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Effect of physical characteristics of coffee grain (*Coffea arabica* L.) cultivated in Temascaltepec, state of Mexico, on the roasting process

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Abstract

The Finca the Illusion produces coffee that earned second place in the 2018 and fourth place in the 2019 and 2021 "Cup of Excellence Mexico" competitions (represented by technician Federico Barrueta). Due to the scarce physicochemical and organoleptic information on coffee from the southern region of the State of Mexico, the objective of this study was to evaluate the physical and sensory characteristics of coffee (*Coffea arabica* L. var. Caturra Rojo) grown at Finca the Illusion in Temascaltepec, State of Mexico. A completely randomized design was established with two treatments (Finca the Illusion and Finca Soconusco) and three repetitions (350 g each). The variables analyzed in the coffee were defects, percentage of defect-free grain, density, moisture, water activity, and sensory evaluation of the beverage. At Finca the Illusion, the main defect was fungal damage, which can be prevented with proper practices during the collection of coffee cherry and classification of green coffee. The moisture (10.1%), density (0.69 kg/L), and water activity value (0.51) were within the optimal range. The roasting was medium-light, and the cupping score was 86, corresponding to an Excellent Specialty Origin coffee.

Keywords: beverage; sensory attributes, physical defects.

Practical Application: defects, density, moisture, water activity, and sensory attributes of coffee.

1 INTRODUCTION

Coffee (*Coffea arabica* L.) is a beverage of worldwide importance cultivated in over 70 countries, with notable production in Brazil, Vietnam, Colombia, Indonesia, and Ethiopia. Mexico is the 11th largest coffee producer. Fifteen states produce the vast majority of Mexican coffee, the top four of which are Chiapas (34%), Veracruz (30%), Puebla (12%), and Oaxaca (11%). The State of Mexico has the 11th largest area of coffee production (539 hectares) (Jáuregui-Arenas et al., 2017; Leguizamo Sotelo, 2023; Leguizamo Sotelo et al., 2023a, 2023b; SIAP, 2020, 2022). Coffee is grown in the southern region of Mexico State, in the municipalities of Almoloya de Alquisiras, Amatepec, Malinalco, Ocuilan, San Simon de Guerrero, Sultepec, Tejupilco, Temascaltepec, and Tlatlaya, under a rustic or mountainous production system (Leguizamo Sotelo, 2023).

In Temascaltepec, coffee crops cover 51 hectares. This municipality contains the locality of San Andres de los Gama, where the Finca the Illusion (trademark cafe Carmesi) is located, which grows mainly Caturra Rojo (a low-growing shrub with wide adaptability to altitude, based in ICAFE, 2011, and International Trade Center, 2022), Bourbon, and Typica varieties. The legal representative is technician Federico Barrueta, who has participated in the sixth, seventh, and eighth "Cup of Excellence Mexico" competitions during 2018, 2019, and 2021 obtaining a score of 90.47 in 2018 (second place winner) and 90.13 in 2019 and 2021 (fourth place in both years). These results reflect the crop's potential as specialty coffee (Juárez González et al., 2021).

Specialty coffee is characterized by preserving both the physical attributes of the grain (shape, size, moisture, and appearance) and the sensory qualities of the beverage (olfactory, visual, and gustatory) (Escamilla Prado & Landeros Sánchez, 2016; Martínez-López et al., 2018). These qualities can be degraded during coffee processing (harvesting, drying, and threshing). The objective of this study was to evaluate the physical and sensory characteristics of coffee (*Coffea arabica* L. var. Caturra Rojo) cultivated in Temascaltepec, State of Mexico, Mexico.

2 MATERIALS AND METHODS

2.1 Description of study site

The municipality of Temascaltepec is located in the southern region of the State of Mexico, covering an area of 547.5 km², representing 2.5% of the state's territory. The altitude ranges from 1,200 to 3,600 m. The temperature ranges between 6 and 24°C, and the precipitation ranges between 1300 and 2,000 mm. The predominant climate is subhumid temperate with summer rains. The vegetation types present in the municipality include *Abies forest, Abies-Alnus, Abies-Pinus, Pinus, Pinus-Abies, Pinus-Quercus, Quercus*, cloud forest, tropical deciduous forest, and induced grassland. In order of importance, the soil types

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are Andosol, Feozem, Cambisol, Regosol, Litosol, and Luvisol (INEGI, 2010; Rojas-Zenteno et al., 2016).

