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POST-HARVEST PRACTICES FOR THE PRODUCTION OF SPECIALTY COFFEES IN CHIAPAS, MEXICO

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ABSTRACT

When it comes to specialty or high-quality coffees, sensory qualities are crucial because coffee marketers use samples to assess bean and cup quality, which is then used to create a score based on the Specialty Coffee Association (SCA) protocol. This score is then used to determine the purchase and price. This study provides a descriptive analysis of the processes developed during training for high-quality coffee production with three shade-grown organic coffee-producing organizations in the state of Chiapas. The goal was to improve harvest and post-harvest practices in order to increase the sensory quality of the coffee. Each training session used the washed, natural, and honey methods to process the coffee. Statistically significant differences were found in the different types of post-harvest processing for each organization. In the sensory analyses, washed coffees were classified as excellent (between 85 and 86 points). In general, the coffees obtained scored between 80 and 86 points, which, according to the SCA protocol, are classified as very good to excellent. The washed processes obtained the highest score; however, the natural and honey processes are a good alternative for producers who lack water during harvesting. Selective harvesting and monitoring of the fermentation processes help to increase the sensory quality of the coffee, improving its opportunity to access specialty markets in order to obtain better prices and greater stability in the medium term.

Keywords: organic coffee, cup quality, fermentation, specialty market, participatory workshops.

INTRODUCTION

Mexico has a long tradition of coffee cultivation in sustainable agroforestry systems. In the states of Chiapas and Oaxaca, organic production is important; however, low prices, global market instability, and pests and diseases (Escamilla-Prado, 2016) have reduced economic sustainability, compromising socio-environmental sustainability. To overcome the challenges faced by producers, it is essential to seek alternatives to

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improve coffee quality, identify novel mechanisms for marketing, and bring producers closer to the final consumer.

In the last three decades, there has been an increase in the production of differentiated coffees (organic, fair trade, shade-grown) and specialty coffees (classified according to SCA criteria), in which the price is determined by the quality of the bean, sensory attributes, and management with sustainable practices and fair treatment, linking the producer with the final consumer through direct trade (Escamilla-Prado, 2012).

Coffee beans have a diverse and complex chemical composition, with over a thousand volatile and non-volatile compounds that contribute significantly to the beverage's distinct flavor (Magalhães *et al*., 2021). Many factors influence their presence and concentration, from the plant to the cup. Poltronieri and Rossi (2016) point out that some of the transcendental factors to obtain quality are: 1) the optimal ripening stage; and 2) post-harvest processes. Puerta-Quintero (2000) assures that a good milling process has a favorable influence on obtaining quality grain; failures in this process can cause up to 80 % of quality problems (Aristizabal-Arias and Duque-Orrego, 2006).

In this study, training on post-harvest practices was carried out with organizations of organic washed raw coffee producers in three municipalities in Chiapas, Mexico, interested in exploring the production of specialty coffees. The training was aimed at detecting opportunities for improvement in coffee processing. The principles of participatory rural appraisal were considered, where social collaboration is a fundamental ingredient to develop projects, promote a substantial improvement in the local quality of life, and conserve natural resources (Ramírez-García and Camacho-Bercherit, 2019). In this context, the objective was to improve harvest and post-harvest practices that help increase the sensory quality of coffee.

MATERIALS AND METHODS

Training on post-harvest practices for the production of specialty coffee for the 2020–2021 harvest cycle was conducted. The first training was held from February 8 to 12, 2021, at the Comon Yaj Noptic Cooperative, in coordination with the technicians and the quality manager, at the Ranchería San Francisco facilities, municipality of La Concordia, Chiapas, Mexico (5° 46′ 00“ N, 92° 58′ 56″ W, at an altitude of 1700 m). The coffee samples used were collected at the same location where the training took place. Seventeen organic coffee producers participated, with the majority focusing on washed raw coffee for export.

The second training was carried out on February 22, 23, and 25, 2021, with Kulaktik Group, located in the municipality of Tenejapa, Chiapas, Mexico (16° 52′ 28“ N, 92° 28′ 28″ W, at an altitude of 1600 m). The coffee samples were collected in the same location where the training took place. Ten coffee producers participated, mainly focused on washed raw coffee for national sale.

