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POSTHARVEST EFFECTS ON THE PHYSICAL QUALITY AND SENSORY CHARACTERISTICS OF *COFFEA CANEPHORA*

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ABSTRACT

Background. Coffee quality is a complex trait influenced by many factors, including atmospheric conditions, shade, humidity, altitude, cultivation practices, and post-harvest processing. These factors ultimately affect bean size and shape, as well as density, color, and other quality parameters. Although coffee quality is well-studied in some species, such as *Coffea arabica*, there is limited information about the species *Coffea canephora*. Therefore, this study aims to evaluate the physical and sensory quality (tasting notes) of the genetic groups Conilon and Robusta from different altitudes in Ecuador.
Materials and methods. In this study, physical and organoleptic analyses were conducted on samples obtained from three different altitudes (12, 625, and 1,700 m.a.s.l.). The bean samples were subjected to three post-harvest processing methods (dry, wet and honey), and American medium roast was prepared. Cuppers recorded favorable (e.g., chocolate, citrus) and unfavorable (bitter, herbaceous) characteristics for statistical analysis.
Results. The study found that better quality scores in terms of bean size and tasting notes were observed for coffee samples obtained at altitudes up to 625 meters processed with all three post-harvest processing methods. Furthermore, there was no significant difference between the contribution of these factors to the physical and cup quality of coffee made from Conilon and Robusta. The study also found that post-harvest processing methods and elevation significantly affected screen retention.
Conclusion. This study concluded that coffee quality is primarily related to bean size and lack of defects, as these characteristics are closely linked to taste, flavor, and price. Coffee flavor is directly influenced by the chemical composition of the beans, which is determined by the cultivar of the beans, farming practices, and post-harvest processing conditions such as fermentation, drying, storage, and roasting. Therefore, an understanding of the complexities of coffee production and a careful consideration of various factors are necessary to produce high-quality coffee. International guidelines for applying good manufacturing practices and criteria for certification and traceability should be followed to manage the quality and safety of coffee.

Keywords: bean damage, bean defects, Robusta, Conilon, food quality, sensory analysis

INTRODUCTION

While Arabica coffee (*Coffea arabica*) is often seen as superior, Robusta coffee (*Coffea canephora*) has several unique qualities that make it a valuable and versatile coffee species. Robusta's stronger flavor, higher caffeine content, and resilience to drought and heat make it ideal for a variety of applications, including blending

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with Arabica coffee to create high-quality coffee products with desirable flavor profiles (Schwan and Fleet, 2014; Chindapan et al., 2019; Byrareddy et al., 2021; Portela et al., 2022). Although Arabica is renowned for its aroma and acidity (Campuzano-Duque et al., 2021), research on Robusta coffee processing parameters is essential to unlock its full potential (Hameed et al., 2018; Kittichotsatsawat et al., 2021). In terms of processing, research has shown that semi-dry processing can produce coffee with more complex and desirable flavor profiles than dry processing (Wulandari et al., 2022; Silva et al., 2022; Girma and Sualeh, 2022). This is because semi-dry processing allows some of the sugars in the coffee cherries to ferment, which can lead to the development of more complex flavors (Nadaleti et al., 2022; Aswathi et al., 2023). Coffee brews processed using the semi-dry and wet methods scored higher as specialty coffee than those processed using the dry method. The dry method produced coffee with a medium fruity body, fresh medium acidity, and chocolate and caramel flavors, while the wet and semi-dry methods produced coffee with citrus and fruity flavors (Cortés-Macías et al., 2022; Linda et al., 2023). By gaining a comprehensive understanding of how various processing methods impact the flavor profile, it becomes feasible to develop more efficient processes for the production of premium *Robusta coffee* products that cater to consumer preferences and demands.

The final cup quality is intricately linked to critical variables such as coffee genotype, bean size, the presence of damaged beans, and the choice of pre- and post-harvest processing methods (Folmer, 2017; Velásquez and Banchón, 2022). Smaller coffee bean sizes are generally regarded as inferior in some countries, do not qualify as specialty coffee, and are priced lower. Furthermore, defective coffee beans account for up to 20% of total coffee production and significantly reduce the quality of coffee beverages worldwide (Ramalakshmi et al., 2007; Belay et al., 2014). The size of coffee beans is a key factor in determining their density and flavor, and the presence of damaged beans can impact the overall quality and taste of the coffee, affecting both coffee yield and the quality of the brewed cup (Luna González et al., 2019; Tassew et al., 2021). The coffee industry is seriously threatened by a variety of pests, and the predominant global menace is the coffee berry borer (CBB), scientifically referred to as *Hypothenemus hampei*, which is renowned for causing substantial damage to coffee crops, resulting in significant yield losses (Johnson et al., 2020). Various factors can influence the extent of CBB damage. For instance, reduced shade tree diversity in *C. canephora* leads to higher CBB infestation rates, as it decreases natural predator diversity (Ayalew et al., 2022; Oliva et al., 2023). Conversely, the presence of shade trees increases bird populations, resulting in a 50% reduction in CBB infestation rates in *C. arabica* and an improvement in coffee quality (Chain-Guadarrama et al., 2019). In general, declining biodiversity in agroforestry systems disrupts ecological interactions, reducing pest control services and impacting crop quality (Torrez et al., 2023). These physical attributes are essential considerations for coffee producers and roasters striving to achieve the best results in their coffee production processes (Belay et al., 2014; Hameed et al., 2018; Bastian et al., 2021).

Ecuadorian historical records trace the introduction of *C. canephora* genetic material back to 1951. Originating from Costa Rica and falling within the “Robusta” category (with a genetic group referred to as putative SG2), this genetic material gradually extended its presence to several coastal provinces and the northern areas of the Ecuadorian Amazon. Subsequently, in 1987, Ecuador imported genetic material of the “Conilon” type (putative SG1) from Brazil (Leroy et al., 2014; Loor Solórzano et al., 2017). In Ecuador, scientists developed a breeding program to improve *C. canephora* coffee plants. In 1998, the National Institute of Agricultural Research of Ecuador (INIAP) identified elite coffee plant clones that are now recommended for commercial planting under the conditions of the northern Ecuadorian Amazon. Crop altitude and post-harvest processing methods are known to have a significant influence on the cupping quality of Ecuadorian coffee plant clones (Velásquez et al., 2022), with altitude being the primary factor, but more information is needed about their effects on specific clones. In this context, it is pertinent to explore the connections between the sensory attributes of coffee cup quality derived from Ecuadorian Robusta and Conilon clones, the altitudes at which they are cultivated, and the physical characteristics of the beans. In these terms, this study’s novelty lies in its categorization of flavor attributes into positive and negative factors, providing a nuanced evaluation of taste profiles and enhancing our comprehension of the sensory characteristics associated with Robusta and Conilon. Accordingly, the aim of this research was to determine how bean size, bean defects, and post-harvest processing methods influence the sensory qualities (taste notes) of Robusta and Conilon beans. The expected outcome of this research is a set of recommendations on the optimum green coffee bean post-harvest methods for farmers at three different altitudes.

