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Relationship between physico-chemical properties in the coffee beans and the cup quality attributes of coffee from the state of Chiapas, Mexico

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Abstract

Chiapas is the main coffee-producing state in Mexico, contributing around 40% of national production in 2018 (SIAP, 2019), with 1.8 million of 69 kg bags, benefiting around 175,000 coffee producers. The state has 13 different coffee-producing regions with different environmental, technical, and socio-cultural characteristics that influence the production of coffee. The objective of the present work was to study the physical and chemical properties of the beans from the 13 regions, and to evaluate their effect on the sensory attributes of the beverage. 139 samples of 12 kg of coffee cherries were directly obtained from coffee plantations, processed *in situ* by the wet route, thus obtaining about 2 kg of parchment coffee. In each sample, physical (shape, size, and defects); chemical (caffeine, trigonelline, and chlorogenic acid), and sensory (aroma/fragrance, taste, aftertaste, acidity, body, balance, and overall appreciation) analyses were performed. The results showed that bean's shape did not affect ($p > 0.05$) the cupping total score, but it did on attributes such as aroma and body. In general, the size of coffee beans had not significant effect on the cup quality attributes of the beverage; only in aroma the middle and small sizes of coffee beans scored higher ($p < 0.05$) than larger beans. Caffeine and trigonelline concentration in the beans had a negative correlation with all the cup quality attributes, contrary to what was found for chlorogenic acid (5-CQA), which improved all the cup quality attributes, especially acidity. In conclusion, physical and chemical properties in the coffee beans can modulate the cup quality attributes of the beverage in coffee samples from Chiapas, Mexico.

Introduction

Coffee production in Mexico is supplied by 12 states, with five of them, namely Chiapas, Veracruz, Puebla, Oaxaca, and Guerrero, providing more than 90% of the total production (SIAP, 2019). Chiapas produces about 40% of the national volume, in 13 coffee producing regions: Ángel Albino Corzo, Bochil, Comitán, Copainalá, Mapastepec, Motozintla, Ocosingo, Ocozocoautla, Palenque, Pichucalco, San Cristóbal de las Casas, Tapachula, and Yajalón (INEGI, 2017). Due to their environmental contrast and plantation management, these regions produce coffee with different quality characteristics.

Quality in coffee can be assessed from a physical, chemical, or sensory point of view. The physical analysis consists of the assessment of attributes in the coffee beans, such as shapes, sizes, and defects, which can be altered during the postharvest processes (Tolessa *et al.,* 2017). The chemical analysis involves the identification and quantification of various compounds, such as caffeine, trigonelline, and chlorogenic acid (5-caffeoylquinic acid, 5-CQA), which function as precursors for the formation of volatile compounds during the roasting process. Finally, the sensory evaluation of the beverage is carried out by specialised people called "cuppers". In this evaluation, the attributes of ground coffee are appreciated through the senses of smell, taste, and general sensations produced by the beverage in the mouth, assigning quantitative scores to the evaluated characteristics and a qualitative description of the aromatic and flavour notes found in the samples (Rosas Arellano *et al.,* 2008).

The caffeine content varies based on the variety and species (Burdan, 2015), and can reach values from 0.2 to 3% in *Coffea arabica* (Bicho *et al.,* 2013). Trigonelline, like caffeine, is a precursor during the roasting process, of volatile compounds such as furans, alkylpyridines, and pyrroles (Perrone *et al.,* 2008). Sridevi and Giridhar (2013) pointed out that the trigonelline content in green coffee beans is within the range of 0.88 to 1.77% for C. *canephora*. Chlorogenic acids (CGA) are a family of esters, formed between one and more derivatives of phenolic and quinic acids

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(Dawidowicz and Typek, 2011). The three main subgroups of CGA are: caffeoylquinic acids (CQA; 5-CQA included), di-caffeoylquinic acids (3-diCQA), and feruloylquinic acids (FQA), representing approximately 80, 15, and 5%, respectively, in *C. arabica* (Ky *et al.,* 2001). The content of these acids in green coffee beans varies based on the species, climate, soil, and degree of maturity (Narita and Inouye, 2015).

