DASOMETRIC PARAMETERS IN AVOCADO TREES (Persea americana Miller) RAZA ANTILLANA AND ITS FRUIT, ARRAIJÁN, WESTERN PANAMA

Francisco Corella[1*], Jay Molino[1,2], Ericka Matus[1,2], Lorena Matus[3], Juan Corella[4], Néstor Valles[5], Natusha González[1,6]

[1]Faculty of Biosciences and Public Health, Universidad Especializada de las Américas, Paseo de la Iguana, 00629 Ancón, Panamá.
[2]Sistema Nacional de Investigación (SNI), SENACYT, Panamá.
[3]Department of Psychology, Iberoamerican University, Mexico City, Mexico.
[4]Faculty of Agricultural Sciences, University of Panama, Panama.
[5]Department of Physics and Mathematics, Division of Engineering and Technology, University of Monterrey, Av. Eugenio Garza Sada 2501 Sur, Tecnológico, 64849, Monterrey, N. L., México.
[6]Thesis student, she worked on this research as part of the degree work. Faculty of Biosciences and Public Health, Universidad Especializada de las Américas, Paseo de la Iguana, 00629 Ancón, Panamá. natusha.gonzalez.6@udelas.ac.pa
[*]To whom correspondence should be addressed: francisco.corella@udelas.ac.pa

Abstract. Avocado is considered an agricultural crop among several species that can contribute to food and nutritional security for the Republic of Panama. Even though the creole avocado of the West Indian race is native to tropical America, there are almost no studies on the dasometric parameters related to the production of its fruits. A study was carried out to evaluate the development of five dasometric parameters in 40 trees of creole avocado, namely: diameter at breast height (DBH), heights, commercial diameters, shape coefficients, and volumes, which were related to fruit production at ages of 10, 15, 20 and 25 years, respectively. For this purpose, the study site was selected (Burunga, Arraiján, Province of West Panamá, Panamá). Ten specimens were chosen for each age level, the dasometric parameters were measured, and the total number of fruits produced/tree/year was counted. The quasi-experimental design was applied with four treatments and ten observations for each treatment. SAS and Excel software was used for statistical analysis. Two procedures were considered: the Kruskal-Wallis test for analysis of variance and quantitative research to obtain more detailed information. The four treatments consisted of the following groups: Group A: 10 years; Group B: 15 years; Group C: 20 years, and Group D: 25 years.

Keywords: Avocado criollo, dasometric parameters, fruit production, age level, nutritional food security, Persea Americana, American variety.

INTRODUCTION

The avocado belongs to the Lauraceae family, which comprises about 50 genera and between 2500 to 3000 species of trees and shrubs (Ge Y. et al., 2019). According to Gómez R. (2014), more than 20 varieties of avocados are cultivated worldwide, spread in different subtropical and tropical areas of the earth, and are divided into three races. The classification is made according to a series of peculiarities relating to flavor, land of origin, shape, amount of fat, and planting altitudes above sea level.

In studies conducted in the Mesoamerican Flora, Van Der Werff (2002) recognized three new species of the genus Persea: *P. albiramea*, *P. brevipetiolata,* and *P. laevifolia*; he also included brief notes with synonyms, distribution, and notable characteristics of these species.

Sanchez and Restrepo (2016), in studies on bio-inputs used in avocados, affirm that they are more environmentally friendly and that these can have variability due to climate factors, production and harvesting seasons, cultural labor, others. According to MIDA (2021), the varieties in Panama are classified into three breeds: Mexican, Guatemalan and Antillean. There are two types in the study area concerning the Antillean: butter and milk. While the

According to research conducted at the Herbarium of the University of Panama (2018), Panamá country has four species of the genus *Persea* distributed throughout its territory, without considering the avocado *Persea Americana Mill*. Species of the subgenus *Persea schiedeana* and the subgenus Eriodaphne: *Persea reigns, Persea veraguasensis,* and *Persea obstusifolia*.

The study conducted by Pinto et al. (2019) on non-invasive and low-cost methods for monitoring and quality control of ripening has boosted its export. They used non-invasive hyperspectral images, with principal component analysis techniques performing tracking using the normalized difference vegetation index, the ratio vegetation index and the photochemical reflectance index, colorimetry indices in color space and the triangular greenness index. The authors conclude that it is possible to characterize avocados using non-invasive hyperspectral images that allow the classification of avocado production on any post-harvest day.