The locality of San Andres de los Gama, which is a coffee-producing area, is situated in the southern part of the municipality of Temascaltepec, at the geographic coordinates 99º 58' 26" N and 19º 02' 14" W and at an altitude of 2,100 m (Figure 1). The vegetation primarily consists of *Quercus* forest (INEGI, 2010).

2.2 Obtainment of plant material

In this study, a completely randomized experimental design was established with two treatments. For Treatment I: from Finca the Illusion, ripe cherry coffee fruits *Coffea arabica* L. var. Caturra Rojo were harvested and then processed using the dry processing method (transformation of cherry coffee into green coffee). A total of 1,050 g of green coffee was obtained, and the quartering method was used to obtain three samples of 350 g each, based on the Specialty Coffee Association (SCA) guidelines (2019). For Treatment II: at Finca Soconusco, Cacahoatan, Chiapas, Mexico, the owner provided 1,500 g of green coffee (*C. arabica* var. Caturra Rojo) that had been processed using the dry method. The sample was divided into three replicates of 350 g using the quartering method (leftover material was discarded). Although the total amount of green coffee obtained from Finca the Illusion was lower than the material obtained from Finca Soconusco (due to the limited amount of plant material at Finca the Illusion), the quantity obtained met the requirements set by the SCA (2019) for conducting analyses related to physical defects of the grain and sensory analysis. The Finca Soconusco coffee was used as a comparative reference against Finca the Illusion coffee.

2.3 Physical analysis

The green coffee grains from Finca the Illusion and Finca Soconusco were visually inspected to identify defects based on SCA criteria (2019). They were manually classified into category 1 defects (counted as the number of grains with defects) (fungus damage, black grain, dried cherry, and foreign matter) and category 2 defects (counted as equivalents) (partial black grain and partial sour grain, where three grains equal one complete defect; "averanado" or wrinkled, husk, shell, immature, split/bitten/cut, for which five grains correspond to one complete defect; and slightly damaged by insects, where 10 damaged grains equal 1 complete defect). The percentage of grain weight without defect was obtained.

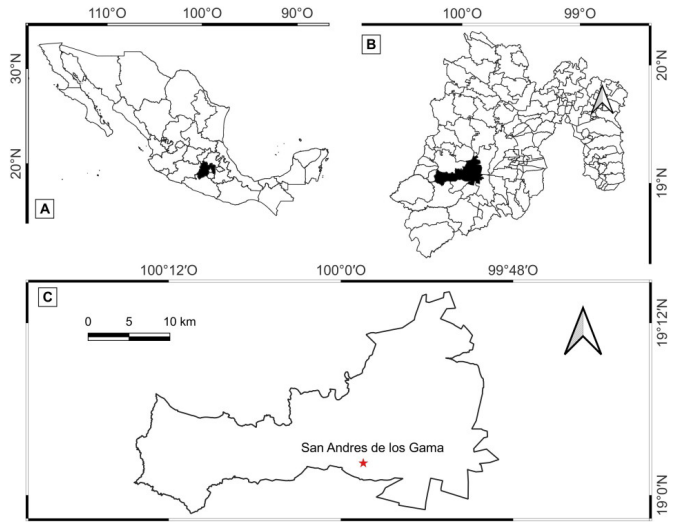

Figure 1. The geographic location of the State of Mexico (A), the municipality of Temascaltepec (B), and the locality San Andres de los Gama (C).

For each of the treatments, we quantified coffee grain density by adding defect-free coffee grains to a 100-mL graduated cylinder by free fall until the contents of the cylinder were leveled, weighed, and converted from g/100 mL to kg/L (i.e., "freely settled density"). The percentage humidity was obtained using an AgraTronix model 08150 hygrometer. The a_w value (water activity) was measured using a portable water activity analyzer (Rotronic model HygroPalm 23-AW-A).

