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RELATIONSHIP BETWEEN ALTITUDE AND PHYSICAL, CHEMICAL AND ORGANOLEPTIC QUALITY ATTRIBUTES IN BEANS OF COFFEA ARABICA L. WITH DENOMINATION OF ORIGIN "PLUMA" FROM OAXACA, MEXICO

RELACIÓN ENTRE LA ALTITUD Y LOS ATRIBUTOS DE CALIDAD FÍSICA, QUÍMICA Y ORGANOLÉPTICA EN GRANOS DE COFFEA ARABICA L. CON DENOMINACIÓN DE ORIGEN "PLUMA" DE OAXACA, MÉXICO

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Relationship between altitude and physical, chemical and organoleptic quality attributes in beans of Coffea arabica L. with denomination of origin "Pluma" from Oaxaca, Mexico

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ABSTRACT

Oaxaca, Mexico, coffee (*Coffea arabica* L.) received its denomination of origin "Pluma" (NOM-255-SE, 2022). Previous studies indicate that the intrinsic characteristics of coffee originate from chemical components that intervene in the organoleptic attributes evaluated during cupping. The objective was to analyze the physical and chemical attributes of medium roasted *Coffea arabica* L. beans from the farms: "La Virginia" (1058 meters above sea level; masl),"La Palma" (1149 masl) and "Nuestra Señora del Carmen" (1343 masl) located in the area of Pluma, state of Oaxaca, Mexico. The physical analysis was performed according to NOM 255-SE-2022, the chemical analysis was attached to the AOAC, 2012, the evaluation of the organoleptic quality was established with respect to the quality standards of the Specialty Coffee Association and the statistical analysis was carried out by Principal Component Analysis. The physical analysis shows that the beans from the "Nuestra Señora del Carmen" farm have greater integrity than the other two farms, categorizing them as "premium" quality.The chemical analysis allowed establishing the existence of a correlation between altitude and the content of lipids, proteins, and titratable acidity, which influence the sensory characteristics of the coffee beverage, mainly in the

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body and acidity.

Keywords: Coffea arabica L., physical quality, chemical quality, organoleptic quality, Oaxaca, Mexico

Relación entre la altitud y los atributos de calidad física, química y organoléptica en granos de Coffea arabica L. con denominación de origen "Pluma" de Oaxaca, México

RESUMEN

El café (*Coffea arabica* L.) de Oaxaca, México, recibió su denominación de origen "Pluma" (NOM-255-SE, 2022). Estudios previos indican que las características intrínsecas del café provienen de los componentes químicos que influyen en los atributos organolépticos evaluados durante la cata. El objetivo fue analizar los atributos físicos y químicos de granos de *Coffea arabica* L. de tueste medio provenientes de las fincas: "La Virginia" (1058 metros sobre el nivel del mar; msnm), "La Palma" (1149 msnm) y "Nuestra Señora del Carmen" (1343 msnm), ubicadas en la región de Pluma, estado de Oaxaca, México. El análisis físico se realizó conforme a la NOM 255-SE-2022, el análisis químico siguió las normas de la AOAC, 2012, la evaluación de la calidad organoléptica se estableció según los estándares de calidad de la Specialty Coffee Association, y el análisis estadístico se llevó a cabo mediante Análisis de Componentes Principales. El análisis físico muestra que los granos de la finca "Nuestra Señora del Carmen" tienen mayor integridad que los de las otras dos fincas, clasificándolos como de calidad "premium". El análisis químico permitió establecer la existencia de una correlación entre la altitud y el contenido de lípidos, proteínas y acidez titulable, los cuales influyen en las características sensoriales de la bebida de café, principalmente en el cuerpo y la acidez.

