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Presence of cadmium in cocoa (*Theobroma cacao,* L.) soils in the province of Esmeraldas-Ecuador

Presença de cádmio em solos de cultivo de cacau (*Theobroma cacao, L.*) na província de Esmeraldas-Equador

Presencia de cadmio en suelos de cultivo de cacao (*Theobroma cacao, L.*) en la provincia de Esmeraldas-Ecuador

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ABSTRACT

The province of Esmeraldas, where the research was carried out, is recognized for the quality of its fine aroma cocoa (Theobroma cacao, L.), which is highly sought after internationally, but the regulation for cadmium by the European Union has restricted its commercialization, for Therefore, with the objective of evaluating the presence of cadmium in the soil, leaves and almonds, to establish its mobility and absorption by the plant, 51 farms from the Eloy Alfaro, Muisne and Atacames cantons were sampled that have cocoa crops of more than 5 years of age, applying a zig zag sampling, the lowest average values of cadmium in the soil were found in Colón Eloy (0.064 ppm.Kg-1), while the highest were obtained in the soils of Muisne and Atacames (0.147 and 0.145 ppm.Kg-1 respectively); in the leaves, the data were 6.96 and 11.50 ppm.Kg-1 for these locations, respectively. In cocoa beans, both in Colón Eloy, Muisne and Atacames, they were high (1.09; 1.99 and 2.08 ppm.Kg-1, respectively) with respect to the maximum limits of Cd, established by the European Union (0.10 to 0.80 µg .kg-1). It is concluded that the analyzed samples yielded values greater than 0.1 ppm.Kg-1 considered contaminants, due to the fact that Cd, due to its mobility, is easily absorbed by cocoa plants, which is reflected in its content in the leaves and fruits, for Therefore, remedial measures must be applied to help producers recover their commercialization in the world.

Keywords: cadmium, fine aroma cocoa, bioaccumulation.

RESUMO

A província de Esmeraldas, onde foi realizada a pesquisa, é reconhecida pela qualidade de seu cacau de aroma fino (Theobroma cacao, L.), desejado internacionalmente, mas a regulamentação do cádmio pela União Européia restringiu sua comercialização, devido to Portanto, com o objetivo de avaliar a presença de cádmio no solo, folhas e amêndoas, para estabelecer sua mobilidade e absorção pela planta, 51 fazendas dos cantões Eloy Alfaro, Muisne e Atacames que possuem cultivos de cacau há mais de 5 anos idade, aplicando uma amostragem em zig zag. Os menores valores médios de cádmio no solo foram encontrados em Colón Eloy (0,064 ppm.Kg-1), enquanto os maiores foram obtidos nos solos de Muisne e Atacames. (0,147 e 0,145 ppm.Kg-1 respectivamente); nas folhas, os dados foram de 6,96 e 11,50 ppm.Kg-1 para esses locais, respectivamente. Nas amêndoas de cacau, tanto em Colón Eloy, Muisne e Atacames, foram altas (1,09; 1,99 e 2,08 ppm.Kg-1, respectivamente) em relação aos limites máximos de Cd, estabelecidos pela União Européia (0,10 a 0,80 µg .kg-1). Conclui-se que as amostras analisadas apresentaram valores superiores a 0,1 ppm.Kg-1, considerados contaminantes, pois o Cd, devido a sua mobilidade, é facilmente absorvido pelas plantas de cacau, o que se reflete em seu teor nas folhas e frutos, para Portanto, medidas corretivas devem ser aplicadas para ajudar os produtores a recuperar sua comercialização no mundo.

Palabras clave: cádmio, cacau de aroma fino, bioacumulação.