MATERIALS AND METHODS

Sampling

The fruits of *C. canephora* genetic groups Robusta and Conilon were gathered from six different Ecuadorian plantations located at various altitudes (Table 1).

Post-harvest processing method

Three different post-harvest processing methods were applied: dry, wet and honey. In the dry method, the entire crop of mature cherries was sun-dried for 12 days, until the requisite 10% water content was reached (Evangelista et al., 2014). The cherries were exposed uniformly to the sun's rays and constantly scraped to prevent fermentation. The unwanted outer layers were removed manually. After drying, the cherries were milled to remove the fruit and the parchment encasing the seed. In the wet process, the pulp and mucilage from ripe coffee cherries were removed using approx. 30 L of water per kilogram of beans for 24 hours. Proteolytic enzymes (Granozyme, Ecuador) were used to break down the mucilage for 2 days. The remaining mucilage was washed off. The parchment coffee was cleaned and dried under the sun (Pereira et al., 2020). In the honey (semi-dry or pulped natural) approach, the coffee skin and pulp were removed using a pulping machine. The seeds were dried under the sun with the mucilage still around them. The parchment layer was removed with a hulling machine (Wulandari et al., 2021).

In all the above processes, to separate the unripe, overripe, and damaged cherries and to get rid of dirt, soil, twigs, and leaves, the gathered cherries were first manually sorted and cleaned.

Physical analysis

For the physical analysis, a quantity of 300 grams of coffee was subjected to a sorting process employing screens with a mesh size number ranging from 14 to 18 (Tassew et al., 2021). The weight of the coffee retained in each sieve was measured and the corresponding percentage was documented (Ameyu, 2016).

In a defects analysis, Specialty Grade (1) coffee should have no more than five complete defects in a 300-gram sample, and primary defects (full black, full sour, pod cherry, large stones, large and medium sticks) are not allowed. Additionally, a tolerance of up to 5% above or below the advertised screen size is permitted (SCA, 2022).

Premium Grade 2 allows a maximum of 8 complete defects in 300 grams, with no restrictions on primary defects, and samples may contain up to three quakers (SCA, 2022).

Table 1. Features of the coffee farms where the fruit samples were gathered

Farm	Province	Coord.	Altitude m.a.m.s.l.	Precipitation[1] mm	Temperature[2] °C	Variety
F1	Santa Elena	2°13′36″S 80°51′30″W	12	487	26°C	Robusta
F2	Santa Elena	2°13′36″S 80°51′30″W	12	487	26°C	Conilon
F3	Santo Domingo	0°15′15″S 79°10′19″W	625	4 000	23°C	Robusta
F4	Santo Domingo	0°15′15″S 79°10′19″W	625	4 000	23°C	Conilon
F5	Bolivar	1°36′S 79°00′W	1 700	4 355	23°C	Robusta
F6	Bolivar	1°36′S 79°00′W	1 700	4 355	23°C	Conilon

[1, 2] Annual mean values for precipitation and temperature are provided.

Preparation of coffee samples (roasting and grinding, beverage preparation)

The roasting process aimed to achieve an American medium roast, a commonly preferred level for Robusta coffee. In a coffee roaster (Fresh Roast SR540, China), each coffee sample was roasted at 210–220°C (American medium roast). This took up to 10 min. To determine the roast level, the Agtron/SCAA E10/E20 color disc with the number 54 was employed as a standard tool. After the roasting process, the coffee samples were cooled and stored at room temperature. For a consistent grind size, the Shardor conical burr coffee grinder was used, producing grounds in the 0.3 to 0.5 millimeter range suitable for pourover brewing (Shardor conical burr coffee grinder, CG9406-UL2, USA). Pourover brewing was selected due to its ability to offer precise control over essential brewing parameters like water temperature and contact time. The amount of ground coffee was 8.75 grams per 150 mL of hot water (90°C).

Sensorial analysis

Five tasters performed the sensory analysis of fruits originating from each altitude. As there were three distinct altitudes, there were a total of fifteen tests. A panel of experts certified by the Coffee Quality Institute (CQI) conducted the sensory study. All of the panellists went through 120 hours of descriptive panel training with a variety of food products (di Donfrancesco et al., 2019). The attribute terminology employed was based on the coffee´s aroma, flavour, and aftertaste, according to the coffee taster´s flavour wheel (SCA, 2022).

Cuppers of coffee recorded odour/flavor attributes in two categories: positive flavour attributes such as chocolate, lemon grass, cocoa, citrus, aromatic, apple, cherry, passion fruit, floral, berries, sweet, vanilla, brown sugar, honey, toffee, pistachio, kiwi, or creamy; and negative flavor characteristics such as rubbery, fermented, coarse, burned caramel, wood, bitter, vinegar, astringent, cereal, dry, mashed, grass, butter, rancid, a little juicy, overripe, silky, loose, straw, vegetables, aged cheese, undercooked, leafy, or unripe (Andueza et al., 2007; Seninde and Chambers, 2020; Pinsuwan et al., 2022).

Numeric scores were assigned to each odor/flavor attribute or tasting note on a scale from 1 to 10, reflecting the intensity of each characteristic as described by the cuppers. Subsequently, the data allowed for the calculation of the percentage of positive and negative tasting notes. A comprehensive statistical analysis was conducted to discern significant differences in tasting notes between coffee species and altitudes.

Statistical analysis

The observational data were analysed by descriptive and inferential statistics using R-project and R-studio with the ggplot2 package (R Core Team, 2022; Wickham, 2016). The effects of physical characteristics, defects, altitude, and post-harvest treatments on the sensory attributes (response variables) were studied using ANOVA and Tukey's range test. Since the two Robusta varieties are not found at the same altitudes, statistical tests were conducted individually for each variety.

RESULTS AND DISCUSSION

Screen size

Figure 1 shows the percentage of Conilon and Robusta coffee beans retained on screens 12–18, with the size distribution of the beans described as follows: screen 12 (caracol) for small beans, screen 14 (terceras) for medium beans, and screens 16–18 (segundas and superior) for large beans. Small caracol beans and terceras beans are two of the smallest coffee bean sizes. According to the results (Fig. 1), small caracol beans were found to make up less than 4% of the total coffee beans at any altitude and for any post-harvest process, while terceras beans made up less than 14% of the total coffee beans at any altitude.

