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Nutritional removal of cacao fruit (*Theobroma cacao* L.) in Mexico

Remoción nutrimental del fruto de cacao (*Theobroma cacao* L.) en México

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ABSTRACT

Objective: To determine the nutritional concentration of the cacao fruit (*Theobroma cacao* L.) in each of its components: shell, mucilage, testa and seed, among different genetic groups.

Design/Methodology/Approach: Nutrient removal was determined for three cacao clones: Criollo (Carmelo), Forastero (PMCT 58) and Trinitario (RIM 88). Ten fruits, or pods, from each clone were collected. Each pod was divided into its components: shell, mucilage, testa and seed. Each of the components were placed in a drying oven for 72 h at 65 °C; then they were ground, packaged, labeled, and sent to the laboratory, where the macro and micro nutrients of each component were determined.

Results: The nutritional removal of the macro and micro nutrients (N, PK, Ca, Mg, and S) of the different structures (shell, mucilage, testa and seed) and genetic groups (Forastero, Trinitario and Criollo), stayed within a range of acceptable values ($0.01<s<0.199$).

Study limitations/Implications: The main influence on nutrient removal is the genetic group of the cacao and the conditions where it is grown.

Findings/Conclusions: The nutritional removal of cacao varies according to its different structures (seed, testa, mucilage and shell) and concentration depends largely on the variety of cacao (Forastero, Trinitario or Criollo). Potassium is the element most absorbed by the shell, followed by calcium, and nitrogen is most absorbed by the seed, followed by phosphorus. In general, the Trinitario cacao (RIM) presented higher nutrient removal in K, N, Mg, and P, followed by the Forastero (PMCT 58) and in lesser quantity the Criollo (Carmelo). For the microelements, the most absorbed were Zn, Fe, and B in Trinitario, Criollo, and Forastero, respectively.

Keywords: Nutrition, Criollo, Trinitario, Forastero.

INTRODUCTION

Cacao (*Theobroma cacao* L.) cultivation in Mexico and on a global scale is representative of one of the more significant economic and social sectors, present as a crop in more than 70 tropical countries and serving as the livelihood for more than five million producers (Tijani *et al*., 2001; Duguma *et al*., 2001; Rafflegeau *et al*., 2015). In Mexico, the largest proportion of cacao is cultivated in the states of Chiapas and Tabasco, currently adding up to a productive surface area of 62,000 ha and benefitting 37,000 producers (SIAP, 2019). The cacao agricultural ecosystem is closed, with constant nutritional recycling, assuming that under those conditions soils have

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favorable natural fertility (Herteminck y Donald, 2005; Harteminck y Baligar *et al*., 2006); however, in order to increase yield, they require high rates of mineral fertilization. (Afrifa *et al*., 2009; Somarriba *et al*., 2001; Van *et al*., 2015). This is a consequence of the harvest residues and agronomic management by products being exposed to intense temperatures, precipitation, and other local climate conditions, all of which accelerate their decomposition with subsequent mineralization and nutritional return to the cacao agroecosystem (Ruf *et al*., 2015). The cacao agroecosystem is much more complex than that of any other crop, since the interplay between its agronomical management and its nutrition is influenced by factors including shade, high population density, pests, and disease, among others; these factors, however, should not limit the attainment of high yields (Ooi, 1988). Consequently, it can be inferred that potential yield depends additionally on excellent management, soil, and climate, as well as the availability of nutrients for growth promoting high yields (Rufi and Bini, 2012). To this end, understanding the nutritional removal of cacao is necessary because this is the main route through which nutrients are absorbed from the soil and the applied fertilizers (Rodríguez *et al*., 2001). The objectives of determining nutritional removal are to reach more effective management of nutrients in order to minimize their loss in the environment, and to adequately provide these nutrients to the crop, maximizing their availability through the process of absorption (interception, diffusion, and mass flow). Site-specific rational mineral fertilization entails the consideration of nutrient removal, yet for cacao, these nutritional standards are not available, and even when certain crop standards exist, this data has not been systematized. Thus, the objective was to determine the nutritional concentration or removal of the harvested pod components (shell, mucilage and testa), and seed of three cacao clones (Criollo, Forastero, and Trinitario).