Palabras clave: Coffea arabica L., calidad física, calidad química, calidad organoléptica, Oaxaca, México

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INTRODUCTION

Worldwide, coffee is the second most consumed beverage after water and the second most consumed product after oil (Cestari, 2021). The two main coffee exporting species are Arabica and Robusta with 18,302 and 11,970 thousand 60 kg bags, respectively (ICO, 2023). Mexico is the eleventh largest producer and within this, the states with the highest national production of cherry coffee in the southeast are Chiapas (35.1%), Veracruz (20.6%) and Oaxaca (18.9%), integrating 74.6% of the national surface (SIAP, 2022). The state of Oaxaca is made up of eight regions, among which is the region of "La Costa", which has natural factors conducive to the cultivation of coffee, such as: mountainous complex located in the Sierra Madre del Sur, a sub-humid climate, warm, semi-warm and humid with an average annual rainfall of 1500 mm^3. "Pluma" coffee must be derived from the fruits of the coffee plants of the *Coffea arabica* species, fundamentally from the *var*. Typica as the original variety and *var*. L. Pluma Hidalgo, as well as the *var*. Bourbon, *var*. Mundo Nov, *var*. Maragogipe, Marsellesa, Oro Azteca, Sarchimor, Geisha and Java *varities*, which are produced in the territory or established protection zone (NOM-255-SE, 2022). Roasted coffee is derived from green coffee under humidity (10-12.5%) and sanitary conditions, subjected to a roasting process (150-250°C). The factors that influence the final quality of the product are: geographical origin, climate, species, harvesting methods, processing and storage (Bressani et al. (Bressani et al., 2020; Dippong et al., 2022; Monteiro et al., 2019). Recent studies seek to establish the present relationship between sensory attributes with climate, agriculture, climate and environmental change and it has been found that some cultivars of *Coffea arabica* L. have the potential to produce high quality coffees (Oestreich-Janzen, 2013; Cordoba et al., 2020; Torres et al., 2022; Figueiredo et al., 2019).

Coffee characteristics after roasting (bitterness, nutty odor, spiciness, and blends) have been evaluated and according to the Specialty Coffee Association of America (SCAA), these are appreciated by consumers (Adhikari et al., 2019). These evaluations are based on the analysis of organoleptic quality through cuppings, in which the beverage has been categorized into two classes which are "Non-Special" and "Special". The first is subclassified into Bad Quality (0 to 59 points) and Commercial (60 to 79 points) and the "Special" is subclassified into "maximum" to the one whose score is above 88 points, "specialty" from 85 to 87.75 points, "premium" from 80 to 84.75 points and "regular" to the one that obtained a score of 72 to 79.75 points (NOM-255-SE, 2022; Yasmeen & Barzola, 2016). Likewise, the importance of the evaluation of the physical and sensory quality of roasted *Coffea arabica* L. beans for different markets has been highlighted (González Vázquez & Alcántara Sánchez, 2022; Huanca, 2018; Juárez González et al., 2021; Quispe Capajaña, 2020; Vazquez-Osorio et al., 2020; Worku et al., 2018).. In addition, it is essential to carry out a chemical analysis, since previous studies indicate that the intrinsic characteristics of coffee originate from its chemical composition (Poltronieri & Rossi, 2016) of those components involved in the organoleptic attributes evaluated during coffee cupping, such as organic acids, carbohydrates, proteins, lipids, fatty acids and volatile compounds, all of which are correlated with the acidity, body, fragrance/aroma and flavor of the coffee beverage (*Specialty Coffee Association*, 2021; Martins et al., 2019). Therefore, the objective of this study was to determine the influence of the altitude of three coffee farms (*Coffea arabica* L.) located in the area with the denomination of origin "Pluma", on the physical and chemical quality attributes as well as their relationship with the organoleptic quality.

METHODOLOGY

Samples of coffee with denomination of origin "Pluma"

These are samples of medium roasted *Coffea arabica* L. from the 2020 harvest, of 500 g each, from three farms at different altitudes, which are "La Virginia", "La Palma" and "Nuestra Señora del Carmen" located in the municipalities of Huatulco, San Miguel del Puerto and Pluma Hidalgo, Oaxaca, Mexico, respectively and whose characteristics are described in Table 1. The climate on these farms is sub-humid and semi- warm, with 47% humidity and an average annual rainfall of 1500 mm cubic meters (NOM- 255-SE, 2022) conditions that have favored the cultivation of coffee and fruit trees such as lemon, mango, tamarind, banana, coconut, orange, papaya, pineapple, watermelon and melon, as well as bean, corn and peanut crops (INEGI, 2020).

