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Review on maximum limits of cadmium in cocoa (*Theobrama cacao L.*)

Revisión sobre limites máximos de cadmio en cacao (*Theobroma cacao L.*)

Nelino Florida Rofner*

Professional career in Soil and Water Conservation Engineering. Universidad Nacional Agraria de la Selva-Perú, Av. Universitaria Km 1.5

*Corresponding author: nelinof@hotmail.com

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Abstract

Cadmium (Cd) tends to bioaccumulate in *Thebroma cacao* beans, affecting human health and its marketing possibilities. For this reason, the European Union (EU) approved Regulation No 488/2014 for processed cocoa products, which applies from January 2019, and motivated authors to conduct research on its bioaccumulation in beans, the potential risks to health, quality, and its export possibilities. The results show high levels in different regions of the main Latin American (LA) producing countries: Brazil, Ecuador, Colombia, Peru, the Dominican Republic, Bolivia, Honduras, and others. However, EU regulation does not stipulate maximum limits for raw cocoa. In the absence of it, research has been classified by reference to the limits for processed cocoa, generating oversized metal levels, controversies in the producer's and setback in replacing illegal coca cultivation in this region. Thus, this review article will detail research on Cd levels in cocoa beans in major Latin American producing countries, the application of EU regulation No 488/2014 to raw cocoa, proposals to set maximum limits on raw beans and their implications for replacing illicit crops.

Keywords: Raw cocoa, Latin American cocoa, beans cadmium, illicit crops, maximum limits, regulations.

Resumen

El cadmio (Cd) tiende a bioacumularse en granos de *Theobroma cacao*, afectando la salud humana y sus posibilidades de comercialización. Esto llevó a la Unión Europea (UE) a aprobar el Reglamento N° 488/2014 para productos procesados del cacao, y motivó a la comunidad científica a realizar investigaciones sobre su bioacumulación en granos, los potenciales riesgos a la salud, calidad, y sus posibilidades de exportación. Los resultados evidencian altos niveles en diferentes regiones de los principales países productores Latinoamericanos (LA): Brasil, Ecuador, Colombia, Perú, República Dominicana, Bolivia, Honduras, y otros. Sin embargo, el reglamento 488/2014 no estipula límites máximos en cacao sin procesar; en ausencia de este, las investigaciones han clasificado estos límites, tomando como referencia los límites para cacao procesado, generando sobredimensionamiento de los niveles del metal, controversias en el mercado y retroceso en la sustitución del cultivo ilegal de la coca en esta región. Por lo tanto, en este artículo de revisión se detallarán las investigaciones realizadas sobre los niveles de Cd en granos de cacao en principales países productores de América Latina, la aplicación del reglamento N° 488/2014 a cacao sin procesar, las propuestas para establecer límites máximos en granos sin procesar y sus implicaciones en la sustitución de cultivos ilícitos.

Palabras clave: Cacao sin procesar, cacao de América Latina, cadmio en granos, cultivos ilícitos, límites máximos, reglamento.

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Orcid ID:

Nelino Florida Rofner: http://orcid.org/0000-0002-8751-4367

1 Introduction

Cadmium (Cd) is a heavy metal with intermediate properties between zinc (Zn) and mercury (Hg) (Pérez and Azcona, 2012; Antoine et al., 2017), that has been widely used in the industry for 50 years (Pérez and Azcona, 2012; Gunnar, 2013). It is currently causing health disorders in vital organs: lungs, kidneys, bone and probably the development of carcinogenesis (Reyes et al., 2016), as a result of its high mobility and bioaccumulative power (Reyes et al., 2016; Engbersen et al., 2019; Raju et al., 2020; Gunnar, 2013). Recent studies consider cadmium, along with lead, mercury and chromium, as dangerous elements for human nutrition (Casteblanco, 2018; Engbersen et al., 2019); fact that has attracted the attention of the scientific community oriented to its description and behavior in biological systems, and propose prevention, control and remediation alternatives.