MATERIALS AND METHODOLOGY

Experiment location: The cacao clones used are found in the Rosario Izapa Experimental Field (CERI), which depends on the National Institute of Forestry, Agriculture and Livestock Research (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, INIFAP), in El Soconusco, Chiapas, along the south pacific region of Mexico (15° 19′ N and 92° 94′ W). It has a Aw_2(w)ig sub-humid warm climate, with an average temperature of 26 °C, relative humidity above 80%, and an average historical precipitation of 4,300 mm (CONAGUA, 2015). Regarding its soil, it is of volcanic origin of the andosol type, with a sandy, crumbly texture (CONABIO, 2015).

Experiment materials: The material consisted of three genetic groups of Criollo cacao (Carmelo), Forastero (PMCT 58), and Trinitario (RIM 88) considered to be stand-out genotypes based on agronomical characteristics such as sanitation, yield, quality, and of fine aroma.

Sample preparation and analysis: With the goal of estimating the nutritional standards of cacao by way of its nutritional removal (NR), 10 pods were collected from each clone. Each pod was divided into its components: shell, mucilage, testa and seeds. These were placed in Petri dishes and left in a drying oven for 72 hours at 65 °C. The mucilage was frozen in liquid nitrogen, crushed, and dried in the oven for one hour at temperatures ranging from 100 °C to 200 °C until dry. After drying the samples, the components were placed in a desiccator for 30 minutes, followed immediately by grinding each component. The various ground portions were sealed in polyethylene bags with capacity of half a kilogram. These samples were duly labeled per clone and its corresponding components, and then sent to the laboratory. There, in accordance with the official guidelines for quality standardization of vegetable sample analysis, the laboratory applied the appropriate methodology for these analyses, determining macro and micro elements for each pod component. Nitrogen (N%) was determined by the Dumas method (Schmitter B.M and T. Rihs. 1989; Thompson *et al*., 2002), while the macronutrients P and K, as well as micronutrients—Ca, Mg, S, Fe, Zn, Mn, Cu, B, Na, Mo, and Ni—were determined using ICP-OES equipment (inductively coupled plasma optical emission spectrometry). This multi-element technique allows for simultaneous analysis of a great number of elements (Gray, 1988; Resano *et al*., 2005; Bosnak *et al*., 2008).

RESULTS AND DISCUSSION

The nutritional removal of cacao highlights the importance of the availability of these nutritional standards, as those approximately constant values, added to the nutritional concentration of the soil and the efficiency of applied mineral fertilizers, would permit the formulation of a rational mineral fertilizer dosage for this crop

(Pinochet, 1999; Rodríguez *et al*., 2001). Concerning the nutritional removal of nitrogen, on average the greatest concentration of this element was found in the seed (2.52%), followed by the testa (1.14%), the shell (1.07%), and the mucilage (0.74%). When comparing the genetic groups, Forastero cacao (PMCT 58) presented more N in the seed and in the testa; Criollo (Carmelo) cacao presented more in the shell, while Trinitario cacao presented more in the mucilage (Figure 1A). With respect to the nutritional removal of phosphorous, the greatest average concentration was in the seed (0.51%), followed by the testa (0.11%), shell (0.10%), and mucilage (0.08%). The Forastero genetic group (PMCT 58) presented the highest value in the shell; the three genetic groups generally presented the same quantity in the seed; in the testa, the Forastero and Trinitario genetic groups presented the same quantity on average; and in the mucilage, the Criollo (Carmelo) genetic group had the highest quantity (Figure 1B). In terms of potassium, on average the highest percentage was found in the shell (4.38%), with lower concentrations in the testa (1.30%). When comparing the genetic groups, Trinitario had the highest amount of K in the shell and testa, Forastero had more in the mucilage, and Criollo had the highest amount in the seed (Figure 1C).