At lower altitudes, there were no notable variations in the 12 screen size of Conilon coffee beans, regardless of the post-harvest processing method employed. Nevertheless, when it comes to both Robusta and Conilon 14 screen size beans, a marked difference emerges: the dry processing method yielded up to 15% screen retention, whereas the other methods exhibited a comparatively lower level of retention. At 12 m altitude, Robusta beans had significantly higher screen 18 retention (62%) than Conilon beans (12%). There were no significant differences in screen 18 retention based on the post-harvest processing method for Conilon beans, but there were significant differences for Robusta beans (Table 2).

Table 2. Summary of F-values from ANOVA for physical and defects analysis

Source of variation	Df	Conilon			Robusta		
		12 m	625 m	1700 m	12 m	625 m	1700 m
Processing method	2	44.8 (***)	5.4 (*)	0.7 (–)	103.6 (***)	5.3 (*)	3.0 (.)
Screen 12/18	1	39.0 (***)	3.1 (–)	83.9 (***)	0.5 (–)	240.1 (***)	680.0 (***)
Processing method: Screen	2	5.6 (*)	14.6 (**)	4.2 (.)	1122.5 (***)	34.1 (***)	13.5 (***)
Defects							
Category-1	2	13.8 (***)	5.5 (*)	2.1 (–)	2.1 (–)	5.7 (*)	4.8 (*)
Category-2	2	2.1 (–)	0.2 (–)	3.1 (.)	0.1 (–)	1.4 (–)	1.4 (–)
Tasting notes							
Processing method	2	85.0 (***)	58.1 (***)	0.6 (ns)	385.6 (*)	513.1 (***)	74.1 (***)

Df = Degrees of freedom. Significance codes: 0 (***) 0.001 (**) 0.01 (*) 0.05 (.) 0.1 (–) no significance (ns).

At higher altitudes, according to Figure 1, Conilon beans from elevations up to 625 m had over 40% screen retention for screen 15–18. Coffee beans above mesh 15 are known as *medium or excelso* (SCA, 2022). At the same 625 m altitude, samples from honey processing screen retention achieved screen 18. Coffee beans above mesh 18 are known as *large*, *superior* or *supremo*. For Robusta processed using the wet-method, major screen retention occurred at screen 18, and for samples processed using the honey-method they reached major screen retention for screen 15 above 625 m. At 1,700 m altitude, screen 15 was obtained with all post-harvest methods (Fig. 1). According to the current study and previous sources, bean size increases significantly at higher elevations (Tassew et al., 2021). According to Table 2, screen retention

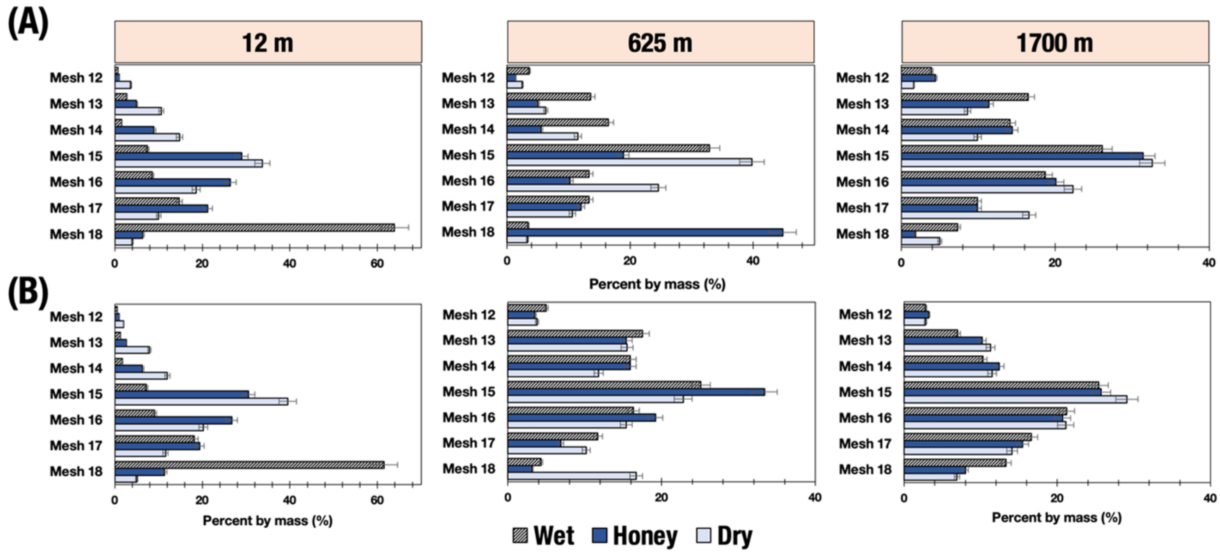

Fig. 1. Percentage of Conilion (A) and Robusta (B) beans from screens 12–18 originating from three altitudes and three post-harvests processes

was affected significantly ($p < 0.05$) by post-harvest processing and elevation. However, at altitudes up to 1,700 meters, the screen sizes from the different post-harvest processes were not statistically different ($p > 0.05$), especially for congolensis samples. In all cases (Fig. 1), there was a size variance of more than 5% among the 350-gram samples; thus, none of the coffee samples from any of the environments and post-harvest treatments would be considered *specialty*.

In addition to assessing the influence of bean size on coffee cup quality, this study also explored potential distinctions between Conilon and Robusta coffee varieties, revealing that the majority of the beverage's cup quality characteristics are independent of the coffee bean variety (Fig. 1, Table 2). Based on the findings of the present study investigating the effects of altitude and post-harvest processing methods on the size of beans in Robusta and *Conilon coffee* samples, there is a significant correlation between higher elevations and increased bean size. Additionally, this study emphasized the significant impact of processing methods and altitude on screen retention for both types of coffee. These findings align with previous research on coffee varieties like Catura, Rume Sudan, and Blue Mountain, which often produce smaller beans associated with reduced cup quality (Njoroge, 1998). This emphasizes the importance of careful selection of the appropriate cultivar, variety, or even coffee species to attain the desired quality. It is worth noting that high-quality coffee typically comprises a blend of flat and caracol beans, incorporating large, medium, and small beans retained above screen size 14 (Hoffmann, 2018; Luna González et al., 2019). Previous studies have shown that coffee beans of screen size 15 have lower acidity, sweetness, and taster scores than those of any other size, with a significant difference in the final score of more than four points compared to the smaller screen size 13 or the larger sizes 17 and 18 (Luna González et al., 2019). Larger beans, often grown at altitudes exceeding 1,000 meters above sea level, tend to yield better-tasting coffee due to their extended maturation period on the tree, which allows for more comprehensive development (Papadopoulos, 2008). Furthermore, notable seasonal variations in the impact of climate on coffee bean size and defects were observed, with reduced rainfall in the late growing season associated with smaller beans, while diminished rainfall during the early growing season had the opposite effect (Kath et al., 2021).

