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Cadmium Levels in Soils and Cacao Beans at Estates with the Cacao Carenero PGI: Barlovento, Miranda State, Venezuela

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ABSTRACT

In recent times, Venezuela has increased its cocoa exports. To overcome barriers to entering international markets in different countries, Venezuela must address several limitations, including the presence of heavy metals such as cadmium. Cadmium is a heavy metal toxic to human health that is present in immature soil, is absorbed by plants, and is accumulated in beans. The Miranda state soil has been marked as a potential cadmium carrier, despite being home to one of the world's best cocoas, which is internationally recognized for use in the production of derivatives, such as chocolate.

Therefore, this study aimed to provide a technical assessment of cadmium concentrations in soil and cocoa beans from PGI (Protected Geographical Indication) production units (farms) located in the Páez Municipality, subregion Barlovento, Miranda State, Venezuela.

The results show that the soil cadmium concentration of the four farms ranged from 1.76 to 3.56 ppm (mg.kg-1) its data coincide with other values reported for soils in cocoa-producing areas in Venezuela. It has been reported that these soils are predominantly highly fertile, alluvial, and rich in organic matter, making them world-famous for cultivating premium Carenero cocoa beans. Cd concentration found in the beans with shell of the four farms which ranging from 0.58 to 0.79 ppm (mg/kg-1), which is good as compared to the reasonable and scientific maximum limit on raw beans must be 0.8-1.22 μg g−1 (ppm) pointed out by reports of literature, and lightly high than those used as common commercial reference standard of 0.6 mg/kg (ppm) in shelled cocoa beans. It is important to note that this difference could be due to the presence of the shell in the cocoa analyzed in this study, as supported by the fact that Cd accumulates better in the cocoa shell.

Likewise, results also show that despite the low pH found in the soil of the region assayed, look like an interaction between low electrical conductivity and low pH in this region's soil could diminish cadmium root absorption by cocoa plants, showing a cadmium bean concentration adequate for consumption based on the concentration in the latest research in the literature.

Keywords: Fine aroma cocoa, cadmium level, cadmium legislation, soil pH, Venezuelan cocoa.

INTRODUCTION

All export-oriented cocoa agri-food supply chains require a rigorous assessment of the safety and quality factors that determine their international competitiveness. The key aspects include adherence to technical regulations, sanitary standards, and labeling requirements. Among the national requirements are laws of origin, local permits, quality control, and international requirements, which include ISO Standards, sanitary regulations, and packaging and labeling.

Venezuelan cocoa is a high-quality exportable product that has been growing internationally in exports in recent years, and it has broken some barriers to entering international markets with different cocoa-exporting countries; there are still limitations, including the presence of heavy metals, especially cadmium, in soils and, therefore, an accumulation in cocoa. Therefore, for official export, it must comply with national and international standards to ensure its quality, safety, and legality in global markets.

Moreover, in the fine-flavor cocoa sector, the presence of heavy metals in the soil and their accumulation in the beans pose a priority scientific and agronomic challenge that could jeopardize access to highly regulated markets (Velásquez-Vélez et al., 2022). Emphasizing cadmium (Cd) determination because it is a quality, food safety, and public health requirement, as cadmium is a highly toxic heavy metal that poses a risk to human health as it can cause kidney and bone damage (García Porras et al., 2025).

Cadmium enters agroecosystems through natural sources such as forest fires, wastewater, volcanic eruptions, and the weathering of rocks, and anthropogenic activities such as: metallurgy, mining, combustion emissions, excessive pesticide use, and phosphate fertilization (Haider et al., 2021; Charkiewicz et al., 2023; Tosto et l., 2023).

According to Chavez et al. (2015), Cd, which has no known metabolic function in plants, can accumulate in roots, shoots, and edible parts such as grains and cacao beans, even at low concentrations. Cadmium causes kidney disease because it accumulates primarily in the kidneys over years, leading to impaired function and kidney stones. Also, induce to bone damage such as osteoporosis and osteomalacia (Itai-itai disease), as well as severe stomach irritation and lung diseases among others (Charkiewicz et al., 2023; García Porras et al., 2025).