The objective of the present work was to find out relationships between the physicochemical characteristics of the green bean with the cup quality attributes of coffee from different coffee producing regions in the state of Chiapas, Mexico.

Materials and methods

Standards and reagents

The standards of caffeine (C11778-1VL), hydrochlorinated trigonelline (T5509-10G), and chlorogenic acid (C3878-1G) were purchased from Sigma Aldrich (Germany) with a degree of purity ≥ 95%.

Collection and processing of samples

Ten of 12 kg samples of coffee cherries were collected per region, considering the municipalities (INEGI, 2017) with the highest production records. Samples were wet-processed *in situ* using a hand disk-pulper (Promor, Mexico). Pulped coffee was allowed to have spontaneous fermentation into a 20 L bucket for 24 h, washed and sun-dried on African beds. About 2 kg of parchment coffee with 11 - 12% humidity were obtained. The samples were transferred into paper bags, covered by a plastic bag, fully labelled, and transported to the Quality Coffee Lab at Colegio de Postgraduados Campus Córdoba for evaluation.

Sample preparation

Following the methodology of Malta and Chagas (2009), 10 g of green coffee beans were weighed and frozen at -20°C for 24 h, then they were ground using a knives' mill (Hamilton Beach, USA) in two steps. In the first step, 5 g of coffee beans were ground and discharged, then another 5 g were ground and used for analysis. 0.5 g of ground green coffee were weighed and poured into 50 mL of boiling water (96°C), agitated for 3 min, and the extract was passed through a conventional filter (Whatman No. 1), and an aliquot of 5 mL was taken and centrifuged at 4,500 rpm for 10 min, in a Model DM0412S centrifuge (Science MED, USA), and finally passed through a 0.22 µm membrane filter.

Chemical analysis

For the identification and quantification of non-volatile compounds: caffeine, trigonelline, and chlorogenic acid (5-CQA) in green coffee, the methodology described by Malta and Chagas (2009) was adapted. An ultra-performance liquid chromatograph UPLC-Acquity I-Class (Waters, USA) coupled to a Xevo G2-XS QTof mass spectrometer (Waters, USA) was used. Three calibration curves (R^2 = 0.999) were prepared using the standards and Type I water with 18.2 Ω resistivity (Milli Q Reference, Merck, USA).

The chromatography system was integrated by a C_{18} column (Acquity UPLC BEH, 1.7 µm, 2.1 × 50 mm, Waters, USA) at 30°C, the mobile phase consisted of water : ACN (90:10 + 0.1% formic acid) at 0.4 mL/min flow, injection volume 5 µL, and 2 min run time. The samples were processed in triplicate. The electrospray ionisation (ESI) source of the mass spectrometer was positively operated for caffeine and trigonelline, while for 5-CQA was negative.

Physical analysis

The physical characteristics of coffee beans were determined using the procedures described in the Mexican standards NMX-F-191-SCFI-2013 (NMX, 2013), NMX-F-194-SCFI-2016 (NMX, 2016), and the Arabic Coffee Defects Manual of the Specialty Coffee Association of America (SCAA, 2004). 500 g of parchment coffee were taken, and the husk was removed in a laboratory mortar (Promor, Mexico). From the green coffee obtained, 350 g were taken to determine the size of the bean, by means of a set of Tyler trays for coffee with circular perforations from 19/64 (Z19 or 7.541 mm) to 15/64 (Z15 or 5.953 mm) inches in diameter, including a bottom tray (Z0). The beans retained on each tray were weighed, forming the following classification groups of bean size: large (Z17 [6.747 mm], Z18 [7.144 mm], and Z19 [7.541 mm]), medium (Z15 [5.953 mm] and Z16 [6.350 mm]), and small size (≤ Z14 [5.556 mm]). To determine shapes, the same 350 g of beans used in determining sizes were used, manually separating flat beans, triangles, elephants, and peaberries; expressing results in percentage of shape. For the classification of defects by type of imperfection, the Arabic Coffee Defects Manual of the Specialty Coffee Association of America (SCAA, 2004) was used. The same 350 g of coffee beans from previous analysis were used. Defective beans were removed from the sample and the remaining beans were used for sensory analysis.