The implementation of Regulation No 488/2014 established tolerable limits from 0.1 to 0.8 μg g^{-1} to cocoa-derived products (Jiménez, 2015; Kruszewski et al., 2018), mentioned in scientific reports that showed high levels of cadmium in soils (Cd) and beans (CdA) (Prieto et al., 2009; Mite et al., 2010; Sánchez et al., 2011; Bravo et al., 2014). In this regard, research has shown that soils generally have low Cd levels and their bioavailability depends on soil characteristics (Bravo et al., 2014; He et al., 2015; Gramlich et al., 2017; Díaz et al., 2018; Gramlich et al., 2018). CdA concentrations higher than the soil itself produced by various factors between the soil-cocoa system are also reported (Chávez et al., 2015; Arévalo et al., 2017b; Gramlich et al., 2017; Hernández et al., 2017; Tantalean and Huauya, 2017; Casteblanco, 2018; Díaz et al., 2018; Florida et al., 2018; Gramlich et al., 2018; Kruszewski et al., 2018; Argüello et al., 2019; Barraza et al., 2019; Florida et al., 2019; Romero et al., 2019; Zug et al., 2019), as well as values that exceed the tolerable limits established by the EU.

In this context, scientific reports have taken as a reference Regulation No 488/2014 (European Union-EU, 2014), in force since January 2019 (Jiménez, 2015; Kruszewski et al., 2018; Meter et al., 2019)for determining Cd levels and establish tolerable limits between 0.1 a 0.8 μg g^{-1} for cocoa products, and do not provide maximum limits for unprocessed beans. In addition, there is an incorrect classification when tolerable limits on derived or processed products are applied to concentrations in raw cocoa beans (Pastor, 2017). Thus, a maximum limit of Cd should be set in dried beans or raw cocoa mass, using certain criteria on the basis of what is already established in the current EU regulation (Meter et al., 2019). In this context, the aim of this review is to detail the research carried out on the Cd cacao levels of the main producers in Latin America to analyze the application of the current EU regulation, explain the proposed limits on raw beans and the implications of the regulatory gap on the producer and on the substitution of illicit crops in the region.

2 Methodology

A search of the literature was conducted on SciELO, Web of Science and Scopus databases, focusing on cadmium in the main cocoa producing countries in Latin America, such as Peru, Colombia, Ecuador, Brazil, Bolivia, Honduras, Venezuela and the Dominican Republic. The search was carried out restricting the results with the keywords: Cadmium, cadmium in cocoa, cadmium in plants, toxicity of cadmium and cadmium in health.

The topic is mainly discussed in the following journals: Science of The Total Environment, Water Air Soil Pollution, Ecotoxicology and Environmental Safety, Agronomic Act and others, as primary sources and as secondary sources institutions such as the Food and Agriculture Organization of the United Nations (FAO), European Union (EU), Codex Alimentarius (CODEX), United States Environmental Protection Agency (USEPA) and Government Sectors of Peru: Ministry of Agriculture and Irrigation - MINAGRI and the Institute of Statistics and Informatics - INEI. Later, the search was extended to other journals through search engines such as Google Scholar, as well as congresses organized by the International Cocoa Organization (ICO). Researches conducted in the last 10 years were selected, excepting some papers that are cited very frequently in the rest of the publications discussed in this review.

3 Cd in Latin American cocoa

Before 2014 and between 2014 and 2019, adaptation period to the entry into force of the EU regulation and after the entry into force, researches have been carried out (Table 1) in the main Latin American producers at national, regional and experimental scales.

Table 1 shows the scientific reports published in indexed and arbitrated journals, and the countries with the most scientific reports are Ecuador and Peru; in addition, the highest average values reported are Peru, Costa Rica, and Venezuela. The classification of Cd levels was carried out according to the tolerable limits of EU Regulation No 488/2014, which sets a maximum tolerable limit of 0.8 μg g^{-1} for chocolates with cocoa solids higher than or equal to 50%. According to this criterion, 70.59% of reports correspond to high levels of cadmium and only 29.4% would be within the limits required by the EU.

The results shown (Table 1), regardless the determination method, were classified in some cases taking as a reference the EU Regulation, despite the fact that they are Cd levels in raw beans. In this sense, different concepts are shown with regard to the application of the EU Regulation:

1. **Authors that differentiate the application of EU regulations,** including Barraza et al. (2017) and Furcal and Torres (2020) explain that the European Food Safety Authority has not set a limit for Cd in the raw matter of chocolate, and that studies show that Cd concentrations in beans may reach levels higher than the ones established by the EU.