With respect to calcium, the shell had the highest concentration (0.45%) and the mucilage had the lowest concentration (0.06%). When comparing the genetic groups, Forastero presented the highest values in the shell, testa, and seed, while Trinitario presented them in the seed (Figure 1D). For magnesium, on average the highest concentration was found in the seed (0.39%), followed by the shell (0.32%), testa (0.21%), and mucilage (0.11%). When comparing the genetic groups, Criollo had the highest amount in the seed, Forastero in the shell and mucilage, and Trinitario in the testa (Figure 2A).

The nutritional removal of sodium only revealed its presence in the mucilage (0.04%) and in the testa (0.01%). When comparing the genetic groups, Criollo had the highest concentration in the mucilage and the three genetic groups presented the same quantity in the testa (Figure 2B). For sulfur, the shell had the highest amount (0.19%), followed by the seed (0.18%), testa (0.10%), and mucilage (0.07%). When comparing genetic groups, Forastero presented the highest concentrations in the seed and testa, while Criollo and Forastero in the shell, and Trinitario and Criollo in the mucilage (Figure 2C).

Nickel registered the highest average concentration in the seed with 1.18 mg kg^{-1}, followed by the testa (0.47 mg kg^{-1}), shell (0.38 mg kg^{-1}), and mucilage (0.16 mg kg^{-1}). When comparing the genetic groups, Forastero had a higher concentration in the seed; Criollo and Forastero in the shell; Criollo in the testa; and Trinitario in the mucilage (Figure 2D). For copper, the highest average concentration was found in the seed (26.07 mg kg^{-1}), followed by the testa (13.73 mg kg^{-1}), shell (7.98 mg kg^{-1}), and mucilage (5.07 mg kg^{-1}). The