RESUMEN

La provincia de Esmeraldas, lugar donde se realizó la investigación, es reconocida por la calidad de su cacao fino de aroma (*Theobroma cacao*,L.), apetecido internacionalmente, pero la regulación para el cadmio por la Unión Europea ha restringido su comercialización, por lo que con el objetivo de evaluar la presencia de cadmio en el suelo, hojas y almendras, para establecer su movilidad y absorción por la planta, se muestrearon 51 fincas de los cantones Eloy Alfaro, Muisne y Atacames que tienen cultivo de cacao de más de 5 años de edad, aplicando un muestreo en zig zag, Los valores promedio más bajos de cadmio en el suelo se encontraron en Colón Eloy (0.064 ppm.Kg^{-1}), mientras que los más altos se obtuvieron en los suelos de Muisne y Atacames (0.147 y 0.145 ppm.Kg^{-1} respectivamente); en las hojas, los datos fueron de 6.96 y 11.50 ppm.Kg^{-1} para estas localidades respectivamente. En las almendras de cacao, tanto en Colón Eloy, Muisne y Atacames, fueron altos (1.09; 1.99 y 2.08 ppm.Kg^{-1}, respectivamente) con respecto a los límites máximos de Cd, establecidos por la Unión Europea (0.10 a 0.80 µg. Kg^{-1}). Se concluye que las muestras analizadas arrojaron valores superiores a 0.1 ppm.Kg^{-1} considerados contaminantes, debido a que el Cd por su movilidad se absorbe con facilidad por las plantas de cacao lo que se refleja en su contenido en las hojas y frutos, por lo que deben aplicarse medidas de remediación para ayudar a los productores a recuperar su comercialización en el mundo.

Palavras-chave: cadmio, cacao fino de aroma, bioacumulación.

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Main topic:
Crop soils analysis
Main practical implications:
The results presented can serve as a guide for the design of future public policies involving high quality agricultural production of cocoa.
Originality/value:
The article addresses in detail a subject that has been little explored in applied sciences in the Ecuadorian context.

INTRODUCTION

Ecuador as a producer of fine aroma cocoa (*Theobroma cacao*, L.) has gained a space in the international market providing 70% - 87% of the demand for this high quality product to the world. (Development Bank of Latin America, 2020).**;** (Mihai et al., 2023) making this cultivar the third in economic importance in the country (Wickramasuriya & Dunwell, 2018); (Barrezueta, 2019)It is one of the main sources of economic income for small and medium producers, as well as representing the basis of family and animal feed (Rajab et al., 2016). (Rajab et al., 2016)**;** (Aguirre et al., 2022)..

Cacao is grown in different environments in the coastal and Amazonian regions, which differ in soil fertility (Herrera et al., 2022).This can be attributed to agroclimatic factors and especially to the soil, which is rich in mineral and organic material (Jaramillo, 2002), (Jaramillo, 2002)although the proportions are not the same in all soils (Pachés, 2019). (Pachés, 2019). In these soils contain between 45 to 48% of mineral material, 3 to 6 % of organic material and less than 1% of organisms with constitutes the biota, which despite being the minority part is essential for agricultural production and soil fertility (Hidalgo, 2020).

According to De La Cruz (2022)in agricultural production, the soil is considered as a living entity, with characteristics that make it special (Morales et al., 2022)The soil is considered as a living entity in agricultural production, with special characteristics that make it special (Morales et al., 2022). (Cañazaca et al., 2022)..

In the mineral part of the soil are found those elements that are used by plants such as iron, boron, phosphorus, magnesium, potassium; but there is also a good portion of unusable minerals where the heavy metals aluminum, lead, zinc, cadmium are found, the latter being one of the trace metals in the soil (Rosales et al., 2021). (Rosales et al., 2021) The latter is one of the most soluble and dangerous trace metals in the soil, due to its high mobility; which, in small concentrations, has harmful effects on plants and on human health (Dueñas & Intriago, 2022).. Cadmium can bioaccumulate and is non-biodegradable (Guerra et al., 2022).

Agricultural soils can be contaminated by the use of phosphate fertilizers because they generate high ionic mobility (Aguirre et al., 2022). (Aguirre et al., 2022).and cadmium binds strongly to organic matter, which serves as a bridge to be incorporated by the plant, thus entering the food chain or remaining immobile in the soil and 90% of it can remain active for up to 300 years (K. Morocho & Puente, 2019).

This metal is absorbed by the plant and is concentrated in the leaves, testa and cotyledon (Vallejos et al., 2022). (Vallejos et al., 2022)..