Defects

In the current research, it was observed that all Robusta and Conilon variants exhibited defects falling within categories 1 and 2. The analysis of variance (ANOVA) results presented in Table 2 indicate that post-harvest processing had a more pronounced impact on the cupping quality of congolensis and Conilon variants at lower altitudes. Additionally, it was noted that higher elevations had a more significant effect on bean screen size, with an observed association between larger bean sizes and altitude. Table 2 suggests that small caracol beans and terceras beans are relatively rare, regardless of the altitude at which Conilon and Robusta coffee beans are grown and the post-harvest processing method. The significance of bean size during the roasting process is attributed to the softening of the bean's cellulose structure and the accumulation of pyrolysis byproducts, establishing bean size as a factor closely intertwined with the coffee's ultimate cup quality (Papadopoulos, 2008). Previous research has indicated that the sensory attributes of coffee brews are notably influenced by both peaberry and flat bean shapes, along with the fermentation process in both wet and semi-dry methods (Luna González et al., 2019). This is attributed to microbial activity during fermentation, which results in the production of diverse end-metabolites, subsequently exerting a substantial influence on the chemical composition of processed coffee (Wulandari et al., 2021; Cortés-Macías et al., 2022).

The flavour quality of brew coffee is an important factor that is linked to the presence of defective coffee beans. According to SCA, *specialty* coffee would not allow defects of category 1. Insect pests have devasting effects on the coffee plant, leading to the production of small low quality berries (Njoroge, 1998). After the threshing stage, defective beans become visible, and these must be identified and eliminated by physical analysis to prevent imbalances in the organoleptic properties of the coffee (Barrios Rodriguez et al., 2020). Higher rainfall during harvest was associated with an increased chance of coffee bean defects like mouldy beans and insect damage (Kath et al., 2021).

Table 3 shows the results of the Tukey HSD test, highlighting variations in cupping quality and

Table 3. Summary of means from Tukey HSD test for physical analysis

Process	Conilon			Robusta		
	12 m	625 m	1,700 m	12 m	625 m	1,700 m
Weight distribution for mesh 15/18						
Wet	14.0 (a)	27.7 (a)	6.9 (a)	34.4 (a)	19.8 (a)	19.6 (a)
Dry	52.3 (b)	39.3 (a)	32.2 (b)	23.5 (b)	18.0 (ab)	18.6 (a)
Honey	27.6 (c)	7.9 (b)	28.4 (b)	20.9 (b)	15.1 (b)	17.5 (a)
Defects of Category 1						
Wet	4.5 (a)	4.0 (a)	3.5 (a)	3.0 (a)	1.5 (a)	2.5 (a)
Dry	2.5 (b)	2.7 (ab)	1.7 (a)	2.3 (a)	0.8 (ab)	1.0 (ab)
Honey	1.0 (b)	1.0 (b)	1.5 (a)	1.5 (a)	0.2 (b)	0.5 (b)
Defects of Category 2						
Wet	3.7 (a)	3.2 (a)	2.7 (a)	3.3 (a)	0.7 (a)	1.5 (a)
Dry	2.0 (a)	2.7 (a)	2.0 (a)	2.5 (a)	0.5 (a)	0.8 (a)
Honey	1.5 (a)	2.5 (a)	0.7 (a)	2.3 (a)	0.5 (a)	0.5 (a)
Tasting notes						
Wet	44.8 (a)	15.4 (a)	5.7 (a)	22.2 (a)	14.0 (a)	6.8 (a)
Dry	54.8 (b)	27.8 (b)	5.6 (a)	35.6 (b)	17.8 (a)	13.4 (a)
Honey	43.4 (a)	14.8 (a)	5.7 (a)	44.8 (c)	42.6 (b)	6.6 (b)

[a,b] Identical letters indicate non-significant differences.

physical characteristics among Conilon and Robusta processed at various altitudes and subjected to different post-harvest processes. According to Table 3, the full defects (Category 1 + Category 2) did not reach a total of 8.0, which means that the samples are categorized as premium coffee (SCA, 2022). For this premium category, primary defects are permitted. A coffee is considered *specialty* when the number of Category 1 defects of green coffee beans is 0 (e.g., full black, sour, fungus damaged, foreign matter, and severe insect damage), and the number of Category 2 defects is ≤5 (e.g., immature/unripe, withered, broken, and floater defects) (SCA, 2022). The study found that all coffee samples from congolensis and Conilon had defects, which are associated with lower flavor quality. Specialty coffee does not allow Category 1 defects. Insect pests can lead to the production of small, low-quality berries. Defective beans must be identified and eliminated to maintain the coffee's sensory properties. The Robusta and Conilon samples in the study were categorized as *premium coffee*, which permits some primary defects.

Tasting notes

Figures 2 and 3 summarize the percentages of positive and negative tasting notes of cup samples prepared from beans of various altitudes using the different post-harvest processes. The results show that the most negative tasting notes came from coffee made from low altitude beans. The organoleptic qualities of canephora coffees were determined to be influenced more by altitude than by processing conditions.

For Conilon and Robusta processed by all three methods, the statistical analysis (Tables 2 and 3) revealed that the honey and wet processes contributed more to coffee cup quality at high altitudes ($p < 0.05$).