The third training was held on March 16, 17, and 18, 2021, at the facilities of the Triunfo Verde Cooperative, located in Jaltenango de la Paz, a town in the municipality of Angel Albino Corzo, Chiapas, Mexico (15° 52′ 16“ N, 92° 42′ 37″ W). The coffee samples were taken in a plot located at 15° 49′ 41“ N and 92° 44′ 38″ W, at an altitude of 1112 m, with the participation of 12 producers of organic coffee, mainly focused on washed raw coffee for export.

Prior to the training sessions, a meeting was held with the coffee producers of each organization on January 14 and 15, 2021, in which a focus analysis was carried out. Participants expressed their wishes and expectations regarding the training on post-harvest practices, wrote them down, and then shared it with the group. Thus, common objectives were identified, the scope of the training was narrowed down, and the group agreed to work on the importance and improvement of selective harvesting, fermentation and washing, and natural and honey processing practices.

Subsequently, activities were designed for each training session. The first part was carried out in the field, where the topics addressed were selective harvesting and verification of the ripening indexes proposed by the producers. It was also accompanied by the measurement of Brix degrees, for which hand-held refractometers were used, with a measuring range from 0 to 32 % °Bx (Ampro, Mexico). After verifying the ripening indexes, ripe fruits were harvested, collected in baskets, and placed in plastic boxes measuring 51 x 31 x 18 cm, with a capacity of 10 kg. The fruits were taken to the mill and hydraulically sorted using clean, non-recirculated drinking water at a rate of 1.6 L kg^{-1} of fruit (Puerta-Quintero, 2015). Floating and damaged fruits were discarded.

A sample of 72 kg of freshly cut coffee fruit was available for each formation, provided by the smallholder organizations. In this exercise, the varieties available at the time were used: 1) Bourbon, which is a *Coffea arabica* cultivar highly appreciated in the world coffee arena (World Coffee Research, 2017), is distributed in all coffee growing regions of Mexico and is the most cultivated variety in Chiapas, particularly by small-scale producers (Santoyo-Cortés *et al*., 1994); 2) Caturra, a low-bearing variety with good yield potential and standard quality in Central America (World Coffee Research, 2017); and 3) Oro Azteca, a low-bearing, high-yielding variety of medium to good cup quality (Escamilla-Prado *et al*., 2015) generated in Mexico by the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) (World Coffee Research, 2017).

Fermentation exercises were carried out in all the training sessions. In each treatment, three replicates and a control were carried out, which corresponded to a 24 h mucilage fermentation. This procedure is practiced by 90 % of coffee growers in Mexico (Moguel and Toledo, 2004), mainly by those who produce washed raw coffee. For this purpose, samples were taken from the fruits harvested at the beginning and at the end of fermentation. A potentiometer (model Hi98107, Hanna Instruments, Mexico) was used to obtain pH data. To measure electrical conductivity, a conductivity meter with a measurement range of 0–9999 μS cm^{-1} and precision ± 2 % (model Hi98130, Hanna Instruments, Mexico) was used. Also, a total dissolved solids (TDS) meter with a range of 0–9999 ppm (model Hi98130, Hanna Instruments, Mexico) and a thermometer to record temperature (model Hi98501, Hanna Instruments, Mexico) were used.

For the fermentation exercises, we worked in a first phase with the coffee fruit in drupe. A total of 12 kg was deposited in high-density polyethylene containers with a capacity of 18 kg of complete coffee fruit. Airlock valves were placed on the lids of the containers to prevent the entry of oxygen but to allow the exit of gases. In this first phase, fermentation was suspended for 48 h (di Cagno *et al*., 2013).
After the first fermentation phase, the three containers were uncovered to remove the coffee berries, which were divided into three equal parts. The first part was used to dry the whole fruit and obtain a natural coffee; in the second part, the fruits were pulped and placed in sieves to obtain honey coffees; and the third part was pulped and left to ferment in the same containers for 16 h until the detachment of the mucilage, to obtain a washed coffee (Peña and Arango, 2009). After fermentation, the coffees were dried in sieves, in thin layers for better drying, until they reached humidity values between 10 and 12 % (Figure 1).