An exposure level of 5 µg/L is considered critical. Permissible and safe levels of cadmium in humans are primarily measured via tolerable weekly intake and concentrations in body fluids: Tolerable Weekly Intake (2.5 µg/kg of body weight), blood cadmium (less than 0.5–5.0 µg/L), in healthy, unexposed individuals, the normal reference value is less than 0.4 µg/L (overall average of 0.1 to 4 µg/L), and urinary cadmium (less than 2–10 µg/g of creatinine). Renal dysfunction is considered unlikely if the values are below 10 µg/g of creatinine (European Union EU, 2014; FAO/WHO, 2020; Abt and Lauren, 2020).

Therefore, the European Union has progressively tightened its controls on heavy metals in cocoa. These regulations were initially established under Regulation No. 488/2014 but have since been ratified in the European Union as Regulation 2023/915, which sets limits for cadmium (ranging from 0.10 to 0.80) directly in chocolate and cocoa-derived products (such as cocoa powder). Despite the European Union's cadmium regulation applying directly to chocolate and cocoa-derived products (such as cocoa powder), rather than to raw cocoa beans, in practice the beans must meet levels that ensure the final limit is not exceeded. To ensure the final chocolate and other cocoa derivatives do not exceed strict international standards, the recommended maximum cadmium limit for cocoa beans (peeled and dried) should fall between 0.3 and 0.6 mg/kg (ppm).

There is no single global legislative limit for raw beans, but buyers and importers apply commercial thresholds calculated mathematically based on the specific type of final product.

In this context, there are several discussions to establish international regulations on admissible levels of Cd in cacao products, promoted by the main cacao-importing countries (WHO and FAO 2023). Suggesting the follow calculation on the basis that cadmium accumulates almost entirely in the non-fat cocoa solids (cake and powder) and is virtually absent from cocoa butter. Consequently, when the bean is processed and the fat extracted, the cadmium becomes concentrated in the solid fraction by a factor of approximately 2:1. If a cocoa bean contains 0.3 mg/kg of cadmium, the resulting powder will double its concentration to 0.6 mg/kg, reaching the exact limit permitted by the European Union for the final consumer.

Therefore, the maximum of 0.3 mg/kg in the bean could be the standard limit required for manufacturers of cocoa powder and high-purity chocolate to ensure compliance with the regulation (final limit of 0.60 mg/kg). However, the figure of 0.6 mg/kg (ppm) in shelled cocoa beans is a widely used commercial benchmark, closely monitored by international buyers.

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Nevertheless, the review of Florida Rofner (2021 a y b) shows a proposal to set a limit based on calculations from the literature that a reasonable and scientific maximum limit on raw beans must be 0.8- 1.22 μg g−1 (ppm). These calculation incorporating criteria of proportionality, genetic variability, and bromatological aspects of cocoa, based on the limits established in the European Union regulation.

Based on the foregoing, the goal of this study was to analyze cadmium concentrations, pH, and Electrical Conductivity in soil and cadmium presence in the cocoa beans growing in the PGI (Protected Geographical Indication) production units (farms) located in the Páez Municipality, subregion Barlovento, Miranda State, Venezuela. The document also analyzes the soil-to-crop transfer and outlines strategies aimed at preserving regional agricultural sustainability.

MATERIALS AND METHODS

Materials

Samples

From several farms in the Barlovento region, four (04) were selected with a surface of 21 Ha (8500 m²) —three of which have held the "Cacao Carenero" PGI (Protected Geographical Indication) status. 35 samples were gathered as follows:

1) 10 samples were collected from the farm El Agradecer, located in the La Represa rural sector, El Guapo Community, Páez Municipality; it comprises 7 hectares and 3,700 square meters, with 4,000 plants cultivated. Owner: Ananías Alvarez.