According to Maddela, et al., (2020) 25% of the world population is a consumer of cocoa products; which is at risk of suffering some symptoms of Cd accumulation, one of the consequences being cancer. (OIRSA, 2020); (Maddela et al., 2020).

Cacao, being deciduous, returns Cd to the soil with the fall and decomposition of the leaves, increasing the toxic level of cadmium in the soil; but the Cd in the fruits reaches human consumption. (Dueñas & Intriago, 2022)with adverse effects on health, even at minimum levels (Tejada et al., 2022).

Studies by Chavez, et al. (2015) and Arguello et al. (2019), indicate that Cd contamination is not generalized in a region or province, but focused; being the sites with the highest concentrations of Cd the southern zone of Guayas and El Oro, the central zone of Manabi, the west of Esmeraldas and the northern zone of Amazonia (Argüello et al., 2019; Chavez et al., 2015).These localities represent the centers of major Ecuadorian cocoa production. In Esmeraldas, these authors found that the coefficient of variation (CV) of Cd by canton is higher than 50% and by province higher than 70%, information that alerts to investigate the magnitude of this contamination in cocoa soils.

Permissible limits for cadmium in the soils of Ecuador should not exceed 0.5 mg/kg, average concentration (Ortiz et al., 2022).

However, recent studies of cocoa beans, cadmium (Cd) levels were found at average concentrations of 0.90 (mg kg^{-1} or ppm) (Development Bank of Latin America, 2015). This situation is of concern to chocolate producers and consumers, as compared to the regulation issued by the European Union as maximum Cd limits of 0.10 to 0.80 µg g^{-1} for cocoa and its derivatives. (EU, 2014). These requirements affect producers who will not be able to access their markets (National Finance Corporation, 2018).

Therefore, the objective of this study was to evaluate the concentration of cadmium in soils, leaves and almonds of *Theobroma cacao* in the province of Esmeraldas, Ecuador, information that will serve as a baseline to propose possible alternative solutions.

METHODOLOGY

Study area

The study was conducted in the province of Esmeraldas, in the cantons:

Table 1. Geographical location of the research areas.

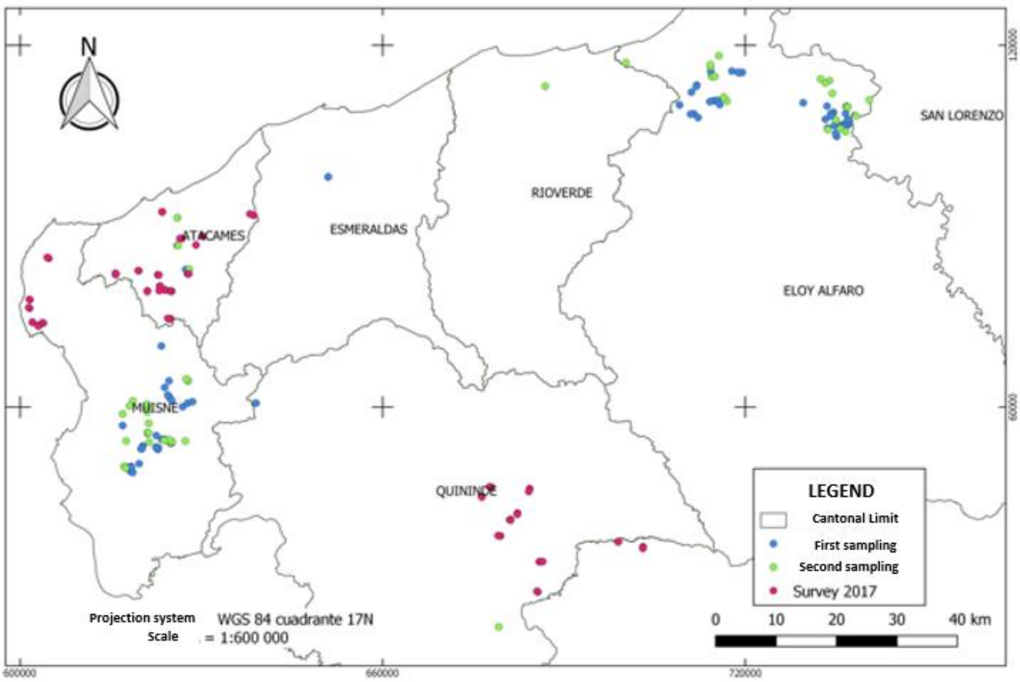
Canton	Temperature	Coordinates	Altitude
Muisne	20 -35° C	(0°36′24″N 80°01′06″O)	0-200 m.a.s.l.
Atacames	25°C	(0°52′00″N 79°50′00″O).	6 m.a.s.l.
Eloy Alfaro	20-35° C	(1°15′00″N 78°59′03″O)	200 m a.s.l.