2. **Authors who differentiate but consider its application to be indistinct,** such as Lanza et al. (2016) state that the EU maximum limit could be equally applied to cocoa grains and that their Cd contents (1.62 μg g^{-1}) exceed the maximum value set out in the EU Regulation.

3. **Authors who do not differentiate the application of EU regulations,** including Gramlich et al. (2018), mention that Cd concentrations in beans (1.1 μg g^{-1}) exceeded the limit proposed by the EU. With this same criterion, Arévalo et al. (2017a) classifies Cd levels (1.13 μg g^{-1}) in cocoa beans grown in the Amazon regions, Piura and Tumbes (Northern Zone of Peru) as high, compared to the EU standard. Florida et al. (2018) classify its Cd levels (0.98 μg g^{-1}) as higher than that allowed by the EU. Also, Zug et al. (2019) refer the Cd in Peruvian cocoa as the highest in relation to the permitted limits, specially the CCN-51 in comparison to fine and flavor cocoa. Finally, Chávez et al. (2015) not only apply incorrectly the Regulation, but are also wrong when referring that Cd in grains above a critical level of 0.6 μg g^{-1} would cause concern in the consumption of chocolate, when the Regulation accepts up to 0.8 μg g^{-1}.

4 EU 488/2014 Regulation

The current EU regulation by the European Food Safety Authority (EFSA) was elaborated by the Technical Committee on Contaminants in the Food Chain (CONTAM). EFSA considered it necessary to change again the maximum levels for certain pollutants such as the Cd, set out in Regulation 1881/2006, incorporating new information and developments in the Codex Alimentarius (European Union-EU, 2014; Zug et al., 2019; Furcal and Torres, 2020).

The current EU regulation is based on three fundamental aspects:

1. **Food exposure;** CONTAM conducted tolerable weekly intake studies and determined the average food exposure of Cd in European countries of 2.5 μg/kg body weight (European Union-EU, 2014; Abt and Lauren, 2020).

2. **Per capita consumption;** high consumption of cocoa derivatives can raise cadmium levels in the body (Table 2); and in the case of the European community, the per capita consumption is three times the consumption of Latin American countries.

3. **ALARA Principle,** by its abbreviation "As Low As Reasonably Achievable" which means as low as possible (European Union-EU, 2014).

For EFSA, it is reasonable that the reduction in exposure of vulnerable consumers could be achieved by establishing a maximum content for cocoa derivatives. Regulation 488/2014 amending Regulation 1881/2006 (Table 3), which adds cocoa derivatives to the list of controlled products, was thus adopted on 12 May 2014 (European Union-EU, 2014; Gramlich et al., 2018; Kruszewski et al., 2018; Argüello et al., 2019; Barraza et al., 2019; Romero et al., 2019; Zug et al., 2019; Abt and Lauren, 2020).

This Regulation assigns a high value to chocolates with a total percentage of dry matter $\geq 50\%$ (Antolinez et al., 2020), and it establishes tolerable limits for Cd in four types of chocolate (final consumption); however, it uses arguments from Environmental Quality Standards (EQAs) and is inconsistent in setting similar values to very different food in origin and representativeness in the total food exposure of cadmium from consumers. They have values with excess and without sufficient scientific research, which can become obstacles to the productive process and technical barriers to trade, by confusing the tolerable limits to derived or processed products for the marketing of cocoa beans (Pastor, 2017).

Table 1. Cd in cocoa beans (*Theobroma cacao* L.) in Latin American Countries

References	Country	Cd Average (µg g-1)	Min. – Max	Determination Method	Reported Level according to Regulation No 488/2014
Furcal and Torres (2020)	Costa Rica	0.44 ± 0.64*	0.0 – 1.8	ICP OES	Nb
		2.25 ± 2.06***	0.0 – 8.7		Na
Argüello et al. (2019)	Ecuador	0.9 ± –	–	ICP MS	Na
Barraza et al. (2019)		1.26 ± 0.18	–	ICP-MS	Na
Barraza et al. (2017)		1.12 ± –	–	ICP-MS	Na
Chávez et al. (2015)		0.94 ± –	–	EAA	Na
Mite et al. (2010)		0.84 ± 0.32	0.32 – 1.80	EAA	Na
Romero et al. (2019)		0.75 ± –	–	ICP OES	Nb
Lanza et al. (2016)	Venezuela	1.62 ± –	0.95 – 2.09	ICP OES	Na
Oliveira et al. (2019)	Brazil	0.13 ± –	0.04 – 0.82	ICP OES	Nb
Gramlich et al. (2018)	Honduras	1.10 ± 0.2	–	ICP OES	Na
Arévalo et al. (2017a)	Peru	1.13 * ± –	–		Na
		0.45 ** ± –	–		Nb
		0.20 *** ± –	–		Nb
Florida et al. (2018)		0.98 ± 1.42	0.18 – 6.7	EAA	Na
Tantalean and Huauya (2017)		1.08 ± –	–	EAA	Na
Zug et al. (2019)		2.46 ± 0.75	0.2 – 12.56	GFAAS	Na
Results exceeding limits according to this criterion (%)					70.59

