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Effect of roasting on the physicochemical and sensory characteristics of coffee (*Coffea arabica* var. Pacas) with various processing methods.

Presented by:

Leonela Vanessa Madrid Mejia

Advisors

Jorge Cardona, Ph.D

Raúl Espinal, Ph.D

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Authorities

SERGIO ANDRÉS RODRÍGUEZ ROYO

President

ANA M. MAIER ACOSTA

Vice President and Academic Dean

ADELA M. ACOSTA MARCHIETTI

Head of Food Science and Technology Department

HUGO ZAVALA MEMBREÑO

General Secretary

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Abstract

Coffee is typically processed in three ways: dry method (Natural coffee), semi-dry method (Honey coffee) and wet method (Washed coffee). The choice of processing method has a significant impact on the overall taste and aroma. Roasting is another critical stage in coffee production. Light, medium, and dark roast are three of the most common roast levels for coffee beans, each offering distinct flavor profiles and characteristics. The investigation aimed to determine the consumer´s preferred and most accepted roast level for the Pacas variety from La Cabaña Farm subjected to three postharvest processing methods and to analyze differences in the physicochemical composition. Density, Moisture, Color, Phenolic Compounds and Titrable Acidity were measured to determine the physicochemical changes. Acceptance and Preference evaluations with untrained panelists were performed to better understand consumer´s preferences. This resulted that preferred roast level for the Pacas variety was Dark, followed by Medium and Light. As for acceptance, consumers did not found differences between roasting levels but did prefer Dark roast in color acceptance, they also showed preference for Honey coffee under Medium roast level. Natural coffee presented higher yield regardless of the roasting level and lighter color compared to the other two processing methods. Acidity and Phenolic Compounds decreased as roasting level increased. In conclusion, this study highlighted the influence of roast level and postharvest processing methods on consumer preferences and physicochemical changes.

Key words: Cupping, Mucilage, Phenolic compounds, Physicochemical characteristics, Post-harvest, Pulping.

Resumen

El café generalmente se procesa de tres formas: método seco (café natural), semi-seco (café melado) y húmedo (café lavado). La elección del método de procesamiento tiene un impacto en el sabor y el aroma en general. El tueste es otra etapa crítica en la producción de café. Los niveles de tostado más comunes son ligero, medio y oscuro, cada uno con perfiles de sabor y características distintas. La investigación tuvo como objetivo determinar el nivel de tostado preferido y más aceptado por los consumidores para la variedad Pacas de Finca La Cabaña, sometida a tres métodos de procesamiento postcosecha, y analizar las diferencias en la composición fisicoquímica. Se midió densidad, humedad, color, compuestos fenólicos y acidez titulable para determinar los cambios fisicoquímicos. Se realizaron evaluaciones de aceptación y preferencia con panelistas no entrenados para comprender las preferencias de los consumidores. El nivel de tostado preferido fue el oscuro, seguido del medio y el ligero. En cuanto a la aceptación, los consumidores no encontraron diferencias entre los niveles de tostado, pero mostraron mayor aceptación por el tostado oscuro en cuanto a la aceptación del color; también mostraron preferencia por la café melado en tueste medio. El café natural presentó un mayor rendimiento independientemente del nivel de tostado y un color más claro. La acidez y los compuestos fenólicos disminuyeron a medida que aumentaba el nivel de tostado. Este estudio resaltó la influencia del nivel de tostado, métodos de procesamiento postcosecha, y cambios fisicoquímicos sobre las preferencias de los consumidores

Palabras clave: Características fisicoquímicas, Catación, Compuestos fenólicos, Despulpado, Mucílago, Postcosecha.

Introduction

Honduras is one of the most important coffee-producing countries in the world, holding the first place in Central America, ranking third in Latin America, and seventh globally (Avila, 2023). According to the Honduran Coffee Institute, coffee is not only the leading agricultural export product but also contributes over 3% to the national gross domestic product and nearly 30% to the agricultural gross domestic product (Instituto Hondureño del Café [IHCAFE], 2016).

The quality of coffee is closely associated with both pre-harvest and post-harvest management practices. Every step, from selecting the right coffee variety for planting to the final coffee preparation, profoundly impacts the cupping quality. Typically, coffee is processed using one of three methods: wet, dry, or semi-dry (Haile & Hee Kang, 2020). Most coffee buyers pay premiums based on quality. In some cases, it may be quite straightforward: all coffees with a score higher than 80 or 84, for instance, receive a higher price. The price of coffee often hinges on its quality and cupping performance, making grain processing a matter of economic importance (Raad T, 2018).

Dry processing, also known as natural processing, is the simplest technique for producing green coffee beans but is known to be challenging for obtaining high-quality coffee (Bastian et al., 2021). In dry processing, whole or intact coffee fruits are dried without removing the exocarp (Taveira et al., 2015). During natural processing, fermentation takes place in the pulp and mucilage of the coffee beans while they are being dried, driven by pectinolytic microorganisms that produce alcohols, organic acids, and other metabolites (Velásquez & Banchón, 2022). These coffees typically have a flavor profile characterized by low acidity, full body, and cherry or fruity/wine-like notes (Bastian et al., 2021). In wet processing, harvested coffee cherries are depulped, spontaneously fermented underwater for various hours, soaked, and dried. This fermentation stage aims to remove the mucilage firmly attached to the beans, and it is carried out by microorganisms originating from the cherry surfaces, plantation environment, or processing equipment (Zhang et al., 2019). The flavor profile of these coffees, which are known as washed, typically includes floral and fruity notes, a light body, and a clean cup. Finally, the honey processed stands as an intermediate approach between the natural and washed processes.

Semi-dry processing combines aspects of both, with coffee fruits mechanically pulped and then dried without removing the mucilage (Velásquez & Banchón, 2022). The mucilage composition consists of polysaccharides, pectin, and monosaccharides, which impart a sugary aroma to the semi-dry process (Bastian et al., 2021). The flavor profile of these coffees in the cup is sweet, fruity, and moderately acidic.

Roasting is another critical stage in coffee production, enhancing color, aroma, and flavor. The mechanism of heat transfer and the temperature profile used are pivotal processing characteristics that significantly impact the physical and chemical qualities of roasted coffee. Roasting is typically conducted at temperatures ranging from 170 °C to 230 °C and involves three main phases: drying, roasting, and cooling (Seninde & Chambers, 2020). The coffee roasting process consists of key phases: drying, where free water is removed, leading to aroma and color changes; the roasting phase, marked by pyrolytic reactions, gas production, and bean swelling. "First crack" initiates actual roasting, resulting in full-bodied, acidic, and aromatic coffee. Subsequent "second crack" leads to dark roasting and oil release, although it diminishes acidity and aroma richness but enhances body. Further roasting causes charring and a pronounced burnt taste. The process concludes with rapid cooling (Yeretzian et al., 2002).

