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Variability and climate change

Scientific and technological research article

Size and weight of coffee beans regarding altitudinal ranges in coffee-growing areas in Toledo, Norte de Santander (Colombia)

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Abstract

The research objective is to establish the relationship between the size and weight of Arabica coffee beans and five altitudinal gradients, from 1,000 to 1,800 MAMSL, in the Toledo municipality, Norte de Santander, Colombia. Four farms were randomly selected per gradient, and the 2017 and 2018 harvests were analyzed, obtaining 40 observations. We classified 120 g of green beans per sample by size and weight using sieves # 18, 16, and 14, and weighed 50 green beans per sample to determine the trends by altitudinal zone. The data obtained were examined by descriptive analysis, variance, and Student's t-test. The highest value of grain size retained in sieve # 18 was 17.99 g ± 8.16 g (Zone 2), and the lowest was 12.87 g ± 5.30 g (Zone 1); in sieve # 16, the highest value was 87.30 g ± 18.60 g (Zone 2), and the lowest was 62.56 g ± 19.49 g (Zone 1); in sieve # 14 the highest value was 52.86 g ± 18.20 g (Zone 1) and the lowest value was 28.60 g ± 10.10 g (Zone 2). As to the residues, the highest value corresponded to floor 5 with an average of 16.03 g ± 10.63 g, and Zone 3 obtained the lowest value with 8.82 g ± 3.54 g.

Keywords: agriculture, altitude, climate, coffee, yield

Tamaño y peso de granos de café en relación con rangos altitudinales en zonas cafetaleras de Toledo, Norte de Santander (Colombia)

Resumen

El objetivo de esta investigación fue establecer la relación del tamaño y el peso de los granos de café arábica (*Coffea arabica* L.) con respecto a cinco gradientes altitudinales, desde los 1.000 hasta los 1.800 m s. n. m., en el municipio de Toledo, departamento de Norte de Santander (Colombia). Se seleccionaron al azar cuatro fincas por gradiente y se analizaron las cosechas de 2017 y 2018, para un total de 40 observaciones. Por cada muestra se clasificaron 120 g de granos verdes según tamaño y peso con las zarandas n.º 18, 16 y 14, y se pesaron 50 granos verdes por muestra para determinar las tendencias por piso altitudinal. Los datos obtenidos se examinaron mediante análisis descriptivo, varianza y prueba t de Student. El mayor valor del tamaño de los granos retenidos en la zaranda 18 fue de 17,99 g ± 8,16 g (piso 2) y el menor fue de 12,87 g ± 5,30 g (piso 1); en la zaranda 16, el mayor valor fue de 87,30 g ± 18,60 g (piso 2) y el menor fue de 62,56 g ± 19,49 g (piso 1); en la zaranda 14, el valor mayor fue de 52,86 g ± 18,20 g (piso 1) y el menor fue de 28,60 g ± 10,10 g (piso 2), y en los residuos, el mayor valor correspondió al piso 5, con media de 16,03 g ± 10,63 g, y el menor valor al piso 3, con 8,82 g ± 3,54 g.

Palabras clave: agricultura, altitud, café, clima, rendimiento

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Introduction

In Latin America, the coffee economy is a cultural legacy around which most mountain peoples have been built (Núñez, 2015). Nonetheless, this critical socioeconomic segment has begun to experience climate change's effects on its growing (Harvey et al., 2018; Kgosikoma et al., 2018; Sada et al., 2014). This environmental phenomenon alters the conditions of ecosystems, particularly the physiological and reproductive variables of plants (Gourdji et al., 2013; Nendel et al., 2018); the migration and infestation of pests, weeds, and diseases (Aguirre, 2013; Čačija et al., 2017; Galindo et al., 2013; Ziska et al., 2018), and a decrease in crop yields and quality (D'Agostino & Schlenker, 2016; Lachaud et al., 2017).