*North area, **Central area, ***South area of the corresponding country, Na is High level, Nb is Low level, EAA Atomic absorption spectrophotometer, ICP OES Optical emission spectrometry with inductive coupling, ICP-MS Plasma mass spectroscopy with inductive coupling, GFAAS Graphite furnace atomic absorption spectrometer, – not specified by the author.

5 Proposals for maximum limits in raw cocoa

The categorization of total cadmium levels in raw beans using Regulation 488/2014 is a mistake (Pastor, 2017; Meter et al., 2019).The above-mentioned EU standard (Table 3) is not applicable to raw whole grains, although, as explained above, most authors point out that their values exceed that set by the EU at a maximum of 0.8 $\mu g\ g^{-1}$; it is therefore tacitly understood that this limit is being used to classify their found levels. It should be noted that the vast majority of cocoa is exported from Peru and other countries of the region in the form of dry fermented grain (MINAGRI, 2019). Paradoxically, tolerable limits for chocolate are being used to judge and adjust the price of raw grain (Pastor, 2017). Therefore, some proposals that do not alter the criteria that originated the current Regulation and incorporate new criteria as a simple proportionality relationship are analyzed below (Meter et al., 2019).

a) Meter Proposal

One of the proposals for Cd levels in beans has been established by Meter et al. (2019), who applies a proportionality ratio to the limits set in the EU Regulation and calculates a maximum Cd limit value in raw dried beans, as the raw mass contains a similar quantity of Cd to that of the grains of origin.

This proposal assumes the following concepts:

- Regulation 488/2014 is for processed products.
- Mass Cd concentration is similar to cocoa liqueur (first derivative of processing).
- The % mass in chocolate is known
- The butter contains minimum levels of Cd (criterion not applied in its formula)
- Proportionality

The calculation formula is:

$$MLCM = \frac{MLEU \cdot P}{X\,\%P} \tag{1}$$

Where:

$MLCM$ = Maximum Cd level in the cocoa mass (μg g^{-1})
$MLEU \cdot P$ = EU maximum level in final P product (μg g^{-1})
$X\,\%P$ = Mass percent in finished product P

Using dark chocolate with 70% mass as an example (dry cocoa solids), and 0.8 μg g^{-1} of Cd set by the EU in the finished product, the maximum Cd level will be:

$$MLCM = \frac{0{,}8}{0{,}7} = 1{,}14\ \mu\text{g g}^{-1} \tag{2}$$

It can be seen that the EU maximum levels are for finished products and not for raw materials. The equation estimates a maximum Cd level at the mass of 1.14 μg g^{-1} that will ensure that the final product remains below the level set by the EU.

Table 2. Per capita consumption of chocolate in Europe and Latin America

Continent	Country	Annual consumption per person (kg)	Annual bars (bar / 70g)	Bars/month
Europe	Switzerland	11.9	170	14
	Ireland	9.9	141	12
	United Kindom	9.5	136	11
	Austria	8.8	126	10
	Belgium	8.3	119	10
	Germani	8.2	117	10
Mean		9.43 ± 1.38	134.8 ± 19.61	11.17 ± 1.6
America	Uruguay	3.1	44	3.7
	Argentina	2.9	41	3.5
	Chile	2.2	31	2.6
	Brazil	1.7	24	2
	Mexico	0.7	10	0.8
	Peru	0.6	9	0.7
Mean		1.87 ± 1.07	26.5 ± 15	2.22 ± 1.3

Source: Jiménez (2015)