Sensory analysis

For the sensory analysis the procedure described in the standards established in the Protocol for Tasting in Cup, published by the Technical Standards Committee of the Specialty Coffee Association of America (SCAA, 2015), was applied. The sensory analysis process consisted of three steps: roasting, grinding, and cupping.

Using a laboratory roaster (PROMOR, México), green coffee samples of 200 g were roasted 24 h before evaluation, for about 10 min until a medium roasting degree, with an initial temperature in the roaster drum of 180°C.

For coffee grinding, a grinder (Hamilton Beach, USA) with a capacity of 80 g was used. 13.75 g of roasted coffee were ground to a medium grind (70% of the grinds pass through the mesh of 0.841 mm or U.S. Standard Sieve number 20) for every five cups per tasting, within 5 min before infusion.

The cup quality evaluation was performed by a group of four specialised coffee tasters, Q-grader certified, with several years of experience in the coffee industry, under the parameters and procedures established by the Specialty Coffee Association of America (SCAA, 2015). They used SCAA standardised cupping formats with nine attributes to be assessed in the following order: fragrance/aroma, flavour, residual flavour/aftertaste, acidity, body, balance, sweetness, uniformity, and clean cup. Accordingly, to the cupper's flavour experience with these nine attributes, they gave an overall impression score for the sample. Each attribute, including the overall score, was rated in a scale ranging from 0 to 10. Finally, a total score was computed by adding the ten individual scores. Five cups per sample were assessed.

Experimental design

The municipalities of Chiapas where coffee production is reported (SIAP, 2019), were grouped into 13 coffee-production regions (INEGI, 2017) or clusters. In the present work, a total of 139 coffee producers were randomly selected from these regions, based on the relative importance of each cluster in the total volume of coffee in the state. A completely randomised design was used in the present work; experimental units were the coffee samples, treatments were the coffee production regions, and responses were physico-chemical properties in coffee beans and sensory attributes in the beverage.

Statistical analysis

Data were processed by using the R language and environment for statistical computing. Regression analysis, correlation analysis, and analysis of variance were performed by fitting general linear models, with the use of type III sums of squares for unweighted means. The separation of means was computed by using the Honest Significant Difference (HSD) of Tukey ($\alpha = 0.05$), available in the *Agricolae* library.

Results and discussion

Physical analysis

The characteristic shape of the coffee beans from Chiapas was the flat bean, with an average percentage of 87.1 ± 5.8 (mean ± sd), presenting significant difference ($p < 0.05$) between the group of regions formed by Comitán, San Cristóbal, and Yajalón, and the group of regions including Bochil, Mapastepec, and Ocozocoautla, with averages of 84.9 ± 4.4, 85.1 ± 7.4, 85.1 ± 5.7, and 89.3 ± 4.9, 90.9 ± 3.2, 90.6 ± 1.7, respectively. The second shape in importance was the peaberry bean, with an average percentage of 8.7 ± 6.5, presenting significant differences between regions, as shown in Table 1. Triangles represented the third most important shape, with an average percentage of 3.6 ± 2.6. As it can be seen from Table 2, triangles show an inverse relationship ($r = -0.358$) to the content of flat beans. The rest of shapes have a marginal importance, since none of them averaged more than 1% of the coffee beans in the sample. In the present work, coffee cherries were harvested and wet processed taking care of removing any float or immature fruit before the process was carried out; so, the number of total defects in green coffee beans was relatively low, with an average percentage of 32.9 ± 37.4. The high variability was caused by samples from a community in the region of Copainalá, in the low altitude zone (685 masl), which at the time of sampling had already finished harvesting and the samples collected were rescued from a last picking of coffee cherries. These samples presented a total number of defects greater than 300.

