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# Physical and sensorial quality of yellow caturra coffee after a carbonic maceration process

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## ABSTRACT

High prices for differentiated coffees with unique flavor profiles have spurred research into processing methods to standardize coffee production and improve quality. Fermentation is a biotechnological tool that may enhance the sensory profile of coffee and boost its overall quality. Carbonic maceration, which uses constant pressure $CO_2$, can be used as a technique to differentiate coffees. In this study, the physical and sensorial qualities of *Coffea arabica* (yellow caturra variety) beans, following carbonic maceration, were assessed. The experiment was carried out during the harvest 2021/22 at La Joya farm. Data were analyzed for both the physical quality of the green coffee beans and the cup quality (sensorial) based on the fermentation process and duration using ANOVA, Friedman and U Mann-Whitney tests, with a significance level of alpha = 0.05. All analyses were conducted using SPSS software version 25. The final score was influenced by both carbonic maceration and the duration of fermentation, with scores for zero-day compositions being lower than those for 5, 10 and 15 days. A significant difference in primary defects, based on the duration of fermentation, was observed. In conclusion, carbonic maceration improved both coffee qualities at day 5 compared to day zero (natural process). However, the physical quality is negatively affected after 10 and 15 days, while the sensory quality increases respectively.

**Key words:** Fermentation; Temperatura; Pressure; Carbon dioxide; Time; Quality.

## 1 INTRODUCTION

The increase in the consumption of differentiated coffees, with unique flavor profiles, has driven scientific research into empirical processing methods that allow standardization to produce high quality coffees. In Mexico, typica, bourbon, red caturra, mundo novo, garnica and yellow caturra varieties are mainly cultivated (Escamilla et al., 2005; Hernández-Solabac et al., 2011; López-García et al., 2016).

The factors that determine the cup quality of coffee are: i) the variety of the coffee plant (Babova; Occhipinti; Maffei, 2016), ii) the geographical location of the farm (Suárez et al., 2015; Giraudo et al., 2019), iii) the climatological conditions of the region (León, 2000; Pohlan; Janssens, 2010; Van Der Vossen; Bertrand; Charrier, 2015), iv) the farm management (Suárez et al., 2015; Scholer, 2018; Muñoz-Belacazar et al., 2021) and v) the type of fruit processing (Batista; Chalfoun, 2014; Pereira et al., 2018).

Assuming that the first four factors have been optimized, the way in which the coffee fruit is processed after harvest could improve the quality of the final product (the beverage). Three post-harvest processing systems are known: i) wet processing (washing/pulping), ii) dry or natural processing and, iii) semi-dry processing (Bee et al., 2005; Pereira et al., 2017). In wet processing, the cherry is pulped (removal of the outer layer) and fermented for 12 to 36 hours, until the mucilage is degraded by the action of microorganisms, while, in natural processing, the cherry is dehydrated directly in the sun until it reaches a humidity of between 10 and 12% (Huch; Franz, 2015). Finally, semi-dry processing is a combination of the first two in which the cherries are pulped, and the coffee beans are dried immediately, without fermentation, being covered by mucilage, obtaining a coffee known as “enmielado” or “honey” (Bee et al., 2005; Huch; Franz, 2015; Pereira et al., 2017).

Fermentation is a biotechnological tool that can modify the sensory profile in the beverage, increasing coffee quality (Silva et al., 2013, 2014; Waters; Arendt; Moroni, 2017; Pereira et al., 2016, 2017, 2018; Wang et al., 2019, 2020), expanding the potential and diversifying the possibilities of processes with different metabolic pathways for the modification of desired cup profiles in a controlled manner. Carbonic maceration, a type of fermentation, has slightly improved beverage quality in *C. canephora* (Gomes et al., 2022). However, for *C. arabica* there is little data, it is practiced empirically as an adaptation from the wine industry, so variants can be found, such as systems with pressure and without constant pressure. The potential of this type of fermentation lies in the fact that some variants could be investigated and implemented by controlling the type of microorganisms inoculated for the fermentation process. In general, these microorganisms could be chosen from a great diversity of yeasts and bacteria, documenting the procedures for the modulation of the sensory profiles of the beverage.