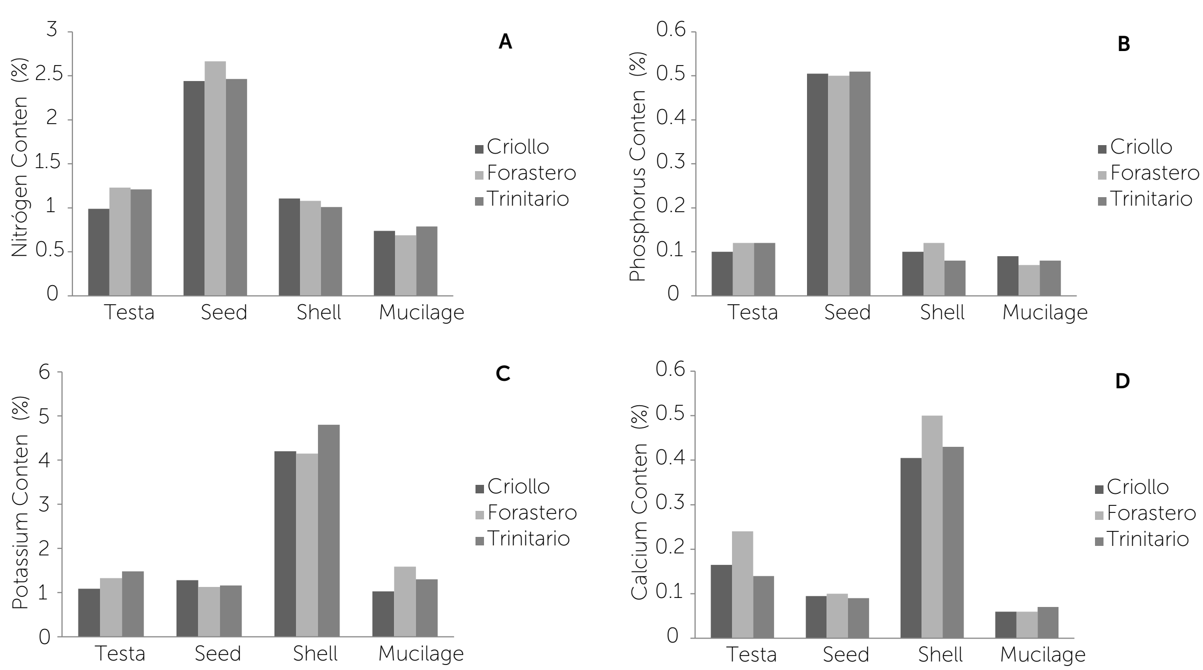

Figure 1. Nutritional removal of cocoa fruit (*Theobroma cacao* L.). A) Nitrogen content; B) Phosphorous; C) Potassium; D) Nickel.

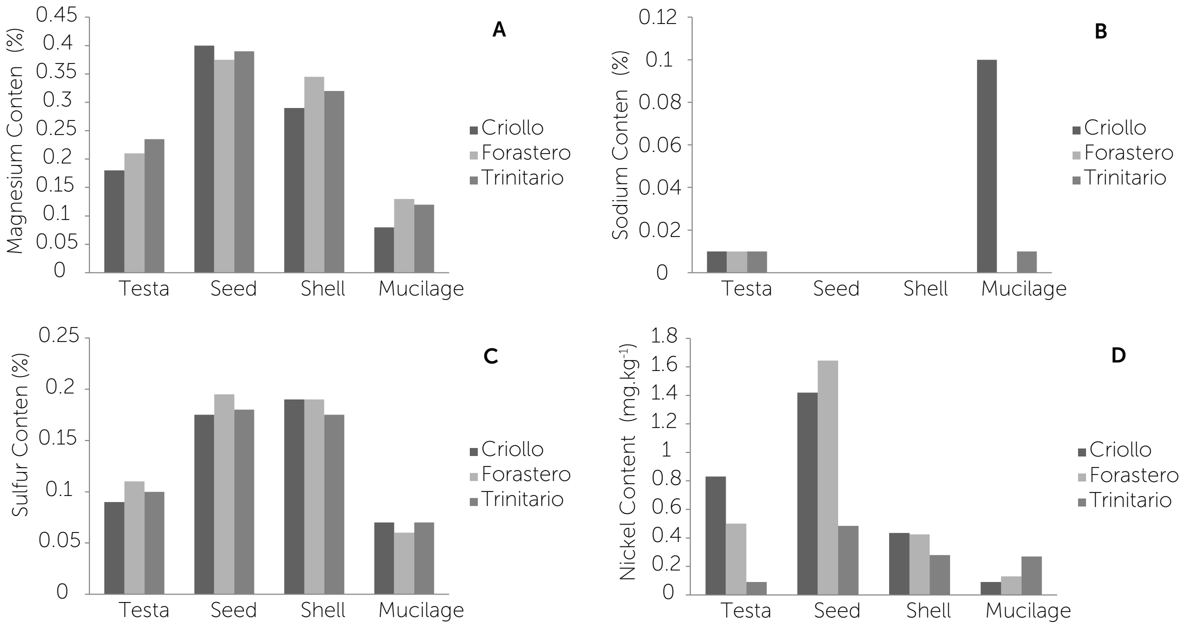

Figure 2. Nutritional removal of cocoa fruit (*Theobroma cacao* L.). A) Magnesium content; B) Sodium; C) Sulfur; D) Nickel.

Forastero genetic group had the highest concentration in the seed and shell, while the Criollo had the highest concentration in the testa and mucilage (Figure 3A).