None of the 13 regions produced more than 20% of beans smaller than, or equal to, 14/64 inches (Z14), while Comitán, Motozintla, and Palenque produce more than 50% of their bean (58.4 ± 17.3, 52.6 ± 17.6, and 51.8 ± 27.8, respectively) of size greater than, or equal to, 17/64 inches (Z17), thus being classified as large bean. The rest of the regions produce medium-sized beans. Scholz *et al.* (2018) report that differences in bean size are related to environmental factors such as altitude. In the present work, however, the Pearson correlation coefficient for altitude and bean size was $r = 0.0163$, which was not significant ($p > 0.05$) to state that these two variables were related to each other.

Chemical analysis

Retention times for caffeine, trigonelline, and 5-CQA were: 1.08, 0.33, and 1.00 min, respectively, coinciding with the times established in the calibration curves of the standards.

Tolessa *et al.* (2017) mentioned that the

Table 1. Percentage of shapes (mean ± sd) and number of defects (mean ± sd) in coffee samples from Chiapas, Mexico.

Region	Flat beans	Peaberries	Triangles	Elephants	Total defects
A. A. Corzo	87.5 ± 6.3[ab]	8.5 ± 6.3[ab]	2.5 ± 1.5[bc]	0.2 ± 0.4[ab]	22.7 ± 13.0[bc]
Bochil	89.3 ± 4.9[a]	7.0 ± 5.4[b]	4.5 ± 4.6[ab]	0.5 ± 0.7[ab]	17.9 ± 22.9[bc]
Comitán	84.9 ± 4.4[b]	9.2 ± 4.0[ab]	4.1 ± 1.8[b]	0.7 ± 0.8[ab]	37.1 ± 21.7[bc]
Copainalá	89.0 ± 5.8[ab]	6.5 ± 3.5[b]	2.5 ± 1.7[bc]	0.6 ± 0.8[ab]	180.2 ± 106.6[a]
Mapastepec	90.9 ± 3.2[a]	6.0 ± 3.0[b]	2.5 ± 0.7[bc]	0.3 ± 0.4[ab]	20.7 ± 12.8[bc]
Motozintla	88.5 ± 3.4[ab]	7.7 ± 2.8[ab]	2.6 ± 1.0[bc]	0.4 ± 0.6[ab]	33.0 ± 25.9[bc]
Ocosingo	86.6 ± 6.6[ab]	7.3 ± 4.9[b]	3.7 ± 2.3[b]	0.9 ± 1.7[a]	31.4 ± 29.3[bc]
Ocozocoautla	90.6 ± 1.7[a]	7.4 ± 1.6[ab]	1.5 ± 0.7[c]	0.2 ± 0.2[ab]	10.6 ± 5.4[c]
Palenque	86.0 ± 2.7[ab]	13.1 ± 10.6[a]	4.7 ± 3.4[ab]	1.1 ± 1.4[a]	37.9 ± 39.1[bc]
Pichucalco	86.0 ± 4.7[ab]	9.7 ± 5.7[ab]	3.6 ± 1.6[bc]	0.2 ± 0.3[ab]	44.8 ± 48.9[b]
San Cristóbal	85.1 ± 7.4[b]	12.6 ± 10.6[a]	4.4 ± 3.0[b]	0.8 ± 1.0[ab]	34.8 ± 32.4[bc]
Tapachula	88.4 ± 6.2[ab]	6.8 ± 7.2[b]	3.2 ± 1.5[bc]	0.1 ± 0.3[ab]	29.1 ± 15.0[bc]
Yajalón	85.0 ± 5.7[b]	10.1 ± 6.7[ab]	6.0 ± 3.1[a]	0.6 ± 0.7[ab]	43.1 ± 43.3[b]