As indicated, carbonic maceration is used in the wine industry, and consists of placing the whole grape fruit in a closed fermentation system, with $CO_2$ injection, causing anaerobic fermentation at a constant pressure. During this process, the grapes begin an intracellular fermentation by means of internal enzymes from microorganisms, which trigger pectolytic and proteolytic phenomena, alcohol production, malic acid degradation, as well as the formation of volatile compounds; with this, the diffusion of phenolic compounds from the exocarp (Flanzy; Flanzy; Bénard, 1995; Tesniere; Flanzy, 2011). These reactions cause the grape to release the must (grape juice) and start an alcoholic fermentation, by the action of yeasts, although a malolactic fermentation by lactic acid bacteria also occurs.

The impact that this process has on the sensory characteristics of the wines produced is an improvement in their quality (color, aroma and sensory profile). The best fermentation conditions and the best wines are produced between 30 and 32 °C, with a process duration of between 5 to 8 days, which can be extended up to 20 days, at low temperatures (15 °C), (Tesniere; Flanzy, 2011; Etaio et al., 2016; Zhang et al., 2019; González-Arenzana et al., 2020). It is these results that have attracted the interest in transferring this technique to the coffee processing industry.

Coffee beans remain metabolically active during the post-harvest process under the conditions to which they are subjected (abiotic stress), such as pulping at the beginning of processing, during fermentation under water (anoxic and acidic conditions) and during drying (drought stress; Kramer et al., 2010; Zhang et al., 2019a). Metabolic responses to stress modify the composition of green coffee beans, thus their physical characteristics and cup sensory profile. However, the evolution of such compounds along the entire post-harvest processing chain remains to be further understood (Zhang et al., 2019a, 2019b). For this reason, our research aimed to evaluate the effect of carbonic maceration, at different times, on the physical quality of the green bean and the cup profile of the coffee variety (*Coffea arabica*) yellow caturra. The caturra variety is a compact plant with good yield and good cup quality, whose growth is optimal at an altitude of more than 1600 m.a.s.l. at latitude 5°N to 5°S; at more than 1300 m.a.s.l. at latitude: 5-15°N and 5-15°S: and at more than1000 m.a.s.l. above 15°N and S. The working hypothesis was that carbonic maceration will increase the quality of both attributes (physical and beverage). To this end, an experiment was conducted with two variants of carbonic maceration: at constant pressure and without additional pressure.

## 2 MATERIAL AND METHODS

### 2.1 Coffee Origins in the Experiment

The experiment involved the utilization of the yellow caturra coffee cherry variety, which was acquired from Finca La Joya during the harvest of 2021/22. Finca La Joya is located in the high mountains of the central region of the state of Veracruz, Mexico, at coordinates 19° 20’ 24.47” N and 97° 02’ 46.68” W, with an altitude of 1400 meters above sea level (m.a.s.l.). The farm is in the municipality of Ixhuacán de los Reyes and experiences a temperate climate, with an average temperature of 17 °C and an annual average rainfall of 1,650 mm. The farm practices shade coffee cultivation and falls under the category of commercial polyculture (Toledo; Moguel, 2012), following agroecological principles (Sarandón, 2002). The specific lot dedicated to the yellow caturra variety covers 7,538.99 m2, featuring approximately 2,437 three-year-old coffee plants, 54 fruit trees (Macadamia, Prunus, Psidium, Carica and Annona cherimola) and 179 shade trees (Trema micrantha, Vachellia farnesiana, Inga vera, among others).

### 2.2 The process of coffee harvesting

During the 2021/22 harvest, at the peak of the season, the coffee cherries were collected in an intermediate cut, selecting the ripe fruits of intense yellow color from the branches. A homogenous sample was formed from the day’s collection and placed in GrainProTM bags for transportation to the Microbeneficio La Joya in Xico, Veracruz. At the processing facility, the cherries underwent extraction to remove floating fruits and foreign matter. The total mature cherry was 144 kg, with an average of 14.5±1.18 °Brix of which three separate lots of 48 kg each were reserved for later use in the experiment.