Altitude is a modifying factor of the appropriate climatic conditions for developing the coffee crop since the temperature decreases at higher altitudes. Colombia has temperatures of 0.61 °C/100 m in the Andean region and 0.55-0.58 °C/100 m in the Pacific, Orinoquía, and Amazonia regions (Jaramillo-Robledo, 2005). Concerning coffee growing in the country, Montoya and Jaramillo (2016) reported that the optimum temperature range is between 18-21 °C; temperatures below this range extend the time for plant production, while higher temperatures affect grain filling.

Temperature is considered the most important climatic variable in the coffee plant's physiological needs (Dos Santos et al., 2015); it has been shown that an increase of 1 °C in temperatures causes damage to crops (Peltonen-Sainio et al., 2016). Besides, extreme variations in rainfall and heat waves cause physiological and water stress in plants (Cremonese et al., 2017; Gu et al., 2016; Sun et al., 2018). These climatic pressures on the crop and coffee growers drive the displacement of traditional planted areas towards higher altitudinal gradients in the search for better climates, soils, and water (Bakri et al., 2018), guaranteeing optimal scenarios for coffee (Gram et al., 2018) and profitable and sustainable production.

Due to the effects of climate change on the distribution and production patterns of crops (García-Martínez et al., 2016), coffee growers have designed responses for mitigation and adaptation (Bakri et al., 2018) to the new environmental conditions, such as the use of shade trees (Moreira et al., 2018; Rahn et al., 2018; Silveira et al., 2016), plant covers for soil protection (Candelaria-Martínez et al., 2014), and changes in the agricultural tasks of growers (Peltonen-Sainio et al., 2016).

The most important economic and commercial effect of climate change on coffee growing is the quality of the bean, whose physical and chemical characteristics are affected by deficits or excesses of temperatures and rainfall. Increases in temperatures negatively influence grain yield and quality (Ramalho et al., 2018), causing detachment of green fruits and cherries (Da Silva et al., 2017), a more significant number of defective and low weight grains (Martins et al., 2015), modifications in the characteristics and sensory attributes of green and roasted beans (Scholz et al., 2018), and fermentation that affect the drink quality and safety (Peixoto et al., 2017).

Likewise, Worku et al. (2018) emphasize the complex interactions of altitude, shade, and post-harvest handling with the biochemical composition of green arabica coffee beans. In studies conducted in Ethiopia, Hagos et al. (2018) found a moderate negative correlation between the caffeine content of green coffee beans and the altitudes where they were grown; that is, the lower the altitude, the higher the caffeine content. Meanwhile, Malau et al. (2017) found a positive correlation between the weight of green beans and the altitude in North Sumatra (Indonesia), and Tolessa et al. (2016) determined small changes between altitude, shade, and the harvest period.

In Colombia, through different studies, Gloria Inés Puerta Quintero noted no relationship between the quality of the cup of coffee, soils, and altitude (Puerta et al., 2016); no association of lower threshing coffee yields is observed at altitudes higher than 1,600 MAMSL with greater damage by borers and defective beans in coffee crops planted below 1,300 MAMSL (Puerta-Quintero, 2016). Besides, there is no influence of single-origin coffee, the climate, soils, beneficiation processes, and growers' coffee culture on Colombian coffee quality (Puerta-Quintero, 2003).

This article aims to present the results of a study carried out in a coffee-growing area in the Toledo municipality (Norte de Santander) to establish the relationship between the size and weight of the coffee bean in various altitudinal gradients to generate knowledge that serve as input for new research and technology transfer programs in the coffee sector.

Materials and methods

The research was carried out in Toledo, located in the central-northeastern region of Colombia, at coordinates 07°19'01"N and 72°28'59"W. The region has a mountainous relief where coffee is grown in small and medium extensions and is recognized for its product quality in international markets (Concejo Municipal Toledo, 2016).

The methodological approach is a quasi-experimental relational study, in which the treatment factor was the division of the coffee-producing units of the municipality into five representative altitudinal gradients. The 20 farms selected at random in the five gradients analyzed plant *Coffea arabica* L. (Rubiaceae), mostly the Castillo, Colombia, Tipico, Caturra, and Bourbon varieties with a permanent shade system and medium and low technology levels. The study used a mixture of beans of those varieties supplied by the coffee growers without distinguishing them.