Avocado represents one of the subtropical and tropical fruit crops of worldwide economic relevance. However, diseases of biotic origin, such as anthracnose, caused by Colletotrichum pp, affect the fruit and jeopardize its commercialization (Trinidad-Ángel E. et al., 2017).

One of the phytosanitary problems limiting avocado production is anthracnose, one of the most frequent diseases (especially during post-harvest). The symptoms of this disease are caused by species of phytopathogenic fungi of the group of Deuteromycetes or imperfect fungi, mainly by those belonging to the genus Colletotrichum (anamorph). However, the species that is considered highly pathogenic for this crop is Colletotrichum gloeosporioides (Tapia-Rodríguez A. et al., 2020).

Thus, diseases of biotic origin directly affect the fruit and have become the greatest threat to international trade. Anthracnose is characterized by dark, sunken, circular, ellipsoidal lesions, with large quantities of spores forming compact masses of salmon, orange or pink color, representing one of the significant avocado diseases that affect fruit quality and reduce production (Trinidad-Ángel E. et al., 2017).

In collaboration with researchers, Growers continue to conduct experiments that minimize those diseases and strengthen their growth. Proof of this is the study in which potassium nitrate was added to the fertilization for avocado production, directly correlating the foliar concentration of nitrogen and potassium that favored higher production (Guerrero-Polanco F. et al., 2018).

Acosta et al. (2013) published a study on the morphological characterization of the fruits of Criollo avocados in the northern region of the state of Nuevo Leon in Mexico. The study reports that three races are recognized for their morphology, physiology, and cultivation in the world; the Mexican (*Persea Americana*) drymifolia variety, the Guatemalan (*Persea Americana*) guatemalensis variety and the Antillean (*Persea Americana*) American type. Hybrid varieties were also considered.

López G. et al. (2021) conducted studies of the genetic plurality of *Persea Americana* Criolla from the state of Nayarit (Mexico) with ISSR genetic markers that are highly polymorphic, finding a high level of gene diversity, while in the molecular analysis, the most accentuated variation was found within populations. It was also observed that genotypes were concentrated among groups according to genetic distances influenced by geographic location or climate influence, valuable information in cultivation and production management.

Alvarez M. et al. (2018) state that the high genetic diversification in criollo avocado increases the opportunity to create different descendants that will prolong the fruit ripening span, increasing the economic value. In addition, Araujo R. et al. (2018) confirms that various nutritional components are obtained in the remains of avocado fruit, perfect quality oils, and essences of high functionality.

As for the peculiarities that correspond to the harvest index, Saborío et al (2015) found that it is essential to take into account the subjective reasoning, as well as the reason that can be observed in the laboratory, to achieve a broader perspective and reduce the losses that occur in the harvest of the fruit in circumstances that are not appropriate for it to ripen properly. As soon as these reasonings about the harvest index are clarified, the harvesting of the fruit can begin. The same authors affirm that if there is adequate pruning in the plantation, the fruit can be harvested manually; if the opposite is the case, where there are large specimens, the fruit can be harvested with a stick, to which a knife is fitted.

The nutritional intake of an avocado provides between 12% and 30% fat and between 3% and 4% protein and vitamins, carbohydrates, and minerals. In addition, they state that in the criollo varieties studied; there are morphological variations of the fruit depending on the early, intermediate, or late harvest and the structure of the orchard (Acosta, Almeyda, & Hernández, 2013).

According to information from farmers in the study region, Simmonds, Choquette, booth, and criollo varieties have been cultivated in recent years. The criollo is subdivided into two types: butter criollo, characterized by a short neck and yellow flesh, while the milk avocado is identified by having a longer neck. In this research, the first type was chosen because there were enough specimens for the study.

The Ministry of Agricultural Development of Panama, MIDA (2018), published a report stating that the consumption of avocado fruit has increased by 64% due to the food and nutritional qualities; this is equivalent to 55 thousand 310 quintals in the last five years.

It is considered an agricultural crop among several species that can contribute to food and nutritional security in the Republic of Panama. Even though the creole avocado of the West Indian race is native to tropical America, no studies were found on dasometric parameters related to fruit production.