### 2.3 The experiment

A repeated measures experiment was designed using a single factor (type of process) with two levels: 1) carbonic maceration with pressure (CM) and 2) carbonic maceration without pressure (SP). Each treatment was repeated three times. From the 48 kg batches previously reserved, 16 kg of samples were randomly assigned to each replicate within each treatment. For both the CM and SP treatments, the 16 kg of samples were placed in 19-liter stainless steel containers and hermetically sealed. In the CM treatment, $CO_2$ was injected into the containers at a constant pressure of 1.50 bar, while the SP containers were equipped with an airlock valve to maintain a constant ambient pressure releasing the $CO_2$ produced. Fermentation of these treatments was maintained at room temperature, with an average of 19.96 ± 1.49 °C. Subsequently, cherry samples (approximately 5 kg) were taken from each vessel at 5, 10 and 15 days and dried on raised beds to a moisture content of 10-12%. The third batch of 48 kg was used for day 0 replicates, was not subjected to fermentation and was dried on raised beds to a moisture content of 10-12%. Drying was 21 days at an average temperature of 28 ± 3.25 °C.

### 2.3 The physical quality of coffee beans

After the coffee was dehydrated, the husk and parchment were removed from each lot obtained. This process was performed using a coffee huller (100MEX). Subsequently, the green coffee was classified by separating it into three groups: clean green coffee, coffee with primary and secondary defects, following the Specialty Coffee Association (SCA) methodology (SCA, 2018b; Centro Nacional de Investigaciones de Café - CENICAFÉ, 2019). To assess the physical quality, several parameters were measured. These, included production performance, (i.e., dried fruit weight/green beans weight), the percentage of total, primary, and secondary defects was also determined. Additionally, density, moisture content (moisture analyzer MC2000), and water activity (water activity meter WA-60A) were measured (Centro Nacional de Investigaciones de Café - CENICAFÉ, 2019).

## 2.4 Sensory Quality Analysis of Coffee

The analysis of the sensory quality of the coffee was performed by a panel of four certified tasters, following the protocol established by the SCA (2018b), with an optimal ratio of 8.25 grams of coffee per 150 ml of water in five cups per sample. Prior to the evaluation, an optimal roasting curve was established using a Giesen roaster for the samples. The cupping samples (150 g) were roasted and ground (Mahlkonig mill, Guatemala Model) to a medium particle size ranging from 1100 to 1300 microns, 24 hours before the cupping session. Coffee quality was determine based on a scoring system, which involved the evaluation of 10 attributes: aroma, flavor, residual flavor, acidity, body, balance, cleanliness, uniformity, sweetness, and overall impression, following the guidelines (SCA, 2018b). Each treatment received a score for each attribute, and the average score was calculated to determine the final quality score for each treatment. For the sensory descriptors, those that coincided among tasters were reported.

## 2.5 Statistical analysis

The impact of processing type on the physical quality of green beans was analyzed using the Mann-Whitney U test. To measure the influence of fermentation days on the physical quality of green beans, a repeated measures Anova (Friedman) was employed with the Wilcoxon test as post hoc analysis. To measure the combined effects of treatments and fermentation days on sensory quality, a repeated measures Anova was conducted, and the Bonferroni statistic was applied for comparisons between groups.

# 3 RESULTS

## 3.1 The physical quality of green coffee beans

A statistical effect of the type of processing was found on the dried fruit to green bean ratio, clean green coffee, total, primary and secondary defects, humidity, and density (Table 1). As for the effect of fermentation time on the physical quality of the green beans, there was statistical significance on the dried fruit to green bean ratio, percentage of primary defects, humidity and water activity (Table 1).