2) 10 samples from the farm El Rey, located in El Verde, El Guapo Community, Páez Municipality; it comprises 10 hectares, with 6,500 plants cultivated. Owner: Reinaldo Pinto.

3) 10 samples from the farm Las Tres Hermanas, located in the Perdomo sector, Río Chico Community, Páez Municipality; it comprises 3 hectares, with 2,700 plants cultivated. Owner: Leny Echenique.

4) 5 samples from the farm Hacienda Caraballo, located in the Río Chico Arriba sector, Río Chico Community, Páez Municipality; it comprises 1 hectare and 5,000 square meters, with 1,500 plants cultivated. Owner: María Mieres.

METHODS

Sampling

Soil sampling:

A stainless-steel shovel and a wooden one were used: the former to open the furrows, and the latter to remove soil that might contain traces of oxide from the steel shovel. Small plastic scoops were used to collect the main sample and the subsamples.

Once the topography was screened for flat and undulating areas, and georeferenced by the surveying UTM (Penn State University/Universal Transverse Mercator), the selected area was carefully cleaned by removing the surface vegetation—specifically, weeds and leaves—without removing the soil layer.

A square-shaped hole was dug using a stainless-steel spade. At each farm, a primary sample was taken at a depth of 40 centimeters, followed by the collection of nine (9) subsamples at a depth of 20 centimeters to form a composite sample.

To this end, using the small plastic scoop, a soil portion approximately 10 centimeters thick was collected. All collected subsamples were placed on a plastic sheet. Using small plastic scoops, a portion of the soil remaining in the hole and a portion of the soil from the sheet were collected; both were placed in the bucket where the

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

composite sample was being gathered. The scoop and plastic bucket were cleaned between samples to reduce the risk of cross-contamination. The main sample and subsamples were mixed (with thoroughly clean hands) in the bucket, and stones, roots, and organic debris were removed. A 1-kilogram final sample was collected from each farm to be sent to the laboratory. Samples were coded and identified with date, farm name, location (locality, municipality, state), sampled area, depth, details of the producer and the technician who took the sample, and UTM coordinates.

Beans sampling:

From the harvested, fermented, and dried cocoa at each farm, samples were collected from the sacks stacked in the warehouse; small amounts were taken from various sacks to yield a total of 100 to 150 grams per sample. Samples were bagged and labeled with details such as sample number, date, time, name of the farm, location (locality, municipality, state), and producer information.

Chemical Analysis

The cadmium concentration was measured by using Flame Atomic Absorption Spectrometry, and the results were expressed in milligrams per kilogram (ppm) as follows:

The digestion and extraction of cadmium (Cd) in Soil and cocoa beans were performed using Sdzawkar et al. (2005 and Norma Chilena 2880 (2004) as follows:

To release the analyte, both soil and cocoa bean samples were subjected to a wet acid digestion process. A reagent mixture consisting of nitric acid (HNO3), hydrochloride acid (HCl), and hydrogen peroxide (H2O2) was used. This procedure ensured complete matrix destruction and the total solubilization of the cadmium present in the samples.

Instrumental quantification: Flame Atomic Absorption Spectrometry was used for cadmium determination. The results obtained were expressed in milligrams per kilogram (ppm).

Physicochemical Analysis

Measurement of pH and the electrical conductivity (EC) of the soil:

The pH was measured using the potentiometric method, employing a pH meter and a glass electrode that detects hydrogen ion activity by generating an electrical potential difference. After calibrating the equipment with buffer solutions, the electrode was immersed in the soil sample, and the reading was recorded once it had stabilized (FAO, 2021a).

Electrical conductivity (EC) was measured by determining the electrical resistance between two parallel electrodes immersed in the soil-water suspension (FAO, 2021b). The principle of the method involves determining the soluble salts present in the soil, which conduct current in proportion to the number of dissolved salts in soil.