Table 3. Regulation 488/2014 for tolerable limits

Product	**Dry matter (%)**	**Maximum limit Permitted (μg g^{-1})***
Milk chocolate	<30	0.1
Milk chocolate	≥30	0.3
Chocolate	<50	0.3
Chocolate	≥50	0.8
Cocoa powder sold to the final consumer or as an ingredient in cocoa in sweetened powder sold to the final consumer (chocolate for drinking)		0.6

* They entered into force since January 2019
Source: European Union-EU (2014); Zug et al. (2019); Abt and Lauren (2020)

b) Author's proposal

The proposal is based on the calculations of Meter et al. (2019), the conclusions of Pastor and Gutierrez (2016) and Pastor (2017) and the general concepts of the average bromatological composition of chocolate and raw beans (Table 4); therefore, the proposal assumes the following concepts:

- Chemically, cocoa consists of 53.05% cocoa fat or butter used for chocolate and the difference is cocoa cake used for sweetened cocoa powder for drinks (Morales et al., 2012), and it takes the 0.5 factor (% TA).
- Bitter chocolates have cocoa butter which normally do not exceed 50% (Sánchez et al., 2016).
- In chocolates with 70% of cocoa butter, the Cd content is reduced to less than half in chocolate compared to grain, so a 0.5 factor of (RP) is applied (Pastor and Gutierrez, 2016).
- The butter contains minimum Cd levels (Meter et al., 2019), which was not considered in its formula and it confirms what was stated by Pastor and Gutierrez (2016).
- Beans bioaccumulate cadmium in varying concentrations according to the cocoa genotype (Table 5), with a variation of approximately 30%, a proportion that must be removed by applying a 0.7 factor (VG) to the partial results of cocoa butter and cake.

According to Table 5, the primary processing products for beans are approximately 50% of cocoa cake used for chocolate sweetened powder for drinks and with an EU tolerable limit of 0.6 μg g^{-1} and cocoa butter in similar proportions 50%, used for chocolates with a maximum level of 0.8 μg g^{-1} (Sánchez et al., 2016). The proposal suggests that butter (Formula 4) and cake (Formula 5) should be calculated separately, and in both cases genotype variation should be incorporated (Table 5), to reduce this partial result by 30% by applying a 0.7 factor; finally, it must be averaged to obtain a maximum limit (Formula 3). Hence, the formula for the calculation is:

$$LCP = \frac{LCMC + LCTC}{2} \tag{3}$$

$$LCMC = \frac{FM}{RP} \times VG \tag{4}$$

$$LCTC = \frac{MCP}{\%TA} \times VG \tag{5}$$

Where:

LCP = Proposed Cd Limit
$LCMC$ = Cd Limit in cacao butter
$LCTC$ = Cd Limit in cacao cake
FM = Formula by Meter et al. (2019), gets a maximum limit of 1.14 μg g^{-1}
RP = Reduction of Cd reported by Pastor and Gutierrez (2016)
VG = Variability by genotype, 30% was eliminated (applying a 0.7 factor to the Cd content in cocoa butter and cake)

MCP = maximum limit for cocoa powder according to EU (0.6 μg g^{-1})
$\%TA$ = % of cake in raw beans 50% (0.5 factor)

Dark chocolate with 70% cocoa mass (0.8 μg g^{-1}), is used and calculated in the formula of Meter et al. (2019):

$$LCMC = \frac{1{,}14}{0{,}5} \times 0{,}7 = 1{,}6\,\mu g\ g^{-1} \quad (6)$$

$$LCTC = \frac{0{,}6}{0{,}5} \times 0{,}7 = 0{,}84\,\mu g\ g^{-1} \quad (7)$$

$$LCP = \frac{1{,}6 + 0{,}84}{2} = 1{,}22\,\mu g\ g^{-1} \quad (8)$$

The proposed equation estimates a maximum Cd level in raw beans of 1.22 μg g^{-1} (Formula 8) ensuring that the processed end product is below the limit set by the EU (0.8 μg g^{-1}). Therefore, in accordance with the proposal of Meter et al. (2019) the categorization of scientific reports (Table 6) varies reasonably.