Source: author's elaboration (2023)

With the support of technical staff from the NGO Maquita and local stakeholders, 23 samples were taken in the canton of Eloy Alfaro, 22 in Muisne, 3 in Atacames where soil, leaves and almonds were sampled from the farms.

On each farm, 4 trees were randomly selected from which six subsamples were collected at a distance of 70 cm from each tree and at a depth of 20 cm. They collected 20-30 medium leaves (5ta or 6ta counted from the apex) and 3-4 mature ears for analysis. The samples were sent to the soil and plant nutrition laboratory of the Escuela Politécnica del Litoral (ESPOL), in polyethylene zip-loc bags, duly labeled with the data of the site and part of the tree to which the sample corresponds, for the corresponding analysis.

Figure 1. Map of samples collected in the province of Esmeraldas, blue dots correspond to the first sampling of almonds, green dots to samples collected in farms, red dots to samples previously collected by the consulting team.



Source: author's elaboration (2023)

The work was carried out under a quantitative approach, in an exploratory and descriptive experimental mode, since the analytical results are compared with data obtained from other studies and with European and national standards on permissible levels to determine soil quality, which allows us to identify which sites are impacted by the presence of Cadmium and its bioavailability in the selected sites.

The Bioaccumulation Factor (BCF) was used to determine the Bioaccumulation Factor according to (Alderete et al., 2019)calculated for leaf (H) and fruit (F), using the following expression:

$$FBC = (Cd_{plant} / Cd)_{suelo}$$

Cd concentration in soil and plant parts was expressed as mg kg-1 dry weight.

Statistical analysis

The data were analyzed by descriptive statistics, and the dispersion of the samples from the Muisne, Atacames and Eloy Alfaro localities was determined. Analysis of variance and Tukey's test were used for multiple comparisons of Cd concentration. Previously, the normal distribution of the data was examined by the Shapiro-Wilk test, at a significance level of a p-value < 0.05. A Pearson correlation analysis was performed to determine whether pH influences the presence of Cd in Cacao. The data were processed using SPSS software.

RESULTS

Analyses of soil samples show that the cocoa crop is grown in slightly acid soils with an average pH 6.1, favorable for the mobility and availability of cadmium, which averages 0.1042 $mg.kg^{-1}$. Cadmium can pass rapidly through the root cell membranes and throughout the system to the bean. Table 2 shows the average pH and cadmium contents of the sampled soil by canton.

Table 2. Presence of cadmium (ppm) and pH of cocoa (Theobroma *cacao* L.) soil.

Location	pH	Cadmium $(mg.kg)^{-1}$
Eloy Alfaro	5.89	0,064
Muisne	6.37	0,147
Atacames	6.71	0,145

Source: author's elaboration (2023)

These data show that pH does not influence the presence of cadmium, which is present with high concentration (more than 1 ppm) in the soils of Muisne and Atacames even when their pH tends to neutrality, as demonstrated by Florida et al., (2018), which is in contrast to Arevalo et al., (2016) who found statistically significant differences between cadmium and pH. the main factor that could affect the values found would be: soil pH (Barrezueta et al., 2021). The Anova of the cadmium level found in the locality soils (Table 3), establishes that there is a highly significant difference.

Table 3. Anova of cadmium levels by locality.

ANOVA

Cadmium levels

	Sum of squares	df	Sq mean	F	Sig.
between groups	,055	2	,027	24,543	,000
inside groups	,049	44	,001		
Total	,104	46			

Source: author's elaboration (2023)

To determine the difference between localities, Tukey's analysis was applied with a 95% probability (Table 4).