RESULT AND DISCUSSION

The analysis of cocoa samples from plantations with the "Cacao Carenero" Protected Geographical Indication reveals key findings regarding food safety and soil quality, particularly within the framework of the European Union Regulation 2023/915 and the FAO Guidelines for Soil Description (European Union (EU), 2023) and those required for the GPI certification (SAPI, 2026).

Table 1 summarizes the chemical and physicochemical results of the four farms. As can be seen the soil cadmium concentration of the four farms is ranging from 1.76 to 3.56 ppm (mg.kg-1). These values coincide with the values reported for soils in cocoa-producing areas in Venezuela.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

Ramirez (2022) reported Cd levels in soil of Venezuelan north central states ranging from 0.5 to 2.5, and Crozzier 2012, have reported 0.03 to 3.52 ppm (mg.kg-1) of Cd in Aragua soil.

However, a report by Marcano et al. 2026 of plantations from 2012 and 2019 through different states of Venezuela, pointed out the soil Cd concentration in the plantations averaged 0.22 µg g−1, lower than the recommended maximum for agricultural soils (0.43 µg g−1) by the USEPA, 2002, but pointed out that plantations in Miranda state, shown the highest values result that have been corroborated by Izquierdo 1998 and Cestari et al. 2020.

Table 1. Description and analysis results of samples from the four plantations

Farm	Location	N° Ha	Farm Age	Cadmium soil ppm (mg/kg-1)	Cadmium beans ppm (mg/kg-1)	Soil pH	Soil E.C 1:1 in water (dS.m-1)
AGRADECER	La Represa El Guapo	7	12	3.56	0.79	4.70	0.02
EL REY	El Verde. El Guapo	10	40	2.98	0.69	4.94	0.2
LAS TRES HERMANAS	Río Chico	3	56	1.76	0.58	5.72	0.12
CARABALLO	Río Chico	1.5	96	2.09	0.62	5.52	0.18

To explain this discrepancy, it is important to point out that the dynamics of Cd in soil depend on its chemical form and the characteristics of the soil (Bohn et al.,1993). For example, its rock composition could elevate the Cd level in soil, but the mature soil which have undergone a long process of transformation over time with well-defined layers (horizons) and a high content of organic matter, and are independent of the parent rock from which they originated usually have low pH, low cation exchange capacity values and thick textures that reduce the concentration of the metal inside of them (Florida Rofner, 2021b).

Therefore, due to its soil composition and maturation, various values of cadmium in soil have been pointed out in the literature, such as 0.43 µg g-1 is recognized internationally as the USEPA in 2002 as critical screening level for cadmium in agricultural soils. This agency argued that any agricultural site measuring above this value requires active monitoring or remediation to prevent heavy metal toxins from entering the human food supply chain.

On the other hand, the European Union, through the Kelley Directive, has indicated that the typical values in uncontaminated soil with cadmium are between 0 and 1 µg g-1 (Acevedo et al., 2005), Bohn et al.,1993) showed that the natural level of cadmium in agricultural soil varies from 0.01 to 7 µg. g-1. However, the studies of Kabata-Pendias, 2010 report 0.07 and 1.1 µg. g-1.m

Consequently, the values found in the soil of the Barlovento region, which varied from 1.76 to 3.56 mg/kg-1 or µg. g-1, are within the ranges reported in the literature, showing cadmium in the beans in accordance with those levels required for security. The soils of the Barlovento region in Miranda State, Venezuela, are predominantly highly fertile, alluvial, and rich in organic matter, making them world-famous for cultivating premium Carenero cocoa beans. Because Barlovento is a massive structural depression fed by the lower Tuy River basin and other mountain streams, its soil profile is deeply tied to its fluvial and coastal geography.