*Means with different letters in the same column are statistically different (α = 0.05).

caffeine content in green beans may be associated with the altitude (masl) of the plantations. Although in the present work, the relationship was significant ($p < 0.05$), it was of low impact (β_1 = -0.0002), where for every 100 m increase in the altitude, the content in percentage of caffeine was reduced by 0.02. The trigonelline content was not significantly ($p > 0.05$) influenced by altitude, while the content of chlorogenic acid (5-CQA) was positively (β_1 = 0.0006), influenced by the altitude from which each sample came from. Considering that traditionally the quality of coffee is associated with the altitude of plantations, it is not a surprise that in the analysis of correlations (Table 2), the cup quality attributes were inversely related with the content of caffeine and trigonelline, while the chlorogenic acid had a positive influence on those parameters, particularly on the acidity of the beverage.

The caffeine content in samples from Chiapas was generally higher than the normal range (0.8 - 1.3%) reported for this analyte in *C. arabica*, with an average percentage of 1.7 ± 0.5, with significant differences ($p < 0.05$) between regions, as shown in Table 3. The average content of trigonelline in the analysed samples (1.2 ± 0.3) was within the range reported by Sridevi and Giridhar (2013) for

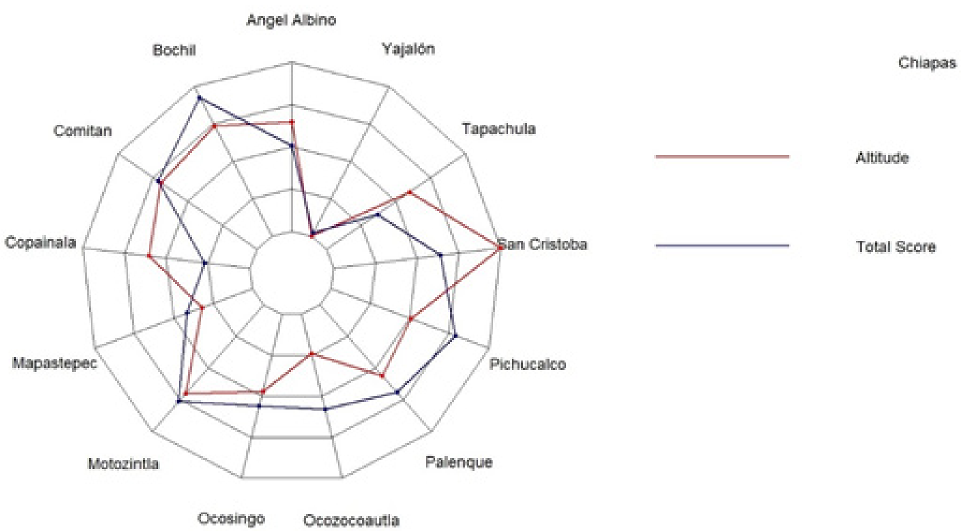

Figure 1. Average altitude and total score of coffee brews by region in the state of Chiapas, Mexico.

Table 2. Pearson's correlation coefficients between physical, sensory, and chemical parameters of coffee from Chiapas, Mexico.