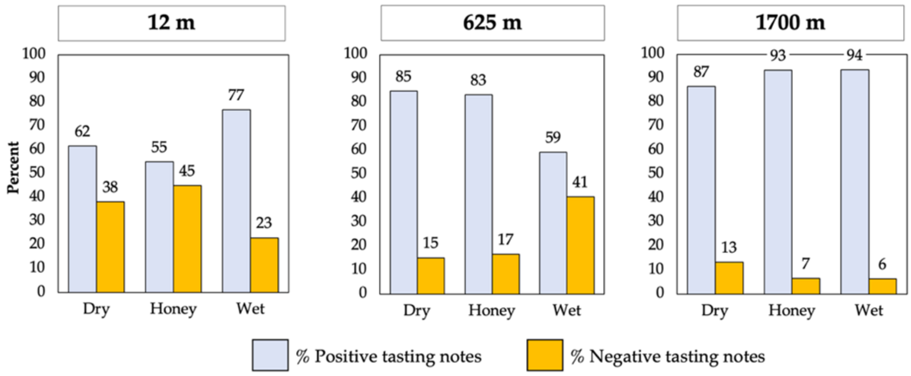

Fig. 2. Percentage of positive and negative tasting notes for Robusta cultivated at different altitudes

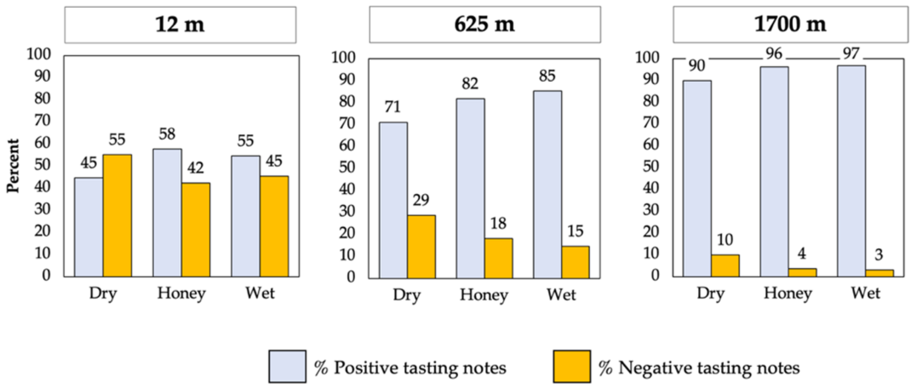

Fig. 3. Percentage of positive and negative tasting notes for Conilon cultivated at different altitudes

Figures 4 and 5 show the average scores for negative tasting notes on a scale from 1 to 10 for Robusta and Conilon coffees cultivated at different altitudes. Negative tasting notes were more prevalent at low elevations than at high altitudes, particularly for Conilon. Wet and honey processes had a favorable effect on the removal of unpleasant flavor notes in both species. Previous studies found that the best treatment for coffee beans was a combination of honey processing, 175ºC roasting temperature, and 15 minutes roasting time (Wulandari et al., 2021). This treatment resulted in high overall acceptance for the brewed aroma, brewed taste, brewed bitterness, ground fineness, and brewed viscosity; ground aroma, brewed acidity, and brewed sweetness were slightly less accepted (Wulandari et al., 2021).

The beverage´s astringent and musty taste and bitterness are due to the concentration of chlorogenic acid, and the proportions of several compounds present in the raw coffee bean; the presence of these acids indicates low product quality (Silva et al., 2022). Light-roasted coffees that emphasize the delightful acidity of a cup of coffee have flavours of citrus, fruit, and flowers (lime, tangerine, orange, raspberry). Dark-roasted coffees are associated with tasting notes of chocolate, caramelized sugars, almonds, smoke, malt, and molasses. Off-flavours like onion taste and butyric and propionic acids adversely affect the quality of coffee beans (Haile and Kang, 2019; Santosa et al., 2021).

The effect of full black, floater, broken, and insect damage defects on coffee cup quality is related to microbial growth, which gives coffee a stinky, dirty,

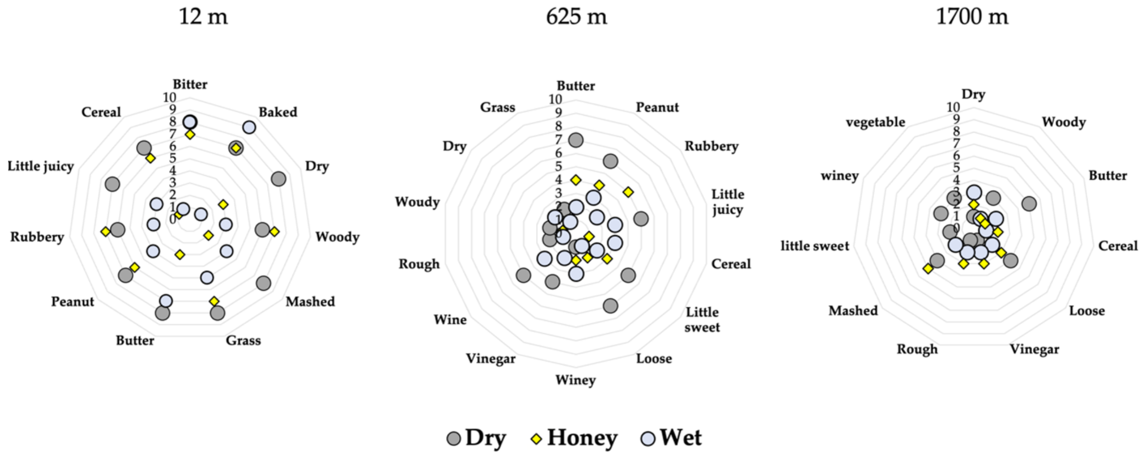

Fig. 4. Average scores for negative tasting notes on a scale from 1 to 10 for Robusta coffee cultivated at different altitudes

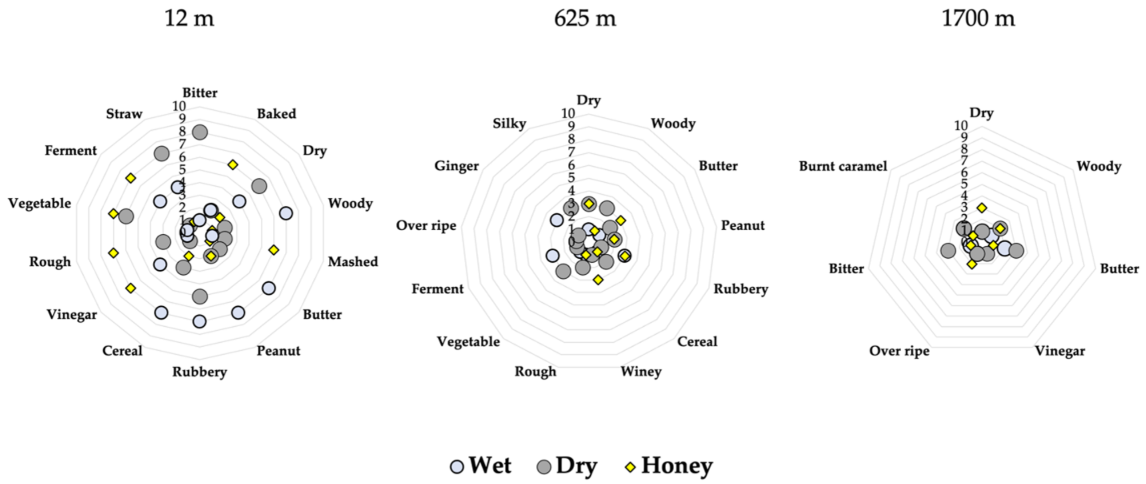

Fig. 5. Average scores for negative tasting notes on a scale from 1 to 10 for Conilon coffee cultivated at different altitudes

mouldy, sour, and phenolic flavour (Franca et al., 2005). Fungus damage affects cup quality by delivering a fermented, mouldy, earthy, dirty, and phenolic flavour (SCA, 2022).