In the study area of the criollo avocado and its surroundings, studies are also carried out with other agricultural species that can supply and guarantee part of the food and nutritional security of the inhabitants of the Arraiján region. Among these species are the pigeon peas (Cajanus cajan), commonly grown during the rainy season, but studies are conducted to extend its cultivation in the dry season due to its high nutrition value. (Corella F. et al., 2020).

The present study evaluates the dasometric parameters of 40 avocado trees considering their fruit production and explores the potential for avocado trees' forest utilization for firewood, timber, and cellulose.

MATERIALS AND METHOD

The trees and their ages were selected to carry out an appraisal. The diagnosis of the site included an interview with the producers, who stated that the most prolific periods of criollo avocado fruit in the region range between 10 and 25 years, which is why this version was chosen. Ten specimens were selected at ages 10, 15, 20, and 25 years. Each tree set met the ideal characteristics to be evaluated: good appearance, intact, without physiological and physical damage, without pest and disease attacks, well-formed, healthy, and in total productivity.

Measurements. Measurements were taken during the period of the best fruit development which was between May 2 and 28, 2020. The production was in full bloom when we measured the DBH (diameter at breast height), which is located at 1.30 m from ground level upwards in each tree, the diameter at commercial stem height (located where the last main branch detaches from the stem), height, shape coefficients and volume of each tree.

Design. Four treatments were applied with ten observations for each treatment. A quasi-experimental design was applied using SAS and Excel programs for the statistical analysis. The four groups (medicines) that integrated ten trees were as follows: Group 1: 10-year-old trees; Group 2: 15-year-old trees; Group 3: 20-year-old trees; and Group 4: 25-year-old trees. The following independent variables were considered: diameter at breast height, diameter at commercial height, height, shape coefficient, volume and age, and the dependent variable: number of fruits per tree.

Statistical analysis. SAS and Excel programs were used for statistical analysis. Two procedures were considered: the Kruskal-Wallis test for analysis of variance and quantitative research to obtain more information from the data.

RESULTS AND DISCUSSION

Dasometric parameters. The measurement of the dasometric parameters: DBH (diameter at breast height), H (height), CD (commercial diameter), SC (shape coefficient), and Vol (volume) related to fruit production are shown in Table 1 and 2. In the first column are the treatments numbered from 1 to 4: treatment 1: ten-year-old trees; treatment 2: fifteen-year-old trees; treatment 3: twenty-year-old trees; treatment 4: twenty-five-year-old trees. The ANOVA parametric inferential statistics test searched for significant differences by variable and tree age (Table 2).

Figure 1 shows the mean comparison analysis for the dasometric indicators in each group according to age.

Table 1

Groups, observations, dasometric parameters, ages, and numbers of fruits

Grupo	Observación	DBH (m)	Al (m)	DC	CF	Vol (m^3)	Nf
1	1	0.30	9.55	0.23	0.75	0.506	252
	2	0.28	9.25	0.24	0.84	0.478	230
	3	0.27	8.50	0.22	0.79	0.384	185
	4	0.29	9.75	0.23	0.78	0.502	247
	5	0.31	10.00	0.24	0.76	0.573	260
	6	0.32	10.25	0.24	0.74	0.609	278
	7	0.33	10.70	0.25	0.74	0.677	284
	8	0.32	10.05	0.24	0.74	0.598	270
	9	0.30	9.85	0.23	0.76	0.529	257
	10	0.27	8.75	0.21	0.77	0.380	182
2	1	0.34	10.55	0.26	0.75	0.718	345
	2	0.35	11.65	0.26	0.73	0.818	379
	3	0.35	11.30	0.27	0.75	0.815	375
	4	0.33	10.85	0.26	0.77	0.695	328
	5	0.34	11.07	0.27	0.78	0.783	360
	6	0.37	11.85	0.28	0.74	0.942	412
	7	0.38	12.05	0.29	0.74	1.011	420
	8	0.36	11.00	0.29	0.78	0.873	393
	9	0.37	11.35	0.28	0.74	0.902	401
	10	0.36	10.90	0.27	0.74	0.820	382
3	1	0.38	10.45	0.30	0.79	0.936	410
	2	0.39	11.50	0.31	0.79	1.381	466
	3	0.40	11.65	0.32	0.80	1.171	440
	4	0.37	10.25	0.29	0.78	0.839	385
	5	0.36	10.15	0.28	0.77	0.795	366
	6	0.41	11.90	0.33	0.80	1.252	450
	7	0.42	12.15	0.34	0.80	1.346	457
	8	0.43	12.00	0.34	0.79	1.376	463
	9	0.39	11.40	0.31	0.79	1.075	430
	10	0.40	12.00	0.31	0.77	1.160	436
4	1	0.40	12.05	0.33	0.82	1.241	380
	2	0.39	11.65	0.32	0.82	1.141	353
	3	0.43	12.50	0.34	0.79	1.433	366
	4	0.44	12.60	0.33	0.75	1.436	368
	5	0.46	12.80	0.35	0.76	1.616	385
	6	0.47	12.95	0.38	0.80	1.797	397
	7	0.43	12.00	0.35	0.81	1.411	357
	8	0.42	12.40	0.35	0.82	1.408	348
	9	0.40	11.96	0.33	0.82	1.232	370
	10	0.43	11.95	0.33	0.76	1.318	384