Parameter	Altitude	Physical										Sensory								Chemical		
		Moisture (%)	Large (%)	Medium (%)	Small (%)	TotDef (Num)	FlatBean (%)	Triangular (%)	Elephant (%)	Peabean (%)	Shell (%)	Aroma	Flavor	Aftertaste	Acidity	Body	Balance	Overall	Total Score	Caffeine	Trigonelline	5CQA
Altitude	1	-0.28*	-0.02	0.02	0.01	0.01	-0.10	0.07	0.02	0.13	0.05	-0.01	0.12	0.13	0.2	0.07	0.18	0.18	0.21**	-0.12	0.06	0.14
Moisture (%)	-0.28*	1	0.11	-0.08	-0.12	0.06	0.01	0.10	0.13	0.10	0.04	0.06	0.10	0.10	0.24**	-0.02	0.18	0.10	0.25**	0.15	0.11	0.33**
Large (%)	-0.02	0.11	1	-0.94*	-0.75*	0.04	-0.08	0.16	0.17	0.04	0.16	-0.08	-0.06	-0.09	0.06	-0.11	-0.04	-0.05	-0.00	-0.03	0.03	0.06
Medium (%)	0.02	-0.08	-0.94*	1	0.47**	-0.06	0.20**	-0.16	-0.19	-0.14	-0.17	0.10	0.09	0.12	-0.07	0.13	0.05	0.06	0.01	0.04	-0.02	-0.04
Small (%)	0.01	-0.12	-0.75*	0.47**	1	0.01	-0.18	-0.10	-0.07	0.17	-0.07	-0.00	-0.01	0.01	-0.02	0.03	0.01	0.02	-0.01	-0.01	-0.03	-0.08
TotDef (Num)	0.01	0.06	0.04	-0.06	0.01	1	-0.26*	0.29**	0.24**	0.22**	0.22**	-0.14	-0.16	-0.13	0.02	-0.18	-0.10	-0.11	-0.02	0.07	0.14	0.11
FlatBean (%)	-0.10	0.01	-0.08	0.20**	-0.18	-0.26*	1	-0.36*	-0.38*	-0.73*	-0.29*	0.10	0.04	0.03	-0.13	0.11	-0.03	0.01	-0.09	-0.01	-0.06	-0.07
Triangular (%)	0.07	0.10	0.16	-0.16	-0.10	0.29**	-0.36*	1	0.42**	0.23**	0.32**	-0.36*	-0.29*	-0.23*	0.05	-0.34*	-0.16	-0.22*	-0.04	0.01	0.17	0.08
Elephant (%)	0.02	0.13	0.17	-0.19	-0.07	0.24**	-0.38*	0.42**	1	0.13	0.46**	-0.12	-0.12	-0.07	0.09	-0.13	-0.03	-0.07	0.03	0.15	0.24**	0.18
Peabean (%)	0.13	0.10	0.04	-0.14	0.17	0.22**	-0.73*	0.23**	0.13	1	0.09	-0.26*	-0.17	-0.12	0.11	-0.28*	-0.07	-0.12	0.05	0.07	0.19	0.14
Shell (%)	0.05	0.04	0.16	-0.17	-0.07	0.22**	-0.29*	0.32**	0.46**	0.09	1	-0.13	-0.10	-0.08	0.04	-0.07	-0.04	-0.07	0.00	0.04	0.10	0.11
Aroma	-0.01	0.06	-0.08	0.10	-0.00	-0.14	0.10	-0.36*	-0.12	-0.26*	-0.13	1	0.64**	0.57**	0.28**	0.51**	0.50**	0.60**	0.47**	-0.06	-0.26*	-0.03
Flavor	0.12	0.10	-0.06	0.09	-0.01	-0.16	0.04	-0.29*	-0.12	-0.17	-0.10	0.64**	1	0.82**	0.55**	0.65**	0.78**	0.86**	0.78**	-0.08	-0.25*	0.02
Aftertaste	0.13	0.10	-0.09	0.12	0.01	-0.13	0.03	-0.23*	-0.07	-0.12	-0.08	0.57**	0.82**	1	0.52**	0.61**	0.75**	0.81**	0.75**	-0.08	-0.22*	0.04
Acidity	0.20	0.24**	0.06	-0.07	-0.02	0.02	-0.13	0.05	0.09	0.11	0.04	0.28**	0.55**	0.52**	1	0.25**	0.75**	0.70**	0.90**	-0.04	-0.07	0.22**
Body	0.07	-0.02	-0.11	0.13	0.03	-0.18	0.11	-0.34*	-0.13	-0.28*	-0.07	0.51**	0.65**	0.61**	0.25**	1	0.55**	0.60**	0.47**	-0.10	-0.37*	-0.11
Balance	0.18	0.18	-0.04	0.05	0.01	-0.10	-0.03	-0.16	-0.03	-0.07	-0.04	0.50**	0.78**	0.75**	0.75**	0.55**	1	0.85**	0.88**	-0.11	-0.21*	0.12
Overall	0.18	0.10	-0.05	0.06	0.02	-0.11	0.01	-0.22*	-0.07	-0.12	-0.07	0.60**	0.86**	0.81**	0.70**	0.60**	0.85**	1	0.88**	-0.14	-0.26*	0.07
Total Score	0.21**	0.25**	-0.00	0.01	-0.01	-0.02	-0.09	-0.04	0.03	0.05	0.00	0.47**	0.78**	0.75**	0.90**	0.47**	0.88**	0.88**	1	-0.08	-0.12	0.18
Caffeine	-0.12	0.15	-0.03	0.04	-0.01	0.07	-0.01	0.01	0.15	0.07	0.04	-0.06	-0.08	-0.08	-0.04	-0.10	-0.11	-0.14	-0.08	1	0.45**	0.37**
Trigonelline	0.06	0.11	0.03	-0.02	-0.03	0.14	-0.06	0.17	0.24**	0.19	0.10	-0.26*	-0.25*	-0.22*	-0.07	-0.37*	-0.21*	-0.26*	-0.12	0.45**	1	0.55**
5CQA	0.14	0.33**	0.06	-0.04	-0.08	0.11	-0.07	0.08	0.18	0.14	0.11	-0.03	0.02	0.04	0.22**	-0.11	0.12	0.07	0.18	0.37**	0.55**	1