Table 1 also summarizes the soil pH and the EC in the four farms studied. Barlovento region is rich in organic matter, which contains humic and fulvic acids that tend to slightly acidify the soil, yet it simultaneously acts as

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

a buffer. This means it helps resist drastic pH changes, keeping the soil within a more stable range. Despite the before established According to the FAO/OMS (2018, and Florida Rofner et al., in 2018, Dogbate et al., 2021, Dos Santos Oliveira et al., 2024, and pH below 5.5 increases the mobility and uptake of cadmium by cacao plant roots.

The values of pH found in the farms from Barlovento studied here varied from 4.70 to 5.72. Two of the four farms evaluated, Agradecer and El Rey farm, have pH values not ideal for cacao cultivation, because cacao develop most efficient a pH range between 6.0 and 7.0 (or slightly acidic, starting at 5.5). However, the soil of Las Tres Hermanas farm is the least acidic soil (5.72), which corresponds to its lower cadmium level in the cacao bean (0.58 mg/kg) (Figure 1).

For bio mitigation of the acidic pH it has been propose liming could be a practice in the management of acidic soils for cacao-growing soils (Rosas-Patiño et al., 2017, FAO/OMS, 2018), and for cadmium adsorption by the plant the use native arbuscular mycorrhizal associations with have an important role in plant growth in heavy metal-contaminated soils, playing a significant part in metal tolerance and accumulation (Solsol-Salis and Vallejos-Torres, 2025); but information on it is scarce

In addition, the low soil electrical conductivity EC value, as shown by the studied farms' soil, reveals that the soil has a small amount of dissolved salts and plant nutrients in its water, low organic matter, and sandy soil. That fact indirectly indicates poor mineral nutrient availability for cacao. Optimal EC values in cacao plantations generally range from 0.4 to 1.0 dS/m, allowing for adequate water and mineral uptake without causing osmotic stress (Huamán Ayala and Aguirre Escalante, 2025.).

To minimize the loss of EC it is recommended to manage the best practices such as; the regulated fertigation, organic amendment (apply compost or biochar to buffer soil properties and naturally manage electrical activity) and flushing protocols (Ensure functional deep drainage channels to remove excess salt accumulation during heavy rainfall seasons)

In regards to the Cd concentration found in the beans with shell of the four farms which ranging from 0.58 to 0.79 ppm (mg/kg-1), it is good as compared to the reasonable and scientific maximum limit on raw beans must be 0.8-1.22 µg g−1 (ppm) pointed out for Florida Rofner in 2021, and with the commercial reference standard of 0.6 mg/kg (ppm) in cocoa unshelled. It is a consensus that in the cacao bean, cadmium accumulates to a greater extent in the Testa (also known as the shell or integument) compared to the cotyledon or inner kernel. The Testa acts as an outer retention layer that concentrates higher levels of this heavy metal during fruit maturation and development (Bravo Arista 2020).

Figure 1 show the correlations among the soil and beans cadmium concentration and the pH value of the farms.