To monitor the behavior of the size of coffee beans, we designed five intervals of altitudinal gradients: 1) 1,000-1,199 MAMSL, 2) 1,200-1,399 MAMSL, 3) 1,400-1,599 MAMSL, 4) 1,600-1,799 MAMSL, and 5) > 1,800 MAMSL. In each altitudinal band, we selected four units of analysis (farms) randomly and analyzed the 2017 and 2018 crops, totaling 40 observations.

The grain benefit was determined using the wet method with drying in cement yards by sunlight exposure, with an average of 12 % humidity. Coffee growers provided the samples of parchment coffee, and the researchers prepared the green bean by separating the parchment layer from the bean manually by continuous rubbing, ventilation, and cleaning of green beans.

We weighed the green coffee samples on an electronic scale and selected 120 grams per sample for sieving in metallic meshes with diameters of 7 mm (sieve 18), 6 mm (sieve 16), and 5 mm (sieve 14), per Resolution 5/2002 of the National Committee of Colombian Coffee Growers. The sieving products were weighed to determine size trends by the altitudinal zone and classified into large grains (sieve 18), medium grains (sieve 16), small grains (sieve 14), and residues or *pasilla* (< sieve 14). We also selected and weighed 50 green coffee beans per sample to determine the bean trends by altitudinal zone.

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We examined the data obtained using descriptive statistical estimators, analysis of variance (ANOVA), and hypothesis tests of multiple comparisons with Student's t-test, when necessary, through Equations 1 (ANOVA) and 2 (first hypothesis contrast).

$$y_{ij} = \mu + \beta_i + \varepsilon_{ij}$$

$$i = 1, 2, 3, \ldots t \quad j = 1, 2, 3, \ldots r \qquad \textit{Equation 1}$$

Where $\boldsymbol{y_{ij}} =$ response observed at the i-th treatment level or factor in its j-th observation or repetition; μ = population mean of the response estimated by the sample mean $\bar{y}_{..}$; $\beta_i =$ effect on the response of the i-th treatment level or factor under study; $\boldsymbol{\varepsilon_{ij}} =$ random error associated with each response $\boldsymbol{y_{ij}}$ and assumed normal and independent with zero mean and sigma squared common variance $\varepsilon_{ij} \sim NID(0; \sigma^2)$.

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 \qquad \textit{Equation 2}$$

$$H_1: \mu_i \neq \mu_j \quad (i \neq j)$$

The null hypothesis H_0 indicates that, regardless of the zone where the coffee is harvested, the mean size and weight of the beans are equal; that is, there are no significant differences between the mean grain size and weight for all altitudinal zones. The alternate hypothesis H_1 assumes that at least two means differ significantly at the various altitudinal zones.

Results and discussion

Grain size trends by altitudinal zone

The beans' physical characteristics, determined from the green coffee samples (*n* = 120 g/altitudinal zone) sieved, are presented in table 1 and figure 1.

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Table 1. Size distribution of green coffee beans altitudinal zone

Grain size	Altitudinal zone	Mean (g)	Deviation (g)	Confidence interval (95 %)
Large (sieve 18)	1	12.87	5.30	4.32-12.35
	2	17.99	8.16	2.62-34.51
	3	16.84	5.22	4.26-24.24
	4	14.38	9.73	0.00-13.18
	5	15.37	5.44	5.35-24.14
Medium (sieve 16)	1	62.56	19.49	36.99-80.16
	2	87.30	18.60	58.65-84.69
	3	83.19	17.59	53.13-96.74
	4	83.15	20.98	46.49-83.72
	5	70.56	7.06	54.59-79.96
Small (sieve 14)	1	52.86	18.20	25.31-66.12
	2	28.60	10.10	6.57-49.44
	3	35.47	16.23	6.30-52.30
	4	33.24	11.26	23.38-58.23
	5	39.05	17.98	7.55-49.37
Residues (< sieve 14)	1	15.87	5.71	25.31-66.12
	2	9.04	3.02	6.57-49.44
	3	8.82	3.54	6.30-52.30
	4	12.72	5.42	23.38-58.23
	5	16.03	10.68	7.55-49.37