Table 4. Multiple comparisons of the presence of Cadmium by locality.

Multiple comparisons

Dependent Variable: Cadmium levels

	(I) City	(J) City	Means diff (I-J)	sd	Sig.	confidence interval (ci) LSL	USL
HSD Tukey	Eloy Alfaro	Muisne	-,06621667*	,01013153	,000	-,0907905	-,0416428
		Atacames	-,08050000*	,02049202	,001	-,1302030	-,0307970
	Muisne	Eloy Alfaro	,06621667*	,01013153	,000	,0416428	,0907905
		Atacames	-,01428333	,02071846	,771	-,0645356	,0359689
	Atacames	Eloy Alfaro	,08050000*	,02049202	,001	,0307970	,1302030
		Muisne	,01428333	,02071846	,771	-,0359689	,0645356
Scheffe	Eloy Alfaro	Muisne	-,06621667*	,01013153	,000	-,0918848	-,0405486
		Atacames	-,08050000*	,02049202	,001	-,1324163	-,0285837
	Muisne	Eloy Alfaro	,06621667*	,01013153	,000	,0405486	,0918848
		Atacames	-,01428333	,02071846	,789	-,0667733	,0382066
	Atacames	Eloy Alfaro	,08050000*	,02049202	,001	,0285837	,1324163
		Muisne	,01428333	,02071846	,789	-,0382066	,0667733

Significant difference at 0.05

Source: author's elaboration (2023)

The multiple range tests (Table 5) show that there is no statistically significant difference between the cities of Atacames and Muisne, with a significance of 0.771, while between the cities of Eloy Alfaro and Atacames, the significance is 0.01, which shows that there is a statistically significant difference. Likewise, there is a statistically significant difference between the cities of Eloy Alfaro and Muisne, with a significance of 0.00.

Table 5. Pearson's correlation between soil pH and presence of Cadmium.

	CORRELATION	Cadmium levels	pH
Cadmium levels	**PEARSON**	1	,516**
	Sig. (bilateral)		,000
	SSCP	,192	,655
	COVARIANCE	,004	,014
	N	48	48
pH	**PEARSON**	,516**	1
	Sig. (bilateral)	,000	
	SSCP	,655	8,388
	COVARIANCE	,014	,178
	N	48	48

Significant CORRELATION at 0.01

Source: author's elaboration (2023)

However, Pearson's correlation table 4, to determine the influence of soil pH on the presence of cadmium in cocoa plantations, shows a moderate positive correlation (0.30 and 0.50), indicating that the correlation is significant.

On the other hand, in Table 5, the averages obtained in the cocoa leaves and almonds indicate that the absorption of the metal is more concentrated in the cocoa leaves in Atacames and Muisne; in addition, the presence of cadmium in the almonds suggests that, when consumed in the different food products made from cocoa, they would exceed the permissible levels required by European regulations for these foods.

Table 5. Presence of cadmium in soil, leaves and cocoa beans, in ppm.

Location	Soil	Sheets	Almonds
Eloy Alfaro	0,064	1,69	1,09
Muisne	0,147	6,96	1,99
Atacames	0,145	11,50	2,08

Source: author's elaboration (2023)

The evaluated data present high variability, evidenced by the high value of the coefficient of variation (> 18%), being the lowest for leaf samples in Eloy Alfaro (< 18%) (Table 4). These results are different from those reported by Karimi et al. (2019), who, in a hydroponic trial, observed higher Cd accumulation in stems of Cynara scolymus L. Likewise, the data.

emissions from this evaluation, are higher than those reported by Lizarazo et al. (2020) and Machado (2016), indicating a high translocation of absorbed Cd to leaves, and high contamination of the artichoke crop in the districts of Nueve de Julio and Mito.