* = Negative correlation coefficients lower than -0.20. All of them significant at $\alpha = 0.05$. ** = Positive correlation coefficients greater than 0.20. All of them significant at $\alpha = 0.05$.

Table 3. Altitude of plantations (mean ± sd) and relative percentage (mean ± sd) of main metabolites analysed in coffee samples.

Region	Altitude (masl)	Caffeine (%)	Trigonelline (%)	5-CQA (%)
A. A. Corzo	1173 ± 275	1.14 ± 0.36^{c}	0.94 ± 0.21^{e}	3.87 ± 1.02^{cd}
Bochil	1215 ± 231	1.65 ± 0.36^{ab}	1.19 ± 0.31^{abcd}	4.33 ± 0.63^{abc}
Comitán	1195 ± 208	1.35 ± 0.46^{bc}	1.12 ± 0.26^{cde}	4.88 ± 1.20^{ab}
Copainalá	1151 ± 372	1.98 ± 0.16^{a}	1.47 ± 0.15^{a}	5.68 ± 0.39^{a}
Mapastepec	1015 ± 257	1.9 ± 0.24^{a}	1.20 ± 0.15^{abcd}	3.82 ± 0.74^{cd}
Motozintla	1198 ± 343	1.87 ± 0.42^{a}	1.04 ± 0.18^{de}	3.46 ± 0.76^{d}
Ocosingo	1087 ± 246	1.71 ± 0.60^{ab}	1.26 ± 0.21^{abc}	4.14 ± 1.34^{c}
Ocozocoautla	975 ± 91	1.81 ± 0.42^{a}	1.14 ± 0.13^{bcde}	4.29 ± 0.95^{bc}
Palenque	1129 ± 187	1.78 ± 0.45^{ab}	1.15 ± 0.41^{abcde}	3.91 ± 1.30^{cd}
Pichucalco	1105 ± 46	1.76 ± 0.19^{ab}	0.99 ± 0.06^{de}	3.66 ± 0.71^{cd}
San Cristobal	1341 ± 284	1.64 ± 0.37^{ab}	1.30 ± 0.31^{ab}	3.84 ± 1.26^{cd}
Tapachula	1149 ± 415	1.98 ± 0.50^{a}	1.20 ± 0.32^{abcd}	4.12 ± 1.22^{cd}
Yajalón	860 ± 228	1.65 ± 0.44^{ab}	1.04 ± 0.35^{de}	3.20 ± 1.20^{d}

* Means with different letters in the same column are statistically different ($\alpha = 0.05$).