## 3.2 Characteristics of sensory analysis in coffee evaluation

The comparison of treatments showed no statistically significant difference in relation to the total SCA score (an effect size $F(3) = 0.218$, $p>0.05$, $\eta 2 = 0.009$, $\beta\text{-}1 = 0.089$). However, a statistical difference was observed between fermentation days and total SCA score [$F(3) = 7.26$, $p<0.05$, $\eta 2 = 0.225$, $\beta\text{-}1= 0.98$], as well as in aroma, flavor and sweetness, within each treatment. The effect of fermentation days is primarily observed at 10 and 15 days, with a notable increase in score observed at 15 days = 85.8 ± 1.89 ($p<0.05$) 95% CI [0.82, 3.97] and at 10 days = 85.4 ± 2.07 ($p<.05$) 95% CI [0.19, 3.13] compared to 0 days = 83.4 ± 1.87. Table 2 presents the scores obtained for each sensory attribute in coffee beverages, with respect to the effect of days of fermentation.

**Table 1:** Effect of fermentation processes and days of fermentation on the physical quality of green beans.

| Physical quality | CM / Fermentation days | | | | SP / Fermentation days | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 5 | 10 | 15 | 0 | 5 | 10 | 15 |
| | Mdn (Range) | Mdn (Range) | Mdn (Range) | Mdn (Range) | Mdn (Range) | Mdn (Range) | Mdn (Range) | Mdn (Range) |
| Dried fruit to green bean ratio | 1.95 (0.08)$^{ab}$ | 2.01 (0.03)$^{*ab}$ | 1.93 (0.02)$^{*cd}$ | 1.84 (0.14)$^{cd}$ | 1.95 (0.08)$^{abcd}$ | 2.11 (0.00)$^{*abcd}$ | 1.90 (0.00)$^{*abcd}$ | 1.84 (0.03)$^{abcd}$ |
| % Clean green bean | 88.63 (2.11)$^{ac}$ | 91.03 (2.56)$^{*bc}$ | 90.36 (9.99)$^{abc}$ | 87.03 (8.55)$^{d}$ | 88.63 (2.11)$^{abcd}$ | 87.38 (1.98)$^{*\ abcd}$ | 87.72 (8.75)$^{abcd}$ | 82.23 (2.94)$^{abcd}$ |
| % Total defects | 11.37 (2.11)$^{ac}$ | 8.96 (2.56)$^{*bc}$ | 9.64 (9.99)$^{abc}$ | 12.97 (8.55)$^{d}$ | 11.37 (2.11)$^{abcd}$ | 12.62 (1.99)$^{*abcd}$ | 12.28 (8.75)$^{abcd}$ | 17.77 (2.94)$^{abcd}$ |
| % Primary defects | .58 (0.14)$^{ab}$ | .38 (1.12)$^{*ab}$ | .82 (1.98)$^{ac}$ | 1.96 (1.16)$^{*c}$ | .58 (0.14)$^{abcd}$ | .12 (0.01)$^{*abcd}$ | 1.17 (0.56)$^{abcd}$ | 3.07 (0.60)$^{*abcd}$ |
| % Secundary defects | 10.79 (1.96)$^{acd}$ | 8.12 (2.36)$^{*bc}$ | 8.90 (10.74)$^{abc}$ | 10.99 (8.58)$^{ad}$ | 10.79 (1.96)$^{abcd}$ | 12.30 (1.91)$^{*abcd}$ | 11.55 (8.63)$^{abcd}$ | 14.84 (2.47)$^{abcd}$ |
| % Humidity | 11.05 (0.35)$^{a}$ | 10.71 (0.70)$^{*bc}$ | 10.62 (0.76)$^{*bcd}$ | 10.52 (0.63)$^{cd}$ | 11.05 (0.35)$^{abcd}$ | 10.30 (0.10)$^{*abcd}$ | 10.20 (0.00)$^{*abcd}$ | 10.53 (0.23)$^{abcd}$ |
| Density | 732 (4.67) | 711 (93) | 730 (93) | 707 (107)$^{*}$ | 732 (4.67) | 707 (28) | 686 (22) | 681 (18)$^{*}$ |
| Water activity | .63 (0.04)$^{ac}$ | .61 (0.03)$^{*abc}$ | .62 (0.03)$^{abc}$ | .64 (0.04)$^{*c}$ | .63 (0.04)$^{abcd}$ | 58 (0.01)$^{*abcd}$ | .61 (0.02)$^{abcd}$ | .67 (0.01)$^{*abcd}$ |

Mdn=Median; * $p<0.05$ between process by Mann-Whitney; $p<0.05$ between fermentation days by Friedman repeated measures Anova. Differences between groups are represented with different letters, with Wilcoxon ($p<0.05$).