Physical analysis of roasted beans of *Coffea arabica* L.

One hundred grams of *Coffea arabica L*. medium roasted beans were taken from each sample and the beans with the characteristics established in the Mexican Official Standard 255 were manually selected for the evaluation of physical attributes, such as expansion, color, roasting lightness, cracking and texture (Table 3).

Chemical analysis of roasted *Coffea arabica* L. beans

Two grams of medium ground roasted *Coffea arabica* L. were used for all chemical attribute tests (Table 3). Method 918.12 was used for pH analysis and 942.15 for titratable acidity (AOAC, 2012) using a HANNA Instruments HI 2215 potentiometer, Rhode, Island, USA. In the case of Moisture and Ash analyses, the methodology of the Mexican Standard for pure roasted coffee beans or ground coffee was followed (NMX-F-013-SCFI, 2010) for the determination of ethereal extract, the AOAC method 945.16 was followed (Horwitz, W., 2010) in a Soxtec TM 8000 extraction unit, and for proteins, method 2001.11 (AOAC, 2012) using a FOSS Micro Kjeldahl digester-distiller. All analyses were carried out in triplicate.

Evaluation of organoleptic quality *Coffea arabica* L.

Green coffee samples from the three farms were roasted, prepared and evaluated by a professional cupper called Q Graders, under the protocol and quality standards established by the Specialty Coffee Association (*Specialty Coffee Association*, 2021; SCA, 2018). For this, he used a roasting equipment brand 100 MEX, MON-110V until reaching a medium roast with a reference value of color #55 on the Agtron scale. Subsequently, he weighed 12.5 g of the roasted grain and ground it in a BUNN G3HD, BLK mill to a particle size of 20 µm. The grist obtained was transferred to a cup for cupping and 290 mL of purified water at 95°C was added. The taster evaluated the attributes of aroma, flavor, acidity, body, aftertaste and balance (Table 2) and entered the obtained results into an application software called Tastify (Sustainable Harvest, 2022) to generate the results in graphical form (Figure 2).

Statistical analysis

For the analysis of the data of the physical and chemical attributes obtained experimentally, an analysis of variance and a Tukey HSD test were performed in Excel (Microsoft Mondo 2016) to determine the significant difference between the means with a significance level of α=0.05 as well as a Principal Component Analysis (PCA) to reduce the dimensionality of the variables and determine their correlation by using IBM SPSS v. 25 (International Business Machines Corp.) Statistical Software, in which only the attributes with values greater than 1 were included.

RESULTS AND DISCUSSION

Physical analysis of roasted *Coffea arabica* L. beans

With respect to the physical attributes of roasted coffee beans in terms of expansion, color, clear to roast and crack, using the Tukey test (p>0.05), it was found that there is a significant difference between the samples from the “La Virginia”, “La Palma” and “Nuestra Señora del Carmen” farms, with the exception of the texture attribute (Table 3). The roasted coffee beans from the "La Virginia" farm showed the greatest expansion (95.33±0.01), which indicates uniformity and provides information about the quality of the work of harvesting the beans and subsequent stages such as drying, selection and wet milling. With respect to color, the beans from the "La Palma" farm showed the least homogeneity (87.33±0.01) in the development of the roasted coffee bean. In the three farms, light beans were found at roasting (3-5 beans/100 g), representing 95.33±0.01, 92.67±0.01 and 98.67±0.01 for the farms "La Virginia", "La Palma" and "Nuestra Señora del Carmen", respectively. The analysis of this parameter allowed us to infer that the beans from the "Nuestra Señora del Carmen" farm are harvested and separated from immature beans in the cherry coffee in an adequate manner. Additionally, the parameter of light roasted beans indicates the magnitude in which the light roasted beans affect the physical and cup quality for high quality coffee preparations. The fissure refers to the opening in the bean while the texture refers to the degree of roughness or lack there of on its surface, both parameters in the development of roasted coffee. In the case of texture, there is no significant difference between the beans from the three farms; however, the beans with the greatest openness (77.67±0.01) are the beans from the "La Virginia" farm.