For the nutritional removal of iron, the highest average concentration was found in the testa (52.62 mg kg^{-1}), followed by the seed (34.73 mg kg^{-1}), mucilage (25.63 mg kg^{-1}), and shell (16.9 mg kg^{-1}). When comparing the genetic groups, Criollo had the highest concentration in the testa and mucilage, Trinitario in the seed, and Forastero in the shell (Figure 3B). For magnesium, the highest concentration was found in the seed with 17.03 mg kg^{-1}, followed by the shell (13.84 mg kg^{-1}), the testa (5.82 mg kg^{-1}), and the mucilage (0.46 mg kg^{-1}). In the Forastero genetic group, the highest concentration was found in the shell, seed, and testa, but in the Criollo group it was found in the mucilage (Figure 3C). In the case of zinc, the highest average concentration was found in the seed (58.50 mg kg^{-1}), followed by the shell (42.93 mg kg^{-1}), the testa (29.18 mg kg^{-1}), and the mucilage (20.23 mg kg^{-1}). The Trinitario group presented the highest concentration in the seed, testa,

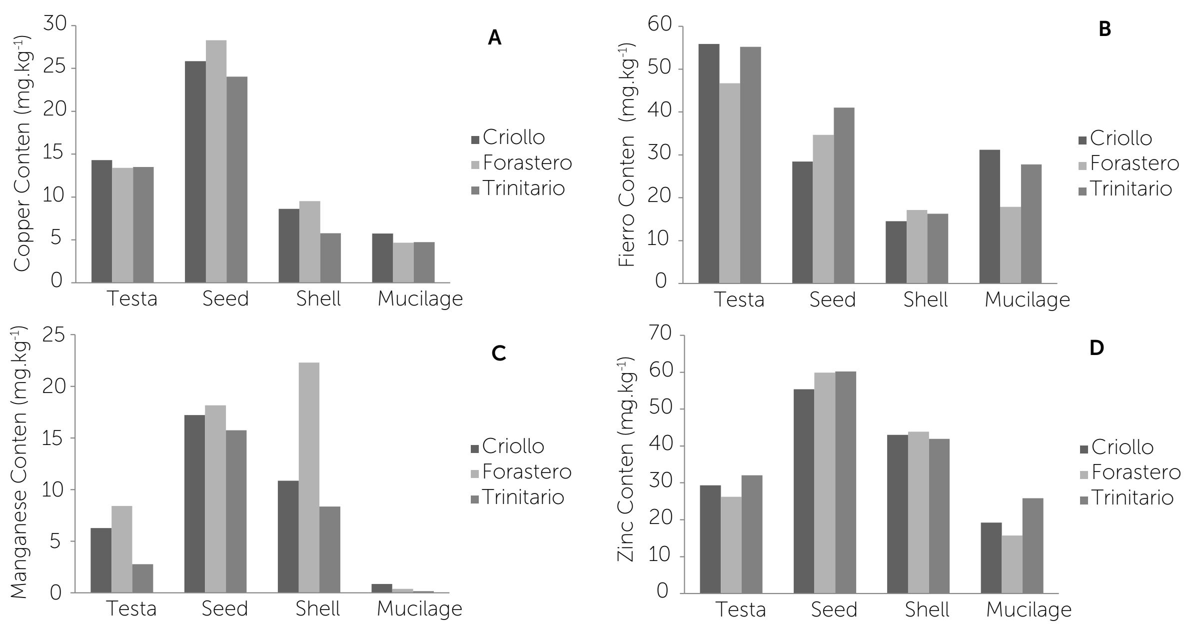

Figure 3. Nutritional removal of cocoa fruit (*Theobroma cacao* L.). A) Copper content; B) Iron; C) Manganese; D) Zinc.

and mucilage, while for Forastero it was in the shell (Figure 3D).