Figures 6 and 7 present the average scores assigned to positive tasting notes, rated on a scale from 1 to 10, for Robusta and Conilon coffee. Notably, the data reveals a greater abundance of positive tasting notes for coffee grown at higher elevations. It is important to highlight that this altitude-driven distinction proved to be more influential than the effects of different processing conditions. In this context, the current findings diverge from those of other studies that claim various post-harvest and processing treatments have an impact on the sensory quality of ground and brewed coffee (Wulandari et al., 2021).

A numerical scoring system, ranging from 1 to 10, quantifies sensory descriptions, enabling easy comparative analysis. Calculating the percentages of positive and negative notes succinctly presents flavor trends for

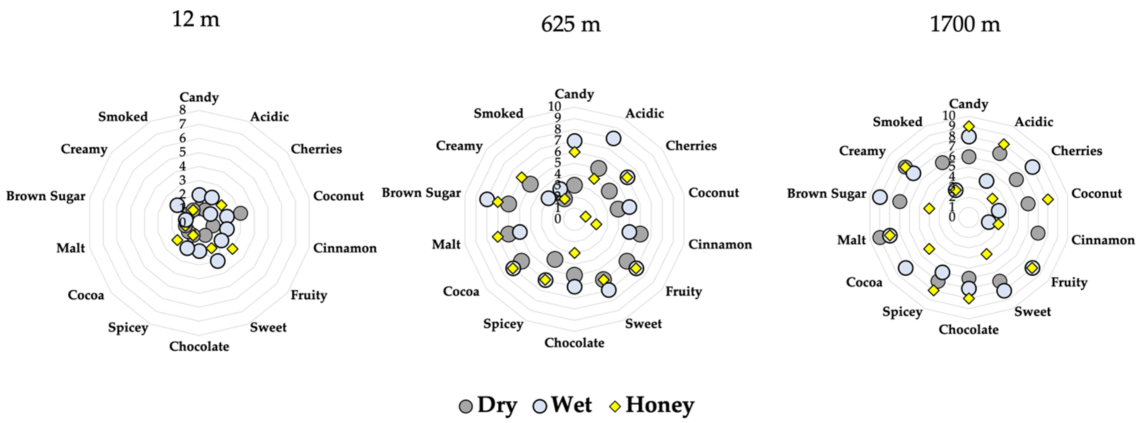

Fig. 6. Average scores for positive tasting notes on a scale from 1 to 10 for Robusta coffee cultivated at different altitudes

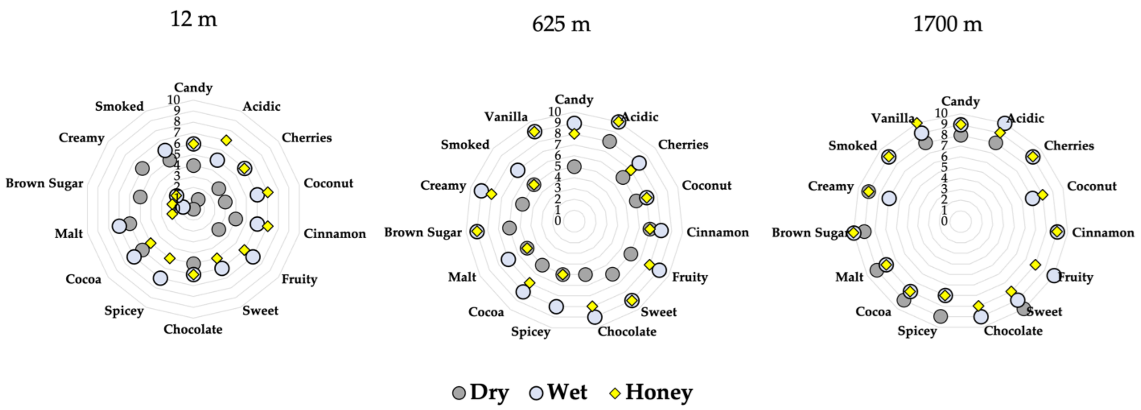

Fig. 7. Average scores for positive tasting notes on a scale from 1 to 10 for Conilon coffee cultivated at different altitudes

coffee species and altitudes, providing an overview of dominant taste traits. In this context, the study revealed that beans from low altitudes exhibited the most pronounced effects related to defects in coffee tasting notes. Altitude notably influenced the organoleptic qualities of Robusta coffees more than processing conditions. No significant difference emerged between the effect of processing method on coffee cup quality for Conilon and the same effect for Robusta. Defects such as full black, floater, broken, insect damage, and fungus damage detrimentally affected cup quality by introducing unpleasant flavors. Varied roasting levels were correlated with distinct tasting notes, spanning from citrus and fruit to chocolate and caramelized sugars.

CONCLUSION

This study investigated the impact of altitude and post-harvest processing methods on bean size, defects, and final cup quality in canephora coffee. The study found that higher altitudes correlated with larger beans, and that processing methods and altitude significantly affected bean screen retention for both coffee varieties. Among both Conilon and Robusta coffees processed using all three post-harvest processes methods, it was observed that the honey and wet processing methods had a more significant impact on the quality of the coffee when cultivated at higher altitudes. Screen retention was significantly affected by post-harvest processing and elevation. However, at altitudes up to 1,700 meters, the screen sizes were not statistically different for the three post-harvest processes, especially for the Congolensis samples. Large coffee beans are generally considered to be of higher quality, but this is not always the case. The findings of this study are aligned with previous research on other coffee varieties, which often produce smaller beans associated with reduced cup quality. To manage the quality and safety of coffee, international guidelines have been developed for the application of good manufacturing practices throughout the entire production and distribution chains, along with criteria for certification and traceability. This work provides insights into the complexities of Robusta coffee production and highlights the need for careful consideration of pre- and post-harvest processing factors in order to produce high-quality coffee.