Gran Sauce Coffee Roaster is a Honduran roaster, established in 2008 when Franklin Madrid won the national Cup of Excellence, creating the necessity of selling Santa Barbara Coffee to not only international consumers. Denilson Madrid and his father Franklin started selling their coffee and noticed the lack of standardization in their coffee´s flavor profiles. Having quality and quantity of coffee meant for them standardizing processes on farm level. This is why the looking for a specific roast and processing method that is preferred by their consumers is vital to ensure both quantity and quality.

Therefore, the present investigation aims to determine the consumer´s preferred and most accepted roast level (dark, medium, or light) for the Pacas variety from La Cabaña Farm subjected to three postharvest processing methods (washed, honey and natural) and to analyze differences in the physicochemical composition of the samples evaluated.

Materials and Methods

Location of the Study

Collection of the coffee samples was done in San Luis Planes, El Sauce, Santa Barbara where the coffee farm is located. Cupping of the samples was carried by the Honduran Institute of Coffee in La Fé, Santa Cruz de Yojoa, Cortés. Roasting, density, humidity, and color were evaluated at the Fruit and Vegetable Processing Plant in Zamorano University. Sensory analyses were performed at the Sensory Analysis Laboratory of the Food Innovation Plant (PIA), the Pan-American Celebration, Smith Falk Student Center and the Fruit and Vegetables Processing plant in Zamorano University. Acidity and phenolic compounds were measured in the Zamorano Food Analysis Laboratory (LAAZ).

Raw Material Collection

43.5 Quintals of ripe coffee beans (var. Pacas) were manually harvested on March 20th in La Cabaña farm Lot #1, located in San Luis Planes, El Sauce in Santa Barbara Department at 1700 meters above sea level. The coffee trees were approximately 10 years old (7th harvest) only ripe cherries were selected on the harvesting following a conventional management.

Ripe beans were immediately depulped after harvest in the same farm using a horizontal ETERNA Model 3 depulping machine for wet and semi-dry processing samples. Washed coffee (wet processing) was depulped and fermented aerobically in a concrete tank, at room temperature (15-20°C) for 24 hours. Upon completion of fermentation, samples were washed to remove the mucilage in the same tank and put on to dry in a solar dryer with lifted structures (African beds). Drying lasted 21 days after set to dry (March 20th to April 11th) for washed coffee. Honey coffee (semi-dry processing) was depulped and immediately set to dry in the solar dryer. Drying of Honey coffee lasted 23 days (March 20th to April 13th). Natural coffee (dry processing) was also set on to dry the same day in the solar dryer. Drying of Natural coffee lasted 24 days (March 20th to April 13th). Moisture was not measured by the farm owner after drying was completed. Drying temperatures were also not measured during the drying of the coffee.

Dried parchment coffee was stored for 61 days and hulled until June 13th. Hulled coffee was stored for 13 days and sent to Zamorano on June 26th packed in two plastic bags and a cardboard box. 6.80 Kilograms of each coffee process in green beans were received.

Three coffee samples were analyzed following the Specialty Coffee Association's Coffee Cupping Protocol. The samples were roasted and allowed to rest, then ground and brewed. Evaluation included attributes like Fragrance/Aroma, Flavor, Aftertaste, Acidity, Body, Balance, Uniformity, Clean Cup, Sweetness, Defects, and Overall. Each attribute was scored, and the Overall score was based on the cupper's appraisal of the combined attributes. The process followed strict temperature-based steps during cooling. The Final Score was calculated by adding all scores, adhering to the Specialty Coffee Association's Protocol.

Experimental Design

The research was carried out using three processing methods and three roasting levels, resulting in a total of nine treatments. Each of the treatments had three replicates, resulting in a total of 27 experimental units. A Completely Randomized Design was used.

Roasting

Roasting of samples was carried out using the IKAWA pro-50 roaster with an electric convection roasting system (hot air flow) and Bluetooth connectivity to link with any electronic device. Three roasting curves (light, medium and, dark) were provided by Gran Sauce Coffee Roasters´ Chief Executive Manager and roaster Denilson Madrid. Light roast started with 150 °C of initial temperature ending at 196 °C in 6.97 minutes, and immediate cooling for one minute. Medium roast started with the same initial temperature (150 °C) ending at 203 °C in 9.43 minutes and immediately cooled down for almost two minutes. Dark roast also started at 150 °C going up to 210 °C in 11.97 minutes and immediately cooled down for two minutes. The three coffee processes were roasted under the same curves (light, medium and dark) previously explained for a total of nine samples.

Grinding

Grinding of the samples was conducted using MAHLKONIG EK43 Allround Grinder. All the samples were grinded on level 12 by recommendations of Denilson Madrid. Samples were grinded one by one with cleaning of the equipment between samples to avoid combining of the coffees.

Density

Density of green and roasted beans was measured using a volumetric test tube and a AND EJ-610 balance. 100 grams of coffee beans were placed inside a volumetric test tube to quantify its volume. Density was calculated using the formula: (grams of coffee/ volume of coffee in mL) x 1,000.

Moisture Content

Moisture measure was done with Sinar® CP7070 Coffee Moisture equipment with an accuracy of ±0.5% for %H2O. Sinar Technology instrumentation uses the relationship between moisture content and the sample´s dielectric constant as the basis of measurement. The dielectric constant of water is 81, whereas the dielectric constant of most materials of vegetable origin is quite low, ranging from 2.2 to 4.0 in a dry condition. The presence of a very small quantity of water in the material will, therefore, cause a considerable change in the dielectric constant of the combined system. Therefore, this direct link between Moisture Content and dialectic content enables Sinar Analyzers to predict, successfully the Moisture Content of a wide range of samples (Sinar Technology, 2016). Results were shown in percentage of moisture content. For each measurement 50 grams of coffee were poured into the equipment and samples were read.

Color Measurement

Color was measured after grinding of each sample using the Colorimeter App which is specifically designed to analyze and evaluate the color of light reflected by objects such as solids, liquids, and powders. The app employs a range of color analysis metrics and algorithms to provide comprehensive insights into the color properties of the sample. So that the results were accurate a cardboard box with a white illuminated interior and a slit where the camera is placed to control the distance and angle of the samples with the camera was used.