**Table 2:** Effect of fermentation time on sensory analysis attributes.

| Attribute | Fermentation days 0 x̄ (SD) | | 5 x̄ (SD) | | 10 x̄ (SD) | | 15 x̄ (SD) | | F | gl | *P* | Statical power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CM | SP | CM | SP | CM | SP | CM | SP | | | | |
| Aroma* | 8.03 (0.39)$^{abcd}$ | 8.03 (0.40)$^{abcd}$ | 8.13 (0.25)$^{abc}$ | 7.92 (0.18)$^{abc}$ | 8.08 (0.32)$^{abcd}$ | 8.06 (0.39)$^{abcd}$ | 8.28 (0.47)$^{acd}$ | 8.31 (0.35)$^{acd}$ | 3.53 | 3 | 0.019 | 0.77 |
| Flavor* | 8.25 (0.17)$^{acd}$ | 8.25 (0.17)$^{acd}$ | 8.01 (0.30)$^{bcd}$ | 7.92 (0.31)$^{bcd}$ | 8.10 (0.43)$^{abcd}$ | 8.00 (0.33)$^{abcd}$ | 8.11 (0.37)$^{abcd}$ | 8.08 (0.48)$^{abcd}$ | 3.4 | 3 | 0.022 | 0.75 |
| Residual flavor | 7.91 (0.21) | 7.91 (0.22) | 7.96 (0.41) | 7.75 (0.31) | 7.88 (0.44) | 7.81 (0.46) | 7.94 (0.42) | 7.89 (0.45) | 0.23 | 3 | 0.875 | 0.09 |
| Acidity | 8.11 (0.39) | 8.11 (0.40) | 7.96 (0.28) | 7.78 (0.20) | 8.04 (0.42) | 7.94 (0.24) | 8.11 (0.32) | 8.03 (0.38) | 2.51 | 3 | 0.065 | 0.6 |
| Body | 7.89 (0.22) | 7.89 (0.22) | 7.82 (0.27) | 7.75 (0.18) | 7.86 (0.25) | 7.83 (0.25) | 7.94 (0.34) | 7.94 (0.21) | 1.94 | 3 | 0.13 | 0.48 |
| Balance | 7.89 (0.27) | 7.89 (0.28) | 7.83 (0.31) | 7.61 (0.31) | 7.85 (0.49) | 7.78 (0.29) | 7.92 (0.39) | 7.80 (0.33) | 1.07 | 3 | 0.368 | 0.28 |
| Uniformity | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | - | 3 | - | - |
| Cleaning | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | 10 (0.00) | - | 3 | - | - |
| Sweetness* | 7.11 (1.02)$^{a}$ | 7.11 (1.05)$^{a}$ | 10 (0.00)$^{bcd}$ | 10 (0.00)$^{bcd}$ | 10 (0.00)$^{bcd}$ | 10 (0.00)$^{bcd}$ | 10 (0.00)$^{bcd}$ | 10 (0.00)$^{bcd}$ | 219.7 | 3 | <0.001 | 1 |
| Overall impression | 8.25 (0.36) | 8.25 (0.38) | 8.19 (0.28) | 7.92 (0.35) | 8.22 (0.56) | 8.05 (0.35) | 8.25 (0.49) | 8.14 (0.60) | 0.73 | 3 | 0.525 | 2.2 |
| Final score* | 83.4 (1.89)$^{ab}$ | 83.4 (1.94)$^{ab}$ | 84.8 (1.63)$^{abcd}$ | 83.6 (1.10)$^{abcd}$ | 84.9 (1.96)$^{bcd}$ | 85.5 (1.99)$^{bcd}$ | 85.7 (1.66)$^{bcd}$ | 86.2 (2.33)$^{bcd}$ | 7.76 | 3 | <0.001 | 0.98 |

x̄=Mean ; SD= standard deviation ; *p<0.05 between days of fermentation by repeated measures Anova; different letters represent statistical differences (Bonferroni p<0.05) between groups.