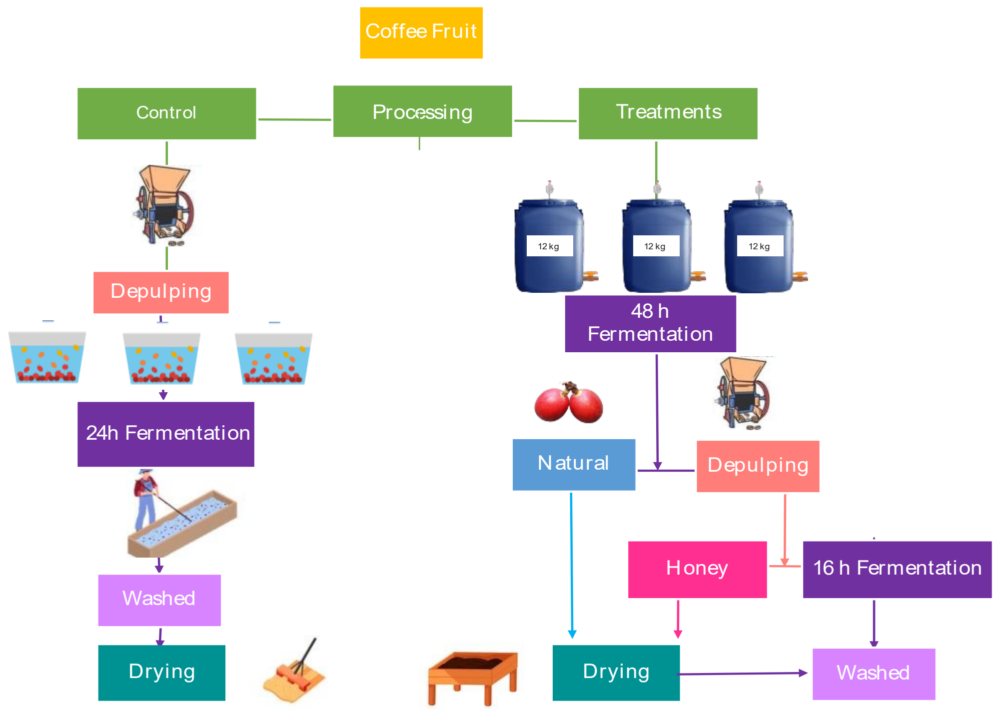

Figure 1. Coffee processing scheme carried out in the post-harvest practices training workshops in Chiapas, Mexico.

After drying, samples were sent to the cupping laboratories of each organization since one of the purposes of the workshops was for the producers to find the best processing for their conditions and varieties. The producers participating in the processing were invited to taste the coffees obtained in the different workshops. Each sample for tasting consisted of five 150 mL cups, and 10 variables (cup attributes) were evaluated and rated according to the SCA standard on an ordinal scale from 0 to 10 (SCA, 2015). Descriptive analyses were used for the sensory quality of the processes. Analyses of variance (ANOVA) were obtained using R software (version 4.2.2) in a completely randomized design with an equal number of observations (n = 12), three treatments, one control, and three replicates. The experimental units were coffees in polyethylene containers with a capacity of 18 kg of coffee fruit.

RESULTS AND DISCUSSION

For the selective harvesting exercise, participants presented the harvesting techniques they were familiar with. Then, each producer made a ripening index (Figure 2A) and indicated which would be the optimal harvesting stage according to their experience (Figure 2B). Subsequently, each index was verified with the help of a hand-held refractometer. It was confirmed that the best technique for harvesting the fruit is one by one, without detaching the petiole from the branches, since this favors coffee quality and facilitates post-harvest work (de Mesquita *et al*., 2016).

Figure 2. Coffee fruit harvest at a suitable stage of maturity. A) ripening index; B) selective harvesting.

It is important to note that different ripening indexes were found, as these depend on environmental conditions and site-specific varieties (Marín-López *et al*., 2003). In the case of the Comon Yaj Noptic Cooperative, the range of °Bx was between 15 and 19; in Kulaktik Group, between 10 and 13 °Bx; and in the Triunfo Verde Cooperative, between 13 and 21 °Bx.