Table 2

Dasometric parameters

Source	DF	Sum of squares	Mean square	F-Value	Pr > F
Diameter at breast height (DBH)					
Model	3	0.091	0.030	66.040	**<0.0001**
Error	36	0.017	0.000		
Total correct	39	0.108			
R-squared = 0.846239; Coef Var = 5.819376; Root MSE = 0.021473; Mean DBH = 0.369					
Tree heights (m)					
Model	3	35.446	11.815	32.420	**<0.0001**
Error	36	13.121	0.364		
Total correct	39	48.567			
R-squared = 0.730; Coef Var = 5.420; MSE Root = 0.604; Mean DBH = 11.138					
Commercial diameter (m)					
Model	3	0.067	0.022	91.760	**<0.0001**
Error	36	0.008	0.0002		
Total correct	39	0.0754			
R-squared = 0.884; Coef Var = 5.367; Root MSE = 0.016; Mean commercial diameter = 0.290					
Shape coefficient (SC) about four ages					
Model	3	0.0116	0.0039	6.9700	**<0.0008**
Error	36	0.0200	0.0006		
Total correct	39	0.0316			
R-squared = 0.367521; Coef Var = 3.038; Root MSE = 0.024; Mean commercial diameter = 0.776					
The volume of trees (m^3)					
Model	3	4.3105	1.4368	55.8500	**<0.0008**
Error	36	0.9261	0.0257		
Total correct	39	5.2366			
R-squared = 0.823143; Coef Var = 16.460; Root MSE = 0.160; Mean height = 0.974					
Number of fruits					
Model	3	187,237.275	62,412.425	71.520	**<0.0001**
Error	36	31,414.700	872.631		
Total correct	39	218,651.975			
R-squared = 0.856326; Coef Var = 8.291; Root MSE = 29.540; Mean of mean fruit = 356.2					