Chemical analysis of roasted *Coffea arabica* L. beans

Table 3 shows that the pH varies among the farms analyzed; however, the titratable acidity expressed in mg of chlorogenic acid per gram of roasted coffee increases as the altitude of the farms studied increases. It can be seen that the sample that presents the highest acidity is the one corresponding to the farm "Nuestra Señora del Carmen" with 23.14±0.82 mg of chlorogenic acid per gram of roasted coffee. The acidity of coffee is related to organic acids such as malic and citric acid (Solis & Herrera, 2005) that influence the pH value related to coffee quality (Martins et al., 2019). (Martins et al., 2019). Acids in coffee are divided into organic and chlorogenic acids (Yeager et al., 2021). The latter compounds found in coffee consist of caffeic and quinic acid, which are flavor precursors and impart bitterness, astringency and acidity to coffee. Chlorogenic acids are esters of quinic acid and the most abundant one is 5-caffeoylquinic acid (Solís & Herrera, 2005). Additionally, acidity is influenced by factors such as the level of maturation of the bean, its subsequent processing, and by roasting (Wang & Lim, 2012). Moisture content depends on the degree of roasting (Farah, 2004). The degree of roasting of the samples from the three farms was medium toasting, and the beans with the highest percentage were those from the "Nuestra Señora del Carmen" farm (4.40± 0.14), followed by "La Virginia" (3.73± 0.14) from Huatulco and "La Palma" (2.87± 0.10) from San Miguel del Puerto. This is due to the climatic characteristics of Pluma Hidalgo and Huatulco, which have a higher humidity in the environment. With respect to ash content, the samples "La Virginia" and "Nuestra Señora del Carmen" do not show significant differences, unlike the "La Palma" farm, which has a statistically significant difference with respect to the other two farms. It is worth mentioning that in both moisture and ash analysis, the analyzed samples were within the permissible limits of moisture (<6%) and ash (maximum 6.5%) of NMX-F-013-SCFI-2010.

In this study, a higher percentage of fat was found for the sample from the "Nuestra Señora del Carmen" farm (14.23±0.04) located in Pluma Hidalgo, followed by the "La Palma" (14.00±0.03) and "La Virginia" (13.37±0.03) farms, which statistically present differences between them in this chemical parameter associated with the body of the beverage. Data described about the fatty acids contained in the lipidic fraction extracted by the Soxhlet method reported a content in percentage of saturated fatty acids 3.58±0.3 (C12:0), 1.99 ±0.3 (C14:0), 43.64 ±0.3 (C16:0), 6.48 ±0.2 (C18:0) and 2.39 ±0.3 (C20:0), monounsaturated such as 8.16 ±0.4 (C18:1) and of the polyunsaturated 32.45 ±0.3 (C18:2) and 1.31 ±0.3 (C18:3) (Somnuk et al., 2017). The lipid fraction is known to contribute to aroma formation during the roasting process due to decomposition and autooxidation reactions as well as provide body to the coffee beverage (Barbosa et al., 2019).

Regarding the percentage of protein obtained in the beans of *Coffea arabica* L. of 8.50±0.04, 8.68±0.04 and 8.85±0.04%, for the farms "La Virginia", "La Palma" and "Nuestra Señora del Carmen" respectively, an increase in the percentage was found (Table 3) as the altitude increases where these farms are located (Table 1) with denomination of origin "Pluma". It is worth mentioning that the reported percentage in fat is below the 17% reported for *Coffea arabica* L. (Ochoa, 2016) roasted, while those of protein obtained fall within the reported 7.5 to 10%. (Farah A., 2012).