Source. Elaborated by the authors

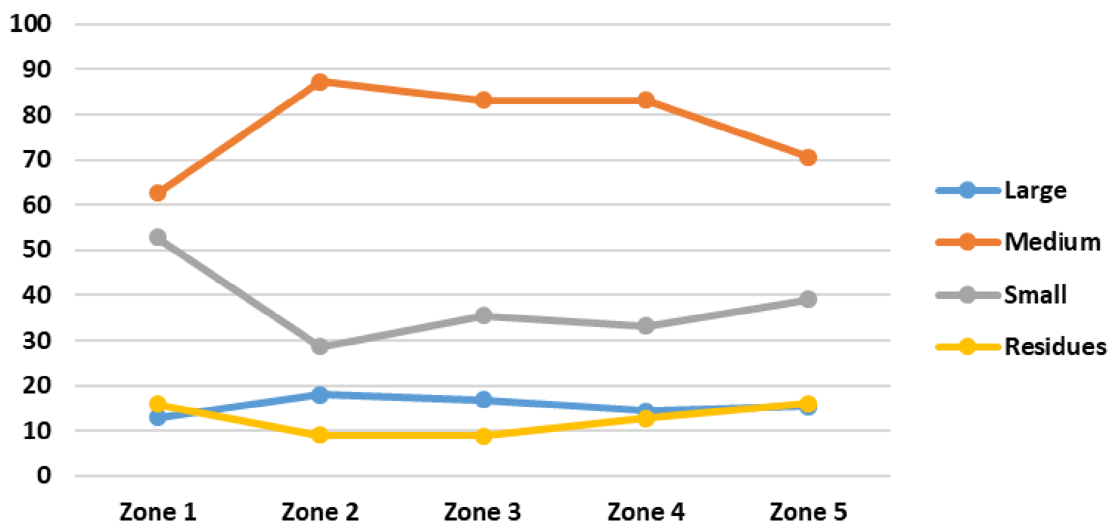

Figure 1. Size distribution of green coffee beans by altitudinal zone.
Source: Elaborated by the authors

Size distribution of the grains by altitudinal zone, in descending order, shows that in Zone 1 (1,000-1,199 MAMSL), the medium grains weigh 62.56 g ± 19.49 g on average; the small ones, 52.86 g ± 18.20 g; the residues, 15.07 g ± 5.71 g, and the large ones, 12.87 g ± 5.30 g. In this gradient, we observed the lowest values of large and medium grains and the highest volume of small grains compared to the other altitudinal zones.

In Altitudinal Zone 2 (1,200-1,399 MAMSL), the mean size of grains indicate that the medium ones have the highest weight with 87.30 g ± 18.60 g; the small ones weigh 28.60 g ± 10.10 g; the large ones, 17.99 g ± 8.16 g, and the residues, 9.04 g ± 3.02 g. In this gradient, we observed the highest value of medium grains compared to the other altitudinal gradients studied.

The distribution of grain sizes in Zone 3 (1,400-1,599 MAMSL) shows that medium grains have a mean weight of 83.19 g ± 17.59 g; the small ones, 35.47 g ± 16.23 g; the large ones, 16.84 g ± 5.22 g, and the residues, 8.82 g ± 3.54 g.

In Altitudinal Gradient 4 (1,600-1,799 MAMSL), the medium grains show a mean weight of 83.15 g ± 20.98 g; the small ones, 33.24 g ± 11.26 g; the large ones, 14.38 g ± 9.73 g, and the residues, 12.72 g ± 5.42 g.

Finally, in Altitudinal Gradient 5 (> 1,800 MAMSL), the size distribution exhibits medium grains with a mean weight of 70.56 g ± 7.06 g; small ones with 39.05 g ± 17.98 g; residues with 16.03 g ± 10.68 g, and large ones with 15.37 g ± 5.44 g. In this gradient, we observed the highest value of residual grains of the five altitudinal levels analyzed.