2.4 Statistical analysis

The data for defects, density, moisture, and a_w were compared between the two treatments as means using ANOVA ($P \leq 0.05$) in the program STATGRAPHICS Centurion v15.1.0. Mean comparisons were conducted using the Tukey test at the 5% significance level.

2.5 Roasting and sensory analysis

The coffee was roasted with a 100MEX® brand roaster model AZTK-2.5K-AD, following a medium-light roasting curve (internal temperatures ranging from 180 to 190°C). Subsequently, the coffee beverage was evaluated through cupping, following the SCA (2003) cupping protocol, with a certified Q Arabica Grader taster who identified notes for aroma and taste attributes. The sensory attributes were evaluated and scored on a scale of 0–10 points, including fragrance/aroma, taste, residual taste, acidity, body, balance, uniformity, clean cup, sweetness, and taster's score. The overall sample was evaluated on a scale of 0–100 points by summing the score for each attribute.

3 RESULTS AND DISCUSSION

The coffee from both Finca the Illusion and Finca Soconusco presented category 1 and 2 defects. The presence of physical defects causes a reduction in the volume of production and consequently decreases economic profitability. The results of the physical analysis of the coffee (Table 1) showed that the coffee from Finca the Illusion had only one defect falling within category 1: fungus-damaged grains (46.3 ± 8.9) (Figure 2), a number higher than obtained for Finca Soconusco (37.3 ± 8.5). However, both treatments exceeded the number of defects allowed by the SCA (2019). To reduce fungal damage to coffee grains, it is necessary to carry out an adequate selection process in which damaged grains are eliminated with greater precision (Bobadilla Peña, 2018). It is worth mentioning that some producers tend to avoid proper selection, considering it a loss of coffee, and prioritize quantity over quality.

Table 1. Defects in coffee grains from the Fincas the Illusion and Soconusco (mean ± standard deviation).

	Finca the Illusion	Finca Soconusco
Number of defect-free grains	1,441.0 ± 86.7 b	1,997.3 ± 49.9 a
Defect-free grains (%)	58.45 ± 1.75b	86.57 ± 1.30 a
Category 1 defects (total number of grains)		
Fungus damage	46.3a	37.3 ± 8.5 a
Black grain	0 ± 0 a	1 ± 1 a
Dried cherry	0 ± 0 b	6.3 ± 2.8 a
Foreign matter	0 ± 0 a	0.6 ± 1.1 a
Category 2 defects (equivalents)		
Partial black grain	0 ± 0 a	0.6 ± 0.5 a
Partial sour grain	22.3 ± 14.3 a	11.6 ± 4.6 a
Immature	9 ± 6.5 a	12 ± 3.4 a
"Averanado" or wrinkled	49.3a	9a
Shell	44a	1b
Split/bitten/cut	71a	33.6b
Husk	3b	14a
Slightly damaged by insects	3.6 ± 1.5 a	2.6 ± 0.5 a

Different letters (a, b) indicate statistically significant differences in the Tukey test ($P \leq 0.05$).