Titratable Acidity

Samples were prepared using the methodology of Jeszka-Skowron et al. (2016) with some modifications. One gram of grinded coffee was weighed into conical centrifuge tubes, 50 mL of distilled water at 90 °C was added, maintaining this temperature for 10 minutes. This extract was centrifuged at 3500 rpm for 5 minutes. Following this, the supernatant was filtered through a coffee filter paper.

Acidity of the brew was measured following the AOAC Official Method 942.15 Acidity (Titrable) of Fruit Products. 250 mL of neutralized water were diluted with 10 g of prepared brew. 100 mL of this solution were titrated using 0.1 M alkali (NaOH) and 0.3 mL of phenolphthalein until pH reached 8.2. Results were expressed in mL of NaOH per 100 g of grinded coffee.

Total Phenolic Compounds

According to the procedure of Singleton et al. (1999) and Wolfe et al. (2003), total polyphenols were quantified using the Folin-Ciocalteu method with modifications. Sixty microliters (60 µL) of the sample were mixed with 3 mL of distilled water and 250 µL of Folin-Ciocalteu's reagent (1 N). Then, it was allowed to stand for 5 minutes at room temperature, and 750 µL of 20% Na2CO3 and 950 µL of distilled water were added. After completing this procedure, it was allowed to equilibrate for 30 minutes at room temperature, and readings were taken using Cary 8454, Agilent Technologies, USA UV/VIS spectrophotometer at 765 nm. To compare the results, a calibration curve was made using gallic acid dissolved in water at concentrations of 100, 200, 300, 400, 500, 700, and 100 parts per million. Results were expressed in milligrams of gallic acid equivalents per gram of roasted coffee. The standard curve had an R^2 of 0.9954.

Sensory Analysis

Coffee was prepared using a Durabrand Coffee Maker of 12 cups by recommendation of Denilson Madrid. Coffee brew was prepared following the SCA Standard 310-2021 Home Coffee Brewers: Specifications and Test Methods (Specialty Coffee Association, 2022). This standard assumes the amounts of coffee and water used are parameters under the consumer’s control, and therefore a good quality of brew and optimal extraction shall be produced by complying brewers under typical

conditions of household use. This standard covers the specifications and test methods for filter coffee electrical brewers designed for home use at atmospheric pressure. In this standard, brew ratio is expressed in grams of coffee per 1 kg of fresh water. Brew ratio used for testing in this standard is 55 g of coffee per 1 kg of fresh water. Brew temperature was 90 to 96 °C. For each panel, 49.5 g of grinded coffee were used to make 900 mL of brew. Panelists were presented with three randomly coded cups each containing approximately 30 mL of brewed coffee.

The sensory analysis was divided in two stages. First stage was evaluation of roasting levels in which panelists were provided with three samples of the same coffee process (Natural, Honey or, Washed) but with different roasting levels (Light, Medium or, Dark). Second stage was evaluation of coffee process (Natural, Honey or, Washed) in which panelists were provided with three samples with the same roasting level (Medium or Dark). A sensory Evaluation Form was completed by each panelist. This form had two parts: Acceptance and Preference. The first part of the evaluation form was Acceptance in which panelists evaluated six variables: Color, Sweetness, Bitterness, Body, Aftertaste, and General Acceptance, with a 9-point hedonic scale from 1 (I am extremely disgusted) to 9 (I extremely like it). The second part was preference, in which panelists ordered the samples numerically being 1 the most preferred. Sensory Analyses had three repetitions of 30 panelists which made a total of 9 panels in the first stage and only 6 in the second stage since two roast levels were evaluated (Medium and Dark) based on results from the first stage.

Statistical Analysis

Results of Sensory Analyses were analyzed on SAS OnDemand for Academics®. A Randomized Block Design and Duncan´s Means separation was used for the Acceptance stage. Basker and Kramer Sum of Categories was used for Preference stage of Sensory Analyses. Analysis of Variance (ANOVA) with $P \leq 0.05$ was used for physicochemical results.

Results and Discussion

Preliminary Sensory and Physical Assessment of Samples

Washed coffee was reported to have a final score of 89.00, Natural coffee had 87.00 and Honey had 86.50. Washed coffee was better evaluated in Fragrance/Aroma, Flavor, Aftertaste, Acidity, Body, Balance, and Cupping Score in comparison with Honey and Natural coffee. Honey had the lowest scores on Flavor and Aftertaste but the same score as Natural in Fragrance/Aroma, Acidity, Body, Balance, and Cupping Score. According to the Alliance for Coffee Excellence, Santa Barbara Coffee has won the Cup of Excellence for two consecutive years (2022 and 2023), and every year Santa Barbara Coffees have placed themselves in the first places (Alliance For Coffee Excellence, 2023). According to Parlor Coffee (2023), the finest Santa Bárbara coffees are dense on the tongue, with saturated sugars, jammy textural tones, and tropical-fruit acidity. Sensory profile described Washed coffee with ripe mango and passionfruit notes with base of almond milk and a background of cinnamon and blueberries. Honey profile was ripe banana with base of walnuts and background of maple syrup and berries. Natural profile presented mint tea notes with base of peanut butter and background of cloves and green grapes. According to the Organoleptic Report, all three samples were fitted as Special Excellent coffee (85-89.99 points).

A Defect count was carried with 350g of green coffee beans by processing method (Washed, Natural and Honey). Washed coffee had more Full Defects than Honey and Natural coffee. Most Full damages for Washed coffee were counted on Full Black (13 Full Defects) and Partial Black beans (10 Full Defects). Full Black beans occur when coffee cherries are picked either unripe or overripe. These beans are the result of over-fermentation inside the fruit before harvesting and processing, resulting in a strong alcoholic fermentation flavor and a heavy, sour vinegar taste in the coffee (IOCoffee, 2023).

Density for all three coffee processes was the same in green beans being 0.746 g/mL. Altitude is one of the main factors that affects the density of coffee beans. At higher altitudes coffee cherries ripen more slowly, resulting in beans that are denser. Denser beans also contain higher levels of sugar, resulting in more complex and sweeter cup profiles. The cherries mature for longer because higher

altitudes typically offer consistently cool temperatures all year round. This is important, as the arabica plant grows optimally at temperatures between 18 and 21 °C. Outside of this range, the fruit will mature too quickly (Castellano, 2021).