Likewise, the cadmium bioaccumulation factor was very high in all sites, with the lowest in Eloy Alfaro and the highest in Atacames; This indicates the high absorption and translocation of this metal in the aerial parts of the cocoa plant, which corroborates Bravo (2021) "cocoa plants are hyperaccumulators of cadmium" as he confuses cadmium with zinc because they have similar valence and there are plants that prefer cadmium more than other ions found in the soil and overload the leaves and stem and when these organs are oversaturated with cadmium it is translocated to the fruits. When the leaves fall to the soil, they reincorporate the cadmium, which is distributed by leaching to a greater depth and the remaining part is inserted into the soil solution or in solid form and will be absorbed again by the plant roots in a cyclical manner.

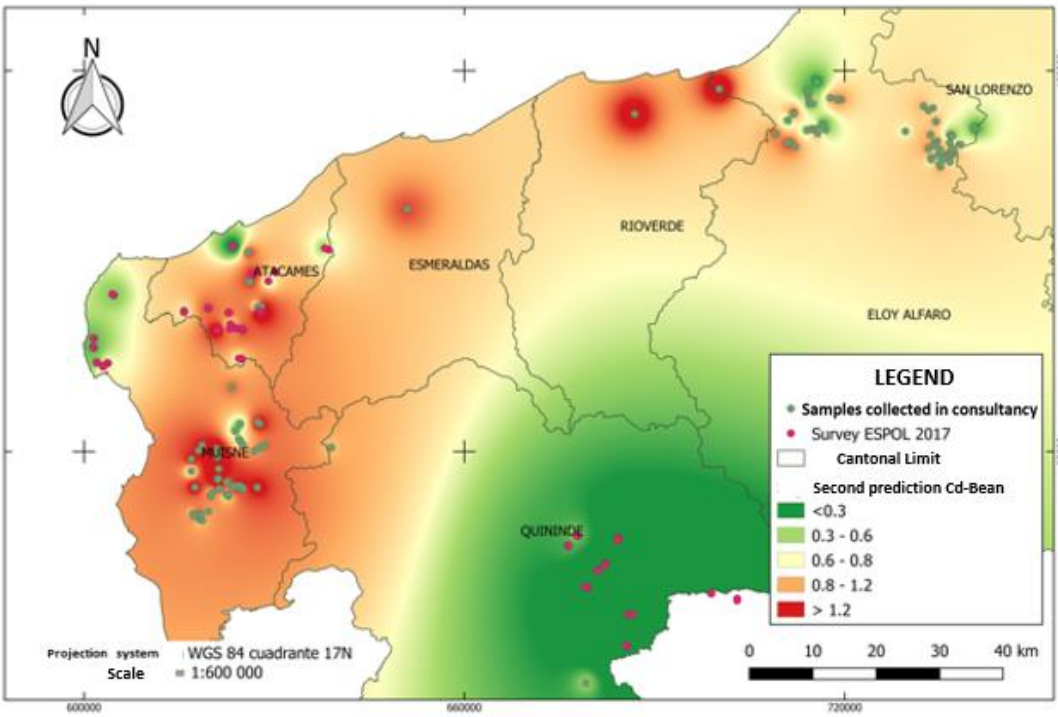
Table 6. Cadmium bioaccumulation factor (BCF), by canton.

Location	FBC
Eloy Alfaro	21,71
Muisne	30,44
Atacames	46,82

Source: author's elaboration (2023)

Figure 2 highlights the georeferenced sites of the samples with the highest cadmium concentration.

Figure 2. Geospatial distribution of cadmium concentration in cocoa beans in the province of Esmeraldas.



Source: author's elaboration (2023)

CONCLUSIONS

The results show that cadmium bioavailability is related to soil factors such as pH and organic matter.

The pH values place these soils as slightly acidic, presenting more cadmium content in soils that are close to neutrality, with averages above 0.1 ppm.Kg -1 considered contaminants, because Cd, due to its mobility, is easily absorbed by cocoa plants, which is reflected in its content in leaves and fruits.

The bioconcentration factor of Cd in the cocoa crop had the following order; leaf, fruit and soil with a high value (from 21.41 to 46.82) indicating that this crop is very bioaccumulative of cadmium. The amount of Cd in the crop is higher in Atacames and Muisne and lower in Eloy Alfaro.