Table 6 shows that the author's proposal is a little different from Meter et al. (2019) but is similar to the one established in Indonesia, which sets maximum limits of 1 μg g^{-1} for cocoa mass. In addition, the percentage of results that would exceed the limits are similar when comparing available reports, however, in comparison with Regulation 488/2014, the levels categorized as high fall from 70.59 to 23.53%, which is more reasonable and consistent. In addition, concepts of metal bioavailability are not yet being incorporated in this analysis since research reveals a great dynamic in concentration and availability in soils (Prieto et al., 2009; Kabata, 2010; Sánchez et al., 2011; Bravo et al., 2014; Gramlich et al., 2017; Díaz et al., 2018; Gramlich et al., 2018; Zug et al., 2019), which may contribute or limit the mobilization and uptake of cadmium by cocoa. Therefore, appropriate actions need to be taken to fill the regulatory gap in health protection and the millions of cocoa producers in Latin American and the world.

Table 4. Physical-chemical characterization in cocoa beans (*Theobroma cacao* L.)

Parameters	Origin of the crop	Average content
	Physical	
Husk %		11 – 12
Grain thickness (g)		1.05 – 1.2
Humidity (%)		7 – 8
	Chemicals*	
Fat (%)	Mountain Cocoa	55
	Tropical Wet Forest	54
	Dry inter-Andean valleys	54
Protein (%)	Mountain Cocoa	14
	Tropical Wet Forest	13
	Dry inter-Andean valleys	13
pH	Mountain Cocoa	5.07
	Tropical Wet Forest	4.97
	Dry inter-Andean valleys	5.54
Fiber (%)	Mountain Cocoa	3
	Tropical Wet Forest	3
	Dry inter-Andean valleys	3
Calories (kcal/100 g)	Mountain Cocoa	629
	Tropical Wet Forest	629
	Dry inter-Andean valleys	625

* Calculated from the study of 15 cocoa genotypes
Source: Ministry of Agriculture and Rural Development- MINAGRICULTURA (2004)

Table 5. Cd levels in different cocoa genotypes (*Theobroma cacao* L.)

Reference	Genotype	Cd beans (μg g^{-1})
Barraza et al. (2017)	CCN-51	1.21
	National Ecuatorian	0.89
Lanza et al. (2016)	HNF	2.09
	PNF	1.9
	PF	1.82
	PFC	1.76
	HF	1.74
	PFM	1.57
	HFC	1.1
	HFM	0.95
Florida et al. (2018)	CCN-51	0.98
Average concentration		$1.45 + 0.43$
CV (%)		29.65

CV Variation coefficient

Table 6. Comparison of Cadmium classification levels

References	Country	Cd average (μg g^{-1})	Level according to Regulation No 488/2014	Level according to Meter et al. (2019)[a]	Level proposed by the Author[b]
Furcal and Torres (2020)	Costa Rica	0.44*	Nb	Nb	Nb
		2.25***	Na	Na	Na
Argüello et al. (2019)	Ecuador	0.90	Na	Nb	Nb
Barraza et al. (2019)		1.26	Na	Na	Na
Barraza et al. (2017)		1.12	Na	Nb	Nb
Chávez et al. (2015)		0.94	Na	Nb	Nb
Mite et al. (2010)		0.84	Na	Nb	Nb
Romero et al. (2019)		0.75	Nb	Nb	Nb
Lanza et al. (2016)	Venezuela	1.62	Na	Na	Na
Oliveira et al. (2019)	Brazil	0.13	Nb	Nb	Nb
Gramlich et al. (2018)	Honduras	1.10	Na	Nb	Nb
Arévalo et al. (2017a)	Peru	1.13*	Na	Nb	Nb
		0.45**	Nb	Nb	Nb
		0.20***	Nb	Nb	Nb
Florida et al. (2018)		0.98	Na	Nb	Nb
Tantalean and Huauya (2017)		1.08	Na	Nb	Nb
Zug et al. (2019)		2.46	Na	Na	Na
Results that exceed limits based on criteria (%)			70.59	23.53	23.53

[a]Max: 1.14 μg g^{-1}, [b]Max: 1.22 μg g^{-1}, Na: high level, Nb: low level

6 Implications of the regulatory gap in the producer and the substitution of illicit crops

In the last decade, cocoa was the second alternative crop to substitute coca production in Peru (INEI, 2017). Cocoa is the most successful cultivation to substitute illegal coca cultivation, and thousands of small family farmers have been rescued from coca cultivation thanks to the cultivation of cocoa (Pastor and Gutierrez, 2016). In Peru, it is cultivated in 16 regions, 57 provinces and 259 districts (MINAGRI, 2019) and similarly Colombia, Bolivia and Ecuador show sustained growth in cocoa production and a reduction in illicit crops (Celis et al., 2020).

