number of 20g of product needed to eat
20-34	0.092	95
35-49	0.095	92
50-64	0.197	44
65-79	0.262	33.4
80-94	0.262	34.5
95-100	0.619	14.22

Table 5 Amounts needed for each product category to reach JECFA's estimated PTMI of cadmium exposure.

The majority of products with the highest level of cadmium are intended to be used as an ingredient, not a finished product. A typical chocolate bar can include ingredients such as emulsifiers, proteins, sweeteners, flavorings, and other additives to create a unique product for the consumer. The products that were seen with the highest levels were in general more niche or luxury products that the consumer would not typically consume in large quantities in a small timeframe. The limits set on cocoa products should be based upon their intended use, the percent cacao, and product type. Setting limits based upon cadmium levels from one specific region or based on cocoa sources from a specific region not only favors the sourcing party, but also has major market implications. By setting limits much lower than an area of possible health implications, it impedes fair trade to countries that have no control over those limits. Many Latin American countries rely on cocoa as a staple crop for their economy. As seen in the past, the sudden removal of a major crop can lead to the failure of the economy of an entire country. Although Africa is the primary producer of cocoa internationally, the world still relies on Latin America for a portion of its cocoa trade.

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Appendix A

Definitions and Terms

i) Cocoa – refers to the chocolate product post fermentation.

ii) Cacao – refers to the chocolate product pre-fermentation.

iii) Cocoa Butter – the fatty pressed product removed from cocoa liquor.

iv) Cocoa Liquor – the byproduct of the pressed cocoa nib after they have been removed from their shell.

v) Cocoa Bean – the seed of the cacao fruit from the *Theobroma cocoa* plant.

vi) Cocoa Nib – fragments of the cocoa bean after roasting.

vii) Cocoa Powder – the product of pulverizing the by-product of cocoa butter extraction from cocoa liquor.

viii) Cocoa Solids – the amount by weight of a product that comes directly from a cocoa ingredient.

ix) Cocoa Products – Any food product that contains cocoa liquor, mass, powder or processed chocolate produced from the dried partially fermented fatty seeds of the *Theobroma cacao* tree

x) PTMI – Provisional Tolerable Monthly Intake – the amount in which is tolerable in humans in a month's period without seeing negative health effects.

xi) Codex – An intergovernmental commission whose purpose is to hold a collection of recognized standards, guidelines, codes of practice and other recommendations relating to foods, food production and food safety.

xii) WHO - World Health Organization

xiii) FAO – Food and Agricultural Organization – a body of the United Nations.

xiv) Renal Endpoint – the point at which negative effects on the kidney are reached.