With respect to boron, the highest average concentration was found in the mucilage (39.73 mg kg^{-1}), followed by the shell (34.32 mg kg^{-1}), testa (29.87 mg kg^{-1}), and seed (15.77 mg kg^{-1}). The Criollo genetic group had the highest concentrations in the shell and seed, while the highest concentrations in the Forastero group were in the testa, and in Trinitario, in the mucilage (Figure 4A). Finally, for the nutritional removal of molybdenum, the highest average value was registered in the mucilage (0.69 mg kg^{-1}), followed by the shell (0.38 mg kg^{-1}), the seed (0.35 mg kg^{-1}), and the testa (0.29 mg kg^{-1}). Criollo cacao presented the highest concentration in the testa and mucilage, and Forastero in the seed and shell (Figure 4B).

Studies carried out on the removal of major nutrients (N, P, and K) in cacao beans in Venezuela and Costa Rica report average values of 39.3 kg of N, 4.6 kg of P, and 10.9 kg of K, respectively, for both countries (Aranguren *et al.*, 1982a; Heuveldop et al., 1988). In Nigeria, average values of 20 kg of N, 41 kg of P, and 10 kg of K have been reported (Ogunlade *et al.*, 2009). In those regions, the concentration of major nutrients in dried cacao beans was highly variable. The values of macronutrients in this study were 36.7 kg of N, 6.2 kg of P, and 24.90 kg of K, similar to those reported by Venezuela and Costa Rica, yet very different from those reported in Nigeria.

Conversely, the concentration of N in the cacao beans (testa and seed) was 37 g kg^{-1}; this value was greater than those reported in similar studies with concentrations of 22.85 g kg^{-1} (Muñiz *et al.*, 2013) and 26.37 g kg^{-1} (Araujo *et al.*, 2017), respectively. Likewise, in this study nitrogen was the most accumulated nutrient in the cacao beans, similar to the results reported in related research (Aikpokpodion, 2010; Muñiz, 2013). With respect to the concentration of phosphorous in the cacao beans, this study found 6.2 g kg^{-1}, which was greater that the results of similar studies that ranged between 1.96 g kg^{-1} and 5.83 g kg^{-1} (Loureiro, 2016; Bertoldi *et al.*, 2016; Cinquanta *et al.*, 2016). Other results reported by Pinto (2013), on the concentration of phosphorous analyzed for the same clone that grew in humid (5.07 g kg^{-1}) and sub-humid (5.01 g kg^{-1}) climate conditions, had very similar values to those reported in this study. Based on this, the former reveals that the concentration of phosphorous in cacao beans is variable, since a similar study reported average values of phosphorous concentration of 2.66 g kg^{-1}, atypical for cacao beans (Araujo *et al.*, 2016). In addition, as Tello (2019) mentioned, the concentration of nutrients in cacao depends on the environment where it developed and its particular variety. Based on the essential significance of phosphorous for this crop, this element was the fifth most-absorbed nutrient by cacao, as is the case with many other crops that present phosphorous deficiencies due to the aforementioned significance (Souza *et al.*, 2012). In relation to the concentration of potassium in cacao beans, this study found 24.9 g kg^{-1}, a value within the range reported by various authors of between 5.66 g kg^{-1} and 25.58 g kg^{-1} (Loureiro, 2016; Bertoldi *et al.*, 2016; Cinquanta *et al.*, 2016). Regarding this nutrient, some studies have revealed that its concentration in cacao beans is closely correlated with the geographic localization of site groups where cacao is established, with its content varying between humid (14.52 g kg^{-1}) and sub-humid (12.31 g kg^{-1}) climate zones, respectively. Thus, the availability of K and its concentration in cacao beans is reiteratively a function of the site groups where the crop is established (Loureiro, 2016). Based on the importance of this nutrient,