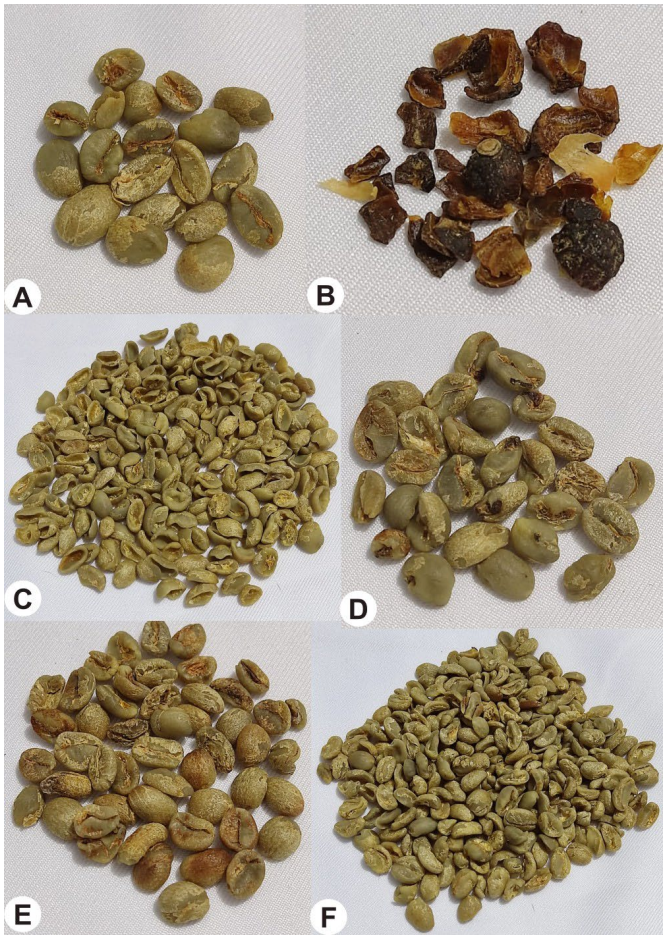

Figure 2. Defects in coffee grains: (A) partial sour grain, (B) husk, (C) shell, (D) slightly damaged by insects, (E) fungus damage, and (F) split/bitten/cut.

In category 2, the following defects were found: partial sour grain, immature, "averanado" or wrinkled, shell, split/bitten/cut, husk, and slightly damaged by insects (Table 1, Figure 2). There was no significant difference between the Fincas the Illusion and Soconusco regarding the partial sour defect. It is advisable to avoid harvesting excessively ripe cherries to avoid producing a beverage with a sour or fermented taste (Córdoba Meza & Araujo Urbano, 2020; SCA, 2019).

There was no significant difference between treatments for the immature grain defect (Table 1). However, the presence of this defect can be attributed to the picking of immature red cherries (Osorio, 2021), highlighting the importance of removing them during screening, either using a color sorter or based on density. Additionally, it is crucial to consider the spectrum of grain ripeness (green or immature, ripe, and overripe) in coffee cherries to recognize the appropriate harvesting time and ensure that only mature fruits are picked (SCA, 2019).

Finca the Illusion had a higher quantity of wrinkled grains (49.3 ± 30.3) compared with Finca Soconusco (9 ± 0), although the difference was not statistically significant. It is important to note that Finca the Illusion experienced a dry season during grain development, which did not occur at Finca Soconusco.

Floating (removing grains that float in a container of water) is recommended to remove withered grains (SCA, 2019). Additionally, this defect can be prevented through proper fertilization and nutrition of coffee plants, as healthy plants are less affected by drought conditions (Louzada Pereira & Rizzo Moreira, 2021; Osorio, 2021).

For the shell defect, Finca the Illusion had a significantly higher number of shells (44 ± 5.2), than Finca Soconusco (1 ± 1). The occurrence of shells is a natural phenomenon influenced by genetics (Louzada Pereira & Rizzo Moreira, 2021), and shells can be removed using a density classifier. To minimize this defect, it is essential to select coffee varieties that are most suitable for the region (SCA, 2019).

For the split/bitten/cut defect, there was a significant difference between Finca the Illusion (71 ± 9.6) and Finca Soconusco (33.6 ± 12.5). This defect originates during the dry milling process due to excessive friction or pressure on grains (Osorio, 2021). To reduce this defect, it is crucial to adjust the pulping machine correctly to prevent excessive friction on the grains. Additionally, the grains with this defect can be eliminated using a density classifier or through screening machines (SCA, 2019).

In the husk defect, Finca the Illusion had a significantly lower quantity than Finca Soconusco, with 3 ± 2.6 and 14 ± 4.3, respectively. Husk is present in coffee that has not been properly cleaned, usually due to improper calibration of the cherry coffee pulping machine (Bobadilla Peña, 2018). Proper calibration of the pulping machine is essential to prevent the presence of husk in green grain (SCA, 2019).