Moisture content of green beans for Natural coffee was 11%, Honey 11.5% and, Washed 12.26%.

Phase I. Physicochemical Analyses

Density

Density results for roasted coffee showed that Dark roasts are less dense than Medium and Light. Roast influenced density results since P= <.0001, while process did not (P= 0.1984), however the interaction of them did influence density results (P= 0.0018). A study by Rodrigues et al. (2003) in which density was measured before and after roasting indicated that volume increases during roasting. According to Sivetz and Desrosier (1979), increase in bean volume results from softening of the cellulose bean structure coupled to the increase in pressure from the release of pyrolysis products during roasting.

Moisture

Final Weight was recovered from batches of 50 g of green beans after roasting. Natural coffee with Light roast had the lowest weight loss of all treatments. Light Honey, Light Washed and Medium Natural were second. Medium Washed, Medium Honey and Dark Natural had the third place of weight loss. Placed in fourth was Dark Honey and fifth was Dark Washed, with the highest weight loss after roast. Roast and processing method influenced water loss in equal proportions (P <.0001 for both). Moisture of roasted beans showed that Natural coffee with Light roast had the highest moisture content, this roast also lost less water in the roasting process. Roast and processing method also influenced moisture content after roasting of the beans since P= <.0001 for both.

In a study performed by Carteri Coradi et al. (2007) the lowest values of total sugars, when compared to type of processing, were found in washed coffee. Natural coffee presented approximately

twice the amount of total and reducing sugars in relation to washed coffee. This is because a large part of coffee sugars is in the husk and mucilage (Lopez, L. M. V. et al, 2000).

As Table 1 indicates, Natural coffee with Light roast lost the lowest percentage of water even when it had a lower initial moisture (11%) than Washed and Honey green beans (12.26% and 11.5% respectively). Light Washed, Light Honey, and Medium Natural were the second and Dark roasts had higher losses. Also, Natural coffee with Medium roast presented the same density as Light roasts. Total sugars in Natural coffee may reduce liberation of water during due to the sugar´s hygroscopic characteristics while roasting and may explain why Natural roasted coffee presented higher weight, less water loss, higher moisture, and density after roasting.

Table 1

Weight, Water Loss (%), Moisture (%) and Density.

Roast	Processing method	Weight (g) Means ± [1]SD	Moisture (%) Means ± [1]sd	Density (g/mL) Means ± [1]sd
Light	Washed	43.67 ± 0.11^{b}	6.70 ± 0.1^{b}	0.41 ± 0.01^{ab}
	Honey	43.70 ± 0.17^{b}	6.63 ± 0.06^{b}	0.43 ± 0.01^{a}
	Natural	44.90 ± 0.10^{a}	7.46 ± 0.15^{a}	0.43 ± 0.01^{a}
Medium	Washed	42.57 ± 0.11^{c}	5.36 ± 0.06^{d}	0.40 ± 0.02^{b}
	Honey	42.63 ± 0.06^{c}	5.57 ± 0.15^{cd}	0.40 ± 0.05^{b}
	Natural	43.83 ± 0.06^{b}	5.73 ± 0.11^{c}	0.42 ± 0.01^{a}
Dark	Washed	41.83 ± 0.15^{e}	4.57 ± 0.11^{f}	0.37 ± 0.04^{c}
	Honey	42.10 ± 0.17^{d}	4.97 ± 0.15^{e}	0.37 ± 0.00^{c}
	Natural	42.63 ± 0.23^{c}	5.40 ± 0.20^{d}	0.36 ± 0.04^{c}
[2]CV%		0.33	2.30	2.36

Note. [1]Standard Deviation. [2]Coefficient of Variation. Values in the same column with different letters indicate statistical difference.

Color

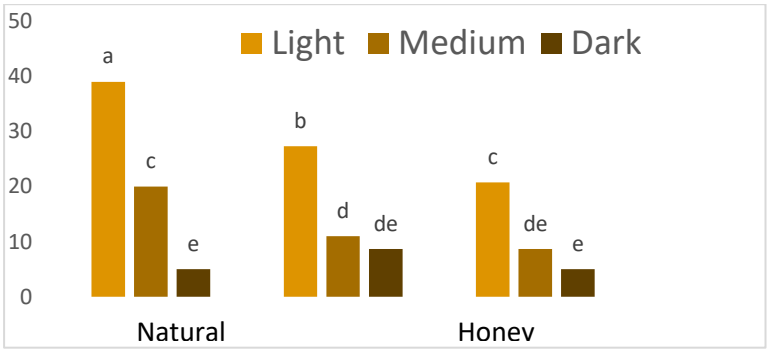
In Figure 1, Luminosity for Light roasts indicated that Natural was the lightest, Honey and Washed had no significant differences between them. As for Medium roasts, Natural was the lightest, Honey was darker than Natural but lighter than Washed. The darkest coffee was Medium Washed and Dark Natural. Luminosity differences were influenced by the type of roast and process (P= <.0001).

In Figure 2, 3 and 4, the "a" dimension (x axis) represents the red-green axis, with positive values indicating red and negative values indicating green. The "b" dimension (y axis) represents the yellow-blue axis, with positive values indicating yellow and negative values indicating blue.

Dimension *b differences were influenced by roast and process (P= <.0001 and P= 0.0003 respectively) but was more influenced by roast. As for *a, neither roast nor process interfered since probabilities were >0.05 (0.0971 and 0.0550 respectively), these results comply with Díaz and Perdomo (2015), where *a was not affected by roast, farm, or variety (Díaz & Perdomo, 2015). Coffee beans subjected to more severe temperature conditions are redder and darker, whereas beans processed under milder conditions are yellower and lighter (Campanha, F. G. et al., 2009).