Bioremediation measures are recommended to reduce the levels of cadmium contamination in cocoa soils and kernels, to help producers recover their commercialization in the world, as well as to reduce the potential risk of toxicity to human health

REFERENCES

Aguirre, H., Viteri, P., León, P., Mayía, Y., Cobos, P., Mero, M., & Pernía, B. (2022). Phytotoxicity of cadmium on the germination and initial growth of Ecuadorian maize varieties. *Bioagro*, *34*(1), 3–14. https://doi.org/10.51372/bioagro341.1

Alderete, B., Valles, M., Canales, S., Peralta, M., & Orrantia, E. (2019). Bioconcentración de pb, cd y as en biomasa de eleocharis macrostachya (Cyperaceae). *Revista Internacional de Contaminación Ambiental*, *35*(Special Issue 3), 93–101. https://doi.org/10.20937/RICA.2019.35.esp03.11

Argüello, D., Chavez, E., Lauryssen, F., Vanderschueren, R., Smolders, E., & Montalvo, D. (2019). Soil properties and agronomic factors affecting cadmium concentrations in cacao beans: A nationwide survey in Ecuador. *Science of the Total Environment*, *649*. https://doi.org/10.1016/j.scitotenv.2018.08.292

Banco de Desarrollo de América Latina. (2015). *InIcIatIva LatInoamerIcana deL cacao*.

Banco de Desarrollo de América Latina. (2020). *OBSERVATORIO DEL CACAO FINO Y DE AROMA PARA AMÉRICA LATINA*. http://bit.ly/CIAT_CGIAR_

Barrezueta, S. (2019). Propiedades de algunos suelos cultivados con cacao en la provincia El Oro, Ecuador. *CienciaUAT*, *14*(1), 155. https://doi.org/10.29059/cienciauat.v14i1.1210

Barrezueta, S., Armijos, I., & Vega, E. (2021). Comparación de niveles de cadmio en hojas, testa y almendra en cultivares de Theobroma cacao. *CIENCIA UNEMI*, *14*(37), 73–80. https://doi.org/10.29076/issn.2528-7737vol14iss37.2021pp73-80p

Cañazaca, E., Terroba, N., Cañazaca, L., & Toiro, A. (2022). *EARTHWORM POPULATION STATUS IN SOILS WITH DIFFERENT DEGREES OF DISTURBANCE*. https://orcid.org/0000-0001-7808-6471https://orcid.org/0000-0001-6857-4236

Chavez, E., He, Z. L., Stoffella, P. J., Mylavarapu, R. S., 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. https://doi.org/10.1016/j.scitotenv.2015.06.106

Corporación Financiera Nacional. (2018). *Cultivo de Cacao - Elaboración de Cacao, Chocolate*.

de La Cruz, S. (2022). *Determinación de las características físico-mecánicas del suelo de la ciudad de Huacho, Lima, Perú*. *15*, 60–64. https://doi.org/10.29076/issn.2528-7737vol15iss39.2022pp60-64p

Dueñas, J., & Intriago, F. (2022). Contenido de metales pesados (Cu, Pb, Ni, Cd) en abonos orgánicos y las materias primas para su elaboración. *La Técnica: Revista de Las Agrociencias. ISSN 2477-8982*, *27*(1), 26–35. https://doi.org/10.33936/la_tecnica.v0i27.3674

Espinoza_Rivas, G. R., Cárdenas_Catalán, J. A., & Echegaray_Peña, N. G. (2022). Presencia de metales pesados en suelos agrícolas de la subcuenca Llallimayo, departamento de Puno. *C&T Riqchary Revista de Investigación En Ciencia y Tecnología*, *4*(1), 12–19. https://doi.org/10.57166/riqchary/v4.n1.2022.83

EU. (2014). *Amending Regulation (EC) No 1881/2006 as regards maximum levels fo cadmium in foodstuffs*.