Sensory profiles and analysis of variance

The first training was held at the Comon Yaj Noptic Cooperative, where the Red Bourbon variety was used. The notes found by the tasters in the natural processes were: hazelnut, fruity, molasses, peach, tamarind, lemony, honey, and caramelized sugar, with a medium body and pronounced acidity. In the honey processes, the notes found were: sweet, vanilla, butter, spices, anise, clove, dark chocolate, and milk chocolate, with medium body and medium acidity. For the coffees washed in two fermentation phases, the following were found: chamomile flower, chocolate, maple, and lemony, with a medium body and medium acidity; and for the controls, hazelnut, chocolate, piloncillo, anise, fresh fruit, tamarind, and vegetable flavors were found, with a medium body and pronounced acidity. The sensory quality results reached average scores of 82.2 to 85.5 points, classified as very good on the SCA scale. The best results were obtained with the washed coffees (Figure 3A).

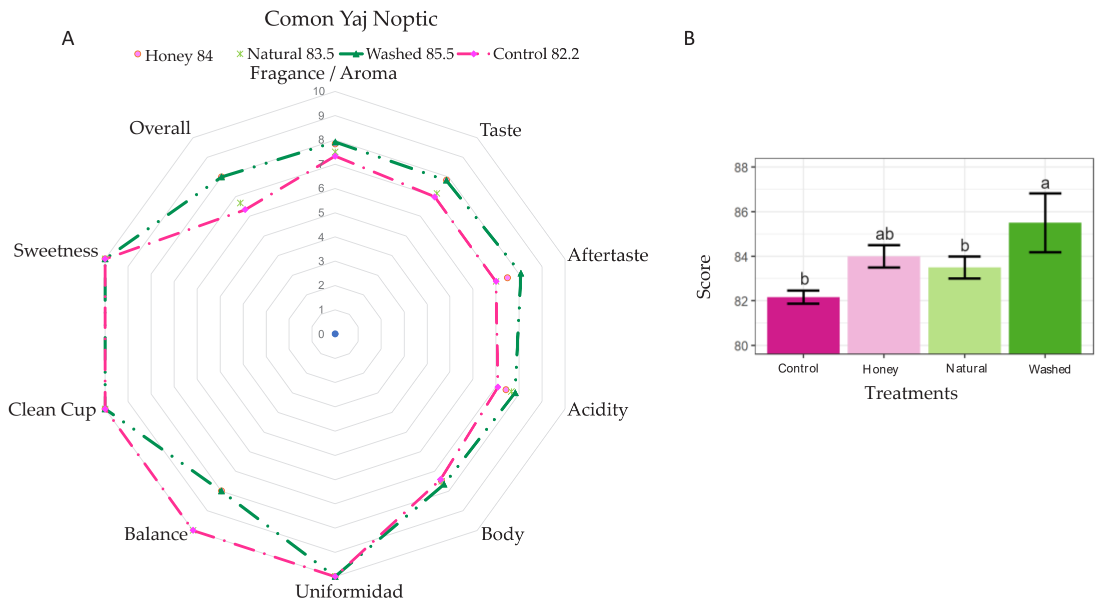

Figure 3. A: Coffee sensory profiles generated at the Comon Yaj Noptic Cooperative from three post-harvest processing of coffee beans in Chiapas, Mexico; B: analysis of variance of primary sensory attributes in post-harvest processing. Different letters present a significant statistical difference ($p < 0.001$).

The analysis of variance determined that there were statistically significant differences between the post-harvest processing carried out in the workshop with the Comon Yaj Noptic Cooperative. The greatest difference in quality was obtained in the washing method with a previous fermentation in fruit and then pulping, compared to the control, which involves a traditional washing (Figure 3B).