Figure 1

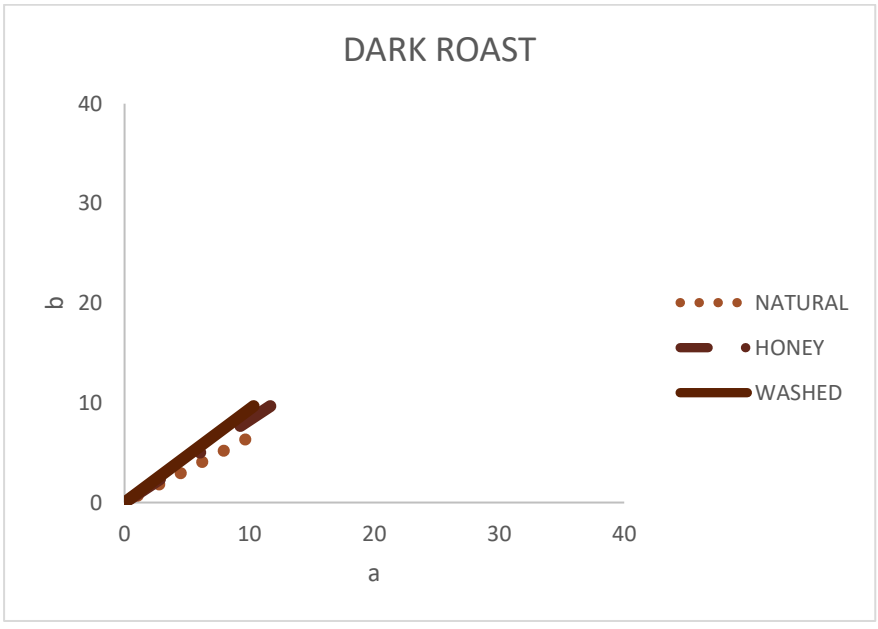
Luminosity of roasted coffee



Note. Luminosity Scale is from 0-100 being 0 black and 100 white. Values in the same column with different letters indicate statistical difference. Coefficient of Variation= 9.84.

Figure 2

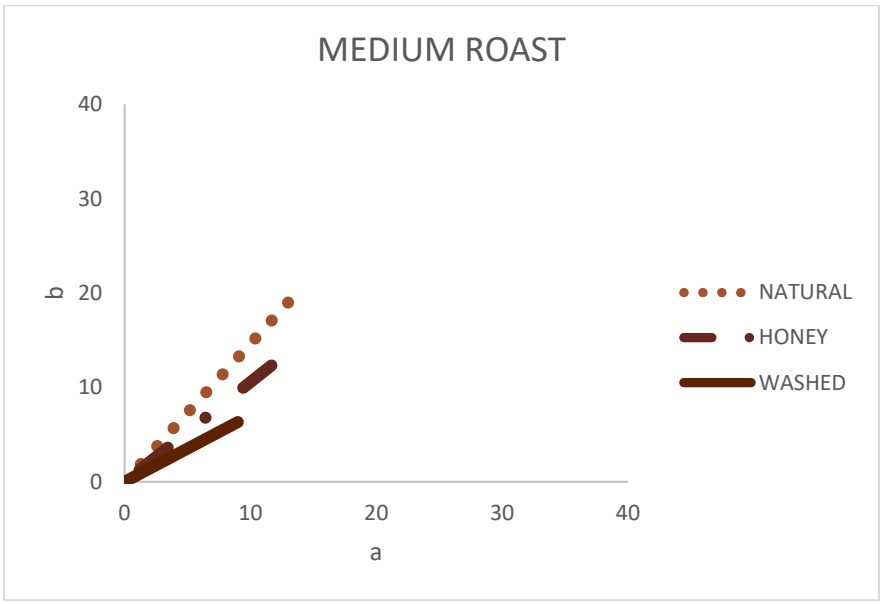
*Dimension *a and *b representation of Dark roasted coffee.*



Note. *a Coefficient of Variation= 13.08. *b Coefficient of Variation= 14.97.

Figure 3

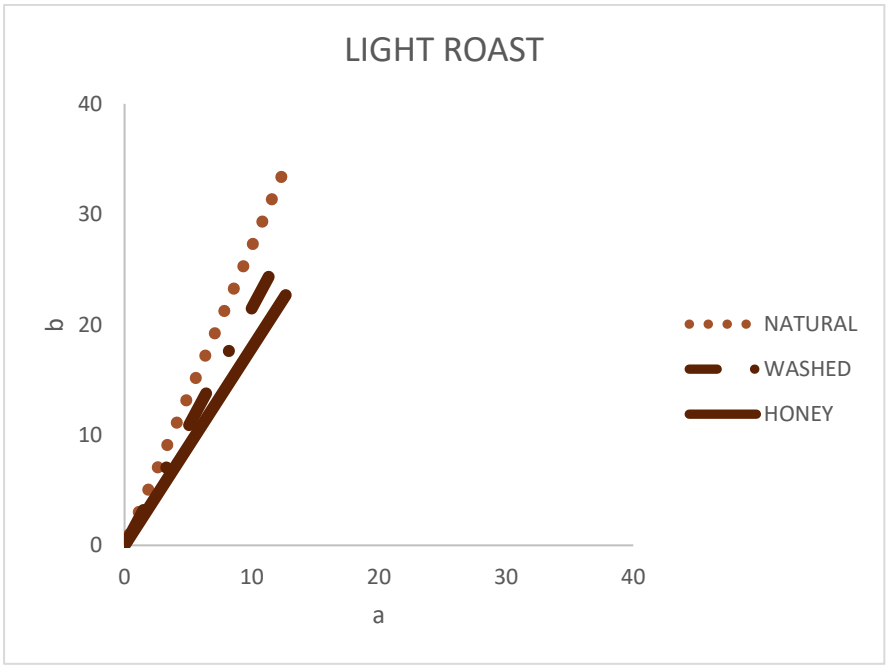
*Dimension*a and *b representation of Medium roasted coffee.*



Note. *a Coefficient of Variation= 13.08. *b Coefficient of Variation= 14.97.

Figure 4

*Dimension*a and *b representation of Light roasted coffee.*



Note. *a Coefficient of Variation= 13.08. *b Coefficient of Variation= 14.97.

Total Phenolic Compounds

Phenolic Compounds were reduced as the roast level incremented. In Table 2, Light Washed was reported to have the highest mg GAE/g coffee, followed by Medium Washed. Medium Natural, Light Natural, and Light Honey were third, with no significant differences between them. In last place were Dark roasts, and Medium Honey. Roast and process influenced Phenolic Compound results in equal proportion (P= <.0001). These results agreed with results from Król et al. (2020), in which they found that roasting degree and storage had a significant effect on the total polyphenols content in coffee beans. The coffee beverage is known for its rich content of bioactive compounds, particularly polyphenols such as chlorogenic acids found in green beans and caffeic acids that develop during roasting. These compounds are known to contribute to the overall intake of polyphenols in our diet and are associated with various health benefits for consumers. However, during the coffee roasting process, there is a noticeable reduction in polyphenolic compounds. This reduction is linked to the breakdown of chlorogenic, malic, and citric acids, which, in turn, affects the coffee's total antioxidant activity. Lighter roasted coffee exhibits a higher antioxidant activity when compared to both dark roasted coffee and unroasted coffee (Vignoli et al., 2011).