An increase in the intricacy of the descriptive notes was observed as the fermentation days advanced (Table 3). Furthermore, it is worth noting that both the overall score and descriptive notes show significant variation in relation to the quality classification established by the SCA. The findings indicate a progression from very good coffees to excellent coffees as a result of the fermentation process.

## 4 DISCUSSION

The results indicated that the physical appearance of green coffee was influenced by both the processing method and fermentation duration. This impact was manifested through a change in coloration, transitioning from green-blue to brownish-yellow, with the most noticeable effect observed in the SP process after a 15-day fermentation period. These results align with those of Sunarharum et al. (2018), who reported significant differences in color and percentage of defects among various processing methods.

Regarding the impact of fermentation time, our study revealed a decline in coffee yield after 10 and 15 days, in contrast to 0 and 5 days. Moreover, there was a noticeable increase in the percentage of defects (both primary and secondary) in the SP process at 10 and 15 days compared to 0 and 5 days. These parameters carry significant importance, as they directly influence the preparation and defects that producers need to consider while deciding on the appropriate processing methods and timeframes. The physical inspection of coffee constitutes a crucial aspect in the determination of its quality and serves as a point of reference for buyers, as it may result in product rejection in certain instances (SCA, 2018a). During the physical analysis, it was noticed that the humidity and water activity levels were conformed to the established standard parameters, specifically 10-12% for humidity and less than 0.70 for water activity (SCA, 2018b).

The study observed a positive effect of carbonic maceration on coffee quality after a 5-day process, similar to what has been observed in the wine industry. This improvement may be linked to the initiation of intracellular fermentation due to the action of enzymes, leading to catalytic reactions that produce alcohols, acids, and volatile compounds, thereby modifying the chemical and physical composition of the coffee bean (Tesniere; Flanzy, 2011; Etaio et al., 2016; Zhang et al., 2019). The analysis of variations in coffee bean chemical compounds resulting from different processing techniques justify the differences in aromatic profiles among various coffee beans (Pereira et al., 2018). In this research, the carbonic maceration process increases the cup quality, with a positive correlation between the quality and the fermentation time. These results coincide with those obtained by Brioschi et al. (2020), who demonstrated an increase in the sensory analysis score from 80.90 ± 1.47 to 85.15± 0.96 using the carbonic maceration technique at a temperature of 38 °C over a 5-day fermentation period. Gomes et al. (2022) increased from 78.64 (24h/18°C) to 83.25

(120h/38°C) sensory quality, by carbonic maceration process. In our case, the initial score increased from 83.44±0.38 (0 days) to 85.93±0.38 points after 15 days of fermentation. Brioschi et al. (2020), fermentation occurred at a faster rate compared to our present study, primarily due to the higher process temperature of 38 °C utilized in their experiment, as opposed to the 19 °C temperature employed in our investigation. The research by Puerta-Quintero (2012), which focused on measuring the growth rate of microorganisms under different fermentation conditions involving varying temperatures and timeframes, revealed that temperature significantly influences fermentation time. Specifically, higher temperatures were associated with shorter optimal fermentation times. Consequently, this suggests that within a certain temperature range, variations in fermentation speed would not significantly impact the final score of the sensory analysis, provided that the fermentation time is appropriately adjusted. Nonetheless, it's crucial to evaluate whether other specific attributes, such as odours and flavours, are unaffected by these adjustments. To guarantee coffee quality and uphold a consistent chemical composition, precise control of time and temperature during coffee processing under different fermentation systems is of utmost importance. As Santamaría (2022) emphasizes, these factors have a direct influence on the ultimate product quality. Consequently, it's recommendable to minimize deviations in both time and temperature during coffee fermentation and to conduct in-depth analyses of their impact on quality, as advocated by Nie et al. (2021) and Zhang et al. (2021).