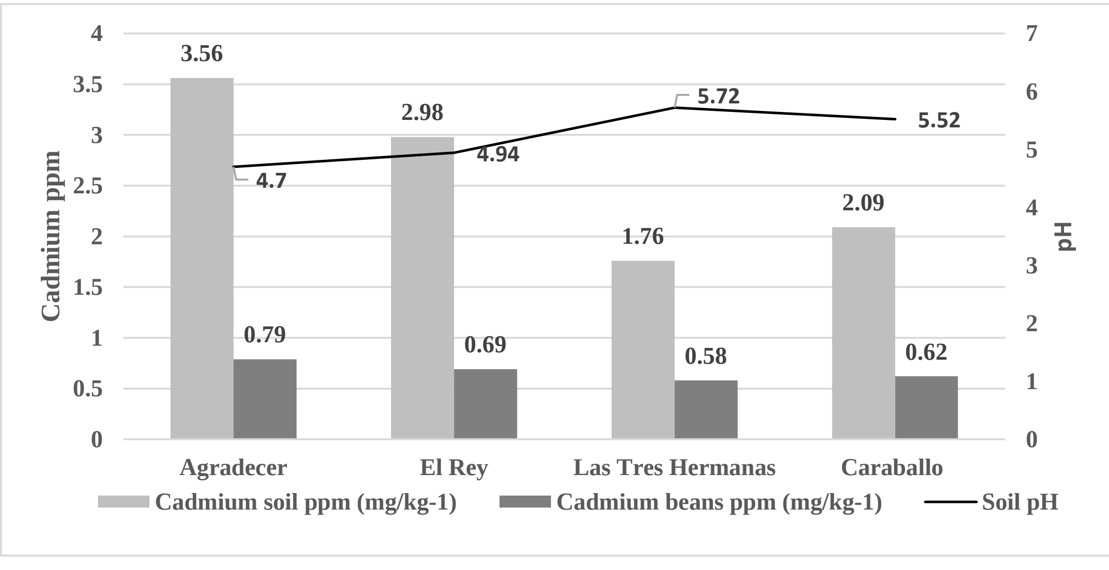

Figure 1. Relationship between pH and Cd concentration in bean and soil

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

As shown in Figure 1, the soil of Las Tres Hermanas farm is the least acidic soil (5.72), which corresponds to its lower cadmium level in the cacao bean (0.58 mg/kg). Although not all of the farms have soil with a suitable pH for optimal plant development and for reducing cadmium intake from the soil, the cadmium concentrations in the beans studied here are within a range acceptable to meet international export requirements.

CONCLUSION

It can be hypothesized that despite the low soil pH of the farm's localities (4.7-5.72), the cadmium concentration in farms soil, which ranged from 1.76 to 3.56 ppm (mg.kg-1), and in the unshelled beans that ranged from 0.59-0.78 (mg.kg-1) are good values to considered the cocoa beans from this region for national consumption and for its export, fulfilling the required cadmium concentration based on the latest discussion reported in the literature. On the other hand, as it was determined that the cadmium concentrations in the soil were not those expected compared to those found in the cocoa beans, this can be attributed to a possible interaction of low pH and electrical conductivity, which could act as a factor in reducing the cadmium intake from the soil for the plant's roots. However, it will need more research on the topic.