Acidity

In Table 2, Dark Natural and Dark Washed had the lowest acidity while Light and Medium roasts had the highest. Roast and process influenced Acidity results (P= <.0001 and P= 0.0011 respectively) but process influenced more than roasting. Coffee acidity results from non-volatile acids such as oxalic acid, malic, citric, tartaric, and pyruvic, as well as volatile, such as acetic, propionic, valeric and butyric, which are produced by internal pathways and undesirable fermentation. The resulting acidity of citric and malic acids has desirable effect on coffee quality, whereas the acids acetic, lactic, propionic, and butyric result in undesirable effects (Martinez et al., 2013). Pinto, Nísia Andrade Villela Dessimoni et al. (2002) studied coffee beverages and found that poor quality coffee, showed higher acidity. Another study mentioned that although acidity is considered an important quality attribute, consumers have a low preference for high-acidity coffee (Cangussu et al., 2020).

Table 2

Total Polyphenols results for mg of Gallic Acid Equivalent/g of roasted coffee and Acidity results in mL of NaOH per 100 g of roasted coffee.

Roast	Processing Method	Total Polyphenols (mg GAE/g coffee) Mean ± [2]SD	Titrable Acidity (mL NaOH/ 100 g) Mean ± [2]SD
Dark	Honey	41.83 ± 2.28[d]	21.66 ± 2.89[d]
	Natural	41.78 ± 0.71[d]	11.67 ± 2.89[e]
	Washed	47.13 ± 0.72[c]	12.67 ± 2.52[e]
Light	Honey	47.27 ± 1.09[c]	40.00 ± 0.00[a]
	Natural	47.40 ± 0.97[c]	33.33 ± 2.89[b]
	Washed	52.20 ± 1.00[a]	30.00 ± 0.00[bc]
Medium	Honey	42.46 ± 1.25[d]	24.67 ± 4.51[d]
	Natural	46.81 ± 0.66[c]	30.00 ± 0.00[bc]
	Washed	49.27 ± 0.64[b]	26.33 ± 5.51[cd]
[1]CV%		1.90	10.66

Note. [1]Coefficient of variation. [2]Standard Deviation. Values in the same column with different letters are statistically different.

Phase II. Sensory Analysis

First Stage Preference

For Natural processing evaluated with three different roast levels (Table 3), Light Roast had the highest Sum of Categories (200), and Dark Roast had the lowest (148). In the Critical Value table, Light roast and Medium roast were not significantly different since the difference did not exceed the Critical Value (31.4), which means panelists did not prefer one over another. Light and Dark roasts difference did exceed the Critical Value, meaning that Dark roast was preferred over Light roast, since it has the lowest Sum of Categories (148) of all treatments. As well, Medium roast compared to Dark roast exceeded the Critical Value, being Dark the most preferred since it has the lowest Sum of Categories of the three treatments. Color of the samples may have presented an influence in preference, since three different roast levels resulted in three different brew colors. Qualitatively, color can affect perceived sensory characteristics moreover, the color and appearance of the product serves as a cue for changes in aroma and flavor such as the browning that occurs during the coffee roasting process (Yeager et al., 2022).

Table 3

Basker Sum of Categories for Natural coffee with Light, Medium and Dark roasts.

Treatments	Sum of Categories	Light Natural	Medium Natural	Dark Natural
		200	192	148
Light Natural	200	0	8	52
Medium Natural	192	-8	0	44
Dark Natural	148	-52	-44	0

Note. Critical Value was 31.4. Number of panelists= 90.

Honey roasts also had significant differences (Table 4). As well as Natural coffee, Dark roast was preferred for Honey coffee. Light roast had no significant difference compared to Medium roast, meaning that panelists did not prefer one over another. Differences did exceed the Critical Value (31.4) when dark roast was compared to light and Medium roasts, meaning that Dark roast was preferred since it has the lowest Sum of Categories (154). According to a study in 2007, 42% of coffee consumers in Tegucigalpa preferred low-cost brands which have dark roasts (Villatoro, 2007).

Table 4

Basker and Kramer Sum of Categories for Honey coffee with Light, Medium and Dark roasts.

Treatments	Sum of Categories	Light Honey	Medium Honey	Dark Honey
		196	190	154
Light Honey	196	0	6	42
Medium Honey	190	-6	0	36
Dark Honey	154	-42	-36	0

Note. Critical Value was 31.4. Number of panelists= 90.

As for Washed coffee (Table 5), there were no significant differences between Light roast and Medium roast. There were also no significant differences between Medium roast and Dark roast, but there were differences between Light and Dark roast, meaning that people did not prefer Dark over Medium, but they preferred Dark over Light roast since Light had the highest Sum of Categories (207) and Dark the lowest (156) and their difference exceeded the Critical Value (31.4). Syukri et al. (2023) found that light roast using a temperature range of 180-205 °C gave characteristics of the coffee bean being light brown in color, dry in texture, lacking the distinctive aroma of coffee and the taste tended to be sour. In that same investigation, Medium roast used a temperature of 210-230 °C with the characteristics of the coffee beans were darker brown than light roasts, texture slightly oily, the

distinctive aroma of coffee had come out and the taste tended to be sweet. While for the dark roast at temperature of 240 °C, coffee beans tended to be black in color, have an oily texture and tended to be bitter in taste. Medium roast temperature and time parameters used in that study were like the Dark roast used in the present investigation.

The annual production of coffee in Honduras is variable; however, on average, it is quantified at approximately 7.0 million quintals, of which the vast majority is exported, and approximately 500 thousand quintals are allocated for domestic consumption, being 95% exported and only 5% left for internal consume (Alvarez, 2018). This percentage is not always the best quality, since the best coffee is exported. Honduran National Roasters usually sell their coffee with dark roasts to standardize their attributes, which is why consumers are adapted and prefer darker roasts.

Table 5

Basker Sum of Categories for Washed coffee with Light, Medium and Dark roasts.

Treatment	Sum of Categories	Light Washed	Medium Washed	Dark Washed
		207	177	156
Light Washed	207	0	30	51
Medium Washed	177	-30	0	21
Dark Washed	156	-51	-21	0

Note. Critical Value was 31.4. Number of panelists=90.