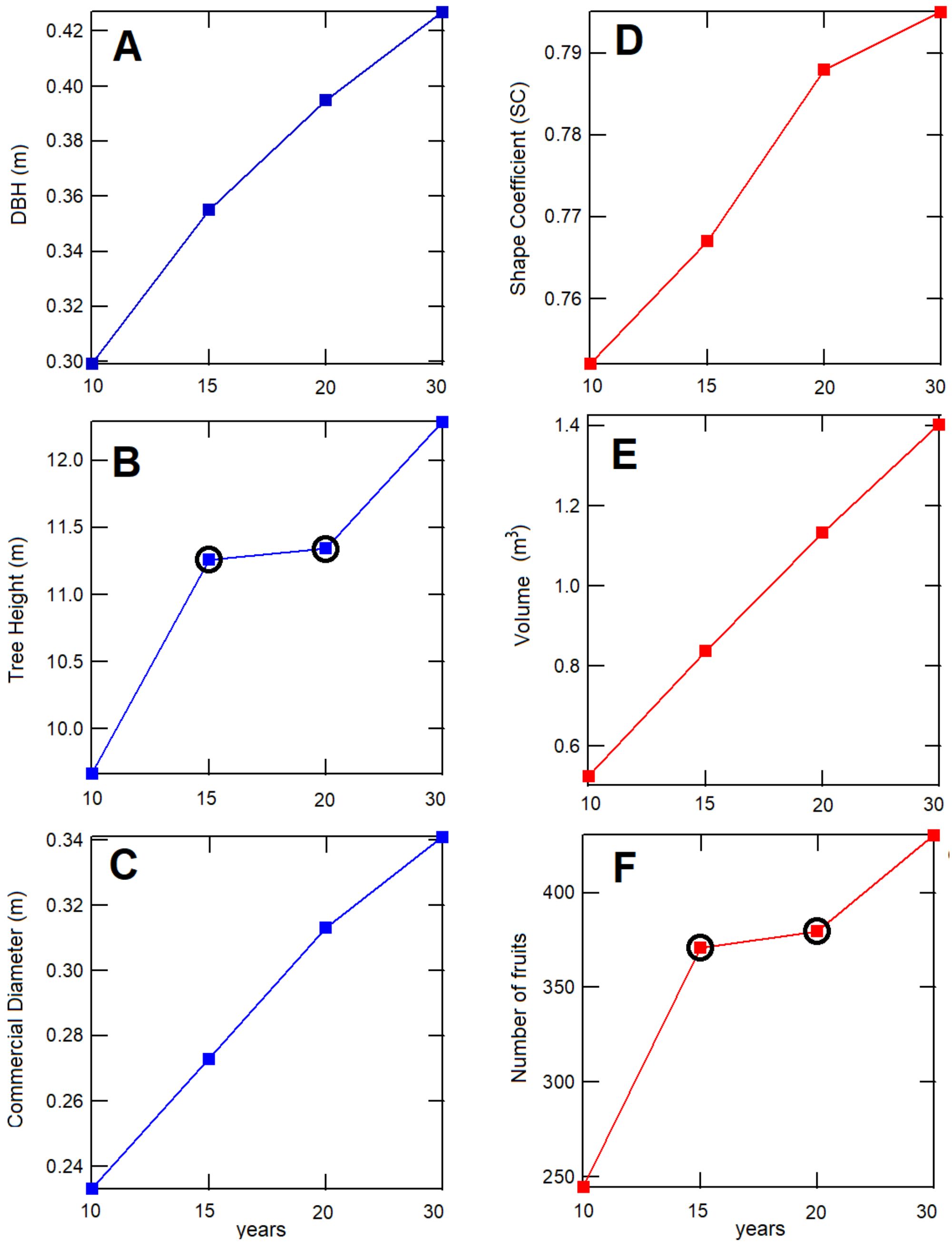

Figure 1. Dasometry: comparison of means of **A.** DBH; **B.** Height**; C.** Commercial Diameter**; D.** Shape Coefficient (SC)**; E.** Tree volume**; F.** Number of fruits**.** Data with statistical differences based on Duncan's clustering test are highlighted in a black circle

The best production was obtained in 20-year-old trees with 430 fruits per tree; however, good production was observed in all the groups studied, with an average of 356 fruits/tree/year.

The multiple correlation coefficient observed between the variables analyzed is 82.37%, indicating a good association between the dasonometric variables studied. The regression and analysis of variance is shown in table 3.

Table 3

Regression statistics, variance and regression parameters

Regression statistics	
Multiple correlation Coefficient	0.8237
Coefficient of determination R^2	0.678
R^2adjusted	0.6313
Standard error	45.4658
Remarks	40

Analysis of Variance

FV	Degrees of freedom	Sum of squares	Mean squares	F	The critical value of F
Regression	5	148369.355	29673.871	14.355066	1.4229E-07
Waste	34	70282.6199	2067.1359		
Total	39	218651.975			

Regression parameters

Dasometric parameters	Coefficients	Standard error	Statistic t	Probability
Interception	-478.0504	979.5473	-0.4880	0.6287
Basal diameter (m)	1,541.0096	2,408.6586	0.6398	0.5266
Height (m)	30.9051	21.4288	1.4422	0.1584
Commercial diameter (m)	714.2082	3,179.5211	0.2246	0.8236
Shape Coefficient (SF)	-73.0687	1,174.0851	-0.0622	0.9507
Volume (m^3)	-235.0012	119.9001	-1.9600	0.0582

The adjusted coefficient of determination or regression coefficient R^2 is 0.6786. The adjusted R^2 is 0.6313; remember that the adjusted R^2 decreases the regression models' incremental tendency when dealing with more than one variable. In this case, the model's dasonometric variables only explain 63.13% of the number of fruits; the rest of the percentage is not explained. The regression error of 45.47 % is the difference between the prediction and actual errors and depends on the given characteristics. It seems to be relatively high and expresses the variability of the mean. Indeed, further research is required to analyze which other variables can be accounted to be influencing the result, for example, agronomic management climate change, among others.