Guerra, B., Arteaga, L., Sierra, S., & Alvarez, J. (2022). Talaromyces santanderensis: A New Cadmium-Tolerant Fungus from Cacao Soils in Colombia. *Journal of Fungi*, *8*(10). https://doi.org/10.3390/jof8101042

Herrera, R., Vásquez, S., Granja, F., Molina, M., Capa, M., & Guamán, A. (2022). Interaction of N, P and K on soil characteristics, growth and quality of cocoa sprouts and fruits in Ecuadorian Amazon. *Bioagro*, *34*(3), 277–288. https://doi.org/10.51372/bioagro343.7

Hidalgo, R. (2020). Indicadores físicos e hídricos y uso del suelo en los frutales. *Suelos Ecuatoriales*, *50*(1y2), 40–53. https://doi.org/10.47864/se(50)2020p40-53_119

Jaramillo, D. (2002). Introducción a la ciencia del suelo. *Introduccion a La Ciencia Del Suelo*, 619.

Maddela, N. R., Kakarla, D., García, L. C., Chakraborty, S., Venkateswarlu, K., & Megharaj, M. (2020). Cocoa-laden cadmium threatens human health and cacao economy: A critical view. *Science of The Total Environment*, *720*, 137645. https://doi.org/10.1016/J.SCITOTENV.2020.137645

Mihai, R., Melo Heras, E. J., Terán Maza, V. A., Espinoza Caiza, I. A., Pinto Valdiviezo, E. A., & Catana, R. D. (2023). The Panoramic View of Ecuadorian Soil Nutrients (Deficit/Toxicity) from Different Climatic Regions and Their Possible Influence on the Metabolism of Important Crops. *Toxics*, *11*(2), 123. https://doi.org/10.3390/toxics11020123

Morales, perla, Estrada, laura, Alor, M., Méndez, C., & Morales, C. (2022). *Condiciones de fertilidad de un suelo en Comalcalco, Tabasco, México*.

OIRSA. (2020). *Determinación niveles de cadmio en cacao en almendras de cacao (Theobroma cacao), en Centro América y República Dominicana*.

Ortiz, M., Pernia, B., Mosquera, A., Gallardo, A., & Landívar, J. (2022). El cadmio y su efecto en el crecimiento de la caña de azúcar (Saccharum officinarum L.). *Revista Científica y Tecnológica UPSE*, *9*(2), 109–117. https://doi.org/10.26423/rctu.v9i2.714

Pachés, M. (2019). *El agua en el suelo: fuerzas de retención*.

Rajab, Y., Leuschner, C., Barus, H., Tjoa, A., & Hertel, D. (2016). Cacao cultivation under diverse shade tree cover allows high carbon storage and sequestration without yield losses. *PLoS ONE*, *11*(2). https://doi.org/10.1371/journal.pone.0149949

Rosales, J., Centeno, L., Cajacuri, J., Breña, J., & Chávez, C. (2021). Identificación de Cadmio y Plomo en los cultivos de Cacao ubicados en la zona de Satipo - Junín. *TECNIA*, *21*(2). https://doi.org/10.21754/tecnia.v21i2.1062

Tejada, C., Villabona, A., & González, Á. (2022). Adsorption Study of Continuous Heavy Metal Ions (Pb2+, Cd2+, Ni2+) Removal Using Cocoa (Theobroma cacao L.) Pod Husks. *Materials*, *15*(19). https://doi.org/10.3390/ma15196937

Vallejos, G., Ruíz, R., Chappa, C., Gaona, N., & Marín, C. (2022). High genetic diversity in arbuscular mycorrhizal fungi influences cadmium uptake and growth of cocoa plants. *Bioagro*, *34*(1), 75–84. https://doi.org/10.51372/bioagro341.7

Wickramasuriya, A., & Dunwell, J. (2018). Cacao biotechnology: current status and future prospects. In *Plant Biotechnology Journal* (Vol. 16, Issue 1, pp. 4–17). Blackwell Publishing Ltd. https://doi.org/10.1111/pbi.12848

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Task	**A1**	**A2**	**A3**	**A4**
A. theoretical and conceptual foundations and problematization:	25%	25%	25%	25%
B. data research and statistical analysis:	25%	25%	25%	25%
C. elaboration of figures and tables:	25%	25%	25%	25%
D. drafting, reviewing and writing of the text:	25%	25%	25%	25%
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