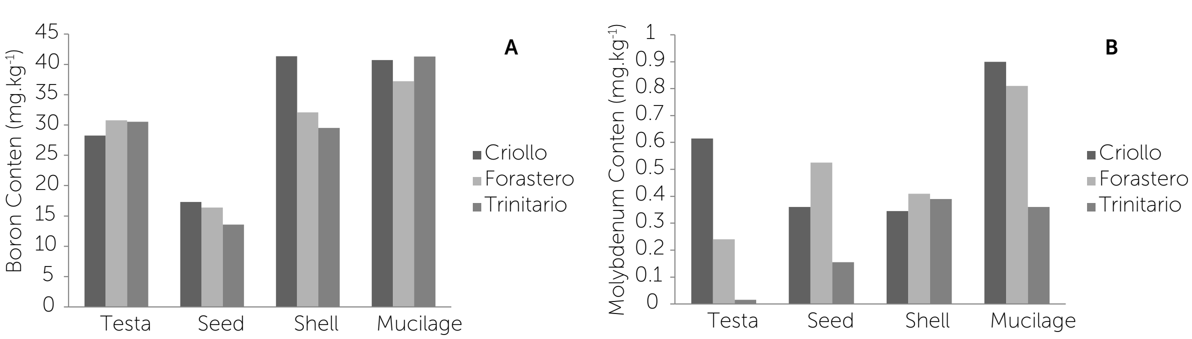

Figure 4. Nutritional removal of cocoa fruit (*Theobroma cacao* L.). A) Boron content; B) Molybdenum

the results for this argument confirm that potassium is the nutrient most absorbed by cacao beans (Sodré *et al*., 2012). With respect to the concentration of Ca (2.77 g kg^{-1}), Mg (5.97 g kg^{-1}), and S (2.83 g kg^{-1}) in this study, the concentration of Ca stayed within the range of values reported in similar research (0.58-2.70 g kg^{-1}), while Mg exceeded the range of values reported in other related studies (1.67-3.83 g kg^{-1}). The specialized literature has not yet revealed the concentration values of sulfur in cacao beans and the nutrient removal in this study was similar to the content of S (2.70 g kg^{-1}) in cacao biomass (Loureiro, 2016; Bertoldi *et al*., 2016; Cinquanta *et al*., 2016; Araujo *et al*., 2017). Conversely, concerning the concentration of micronutrients in cacao beans, the results of this study include Fe (87.35 mg kg^{-1}), Mn (22.85 mg kg^{-1}), Zn (87.68 mg kg^{-1}), and Cu (39.80 mg kg^{-1}), all of which are within the ranges reported by other studies in relation to these micronutrients: Fe (10.38–187 mg kg^{-1}), Mn (12.73–64.56 mg kg^{-1}), Zn (18.92–109 mg kg^{-1}), and Cu (2.4–88 mg kg^{-1}), in addition to the previous micronutrients (Aikpokpodion, 2010; Aikpokpodion *et al*., 2013; Cinquanta *et al*. 2016). This study also determined Ni (1.66 mg kg^{-1}), B (45.63 mg kg^{-1}), and Mo (0.64 mg kg^{-1}), of which there are no specific references for their concentration in cacao beans in other specialized sources. The variability of nutritional removal related to macro and micro nutrients that has been reported in reference research, and its relation to the findings of this study, allow us to infer that this variability is axiomatic, since the heterogeneity of the soil groups in different sites considerably influences the nutritional concentration and this depends on the geographic location where the cacao crop and its genetic group grows (Tello, 2019). This is because the results referred indicate that the variation in estimated nutritional removal in this and other studies corresponds to different ecosystems where cacao is cultivated, entailing variability in decomposition, accumulation of organic material, and nutritional release.

CONCLUSIONS

The nutritional removal of cacao varies according to the different structures (seed, testa, mucilage and shell), and concentration depends in large part on the cacao variety (Forastero, Trinitario or Criollo). Potassium was the element most absorbed by the shell, followed by calcium, and in the seed, it was nitrogen followed by phosphorous. In general, Trinitario cacao (RIM) presented higher nutritional removal of K, N, Mg and P, followed by Forastero (PMCT 58), and Criollo (Carmelo) with the lowest removal. The most absorbed microelements were Zn, Fe, and B in Trinitario, Criollo, and Forastero, respectively.

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