The second training was conducted with Kulaktik Group, where Bourbon and Caturra varieties were used. The notes found by the tasters in the natural processes were: red fruits, apple, walnut, and milk caramel, with a medium body and malic acidity. In the honey method, the notes found were: lime, floral, spices, soft caramel, and lemon, with medium body and citric acidity. For the coffees washed in two fermentation phases, the following notes were found: jasmine flowers, chocolate, walnut, maple, soft caramel, and spicy flavor, with a soft, delicate body and pronounced acidity; while for the controls, the following notes were found: ripe fruit, red apple, and mango, with a medium body and pronounced acidity. The sensory quality results reached average scores of 80.8 to 86 points, classified as very good to excellent on the SCA scale (Figure 4A). The best results were obtained by coffees washed in two fermentation phases.

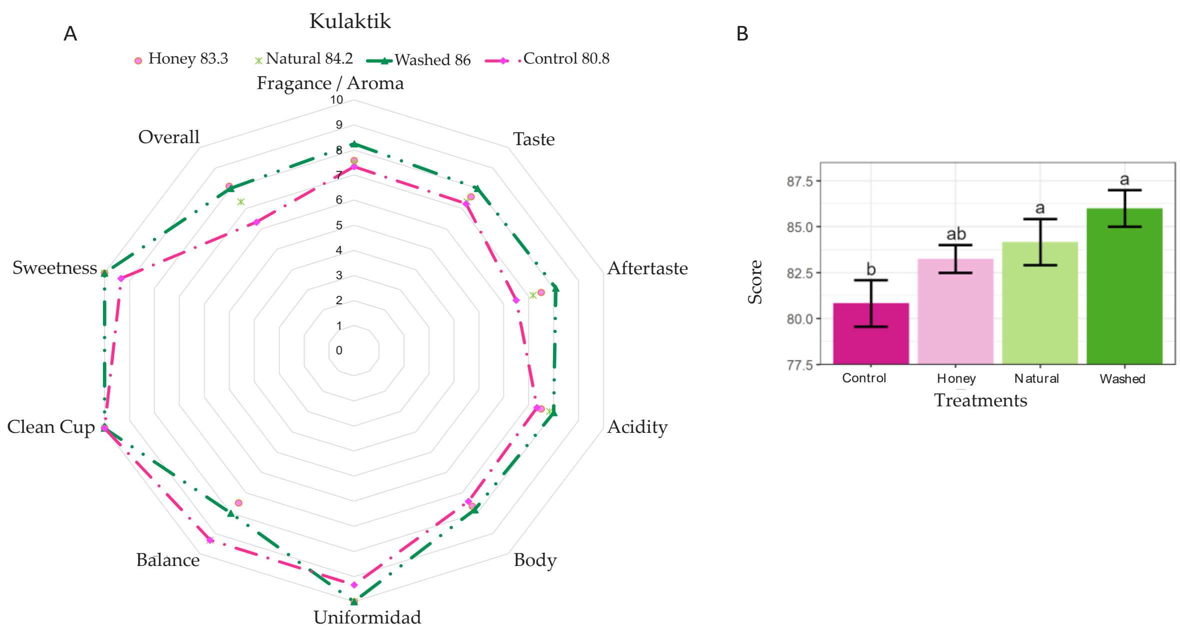

Figure 4. A: Coffee sensory profiles generated at the Kulaktik Cooperative from three post-harvest processing of coffee beans in Chiapas, Mexico; B: analysis of variance of primary sensory attributes in post-harvest processing. Different letters present a significant statistical difference ($p < 0.001$).

The analysis of variance showed that there were statistically significant differences between the post-harvest processing carried out in the workshop with the Kulaktik organization. The treatments that showed differences with the control were natural processing and washing after fermentation in fruit (Figure 4B).

The third training was carried out at the facilities of the Triunfo Verde Cooperative, where a blend of Bourbon and Oro Azteca was used. The notes described by the tasters belonging to the association of natural coffee processes were: red fruits, red apple, and plum, with a medium body and high acidity. For the honey processes, the notes found were: chocolate, citrus, ripe fruits, green apple, and lemon, with a light body and medium acidity. In the coffees washed in two fermentation phases, the following

were found: red fruits, cherries, plums, citrus lemon, and red wine, with a medium body and high acidity, balanced and round cup; while in the controls, the following were found: hazelnut, chocolate, piloncillo, anise, fresh fruit, tamarind, and vegetable flavor, with medium body and pronounced acidity. Sensory quality results reached scores averaging 80.7 to 85.2 points, classified as very good on the SCA scale. The best results were obtained by the washed coffees in two fermentation phases (Figure 5A).
In the analysis of variance of the scores obtained in the workshop with Triunfo Verde, statistical differences were found between the post-harvest processes, specifically between the washed coffee with pre-fermentation and the control, while the natural processing showed no difference with the control (Figure 5B).