Evaluation of the organoleptic quality of *Coffea arabica* L. beverage

The evaluated cups of roasted *Coffea arabica* L. beans were found in the premium category with 82.75, 81.85 and 82.75 points, for the "La Virginia", "La Palma" and "Nuestra Señora del Carmen" farms (Table 2), respectively, which indicates that according to the Specialty Coffee Association they fall within the category of specialty coffees (NOM-255-SE, 2022; Yasmeen & Barzola, 2016; Yasmeen & Barzola, 2016). It can also be observed that in aroma, aftertaste, flavor and in general, the beans coming from "La Virginia" farm (7.75) presents the highest score, in acidity and balance, the cupper perceived the same since it has the same score for the three samples, however, in body the farms of "La Palma" and "Nuestra Señora del Carmen" present more values, however, in final score or score, the farms of "La Virginia" and "Nuestra Señora del Carmen" obtained the same and higher with respect to "La Palma". Previous studies mention the influence of the altitude of the cultivation areas on cup quality, such as the one carried out in Brazil, where the effect of the orientation of the mountains, altitude and variety on the quality of the beverage from the Matas de Minas region was evaluated (Ferreira et al., 2002) and where a significant influence of altitude on sensory attributes was found. Finally, in the samples, sensory descriptors (Table 2) were found in common such as chocolate, dried fruit and sugarcane flavor, clean (no off-flavors) and raisins. In the sample from the farm "La Virginia", Huatulco, peanut flavor was described, which has been widely cultivated in this municipality. In the "Nuestra Señora del Carmen" farm, additional descriptors such as cocoa and nutty were perceived. These sensory descriptors are associated with the values obtained in the cupping of the coffee beverage (Figure 2), which shows a tendency towards a greater aroma/fragrance, flavor and balance of the sensory attributes mentioned above.

Principal Component Analysis (PCA)

It was reduced from a dimension of 12 variables to 6 in component 1 (expansion, color, cracking, pH, moisture and ash), which could be called "physicochemical quality parameters" and 6 in component 2 (altitude, texture, titratable acidity, lipids, proteins and clear to roast), which we call "chemical variables associated with altitude". Table 4 shows a high relationship between altitude and the percentage of proteins and lipids, and the latter with titratable acidity, as well as color with the expansion or uniformity of the grain and pH. There is also a minor relationship between ash content and moisture, color and roasting lightness, as well as between protein content and titratable acidity.

Figure 3 shows the scatter plot of the variables with a total variance explained of 97.609%, being 52.20 and 45.41% for component 1 and 2, respectively. The height of the location of the farms sampled was highly related to the percentage of lipids and proteins, as well as of manually selected roasting spacings with the moisture and ash content. Grain cracking with color and pH are inversely proportional and there is proportionality between protein content and grain texture. The regression of components 1 and 2, in Figure 3, shows the spatial distribution of the farms analyzed, in which it is observed that the farms "La Palma" and "La Virginia" are inversely proportional, while the farm "Nuestra Señora del Carmen" has the highest values with respect to the other two farms, because the data obtained show that at higher altitudes some variables that are closely related to this variable are affected, such as the percentage of proteins, lipids and titratable acidity. This coincides with studies where the influence of altitude on the body was analyzed in relation to the percentage of lipids and titratable acidity in grains of *Coffea arabica* L. grown in 40 provinces of Ecuador (Duicela Guambi et al., 2017).

CONCLUSIONS

According to the physical attributes, the grains of the sample from Pluma Hidalgo (98.67±0.01) showed greater integrity than the other two samples. The analysis of the chemical composition indicates that there is a relationship between the altitude (masl) of the location of each of the farms sampled with respect to the percentage of lipids (13.37±0-03- 14.23±0.04) and proteins (8.50±0.04-8.85±0.04). With respect to the evaluation of the cup quality of the coffee, all the samples were categorized as specialty coffees in the "premium" subcategory.

The principal component analysis explains the dimensionality model of components 1 and 2 with 97.61% of total variance explained and indicates that fat composition, protein and titratable acidity are highly related to altitude and all these parameters are directly related to the percentage of light to roast, moisture and ash. There is also an inversely proportional relationship between altitude and texture.

It is suggested that another analysis of *Coffea arabica* L. beans from farms with higher altitudes than those considered in this study and that are also within the area with the "Pluma" denomination of origin be carried out.

Conflict of interest

The authors declare that they have no conflicts of interest.