In the slightly damaged by insect defect, there was no statistically significant difference between Finca the Illusion (3.6 ± 1.5) and Finca Soconusco (2.6 ± 0.5). This defect affects the appearance of the coffee bean, making it necessary to implement cultural, biological, or chemical control to manage or prevent

the presence of insects on the fruits. It is worth mentioning that in Mexico, there are approximately 27 species of insects and two mites of economic importance to coffee cultivation (Barrera et al., 2008).

At Finca the Illusion, there were no black grain or partial black grain defects, which was not significantly different from Finca Soconusco, where the presence of a black grain and a partial black grain were recorded. The occurrence of these defects can be avoided by harvesting only ripe fruits from the coffee plants (Duicela Guambi et al., 2004). Additionally, black grains can be manually or mechanically removed using a sorting machine (SCA, 2019).

The dried cherries defect was not recorded at Finca the Illusion, which occurred at Finca Soconusco. Diseases and lack of water can cause the fruit to dry on the plant and eventually fall. It is necessary to avoid picking dried cherries directly from the ground, eliminate floating grains during reception, and properly calibrate the hulling machine (Bobadilla Peña, 2018; SCA, 2019).

There was no statistically significant difference between the two fincas for the foreign matter defect, which causes a bad taste in coffee, affects the appearance of green coffee, damages roasting equipment, and can pose health problems for consumers (Bobadilla Peña, 2018). The presence of foreign matter can be prevented through careful attention during cherry picking, drying, and dry milling. Stone eliminators and magnets can be used to remove foreign matter (SCA, 2019).

Finca the Illusion had 58.45% of defect-free grains, which was significantly lower than Finca Soconusco (86.57%). This reflects a better physical quality of coffee grains from the Finca Soconusco, which had a percentage of defect-free grains similar to the Colombian national average for clean grains (defect-free green coffee) of 74% (Osorio 2021). The importance of defect-free coffee lies in the fact that fewer kilograms of green coffee are required to produce a bag of specialty coffee, and a higher percentage of clean grains results in a higher price in coffee trading (FNC, 2024).

The coffee from Finca the Illusion and Finca Soconusco exhibited a moisture content of 10% (with no statistically significant difference between them), placing both within the range of 10–12% stipulated by the SCA (2019), Finca the Illusion with 10.1 and Finca Soconusco with 10.03. The moisture content demonstrates the quality and good practices in drying and storing coffee grains, which prevents deterioration and fungal contamination, thus enhancing the sensory characteristics of the coffee. It is crucial to maintain this moisture percentage, as a 1% loss of moisture represents a 1% reduction in coffee weight. Furthermore, moisture content below 10% compromises the coffee quality and results in the loss of taste notes during cupping (Castillo, 2021).

At Finca the Illusion, the coffee bean density was 0.69 kg/L, which did not differ significantly from Finca Soconusco (0.70 kg/L). Denser grains are characterized by higher sugar levels, resulting in favorable sensory characteristics in the cup (Hurtado Nader, 2022). They require more energy during roasting and exhibit greater resistance than low-density grains, which are more fragile (Fürst, 2021).

The water activity at Finca the Illusion was 0.51, which was significantly higher than Finca Soconusco, which had a water activity of 0.48. These results indicate that at both sites, the coffee beans are stable against deterioration by microorganisms, which can grow at a minimum water activity value of 0.6, as reported by Juárez González et al. (2021).

At Finca the Illusion, the roasting time was longer (10 min 22 s) and had a lower development factor (12.9%), indicating a higher roast level compared with Finca Soconusco, which had a roasting time of 9 min 45 s. These parameters favor the coffee's sensory characteristics. Additionally, for coffee from Finca the Illusion, the Maillard reaction started at 5 min 08 s, indicating that the coffee underwent flavor development earlier during roasting. In the coffee of the Finca Soconusco, the first crack occurred earlier (8 min 25 s) than in Finca the Illusion (9 min 02 s), indicating a lighter roast in the coffee of Finca Soconusco, which influences the acidity of the coffee (Table 2).