First Phase Acceptance

According to Color Acceptance results in Table 6, Washed Light Roast had the lowest acceptance rate and Dark the highest. For Sweetness Acceptance, there were no significant differences between Light roast and Dark roast or between Dark and Medium, but there were differences between Medium and Light, being Medium more accepted than Light. As for Body, there were no significant differences between samples. General Acceptance results demonstrated that Light and Medium had no significant differences as for Dark and Medium. Light and Dark were significantly different, being Dark more accepted than Light.

Table 6

Acceptance Sensory Analysis results for Washed coffee with Light, Medium and Dark roasts.

Roast	Proce-ssing Method	Attribute					
		Color [4]M ± [2]SD	[3]SW [4]M ± [2]SD	Acidity [4]M ± [2]SD	Body [4]M ± [2]SD	Aftertaste [4]M ± [2]SD	Acceptance [4]M ± [2]SD
Light	Washed	5.93 ± 1.46[c]	5.58 ± 1.75[b]	5.69 ± 1.92[b]	6.17 ± 1.72[b]	5.95 ± 1.89[b]	6.17 ± 1.71[b]
Medium	Washed	7.21 ± 1.41[b]	6.14 ± 1.50[a]	6.04 ± 1.86[ab]	6.65 ± 1.44[b]	6.61 ± 1.75[a]	6.75 ± 1.53[ab]
Dark	Washed	7.65 ± 1.33[a]	5.95 ± 1.86[ab]	6.25 ± 1.90[a]	7.07 ± 1.47[b]	6.45 ± 2.07[ab]	6.81 ± 1.75[a]
[1]CV%		20.58	29.29	30.41	22.75	30.58	25.29

Note. Attributes in the same column with different letters are statistically different (P<0.05). [1]Coefficient of Variation. [2]Standard Deviation. [3]Sweetness. [4]Mean.

For Color attribute (Table 7), there were significant differences, being Dark Honey the most accepted, Medium Honey the second and Light the least accepted. For Body and General Acceptance, there were no significant differences. According to a study by Firdissa et al. (2022), semi washed processing method showed an economical and effective method for producing the highest total specialty cup quality compared with the fully washed method coffee beans processed by the semi washed method, in general, produced fewer primary defects, better body, acidity, and preliminary total quality, while the wet processing method produced better color and flavor for coffee beans.

Table 7

Acceptance Sensory Analysis results for Honey coffee with Light, Medium and Dark roasts.

Roast	Processing Method	Attribute					
		Color [4]M ± [2]SD	[3]SW [4]M ± [2]SD	Acidity [4]M ± [2]SD	Body [4]M ± [2]SD	Aftertaste [4]M ± [2]SD	Acceptance [4]M ± [2]SD
Light	Honey	5.67 ± 1.76[c]	5.92 ± 2.10[a]	6.00 ± 2.17[a]	6.38 ± 1.66[a]	6.27 ± 2.10[a]	6.28 ± 1.91[a]
Medium	Honey	6.99 ± 1.83[b]	5.86 ± 1.82[a]	6.03 ± 2.08[a]	6.42 ± 1.75[a]	5.95 ± 1.87[a]	6.52 ± 1.68[a]
Dark	Honey	7.65 ± 1.33[a]	6.00 ± 1.94[a]	6.05 ± 1.83[a]	6.83 ± 1.82[a]	5.92 ± 2.00[a]	6.53 ± 1.72[a]
[1]CV%		23.69	32.54	32.73	26.21	33.47	27.35

Note. Attributes in the same column with different letters are statistically different (P<0.05). [1]Coefficient of Variation. [2]Standard Deviation. [3]Sweetness. [4]Mean.

In Table 8, for Color Attribute, Natural coffee with Light roast had the lowest acceptance rate while Medium and Dark roasts were higher but not significantly different between them. For Acidity, Body, Aftertaste and General Acceptance, treatments showed no statistical difference. According to

Monteiro et al. (2010), consumers prefer the most darkly roasted coffees, regardless of the type of beverage.

Table 8

Acceptance Sensory Analysis results for Natural coffee with Light, Medium and Dark roasts.

Roast	Processing Method	Attribute					
		Color [4]M ± [2]SD	[3]SW [4]M ± [2]SD	Acidity [4]M ± [2]SD	Body [4]M ± [2]SD	Aftertaste [4]M ± [2]SD	Acceptance [4]M ± [2]SD
Light	Natural	6.41 ± 1.88[b]	5.76 ± 1.93[a]	6.13 ± 1.84[a]	6.58 ± 1.67[b]	6.25 ± 1.92[a]	6.35 ± 1.56[a]
Medium	Natural	6.97 ± 1.54[a]	5.80 ± 1.98[a]	6.31 ± 1.69[a]	7.13 ± 1.36[a]	6.48 ± 1.80[a]	6.69 ± 1.41[a]
Dark	Natural	7.21 ± 1.78[a]	5.41 ± 2.38[a]	6.19 ± 2.05[a]	7.05 ± 1.31[a]	6.51 ± 2.03[a]	6.78 ± 1.77[a]
[1]CV%		24.91	35.50	28.95	20.29	27.71	21.99

Note. Attributes in the same column with different letters are statistically different (P<0.05). [1]Coefficient of Variation. [2]Standard Deviation. [3]Sweetness. [4]Mean.

Second Phase Preference

For Dark roast Preference Evaluation (Table 9), there was no significant difference for none of the three coffee processes. Even though there were no differences, Honey coffee had the lowest Sum of Categories (172) and Washed coffee had the highest (192). According to Monteiro et al. (2010) the type of roast has a greater impact on sensory characteristics, while the type of beverage exerts little influence. Coffee samples in Monteiro´s study subjected to dark roasting were more accepted in all four attributes evaluated (color, aroma, flavor, and overall impression) by a larger group of consumers, and the coffee sample subjected to light roasting was less accepted by a significant portion of consumers in all evaluated attributes.

Table 9

Basker Sum of Categories for Dark roast with Washed, Honey and, Natural coffee process.

Treatments	Sum of Categories	Dark Washed	Dark Honey	Dark Natural
		192	172	176
Dark Washed	192	0	-20	-16
Dark Honey	172	20	0	4
Dark Natural	176	16	-4	0

Note. Critical Value was 31.4. Number of panelists=90.

For Medium roast Preference Evaluation (Table 10), Natural coffee had the highest Sum of Categories (193) and Honey had the lowest (157). The difference between Washed and Honey

exceeded the Critical Value, being preferred Honey over Washed. Honey and Natural also exceeded the Critical Value meaning that Honey was also preferred over Natural. In this Phase, color did not affect consumer´s perception, since it was the same roast, all samples presented same or very similar color. According to Syukri et al. (2023), coffee processing can improve the quality and taste of coffee. Ghosh (2014) also pointed that coffee produced by the wet method had less body and higher acidity; it was also more aromatic than coffee produced by the dry method, resulting in a higher acceptance by consumers.