C. canephora. The concentration of chlorogenic acid (5-CQA) was maintained in the range of 3 - 5%, with an average content of (4.0 ± 1.2). Such value is within the range reported as normal for this analyte by Cheng *et al.* (2016).

Sensory analysis

As observed in the chemical analysis, altitude significantly influenced the content of caffeine and chlorogenic acid in the coffee beans. Here, it was verified, by means of regression analysis (Eq. 1), that for every 100 m increase in altitude, the total score in the sensory analysis increased by 0.32 points ($\beta_1 = 0.0032$).

*Total Score = 78.4492 + 0.0032*Altitude (masl)* (Eq. 1)

The fact that an increase in the altitude also increases the chlorogenic acid and the total score (Figure 1) does not necessarily imply that the chlorogenic acid is solely responsible for improving the sensory attributes of the beverage, even though its correlation with the score of acidity was significant ($p < 0.01$). Beverages with higher acidity are very likely to reach higher final scores as well, as acidity is the most influential ($r = 0.90$) quality attribute to the total score of a cup of coffee. Sensory attributes are highly correlated between them, showing that if a sample scores high in a particular attribute, it is likely to score high in the rest of attributes as well, however, no all attributes have the same relevance. To the taster's overall appreciation, flavour ($r = 0.86$), aftertaste ($r = 0.81$), and balance ($r = 0.85$) were found to be more important; meanwhile to the total score, the more influential attributes were acidity ($r = 0.90$), balance ($r = 0.88$), and the overall appreciation ($r = 0.88$).

Several authors have tried to relate the chemical composition of the coffee beans with the cup quality attributes, but without conclusive findings. Farah (2012) points out that the taste of high-quality coffee can vary considerably between samples of the same species and variety grown in different areas, because chemical compounds can cause considerable changes in the sensory attributes of the beverage. For Sunarharum *et al.* (2014), coffee flavour is extremely complex and arises from numerous chemical, biological, and physical influences of the cultivar; the maturity of the coffee cherry, geographical origin, production, post-harvest processing, roasting, and brewing. Meanwhile, Liu *et al.* (2019) reported that aroma in coffee is directly related to the chemical composition of green beans.

Coffee from Chiapas can be considered as specialty coffee, 11 out of the 13 coffee regions produced samples with at least 80 points in the SCA scale, excelling in average score Bochil (84.6 ± 3.9), which presents significant differences ($p > 0.05$) with Copainalá (79.9 ± 2.9), Tapachula (80.6 ± 3.3), and Yajalón (78.2 ± 5.0). Puerta-Quintero (2016) reports that the quality of the coffee beverage is influenced by the physical characteristics of the beans, including moisture and the number of defects. In the present work, a positive and significant correlation (r = 0.2504) between the moisture content in the beans and the total score of the beverage was found.

Conclusion

The 13 coffee regions in the state of Chiapas present significant differences between them on physical and chemical variables of the green coffee beans, as well as significant differences on sensory attributes of the beverage. The lowest number of total defects and the highest total score in the coffee brew was obtained by Bochil, while Yajalón achieved the highest concentration of caffeine in green coffee beans and the lowest total score. There was a positive and significant correlation (r = 0.2148) between altitude and the total score; as well as a positive and significant correlation (r = 0.3335) between moisture and 5-CQA in green coffee beans. Coffee beans with high content of 5-CQA also scored higher in acidity. 11 out of the 13 coffee regions scored in average 80 points or higher, highlighting the importance of Chiapas as a provider of excellent quality coffee.

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