Given that p_value is 1.4229E-07 and a value much less than 0.05, the null hypothesis is rejected, and it is accepted that this is multiple linear models. The possible regression equation to predict the number of fruits in future harvests is as follows:

$$N_{fruit} = -478.05 + 1541.01\,\mathrm{DAP} + 30.91\mathrm{H} + 714.21\mathrm{DC} - 73.07\mathrm{SF} - 235\mathrm{Vol}$$

Note that the dependent variable is the number of fruits to be produced, and the independent variables are all the ones that appear as dasonometric parameters. In the first data analysis with the five parameters, none had a p_value (probability) lower than 0.05, and it was determined that there was no significant statistical difference between them. In the second analysis with the four variables, the only one that did not show a significant difference was the shape coefficient (SC) variable, so it was eliminated from the prediction model. The commercial diameter variable was removed in the third analysis with three variables because it didnot show significance. The height variable was eliminated in the fourth data analysis because it did not show effectiveness. The volume variable was removed in the fifth data run because it was not significant. The only variable that showed significance in four of the five runs was basal diameter, and the only variable that did not show effectiveness in any run was shape coefficient.

From the P-value ANOVA of the multiple regression model, it is derived that the model is linear but that the variables do not contribute directly to predicting the number of fruits to be produced per tree. The simple regression models indicate that there is statistical significance between fruit production and the variables basal diameter (Db), height (H), commercial diameter (DC), and volume (Vol), but not for the shape coefficient (FC). The figures followed by the same letter are not statistically different in each column, based on the Duncan test ($P \leq 0.05$). As shown in table 4.

With the data in the previous tables, it is possible to derive the multiple correlation coefficients 0.8237 (degree of association), which is applied to the situation of the variables considered and which is called Y, No. of fruits of Criollo avocado, which supposedly has been isolated to examine its relationship with the set of the other dasometric variables analyzed. In general, the value of a multiple correlation coefficient, R, is between zero and one. The closer it is to one, the greater the association between the variables considered. In this case, for the avocado tree dasometric data.

Table 4

Correlation Matrix for the dasometric parameters of the Criollo avocado tree

Variables considered	Basal diameter (m)	Height (m)	Commerce al diameter (m)	Form Coefficient (CF)	Volume (m3)	Fruit numbers
Basal diameter (m)	1					
Height (m)	0.9303032	1				
Commercial diameter (m)	0.9753614	0.893593	1			
Form Coefficient (CF)	0.2640451	0.145954	0.463071	1		
Volume (m3)	0.9788836	0.920724	0.978128	0.358785	1	
Fruit numbers	0.7872945	0.779799	0.749382	0.106961	0.734261	1

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest. The sponsors had no role in the design of the study, in the collection, analysis, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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AUTHORS' CONTRIBUTIONS

Francisco Corella: Conceptualization, Methodology, investigation, formal analysis, resources, project administration, writing of original draft, review and editing. **Jay Molino:** formal analysis, data curation, resources, supervision, project administration, funding acquisition review, editing. **Ericka Matus:** Validation, formal analysis, data curation, writing of original draft, review and editing. **Lorena Matus:** Validation, formal analysis, data curation, writing of original draft, review and editing. **Juan Corella:** Validation, formal analysis, data curation, writing of original draft, review and editing. **Néstor Valles:** Formal analysis, review and editing. **Natusha González:** field work and formal analysis.

CONCLUSIONS

The Criollo avocado is a species that has contributed, favors, and will continue to benefit the country's food sovereignty with nutritious fruits. The data of the variables investigated are essential indicators for future research on the dasometry of the Criollo avocado in Panama.

The correlation coefficient (0.8237) or degree of association of the avocado dasometric variables was determined and the adjusted coefficient of determination (0.6313). Still, it was not possible to explain how the independent variables influence the fruit production of the Criollo avocado.

The results obtained in this research show that the alternative hypothesis was fulfilled since a linear regression model was derived. It is expected that further studies will be carried out to identify the variables that influence the fit of the regression model.

The work carried out made it possible to obtain basic information for the differentiation and perspective of creole avocado production that contributes to Panama's food sovereignty.

From the research conducted, it can be inferred that every Panamanian in the countryside can obtain at least one avocado fruit per day for their livelihood by planting a tree that contributes to the country's food and nutritional security.

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