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Figure 1. Graphical representation of the sensory attributes of the farms "La Virginia", "La Palma" and "Nuestra Señora del Carmen”

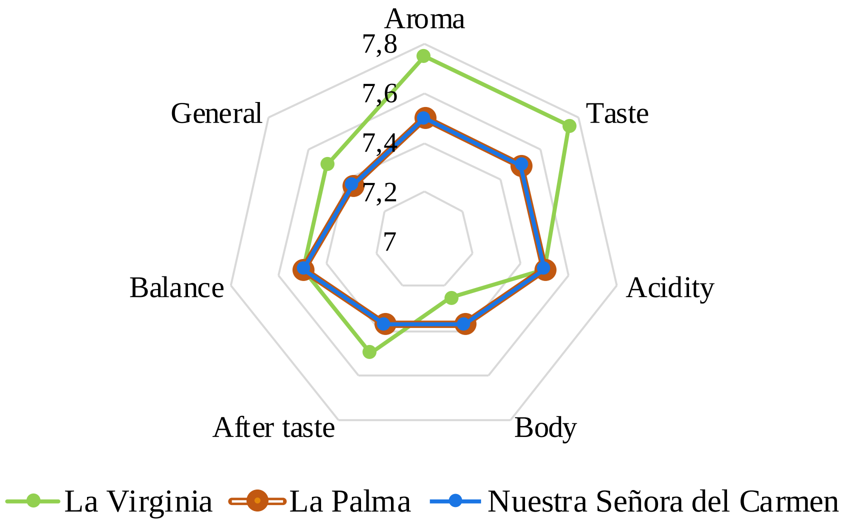

Figure 2. Clustered dispersion of linear regression of component 1 and 2 by farms with the variables associated with the PCA

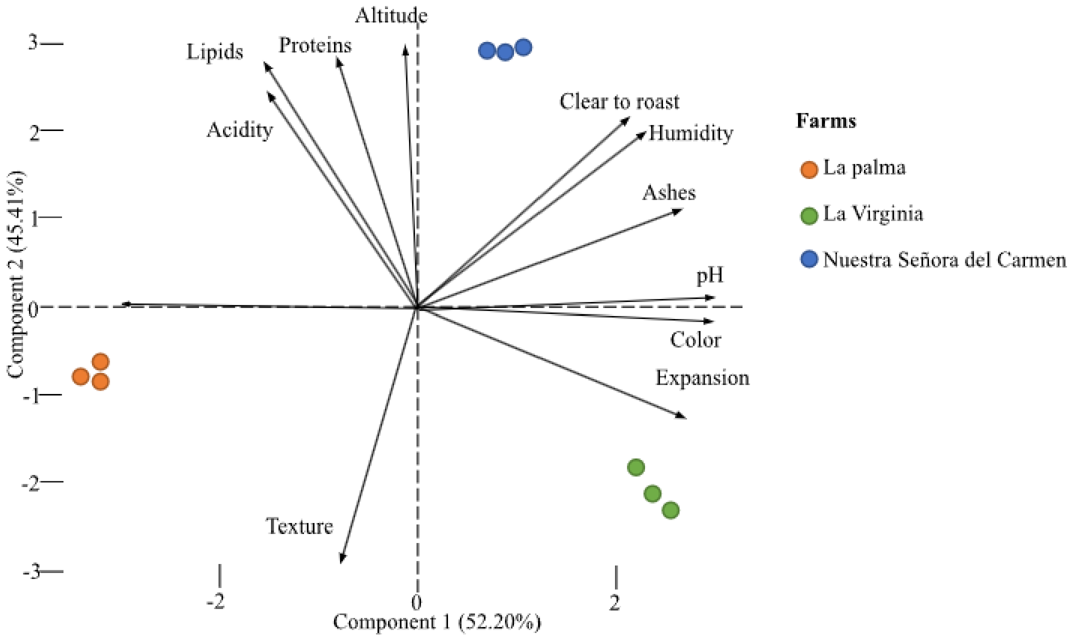

Table 1 Location of the study farms *Coffea arabica* L. with denomination of origin "Pluma"

Finca	**Location**	**Altitude (masl)**	**Coordinates**
La Virginia	Huatulco	1058	15°55'45"N 96°28'51"W
La Palma	San Miguel del Puerto	1149	15°52'29"N 96°23'12"W
Nuestra Señora del Carmen	Pluma Hidalgo	1343	15°52'46"N 96°23'19"W