REFERENCES

1. Abt, E.; & Lauren, P. (2020). Perspective on cadmium and lead in cocoa and chocolate. Journal of Agricultural and Food Chemistry, 68(46):13008–13015. Online: https://bit.ly/3xIThQf
2. Acevedo, E.; Carrasco, M.A.; León, O.; Martínez, E.; Silva, P.; Castillo, A.; Ahumada, I.; Borie, G.; & González, S. (2005). Informe sobre criterios de calidad de suelos agrícolas. Servicio Agrícola y Ganadero, Chile.205 pp.
3. Bohn, H.L.; McNeal, B.L.; & O`Conor G.A. (1993). Soil chemistry. 1stEdition. Editorial Limusa S.A. México. 363 p.
4. Bravo Arista, WL. (2020). Determinación del cadmio (CD^{++}) en almendras de tres cultivares de Theobroma cacao L (cacao) en el proceso de poscosecha en el distrito Daniel Alomía Robles - Huánuco – Perú, Tesis de Grado. Universidad Nacional Agraria de la Selva Facultad de Agronomía
5. Cestari; S.; Telleria-Mata, N.; Villanueva, S.; & Henríquez, M. (2020). Cadmium in Barlovento, Edo. Miranda, Venezuela, and possible effect of tuy river on the contents of this metal in cocoa fields. In: XI Congreso Científico de La Universidad Del Oriente. 2020-11-25 | Conference Paper. Sucre, Venezuela. https://zenodo.org/records/4509531
6. Chavez, E.; He, Z.; Stoffella, P.; Mylavarapu, R.; Li, Y.C.; Moyano, B.; & Baligar. V.C. (2015). Concentration of cadmium in cacao beans and its relationship with soil cadmium in southern Ecuador Science of the Total Environment, 533:205–214.
7. Charkiewicz, A.E.; Omeljaniuk, W.J.; Nowak, K.; Garley, M.; & Nikliński, J. (2023). Cadmium toxicity and health effects—A brief summary. Molecules, 28(18), 6620
8. Crozier, J. (2012). Heavy metals in cocoa. International workshop on possible E. U. regulations on cadmium in cocoa and chocolate products. 3er and 4th may
9. Dogbatse, J.A.; Arthur, A.K.; Awudzi, G.K.; Quaye A.K.; Konlan, S.A.; & Amaning, A.A. (2021). Influence of acidic soils on growth and nutrient uptake of cocoa (*Theobroma cacao* L.) varieties. International Journal of Agronomy, (7):1-10.
10. Dos Santos Oliveira, A.; de Souza Júnior, J.O.; Lima Neves, J.C.; dos Santos Neto, J.A.; & Ahnert, D. (2024). Temporal variation of soil acidity attributes in cocoa growing areas. Acta Agronómica, 73(1): 92-98.
11. European Union-EU. (2014). Regulation no. 488/2014. they modify EC regulation no 1881/2006 regarding the maximum content of cadmium in food products. Technical report, Official Journal of the European Union. Online: https://bit.ly/3uvfOxT
12. Europea Union-EU. (2023). Reglamento (UE) 2023/915 de la Comisión de 25 de abril de 2023 relativo a los límites máximos de determinados contaminantes en los alimentos y por el que se deroga el Reglamento (CE) N.O 1881/2006 (Texto pertinente a efectos del EEE): In: https://eur-lex.europa.eu/legal-content/ES/ALL/?uri=CELEX:32023R0915.