According to the ANOVA, the null hypotheses were accepted in the three sizes of green grains; that is, the mean weights of the sizes are the same for all altitudinal zones. However, in the hypothesis tests between the altitudinal zones, significant differences were found for large, medium, and small grains and residues (table 2, figure 2).

Table 2. Comparison of green coffee bean size measurements

Grain size	Mean (g)	Median (g)	Deviation (g)	Coefficient of variation (%)	Minimum (g)	Maximum (g)	Confidence interval (95 %)
Large	12.45	10.21	7.25	58.27	0.00	30.77	9.05-15.84
Medium	67.51	67.65	11.59	17.16	39.88	91.35	62.09-72.93
Small	34.46	37.10	13.82	40.10	14.34	64.16	27.99-40.92
Residues	14.09	12.82	7.30	51.78	6.38	36.85	10.67-17.50

Source: Elaborated by the authors

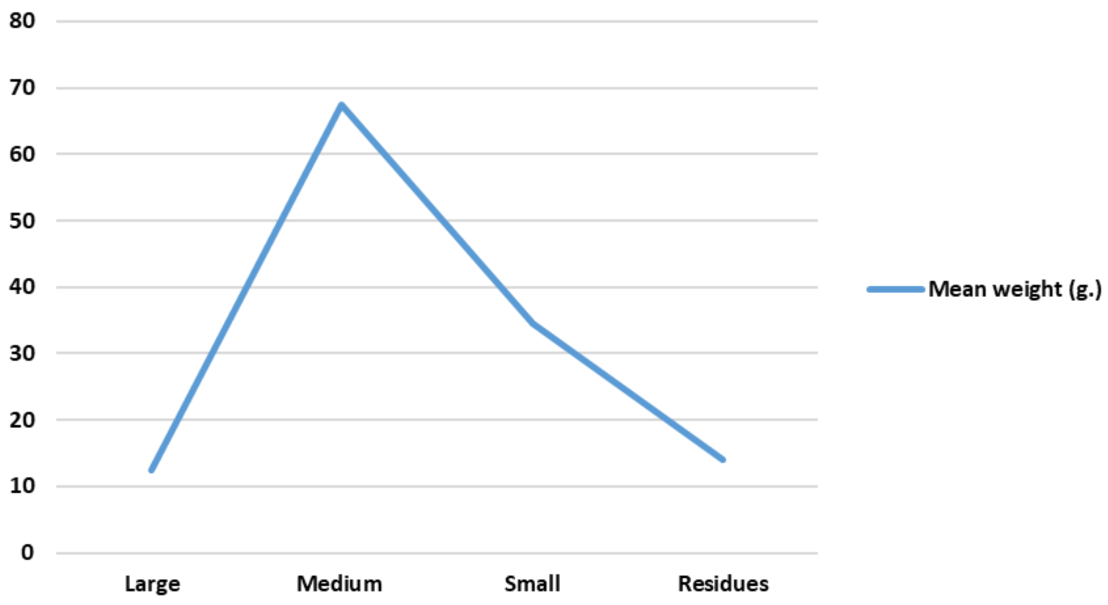

Figure 2. Comparison of the weight of grain size between the altitudinal zones.
Source: Elaborated by the authors

The weights for each grain size, including the residues, showed that the highest weight is associated with the medium-sized grain (67.51 g) and the lowest with the large grain (12.45 g). The median indicates that, in the medium grain, 50 % of the weights were less than 67.65 g, and 50 % of the remaining weights were above this value. The variability exhibited disparity; the most homogeneous one occurred in the medium grain with 17.16 %. The highest coefficient of variation was 58.27 % and corresponded to large-sized grains, denoting high heterogeneity. For the residues, 51.78 % of the variability was high because they contain many impurities and remains of the grains that passed through sieve 13 (5 mm) and were different for each altitudinal zone.