REFERENCES

Ameyu, M. A. (2016). Physical Quality Analysis of Roasted Arabica Coffee Beans Subjected to Different Harvesting and Postharvest Processing Methods in Eastern Ethiopia. Food Sci. Qual. Manag., 57.

Andueza, S., Vila, M. A., Paz de Peña, M., Cid, C. (2007). Influence of coffee/water ratio on the final quality of espresso coffee. J. Sci. Food Agric., 87(4), 586–592. https://doi.org/10.1002/jsfa.2720

Aswathi, K. N., Shirke, A., Praveen, A., Chaudhari, S. R., Murthy, P. S. (2023). Pulped natural/honey robusta coffee fermentation metabolites, physico-chemical and sensory profiles. Food Chem., 429, 136897. https://doi.org/10.1016/j.foodchem.2023.136897

Ayalew, B., Hylander, K., Zewdie, B., Shimales, T., Adugna, G., Mendesil, E., Nemomissa, S., Tack, A. J. M. (2022). The impact of shade tree species identity on coffee pests and diseases. Agric. Ecosyst. Environ., 340, 108152. https://doi.org/10.1016/j.agee.2022.108152

Barrios Rodriguez, Y. F., Salas Calderon, K. T., Girón Hernández, J. (2020). Comparison of sensory attributes and chemical markers of the infrared spectrum between defective and non-defective Colombian coffee samples. Coffee Sci., 15, 1-10. https://doi.org/10.25186/.v15i.1659

Bastian, F., Hutabarat, O. S., Dirpan, A., Nainu, F., Harapan, H., Emran, T. B., Simal-Gandara, J. (2021). From plantation to cup: changes in bioactive compounds during coffee processing. Foods, 10(11), 2827. https://doi.org/10.3390/foods10112827

Belay, A., Bekele, Y., Abraha, A., Comen, D., Kim, H. K., Hwang, Y.-H. (2014). Discrimination of defective (full black, full sour and immature) and nondefective coffee beans by their physical properties: defective and nondefective physical properties. J. Food Proc. Eng., 37(5), 524–532. https://doi.org/10.1111/jfpe.12113

Byrareddy, V., Kouadio, L., Mushtaq, S., Kath, J., Stone, R. (2021). Coping with drought: Lessons learned from robusta coffee growers in Vietnam. Clim. Serv., 22, 100229. https://doi.org/10.1016/j.cliser.2021.100229

Campuzano-Duque, L. F., Herrera, J. C., Ged, C., Blair, M. W. (2021). Bases for the establishment of robusta coffee (*Coffea canephora*) as a new crop for Colombia. Agronomy, 11(12), 2550. https://doi.org/10.3390/agronomy11122550

Chain-Guadarrama, A., Martínez-Salinas, A., Aristizábal, N., Ricketts, T. H. (2019). Ecosystem services by birds and bees to coffee in a changing climate: A review of coffee berry borer control and pollination. Agric. Ecosyst. Environ., 280, 53–67. https://doi.org/10.1016/j.agee.2019.04.011

Chindapan, N., Soydok, S., Devahastin, S. (2019). Roasting kinetics and chemical composition changes of robusta coffee beans during hot air and superheated steam roasting. J. Food Sci., 84(2), 292–302. https://doi.org/10.1111/1750-3841.14422

Cortés-Macías, E. T., López, C. F., Gentile, P., Girón-Hernández, J., López, A. F. (2022). Impact of post-harvest treatments on physicochemical and sensory characteristics of coffee beans in Huila, Colombia. Postharvest Biol. Technol., 187, 111852. https://doi.org/10.1016/j.postharvbio.2022.111852

di Donfrancesco, B., Gutierrez Guzman, N., Chambers, E. (2019). Similarities and differences in sensory properties of high quality Arabica coffee in a small region of Colombia. Food Res. Int., 116, 645–651. https://doi.org/10.1016/j.foodres.2018.08.090

Evangelista, S. R., Silva, C. F., da Cruz Miguel, M. G. P., Cordeiro, C. de S., Pinheiro, A. C. M., Duarte, W. F., Schwan, R. F. (2014). Improvement of coffee beverage quality by using selected yeasts strains during the fermentation in dry process. Food Res. Int., 61, 183–195. https://doi.org/10.1016/j.foodres.2013.11.033

Folmer, B. (Ed.). (2017). The craft and science of coffee. Vol. 1. Cambrigde, MA: Academic Press.

Franca, A. S., Oliveira, L. S., Mendonça, J. C. F., Silva, X. A. (2005). Physical and chemical attributes of defective crude and roasted coffee beans. Food Chem., 90(1-2), 89–94. https://doi.org/10.1016/j.foodchem.2004.03.028

Girma, B., Sualeh, A. (2022). A Review of Coffee Processing Methods and Their Influence on Aroma. Int. J. Food Eng. Technol., 6(1), 7. https://doi.org/10.11648/j.ijfet.20220601.12

Haile, M., Kang, W. H. (2019). The role of microbes in coffee fermentation and their impact on coffee quality. J. Food Qual., 2019, 1–6. https://doi.org/10.1155/2019/4836709

Hameed, A., Hussain, S. A., Ijaz, M. U., Ullah, S., Pasha, I., Suleria, H. A. R. (2018). Farm to consumer: factors affecting the organoleptic characteristics of coffee. II: Postharvest processing factors: farm to consumer… Compr. Rev. Food Sci. Food Saf., 17(5), 1184–1237. https://doi.org/10.1111/1541-4337.12365

Hoffmann, J. (2018). The World Atlas of Coffee: From beans to brewing—Coffees explored, explained and enjoyed. London: Octopus.