Table 2. Sensory scores and descriptors obtained from the organoleptic evaluation of the coffee beverage made from *Coffea arabica* L. beans with denomination of origin "Pluma"

Sensory Attribute	La Virginia	La Palma	Nuestra Señora del Carmen
Aroma	7.75	7.5	7.5
Taste	7.75	7.5	7.5
Acidity	7.5	7.5	7.5
Body	7.25	7.37	7.37
Aftertaste	7.5	7.37	7.37
Balance	7.5	7.5	7.5
General	7.5	7.37	7.37
Score	82.75	81.85	82.75
Sensory descriptors	chocolate, peanut, clean,dried fruit, fresh, raisinsand sugar cane	chocolate, clean, dried fruit, fresh, raisins and sugar cane	cocoa, chocolate, nuts, herbs, sugar cane and candies

Table 3. Physical and chemical attributes of *Coffea arabica* L. with denomination of origin "Pluma"

Farms	Physicists						Chemicals				
	Expansion	**Color**	**Clear to roast**	**Crack**	**Texture**	**pH**	**Acidity**	**Humidity**	**Ashes**	**Grease**	**Protein**
La Virginia	95.33±0.01a	90.33±0.01a	95.33±0.01a	77.67±0.01a	98.67±0.01a	5.56±0.01a	19.37±0.82a	3.73±0.14a	4.08±0.01a	13.37±0.03a	8.50±0.04a
La Palma	91.67±0.01b	87.33±0.01b	92.67±0.01b	94.67±0.01b	98.67±0.01a	5.41±0.01b	22.20±0.82b	2.87±0.10b	3.82±0.02b	14.00±0.03b	8.68±0.04b
Nuestra Señora del Carmen	92.67±0.01b	90.33±0.01a	98.67±0.01c	82.67±0.01c	97.67±0.01a	5.53±0.01c	23.14±0.82b	4.40±0.14c	4.13±0.10a	14.23±0.04c	8.85±0.04c

*mg of chlorogenic acid per gram of ground roasted coffee.
Values in the same column with different letters indicate statistical differences obtained by Tukey's test (p>0.05).

Table 4. Correlation matrix based on altitude and physical and chemical attributes

	Altitude	**Expansion**	**Color**	**Clear to roast**	**Crack**	**Texture**	**pH**	**Titratable Acidity**	**Humidity**	**Ashes**	**Lipids**	**Proteins**
Altitude	1.000	-0.486	-0.127	0.666	0.084	-0.950	-0.020	0.816	0.602	0.313	0.890	0.952
Expansion	-0.486	1.000	0.929	0.327	-0.912	0.189	0.881	-0.774	0.390	0.626	-0.826	-0.654
Color	-0.127	0.929	1.000	0.655	-0.999	-0.189	0.992	-0.532	0.698	0.844	-0.559	-0.338
Clear to roast	0.666	0.327	0.655	1.000	-0.687	-0.866	0.730	0.222	0.984	0.873	0.258	0.471
Crack	0.084	-0.912	-0.999	-0.687	1.000	0.231	-0.995	0.499	-0.728	-0.861	0.523	0.298
Texture	-0.950	0.189	-0.189	-0.866	0.231	1.000	-0.293	-0.640	-0.816	-0.576	-0.705	-0.836
pH	-0.020	0.881	0.992	0.730	-0.995	-0.293	1.000	-0.442	0.766	0.894	-0.464	-0.247
Titratable Acidity	0.816	-0.774	-0.532	0.222	0.499	-0.640	-0.442	1.000	0.114	-0.125	0.914	0.857
Humidity	0.602	0.390	0.698	0.984	-0.728	-0.816	0.766	0.114	1.000	0.895	0.185	0.420
Ashes	0.313	0.626	0.844	0.873	-0.861	-0.576	0.894	-0.125	0.895	1.000	-0.120	0.112
Lipids	0.890	-0.826	-0.559	0.258	0.523	-0.705	-0.464	0.914	0.185	-0.120	1.000	0.947
Proteins	0.952	-0.654	-0.338	0.471	0.298	-0.836	-0.247	0.857	0.420	0.112	0.947	1.000

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