These findings are consistent with those obtained by Fischer and Victor (2014) in Guatemala, who established that the production of high-quality coffee occurs above 1,372 m of altitude; therefore, the low areas are appropriate to produce other agricultural items. Climatic drives pressure the altitudinal migrations from agricultural areas that have become marginal towards ecosystems with better soil, water, and climate conditions (De Sherbinin et al., 2012; Hsiung et al., 2018; Ocampo López & Álvarez-Herrera, 2017).

Similarly, in their study on the interactions between altitude and coffee bean quality, Do Carmo et al. (2020) analyzed the correlation between both variables and the drying methods and found that the coffee fruits harvested at 1,050 MAMSL have sensory attributes superior to those grown at 850 MAMSL, demonstrating positive correspondence between altitude and grain quality. In other studies, Bodner et al. (2019) found a significant interaction with a strong influence on quality between the altitude at which the fruits are harvested and the roasting level of the beans and, when studying the composition of fatty acids, Tsegay et al. (2020) found an inversely proportional relationship between altitude and fatty acid content.

In Peru, Guevara-Sánchez et al. (2019) compared two drying methods (traditional and mechanical) with altitude and found no influence of the latter on grain quality (size and moisture). Moreover, Torres (2018) determined that, in Arabica coffee varieties, grain moisture decreases with altitude, while the husk content (residues) increases and the sensorial grain qualities improve at higher altitudes. Paima (2019) found larger grains in high areas, a higher percentage of defective grains in low areas, and the highest yields in the middle areas (1,150 MAMSL).

In the phytosanitary field, Asfaw et al. (2019) established that after evaluating the coffee borer infestation in different altitudinal zones, the damage to the fruits, the number of holes per fruit, and the number of adult insects were lower in medium and high zones. In other words, the effects of the pest are more intense in cultivated areas at higher temperatures.

Grain weight trends per altitudinal zone

In the variations of the grain weight (n = 50 grains/altitudinal zone) for the altitudinal gradients, we identified significant differences between the five zones (table 3, figure 3).

Table 3. Coffee bean weight per altitudinal zone

Weight of 50 green beans	Mean (g)	Median (g)	Deviation (g)	Coefficient of variation (%)	Minimum (%)	Maximum (%)	Confidence interval (95 %)
Zone 1	8.20	7.74	1.0772	13.13	7.52	9.81	6.49-9.92
Zone 2	9.77	9.68	0.4281	4.38	9.40	10.32	9.09-10.45
Zone 3	9.09	9.00	0.5916	6.51	8.54	9.81	8.14-10.03
Zone 4	9.39	9.43	0.3413	3.63	9.00	9.71	8.85-9.93
Zone 5	8.73	9.00	0.5294	6.06	8.12	9.07	7.41-10.05