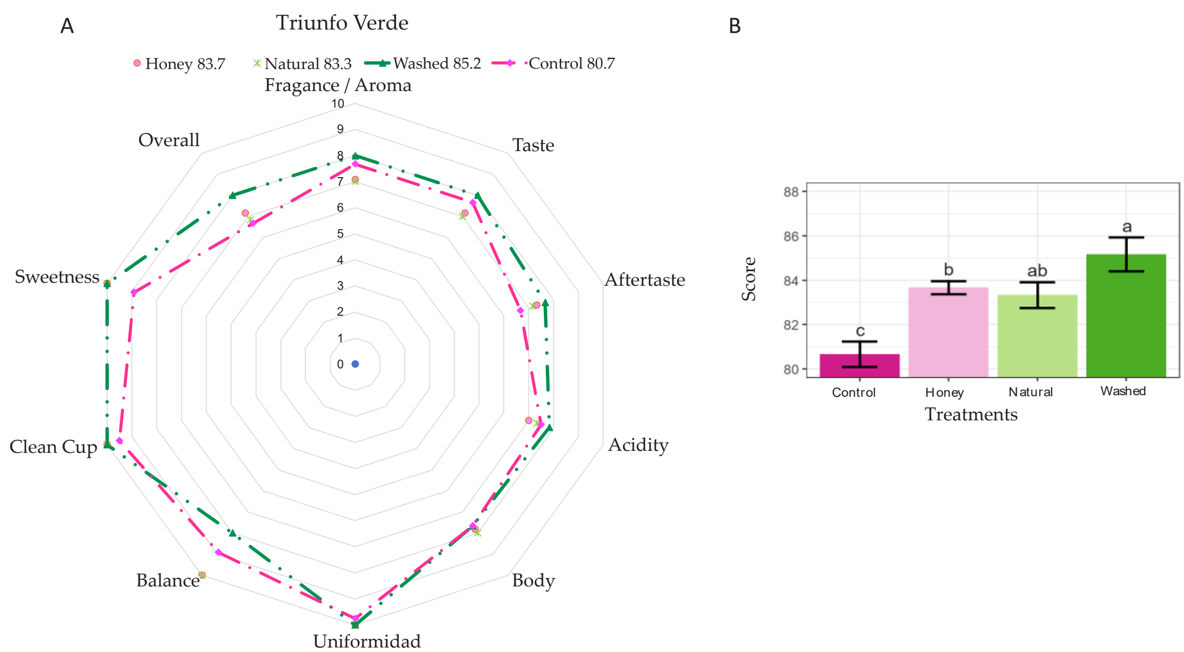

Figure 5. A: Sensory profiles of coffee generated at the Triunfo Verde Cooperative from three post-harvest processing of coffee beans in Chiapas, Mexico; B: analysis of variance of primary sensory attributes in post-harvest processing. Different letters show a significant statistical difference ($p < 0.001$).

Measurement and control of parameters in fermentation processes.

For the monitoring of parameters during fermentation, pH, electrical conductivity (CE), total dissolved solids (TDS), Brix degrees, and temperature were measured at the beginning and end of the process (Table 1).
At the beginning of the fermentations, a pH between 5.2 and 5.43 was obtained, and participants related the degree of acidity to the maturity of the coffee. Puerta-Quintero (2012) indicates that coffee fruits classified with water after pulping have

Table 1. Mean values of parameters recorded at the beginning and end of coffee fermentation carried out in training workshops on post-harvest practices in Chiapas, Mexico.