13. Joint FAO/WHO (2020) Expert Committee on Food Additives Safety Evaluation of Certain Food Additives and Contaminants: Prepared by the Seventy-Third Meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA); Proceedings of the Meeting, 73th & World Health Organization; Geneva, Switzerland. 9–14 November 2020; Geneva, Switzerland: World Health Organization; 2011. Available online: https://apps.who.int/iris/handle/10665/44521FAO/OMS 2018.
14. FAO. (2021a). Standard operating procedure for soil pH determination. Rome.
15. FAO. (2021b). Standard operating procedure for soil electrical conductivity, soil/water, 1:5. Rome
16. Florida Rofner; N.; Shilthon Lineker, C.; & Gómez Bernal, R. (2018). El pH y la absorción de cadmio en almendras de cacao orgánico (Theobroma cacao L.) en Leoncio Prado, Huánuco, Perú. Folia Amazónica, Revista del Instituto de Investigaciones de la Amazonía Peruana, 27 (1). 1-8
17. Florida Rofner, N. (2021a). Review on maximum limits of cadmium in cocoa (*Theobroma cacao* L.). Revisión sobre límites máximos de cadmio en cacao (Theobroma cacao L.). La Granja: Revista de Ciencias de la Vida, 34(2) 2021:113-126. ©2021, Universidad Politécnica Salesiana, Ecuador.
18. Florida Rofner, N. (2021b). Cadmio en suelos y granos de cacao de origen peruano y sudamericano Revista Facultad Nacional de Agronomía Medellín, 74(2):9499-9515.
19. García Porras, G.A.; Santos, J.A.; Carvalho, MR.d.; Pinzón-Sandoval, E.H.: Pereira, A.A.S.: & Guilherme, L.R.G. (2025). Addressing Cadmium in Cacao Farmland: A Path to Safer, Sustainable Chocolate. Agriculture, 15(4), 433.
20. Haider, F.U.; Liqun, C.; Coulter, J.A.; Cheema, S.A.; Wu, J.; Zhang, R.; Wenjun, M.; & Farooq, M. (2021). Cadmium toxicity in plants: Impacts and remediation strategies. Ecotoxicology and Environmental Safety, 211, 111887.
21. Huamán Ayala, J.L.; Aguirre Escalante, C. (2025). Calidad de suelo en parcela en *Theobroma cacao* (cacao) de diferentes edades en el fundo Fortaleza de Tingo María – Huánuco, 2023. Revista de Investigación y Amazonía, 15(20): 51–61
22. Izquierdo, A (1998) Determinación de contaminación con cadmio En El cultivo de cacao (*Theobroma cacao* L) y su posible origen en la región de barlovento, Edo. Miranda. Master Tesis, Universidad Central de Venezuela. Venezuela
23. Kabata-Pendias, A. (2011). Trace elements in soils and plants. Fourth Ed. In: Book by CRC Press, pp. 548.
24. Marcano, E.; Arrieche, D.; Rodríguez-Ramos, F. (2026). Cadmium screening in soils and cacao beans from the main plantation sites in Venezuela. Bulletin of Environmental Contamination and Toxicology, 117(4):1-8.
25. Norma Chilena Oficial Nch. 2880. (2004). Compost clasificación y requisitos.
26. Penn State University. (2026). La naturaleza de la información geográfica. La cuadrícula UTM y la proyección Mercator transversal. In: https://courses.ems.psu.edu/natureofgeoinfo/c2_p22.html
27. Ramírez, R. (2022). Contaminación de suelos y cultivos con metales pesados y nutrientes en Venezuela. Revista de la Facultad de Agronomía (UCV), 48: 01–17
28. Rosas-Patiño, G.; Puentes-Páramo, Y.J.; &Menjivar-Flores, J.C. (2017). Relación entre el pH y la disponibilidad de nutrientes para cacao en un entisol de la Amazonia colombiana. Corpoica Ciencia y Tecnología Agropecuaria, 18(3): 529-541.
29. SAPI (Servicio Autónomo de la Propiedad Intelectual en Venezuela). (2026). Indicaciones Geográficas Protegidas. In: https://sapi.gob.ve/indicaciones-geograficas/
30. Sdzawkar, A.; Carrasco, M.; Grezz, R.; & Mora M. (2005). Método de análisis de compost. Revisión 2005. Instituto de Investigaciones Agropecuaria INIA Santiago de Chile, Chile.
31. Solsol-Salis, S.; & Vallejos-Torres, G. (2025). Micorrización y concentración de cadmio en sistemas agroforestales con cacao (*Theobroma cacao* L.), en San Martín. Revista Agrotecnológica Amazónica, 5(2), e790.
32. Tosto., T.F.; de Almeida, A.A.F.; Oliveira, B.R.M.; Paiva, A.Q.; Ahnert, D.; Reis, G.S.M.; & Baligar, V.C. (2023). Physiological, biochemical, and molecular responses of young cacao plants grown in coastal plain compacted soil, with location and phosphorus limitation. Journal of Plant Growth Regulation, 42, 2389–2407.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

33. USEPA. (2002). United States Environmental Protection Agency. Supplemental guidance for developing soil screening levels for super fund sites. http://www.epa.gov/ superfund/health/con media/soil/ind ex.htm
34. Velásquez-Vélez, M.I.; Galvis-Lora, C.; Mejía-Córdoba, C.A.; & Zapata-Guzman, J.E. (2022). Implicaciones de la acumulación de Cadmio en la cadena productiva del cacao. Manglar, 19(4), 391-397.
35. WHO/FAO. (2023). Code of Practice for the Prevention and Reduction of Cadmium Contamination in Cocoa Beans. Codex Alimentarius Code of Practice No. CXC 81–2022. Codex Alimentarius Commission. Rome, Italy. https://doi.org/10.4060/cc5333en%0A