Source: Elaborated by the authors

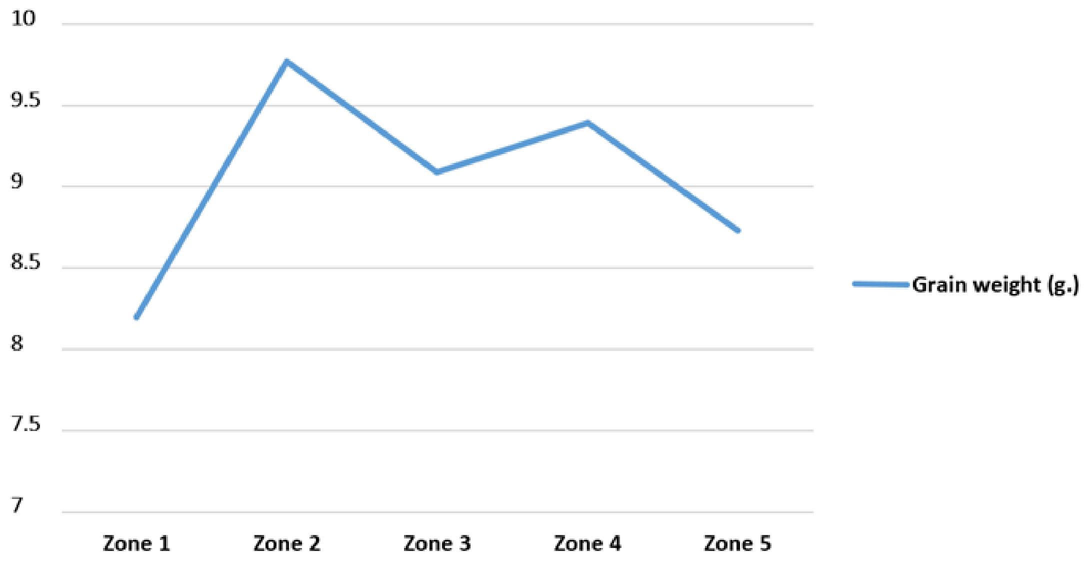

Figure 3. Coffee bean weight per altitudinal zone.
Source: Elaborated by the authors

According to the data reported, we observed that the means of the green bean weights indicate that the highest value is found in Zone 2 (9.77 g) and the lowest value in Zone 1 (8.20 g). Regarding the variation, we appreciated a moderate difference, except for Zone 1, where the coefficient of variation was 13.13 %. The lowest variation was found in Zone 3, with 3.63 %.

In the ANOVA, the rejection of the null hypothesis allows us to infer that the mean weights differ by at least two altitudinal zones. When harvested in the different altitudinal zones, we noted that coffee produces grains that differ significantly at 5 % in their mean weights.

The multiple mean comparison test or Student's t-test determined two homogeneous groups within which the means do not differ significantly from each other. The weights of the grains harvested in Zones 2, 4, 3, and 5 are in the first homogeneous group, while Zones 1, 3, and 5 make up the second group —the overlap in the groups is natural in this test—. The first group contains the zones that generate the highest and best weights. These results confirm the findings in the grain classification by size of the five altitudinal zones studied.

The results of the variations in the physical characteristics of green coffee bean weight and size are consistent with those of Malau et al. (2017), who found a positive correlation between weight and altitude; Scholz et al. (2018), who analyzed the influence of environmental conditions on the alteration of the characteristics and attributes of green coffee; Alfaro (2015), who found significant increases in the apparent and real density of coffee beans (green coffee) at higher altitudes in Costa Rica, and Martins et al. (2015), who reported that water deficit and temperature are the most determining factors in coffee yield.

In studies on coffee behavior regarding climatic variations, Pham et al. (2019) reported that climatic changes negatively influence yield and cause the loss of optimal cultivation areas. Torres et al. (2020) and Asfaw et al. (2019) proved that, at higher temperatures, coffee berry borer and rust attacks are economically significant, so that the displacement of coffee-producing areas towards higher

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altitudinal zones constitutes a natural barrier to mitigate the effects of climate change on coffee production.

Conclusions

The results showed that in size distribution, the highest value of the grains retained in sieve 18 was 17.99 g ± 8.16 g (Zone 2), and the lowest was 12.87 g ± 5.30 g (Zone 1); in sieve 16, the highest value was 87.30 g ± 18.60 g (Zone 2), and the lowest was 62.56 g ± 19.49 g (Zone 1); in sieve 14, the highest value was 52.86 g ± 18.20 g (Zone 1) and the lowest value was 28.60 g ± 10.10 g (Zone 2), and in the residues or *pasilla*, the highest value corresponded to Zone 5, with a mean of 16.03 g ± 10.63 g, and the lowest value to Zone 3, with 8.82 g ± 3.54 g.

The weights per altitudinal zone indicated that the highest values were recorded in Zones 2 (9.77 g ± 0.42 g), 3 (9.09 g ± 0.59 g), and 4 (9.39 g ± 0, 34 g), while the lowest values occurred in Zones 1 (8.20 g ± 1.07 g) and 5 (8.73 g ± 0.52 g). In the analysis of variance, significant differences were found at 5 % between the altitudinal levels for large, medium, and small coffee beans and residues.

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Disclaimers

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