Organization	Variety	Treatments	pH	Electrical conductivity ($\mu S\ cm^{-1}$)	TDS* (ppm)	Temperature (°C)	Brix (°Bx)
		Parameters at the beginning of fermentation					
Comon Yaj Noptic	Red Bourbon	Natural	5.2	3040	1460	17	16
		Honey	5.4	3350	1956	17	18
		Washed	5.4	3140	1700	18.9	19
		Controls	5.4	2974	1650	18.9	15
Kulaktik	Bourbon/ Caturra	Natural	5.3	2736	1435	23	11
		Honey	5.42	3192	1652	22	12
		Washed	5.5	3238	1843	24	13
		Controls	5.2	3173	1689	23	13
Triunfo Verde	Bourbon/ Oro azteca	Natural	5.43	3457	2907	27.5	17
		Honey	5.3	3814	3143	28	18
		Washed	5.43	3732	3049	28.5	21
		Controls	5.4	3623	1678	26	13
		Parameters at the end of fermentation					
Comon Yaj Noptic	Red Bourbon	Natural	3.9	5168	3358	17	2
		Honey	3.8	5695	4499	16	1
		Washed	3.8	5338	3910	17	2
		Controls	3.8	5056	3795	18	3
Kulaktik	Bourbon/ Caturra	Natural	3.7	4651	3301	22	2
		Honey	3.6	5426	3800	21	1
		Washed	3.8	5505	4239	23	3
		Controls	3.5	5394	3885	23	1
Triunfo Verde	Bourbon/ Oro azteca	Natural	3.4	5877	6686	27	2
		Honey	3.7	6484	7229	24	3
		Washed	3.6	6344	7013	26	2
		Controls	3.7	6159	3859	26	2

an average pH value of 5.4, which coincides with what was found in the sampling. In addition, workshop participants considered that the decrease in pH was due to the transformation of compounds in the coffee mucilage. This conclusion is in line with references found in the literature, pointing out that the decrease in pH is due to microbial metabolism during fermentation, where organic acids are produced when decomposing the coffee mucilage, which causes the pH to decrease (de Carvalho *et al*., 2017; Evangelista *et al*., 2015). The decision on when to end fermentations was made according to the experience of the producers. At that time, pH values of 3.4 to 3.9 were found, which agrees with Velmourougane (2013), who estimated that the fermentation end point can be determined by the decrease of the pH of the coffee mass from 5.5 to 3.5.

Temperatures at the beginning of fermentation ranged from 17 to 28° C, and at the end, from 16 to 27° C (Table 1). Participants agreed that this variable depends on the location and environmental conditions where coffee processing is carried out. Participants explained that in their experience, there is an inversely proportional relationship between temperature and fermentation time. This coincides with Liu *et al*. (2016), who point out that fermentation temperature not only affects the time of the process, but also exerts a marked effect on the metabolic rate of the microorganisms that can affect the organoleptic properties of the fermented product.

The coffee processed at the lowest temperatures was the one made at Comon Yaj Noptic, with values from 17 to 16° C during the fermentation process. After 48 h, an average pH of 3.8 was obtained (Table 1). According to Puerta-Quintero (2012), the pH of the mucilage depends on the temperature in the system. In contrast, the coffee processed in Triunfo Verde had the highest temperature conditions, starting fermentation at 28° C with a pH value of 5.43. After 48 h, fermentation was interrupted, and a temperature of 27° C and a pH value of 3.4 were recorded. This result agrees with the FAO (2006) report, which argues that time and temperature are crucial parameters of the fermentation process in coffee processing.

The participants related the Brix degrees of coffee mucilage to the concentration of sugars contained in the fruits and, in turn, to the degree of maturity. The Brix degrees recorded at the beginning of the fermentations ranged from 13 to 21 °Bx, but at the end, a drastic reduction in the values was found, obtaining between 1 and 3 °Bx (Table 1). This was attributed, according to the participants, to the transformation of sugars into acids and alcohols, among other compounds. This agrees with de Carvalho *et al*. (2017) and Elhalis *et al*. (2020), who reported in different studies that the reduction of sugars during fermentation is accompanied by the accumulation of acids, such as lactic acid, acetic acid, and succinic acid, which are formed due to the action of microorganisms that use sugars as a carbon source for their growth.