In general, the sustainability of cocoa production is threatened in these countries of the region (Argüello et al., 2019; Abt and Lauren, 2020) and some influential aspects can be identified, including:

1. **Regulation 488/2014;** the EU's regulatory imposition with high limits on cocoa derivatives, whereas more than 60% of Latin American production volume is exported to the EU (MINAGRI, 2016; Meter et al., 2019).

2. **Forced eradication;** countries such as Peru, through the National Commission for Development and Life without Drugs - DEVIDA and the United States Agency for International Development - USAID, carry out forced eradication, eliminating the illicit cultivation of coca in its entirety, causing greater socio-economic imbalances (Chocce, 2015).

3. **Inefficiency of public investment;** caused by individual and institutional factors, alternative projects (cocoa) to illicit coca cultivation and rural development projects do not generate socio-economic improvements expected by the producer; this was observed in Peru (Alvarado et al., 2020) and Ecuador (Viteri, 2013) and is very likely to occur in other producing countries of the region.

The critical aspect is that both forced eradication and inefficiency in public investment are problems our region has faced for decades, and the emergence and enforcement of Regulation 488/2014 plays a trigger role to the previous ones, which is unfavorable to the producer and may discourage families who have replaced coca cultivation with cocoa (Pastor, 2017; Abt and Lauren, 2020). Therefore, the tolerable levels of Cd in processed cocoa set by the EU to classify the levels in raw beans represent an error (Pastor, 2017; Meter et al., 2019) and it requires agencies such as Codex and the EU to consider evaluating these levels in order to recalculate and record tolerable limits of Cd in raw cocoa beans to avoid oversizing the problem that represents the presence of this metal in cocoa in Latin America.

In order to contextualize the implications, cultivation has spread commercially in 23 countries in Latin American and The Caribbean until 2016, with a volume of more than 675 000 t and about 1 700 000 ha, where Brazil, Ecuador, Dominican Republic, Peru, Colombia and Mexico account for more than 90% of production (Arvelo et al., 2017), and in 2018 it accounts for more than 18% of the world's imports of cocoa beans (836 000 t in the period 2017 - 2018) and in cases such as Peru, 54.3% of the total exported in 2018 corresponds to raw cocoa beans (López et al., 2020). In addition, countries such as Ecuador, Peru and Colombia have shown an average growth of more than 9% per year in the last decade (MINAGRI, 2016; Meter et al., 2019), and in the case of Ecuador, it rose from 3 to 6% of the world's production, reaching fourth among the producing countries, surpassing Brazil (Cunha, 2018).

Finally, the lack of maximum limits on raw cocoa is considered as a threat to the sustainability of cocoa production (Argüello et al., 2019; Abt and Lauren, 2020) and has caused some confusion and speculation, including: a) confusion in the scientific community in classifying raw cocoa, applying the limits of the European standard for processed cocoa; b) concern to the cocoa sector throughout Latin America and c) market distortions at the time of negotiations since the producer is hardly in a position to counter and buyers prefer low Cd content to ensure its use in any recipe, with the consequent negative effect on the price for the grain (Pastor, 2017; Meter et al., 2019).

7 Conclusions

Scientific reports reveal important advances of Cd in cacao beans. In the region, the highest average values reported are Peru, Costa Rica, Venezuela and Ecuador. In addition, European Union Regulation No 488/2014 establishes maximum limits for processed cocoa, and is being used as a basis for classifying the cadmium concentration in raw beans, generating confusion in the scientific community and concern to the cocoa sector.

There are calculation proposals to determine a reasonable and scientific limit, incorporating criteria of proportionality, genetic variability and bromatological aspects of cocoa, on the basis of the limits established in the European Union regulation. The calculation proposals determine a maximum cadmium limit in raw beans of 1.14 (Meter) y 1.22 μg g^{-1} (author), by reducing the levels categorized as high (according to the EU), from 70.59 % to only 23.53 %, a reasonable and consistent figure that will contribute to maintaining the quality of the product for the final consumer, avoid market distortions by protecting the producer and the substitution efforts of illegal coca cultivation in Peru, Colombia, Bolivia and other countries of the region.

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