Table 10

Basker Sum of Categories for Medium roast with Washed, Honey and, Natural coffee process

Treatments	Sum of Categories	Medium Washed	Medium Honey	Medium Natural
		190	157	193
Medium Washed	190	0	33	-3
Medium Honey	157	-33	0	-36
Medium Natural	193	3	36	0

Note. Critical Value was 31.4. Number of panelists=90.

Second Phase Acceptance

For Dark roasts (Table 11), there were no significant differences for any attribute. Color was labeled as “I like it moderately”, Sweetness as “I neither like it nor dislike it”, Body, Aftertaste and General Acceptance as “I like it slightly”. In a study by Bressani et al. (2021), where different quality coffee was evaluated, even though consumers were able to recognize the quality of the beverage, they still had limited perception to describe the sensory characteristics. Therefore, the sensory evaluation performed by trained Q-Grader tasters is essential because it helps establish the purchase and sale value of specialty coffees through their score based on SCA protocol and the perceptions of sensory descriptors.

Table 11

Acceptance Sensory Analysis results for Dark roast with Washed, Honey and, Natural coffee process.

Roast	Processing Method	Attribute					
		Color	[3]SW	Acidity	Body	Aftertaste	Acceptance
		[4]M ± [2]SD	[4]M ± [2]SD	[4]M ± [2]SD	[4]M ± [2]SD	[4]M ± [2]SD	[4]M ± [2]SD
Dark	Washed	7.30 ± 1.29	5.72 ± 1.89	6.19 ± 5.56	6.67 ± 1.38	5.67 ± 2.18	6.13 ± 1.90
Dark	Honey	7.30 ± 1.27	5.97 ± 1.81	6.18 ± 1.82	6.74 ± 1.33	6.13 ± 2.08	6.41 ± 1.76
Dark	Natural	7.31 ± 1.57	5.77 ± 1.73	5.85 ± 1.89	6.68 ± 1.15	6.20 ± 1.70	6.33 ± 1.52
[1]CV%		16.56	29.84	30.49	19.75	32.35	26.55

Note. P>0.05. [1]Coefficient of Variation. [2]Standard Deviation. [3]Sweetness. [4]Mean.

In Table 12, Medium roasts, as well as Dark roasts, had no significant differences between any attributes. In a study performed by Díaz and Perdomo (2015), there was no difference between almost all attributes except for acidity, since it was the same variety. Comparing Medium roasts Color results with Dark roast Color results, even though panelists did not accept any treatment over another, Dark roasts were categorized as “I like it moderately” while Medium was set as “I slightly like it” in the hedonic scale. As well, Sweetness in Dark washed was closer to “I slightly like it” (6) than Sweetness on Medium roast.

Table 12

Acceptance Sensory Analysis results for Medium roast with Washed, Honey and, Natural coffee process.

Roast	Processing Method	Attribute					
		Color	[3]SW	Acidity	Body	Aftertaste	Acceptance
		[4]M ± [2]SD	[4]M ± [2]SD	[4]M ± [2]SD	[4]M ± [2]SD	[4]M ± [2]SD	[4]M ± [2]SD
Medium	Washed	6.76 ± 1.62	5.21 ± 2.00	5.82 ± 1.86	6.82 ± 1.58	5.98 ± 1.93	6.20 ± 1.93
Medium	Honey	7.14 ± 1.41	5.64 ± 1.85	5.85 ± 1.89	6.81 ± 1.82	6.08 ± 2.11	6.30 ± 1.78
Medium	Natural	6.87 ± 1.66	5.33 ± 1.02	5.68 ± 1.95	6.78 ± 1.45	6.00 ± 1.98	6.36 ± 1.76
[1]CV%		22.76	34.77	32.69	22.74	32.75	29.11

Note. P>0.05. [1]Coefficient of Variation. [2]Standard Deviation. [3]Sweetness. [4]Mean.

Conclusions

The preferred roast level for the Pacas variety was Dark as indicated by consumer preferences, and for acceptance, consumers did not found differences between roasting levels but preferred Dark roast in color acceptance.

Consumers showed a preference for the Honey processing method with Medium roast level, and for acceptance, consumers did not found differences between processing methods.

Natural coffee presented higher yield in the three roasting levels regardless of the roasting level.

Acidity and Phenolic Compounds decreased as roasting level increased.

Recommendations

Study the behavior of other varieties at different roasting levels and evaluate why coffee presented different yield levels over the same roast.

Determine why coffee processing methods did not have the same color while submitted to the same roast.

Conduct a structural (macro/micro analysis) of coffee structure with different coffee processing and roasting.

Assess Caffeine, Chlorogenic Acids, and other co-products of chemical reactions on different roasting levels.

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Appendices

Appendix A

Organoleptic Analysis results.

Coffee Process	Fragrance /Aroma	Flavor	[1]Aftert.	[2]Acid.	Body	[3]Bal.	Cupping Score	[4]Unif.	[5]Clean.	Sweetness	Final Score
Natural	8.00	8.25	8.25	8.00	8.25	8.00	8.25	10.00	10.00	10.00	87.00
Honey	8.00	8.00	8.00	8.00	8.25	8.00	8.25	10.00	10.00	10.00	86.50
Washed	8.50	8.50	8.50	8.25	8.50	8.25	8.50	10.00	10.00	10.00	89.00

Note: [1]Aftertaste. [2]Acidity. [3]Balance. [4]Uniformity. [5]Clean cup.

Appendix B

Full defects tabulation

Coffee Process	Full Black	Full Sour	Dried Cherry	Partial Black	Partial Sour	Parchment	Shell	Broken	Hull	Foreign matter	Full Defects
Natural	4	1	2	3	0	0	0	2	6	0	9
Honey	1	4	0	9	0	0	16	0	0	2	13
Washed	13	0	4	33	11	27	0	28	0	0	40

Note: Full Defects were calculated using SCA Defect Handbook.

Appendix C

Color representation of treatments.

Note. [1]Light Natural. [2]Light Washed. [3]Light Honey. [4]Medium Natural. [5]Medium Honey. [6]Medium Washed. [7]Dark Natural. [8]Dark Honey. [9]Dark Washed.