Concerning sensory descriptors, the impact of fermentation time was evident. Initially, the descriptors exhibited simpler notes, including the smell of sugar cane, molasses, fruit (tejocote, blackberry), spices (cinnamon, cardamom), medium-low citric acidity, and a light body, among others, with a reduction in these attributes as fermentation duration decreased. However, after a 15-day fermentation period, the sensory descriptors became more complex, revealing new notes such as sweetness (chocolate, cocoa, vanilla, nuts), fruity (cherry, pomegranate), medium-high citric acidity, medium-high body, and a wine-like quality.

While fermentation plays a significant role in coffee quality, other factors, such as cherry variety (Babova; Maffei, 2016), degree of maturity during processing, and various aspects of the processing itself (time, temperature, type of fermenter, $CO_2$ condition, with or without inoculum, among others), also contribute to the final cup quality (Batista; Chalfoun, 2014; Pereira et al., 2018). Further research  necessary to explore the interactions between these factors and fermentation processes to optimize coffee quality.

**Table 3:** Sensory characteristics and quality classification of beverages derived from two distinct carbonic maceration processes and varied fermentation days.

| Type of process | Fermentation time | Sensory descriptors | SCA Quality |
|---|---|---|---|
| CM | 0 days | Sweet (sugar cane, molasses), fruity (tejocote, blackberry), spicy (cinnamon, cardamom), medium-low citric acidity, light body. | Specialty coffee - Very good |
| | 5 days | Sweet (chocolate, caramel, syrup), fruity (cherry, strawberry, blackberry), medium citric acidity, medium body, clean without ferment. | Specialty coffee - Very good |
| | 10 days | Sweet (chocolate, caramel, vanilla), fruity (red berries), medium acidity, medium-low body, winey. | Specialty Coffee - Excellent |
| | 15 days | Sweet (chocolate, cocoa, vanilla, nuts), fruity (cherry, pomegranate), medium-high citric acidity, medium-high body, winey. | Specialty Coffee - Excellent |
| SP | 0 days | Sweet (sugar cane, molasses), fruity (tejocote, blackberry), spicy (cinnamon, cardamom), medium-low citric acidity, light body. | Specialty coffee - Very good |
| | 5 days | Sweet (dark chocolate, hazelnut cream, caramel), fruity (apple, green grape), medium citric acidity, medium body, clean without ferment. | Specialty coffee - Very good |
| | 10 days | Sweet (cocoa, chocolate, nuts), fruity (strawberry, litchi, soursop), high acidity, medium-high body, smooth, winey. | Specialty Coffee - Excellent |
| | 15 days | Sweet (chocolate, cocoa, nutmeg, vanilla) fruity (strawberry, cherries), bright lactic acidity, medium-high body, winey. | Specialty Coffee - Excellent |

CM = with pressure; SP = without pressure.

## 5 CONCLUSION

In conclusion, carbonic maceration compromises the physical quality of coffee beans by decreasing yield and increasing secondary defects after 10-15-days, which producers should consider. Finding a balance that improves both physical and sensory quality through fermentation processes is crucial. Carbonic maceration, with or without constant pressure, improved the sensory profile of yellow caturra coffee, with the fermentation time at constant temperature (19 °C) playing a significant role. The highest sensory score (85.9) was achieved after 15 days of fermentation, associated with more complex aroma, flavour, acidity, and sweetness notes, ultimately enhancing the quality of the beverage.

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## 7 AUTHORS' CONTRIBUTION

GHA and SRS wrote the manuscript and performed the experiment, EAG and JA supervised the experiment and co-worked the manuscript, EAG and JA review and approved the final version of the work, GHA and EAG conducted all statistical analyses.

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