The coffee with the lowest °Bx value was found in the workshop with Kulaktik Group (11 °Bx), although the selected coffee presented a crimson red coloration. This was attributed to the presence of rain during harvesting, since relative humidity and the amount of rain are also factors that inversely affect this parameter. This differs from what was proposed by Puerta-Quintero (2012), who states that lower average values are recorded in the mucilage of pinto coffee (14.1 %), ripe coffee (17.1 %), and overripe coffee (20.1 %), which will depend on the agro-climatic conditions of each producing region.

The CE parameter is an indicator for the evaluation of the state of maturity and quality of the fruit (Rehman *et al*., 2011), information that was shared with the producers. This variable was measured before the beginning and at the end of the fermentation processes, and an increase was observed. Paquet *et al.* (2000) mentioned that changes in CE and pH values during fermentation are closely related and that the former could be used to follow acidification during fermentation. Likewise, Loo-Miranda *et al*. (2022) reported that the CE of whole cocoa beans with shells at the beginning of the process limits the migration of ions into solution; therefore, the CE had a lower value than fermented unshelled beans, but as fermentation progresses, the number of ions in solution increases, resulting in a higher CE value. This coincides with what was found in the different processes carried out in this work, where the value of the CE at the beginning was lower in the processing of natural coffees containing the husk and higher in those in which the husk was removed, as in the washed and honey processes.

The TDS were measured before and at the end of the fermentations, where an increase was also observed because it is one of the most relevant parameters in anaerobic digestion due to the movement and growth of bacteria and the ease of dissolution and transport of nutrients (Sadaka and Engler, 2003). In general, TDS increase during fermentative processes (Mariyam *et al*., 2022). Likewise, Mariyam *et al*. (2022) found that fermentation TDS are inversely proportional to the pH of coffee beans. TDS are the sum of the compounds, essentially sugars and pectic substances, of coffee dissolved in water (Avallone, 2001). Most of the fermentation studies only report the number of Brix degrees without considering the behavior of the TDS; for this reason, there is little information on this parameter.

The best result in the sensory evaluations was obtained for coffees with washed processes, selective harvest, two fermentation phases, 48 h of fermentation in drupe, and 16 h of pulped fermentation. These achieved scores on the SCA scale of 85.2 with Triunfo Verde, 85.5 with Comon Yaj Noptic, and 86 with Kulaktik. These results were mainly due to the selective harvesting of ripe fruits, which coincides with the observations by Mazzafera and Purcino (2004), where coffees from wet processing presented better quality. The sensory characteristics were mainly attributed to the fact that only fully ripe coffee cherries are used for wet processing (Knopp *et al*., 2006).

In the different types of fermentation, an increase of 3 to 6 points was observed in selected coffees compared to the controls without selection at harvest (Table 1). Similarly, Ramos *et al*. (2019) found that the best score was obtained from samples of coffee growers who promote selective harvesting, processing, and adequate drying.

On the other hand, producers correctly identified the most important parameters for monitoring. They indicated that, for them, the most important are pH, °Bx, and average temperature, variables that are linked to the fermentation process. In participatory research, without the integrated, conscious, and harmonious participation of all those involved, it is impossible to achieve transformation (Espinoza-Freire, 2020). This work linked the experience of coffee producers in the collective application of techniques for processing organic coffee, which seek to innovate in post-harvest processes to obtain higher quality and, consequently, a better price and thus expand the options for improving the livelihoods of shade-grown coffee-producing families.

CONCLUSIONS

Selective harvesting is important in post-harvest processes. It is indispensable to create maturity indexes to harvest ripe fruits according to the variety being used, selecting before processing the coffee by removing green, dry, and severely damaged fruits by berry borer and vain fruits. This practice helps to ensure the quality of subsequent processes. Producers were able to experience the preparation of different processes and verify their results through a sensory exercise. In addition, the intervention of the people involved in the processes was promoted to improve the quality and traceability of the coffee.

Statistically significant differences were found between the different types of post-harvest processing in the exercises conducted in all cooperatives. The coffees scored higher than 85 points and had very good to excellent quality, according to the Specialty Coffee Association protocol, which increases their opportunity to access niche markets. The washed processes obtained the highest score; however, natural and honey processes are a good alternative for those producers who lack water during harvest.

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