At Finca the Illusion, the taster assigned a score of 8 to most of the coffee attributes, except for uniformity, clean cup, and sweetness, which received a score of 10 points (Table 3).

Table 2. Roast profile characteristics of coffee from Finca the Illusion and Finca Soconusco.

Variable	Finca the Illusion	Finca Soconusco
Roasting time (min)	00:10:22	00:09:45
Background temperature at the start of roasting (°C)	112.9	112.6
Drying temperature (°C)	104.2	104.2
Time to Maillard reaction (min)	00:05:08	00:05:17
Maillard reaction temperature (°C)	154.2	163.3
Time to first crack (min)	00:09:02	00:08:25
Temperature at the first crack (°C)	182.8	185.9
Time of development (min)	00:01:20	00:01:20
Final temperature (°C)	186.6	187.9
Development factor (%)	12.9	13.7

Table 3. Sensory evaluation of coffee from Fincas the Illusion and Soconusco by tasting by a Q Arabica Grader.

Attribute	Finca the Illusion	Finca Soconusco
Aroma notes	Floral and yellow fruits	Sweet, floral, light notes of wood
Taste notes	Brown sugar and dark chocolate	Citrusy fruit, light dry wood
Fragance/aroma	8.0	7.5
Taste	8.0	8.0
Residual taste	8.0	8.0
Acidity	8.0	8.0
Body	8.0	7.5
Balance	8.0	7.5
Uniformity	10	10
Clean cup	10	10
Sweetness	10	10
Taster's score	8.0	7.5
Total	86	84

The taster described the coffee with notes of floral fragrance and yellow fruit, taste of brown sugar and dark chocolate, medium-low citric acidity, and a dense creamy medium-high body. The coffee maintained balance when cold, with improved sweetness and body. This indicates a better selection of coffee grains and a slightly higher roast compared with the coffee from the Finca Soconusco, where the score was 10.0 for uniformity, clean cup, and sweetness; 7.5 for fragrance/aroma, body, balance, and overall; and 8.0 for the remaining attributes. At Finca Soconusco, the taster described the coffee with sweet, floral, and light woody notes; medium citric acidity, juicy, slightly cutting or sharp at the end when cold; citrusy fruity taste, light dry wood; silky medium body with a slight roughness at the end when cold; it loses balance when cold, becoming dry and rough in aftertaste and mouthfeel. The sensory analysis suggests that at Finca Soconusco, appropriate grain selection is necessary, especially with respect to secondary defects such as shells, to enhance the sensory quality of the coffee.

The coffee from the Finca Soconusco is categorized as "Very Good (Special)" and the coffee from Finca the Illusion is rated as "Excellent (Special Origin)" based on the total score quality classification established in the SCA cupping protocol (2003). This demonstrates the care for coffee plants and the attention given during the grain processing, especially at Finca the Illusion.

4 CONCLUSIONS

It is advisable to further improve the dry processing method and grain selection to reduce the number of defective grains, especially fungal damage (category 1), wrinkled, shell, and split/bitten/cut (category 2). Increasing the percentage of defect-free grains will lead to higher yields and better quality.

At Finca the Illusion, the moisture content is within the acceptable range ($\geq 10\%$ and $\leq 12\%$). The water activity value of coffee grains (0.51) is ideal because it is below the value of 0.6 (which would favor the growth of microorganisms). This reflects an efficient drying process of coffee grains, preventing the presence of fungi that produce mycotoxins that can cause economic losses for producers and health risks for consumers.

The coffees from Finca the Illusion and Finca Soconusco are characterized by exceptional quality in uniformity, clean cup, and sweetness. The coffee from Finca Soconusco exhibits excellent quality in taste, residual taste, and acidity and is considered very good in terms of fragrance/aroma, body, balance, and overall score. On the contrary, the coffee from Finca the Illusion displayed more sensory attributes of excellent quality (fragrance/aroma, taste, residual taste, acidity, body, balance, and taster's score) showcasing the potential of the coffee and contributing to increasing its price and enhancing the marketing for both green and roasted grains.

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