Johnson, M. A., Ruiz-Diaz, C. P., Manoukis, N. C., Verle Rodrigues, J. C. (2020). Coffee berry borer (*Hypothenemus hampei*), a global pest of coffee: perspectives from historical and recent invasions, and future priorities. Insects, 11(12), 882. https://doi.org/10.3390/insects11120882

Kath, J., Mittahalli Byrareddy, V., Mushtaq, S., Craparo, A., Porcel, M. (2021). Temperature and rainfall impacts on robusta coffee bean characteristics. Clim. Risk Manag., 32, 100281. https://doi.org/10.1016/j.crm.2021.100281

Kittichotsatsawat, Y., Jangkrajarng, V., Tippayawong, K. Y. (2021). Enhancing coffee supply chain towards sustainable growth with big data and modern agricultural technologies. Sustainability, 13(8), 4593. https://doi.org/10.3390/su13084593

Leroy, T., De Bellis, F., Legnate, H., Musoli, P., Kalonji, A., Loor Solórzano, R. G., Cubry, P. (2014). Developing core collections to optimize the management and the exploitation of diversity of the coffee *Coffea canephora*. Genetica, 142(3), 185–199. https://doi.org/10.1007/s10709-014-9766-5

Linda, M., Bastian, F., Mahendradatta, M., Tawali, A. B., Laga, A. (2023). The effect of several postharvest processing on the quality of Robusta Coffee (*Coffea canephora*). IOP Conference Series: Earth and Environmental Science, 1200(1), 012011. https://doi.org/10.1088/1755-1315/1200/1/012011

Loor Solórzano, R. G., De Bellis, F., Leroy, T., Plaza, L., Guerrero, H., …, Vera, D. (2017). Revealing the diversity of introduced *Coffea canephora* germplasm in Ecuador: Towards a National Strategy to Improve Robusta. Sci. World J., article ID 1248954, 1–12. https://doi.org/10.1155/2017/1248954

Luna González, A., Macías Lopez, A., Taboada Gaytán, O. R., Morales Ramos, V. (2019). Cup quality attributes of Catimors as affected by size and shape of coffee bean (*Coffea arabica* L.). Int. J. Food Properties, 22(1), 758–767. https://doi.org/10.1080/10942912.2019.1603997

Nadaleti, D. H. S., de Rezende Abrahão, J. C., Malta, M. R., Dos Santos, C. S., Pereira, A. A., Carvalho, G. R. (2022). Influence of postharvest processing on the quality and sensory profile of groups of arabica coffee genotypesc. J. Sci. Food Agric., 102(15), 6899–6906. https://doi.org/10.1002/jsfa.12051

Njoroge, J. M. (1998). Agronomic and processing factors affecting coffee quality. Outlook Agric., 27(3), 163–166. https://doi.org/10.1177/003072709802700306

Oliva, M., Rubio, K. B., Chinguel, D., Carranza, J., Bobadilla, L. G., Leiva, S. (2023). Coffee berry borer infestation and population per fruit relationship with coffee variety, shade level, and altitude on specialty coffee farms in Peru. Int. J. Agron., 2023, 1–10. https://doi.org/10.1155/2023/6782173

Papadopoulos, K. N. (2008). Food chemistry research developments. Hauppauge, NY: Nova Science Publishers.

Pereira, L., Guarçoni, R., Pinheiro, P., Osório, V., Pinheiro, C., Moreira, T., Schwengber, C. (2020). New propositions about coffee wet processing: Chemical and sensory perspectives. Food Chem., 310, 125943. https://doi.org/10.1016/j.foodchem.2019.125943

Pinsuwan, A., Suwonsichon, S., Chompreeda, P., Prinyawiwatkul, W. (2022). Sensory drivers of consumer acceptance, purchase intent and emotions toward brewed black coffee. Foods, 11(2), 180. https://doi.org/10.3390/foods11020180

Portela, C. da S., Almeida, I. F. de, Reis, T. A. D. dos, Hickmann, B. R. B., Benassi, M. de T. (2022). Effects of brewing conditions and coffee species on the physicochemical characteristics, preference, and dynamics of sensory attributes perception in cold brews. Food Res. Int., 151, 110860. https://doi.org/10.1016/j.foodres.2021.110860

R Core Team (2022). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Accesed from: https://www.R-project.org/

Ramalakshmi, K., Kubra, I. R., Rao, L. J. M. (2007). Physicochemical characteristics of green coffee: comparison of graded and defective beans. J. Food Sci., 72(5), S333–S337. https://doi.org/10.1111/j.1750-3841.2007.00379.x

Santosa, K. M., Supriyadi, S., Anggrahini, S., Rahmadian, Y. (2021). Sensory analysis, caffeine, chlorogenic acid and non-volatile taste compounds of arabica coffee

(*Coffea arabica*) fermented with sugar addition for brew taste. Indones. Food Nutr. Prog., 17(2), 37. https://doi.org/10.22146/ifnp.52241

SCA (2022). Protocols & Best Practices. Specialty Coffee Association. Accessed from: https://www.scaa.org/PDF/resources/cupping-protocols.pdf

Schwan, R., Fleet, G. (2014). Cocoa and Coffee Fermentations. 1st ed. Boca Raton: CRC Press.

Seninde, D. R., Chambers, E. (2020). Coffee Flavor: A Review. Beverages, 6(3), 44. https://doi.org/10.3390/beverages6030044

Silva, C. S. da, Coelho, A. P. de F., Lisboa, C. F., Vieira, G., Teles, M. C. de A. (2022). Post-harvest of coffee: Factors that influence the final quality of the beverage. Revista Engenharia Na Agricultura – REVENG, 30, 49–62. https://doi.org/10.13083/reveng.v30i1.12639

Tassew, A. A., Yadessa, G. B., Bote, A. D., Obso, T. K. (2021). Influence of location, elevation gradients, processing methods, and soil quality on the physical and cup quality of coffee in the Kafa Biosphere Reserve of SW Ethiopia. Heliyon, 7(8), e07790. https://doi.org/10.1016/j.heliyon.2021.e07790

Torrez, V., Benavides-Frias, C., Jacobi, J., Speranza, C. I. (2023). Ecological quality as a coffee quality enhancer. A review. Agron. Sustain. Dev., 43(1), 19. https://doi.org/10.1007/s13593-023-00874-z

Velásquez, S., Banchón, C. (2022). Influence of pre-and post-harvest factors on the organoleptic and physicochemical quality of coffee: A short review. J. Food Sci. Technol., https://doi.org/10.1007/s13197-022-05569-z

Velásquez, S., Banchón, C., Chilán, W., Guerrero-Casado, J. (2022). Effect of three post-harvest methods at different altitudes on the organoleptic quality of *C. canephora* coffee. Beverages, 8(4), 83. https://doi.org/10.3390/beverages8040083

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. 1st ed. New York: Springer-Verlag. Accessed from: https://ggplot2.tidyverse.org

Wulandari, S., Ainuri, M., Sukartiko, A. C. (2021). Biochemical content of Robusta coffees under fully-wash, honey, and natural processing methods. IOP Conference Series: Earth and Environmental Science, 819(1), 012067. https://doi.org/10.1088/1755-1315/819/1/012067

Wulandari, S., Ainuri, M., Sukartiko, A. C. (2022). Sensory evaluation of robusta coffee under various postharvest and processing. 2nd International Conference on Smart and Innovative Agriculture (ICoSIA 2021), Yogyakarta, Indonesia. https://doi.org/10.2991/absr.k.220305.061