EVALUATION OF THE COMPOSITION EFFECT OF HARVESTED COFFEE IN THE ORGANOLEPTIC PROPERTIES OF COFFEE DRINK

EVALUACIÓN DEL EFECTO DE LA COMPOSICIÓN DEL CAFÉ COSECHADO EN LAS PROPIEDADES ORGANOLÉPTICAS DE LA BEBIDA DE CAFÉ

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ABSTRACT

Background: The current flourishing of the specialty coffee market has motivated the development of this research on the basis that the harvested coffee fruits are a determining factor in drink quality. **Objectives**: The aim of this study was to evaluate the effect of the composition of harvested coffee (*Coffea arabica* L.) regarding the organoleptic quality of the coffee drink for the varieties Caturra and Colombia. **Methods**: Treatments for the assessed varieties were defined with different percentage compositions of coffee fruits M1 (100R), M2 (80R, 13OV, 7SR), M3 (60R, 26OV, 12SR, 2UR) and the control M4, which included fruits in different ripening stages, ripe (R), overripe (OV), semi-ripe (SR) and unripe (UR), in different proportions in experimental units of 10 kg of harvested coffee. The experimental design envisaged 3 rounds (repetitions) of harvest. The harvested coffee was classified manually according to its ripening stage using a previously developed scale based on colorimetry and recording the degrees Brix of 50 fruits in each ripening stage. The standardized wet processing method was carried out; a Q Grader cupping panel of five members was used for the sensory analysis of the coffee drink. **Results**: The results showed that for the variety Caturra statistical differences in cup quality between treatments were not found, whereas for the variety Colombia, treatments M1 and M3 showed similar behavior, with statistically significant differences regarding M2 and M4. Finally, the mathematical modeling obtained to predict the cup score depending on the coffee ripening stages composition, counted with coefficients of determination R^2 of 0.946 and 0.852 with an error of 1.40 and 1.03% for the varieties Caturra and Colombia, respectively. **Conclusions**: The model developed with fuzzy logic and validated with information from other farms, presented an error of less than 2% in the estimation of the cup as a function of the ripening stages composition of the coffee varieties Caturra and Colombia.

Keywords: *Coffea arabica*, wet processing, coffee ripeness stages, specialty coffees, fuzzy logic.

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RESUMEN

Antecedentes: El progreso en el mercado de los cafés especiales, ha motivado el desarrollo de la presente investigación tomando como base que los frutos de café cosechados son un factor determinante en la calidad de la bebida. **Objetivo:** El objetivo del estudio fue la evaluación del efecto de la composición del café (*Coffea arabica* L.) cosechado respecto a la calidad organoléptica de la bebida para las variedades Caturra y Colombia. **Métodos:**, se definieron los tratamientos (composiciones en porcentaje) de café cereza M1 (100M), M2 (80M, 13SM, 7P), M3 (60M, 26SM, 12P, 2V) y testigo M4, las cuales contemplan para los estados de maduración maduro (M), sobremaduro (SM), pintón (P) y verde (V) en proporciones diferentes en unidades experimentales de 10 kg de café cereza. El diseño experimental contempló 3 pases (replicas) de cosecha. Una vez cosechado al café se realizó la clasificación manual de los estados de maduración con ayuda de una escala previamente elaborada, así como la verificación objetiva por colorimetría y el registro de los grados Brix para 50 frutos en cada estado de maduración. Se realizó un proceso de beneficio húmedo estandarizado; se utilizó un panel de catación Q Grader de cinco integrantes para el análisis sensorial de la bebida. Un análisis de varianza fue empleado para comparar los resultados y se usó lógica difusa para elaborar un modelo matemático predictivo de la calidad en taza en las dos variedades. **Resultados:** Los resultados mostraron que para la variedad Caturra no se encontraron diferencias estadísticas de calidad en taza entre los tratamientos, mientras que para variedad Colombia los tratamientos M1 y M3 presentaron igual efecto con diferencias estadísticas significativas respecto a M2 y M4. Finalmente, el modelamiento matemático obtenido para predecir la puntuación de la taza en función de la composición de los estados de maduración del café, contó con coeficientes de determinación R^2 de 0,946 y 0,852 con errores de 1,40 y 1,03% en variedad Caturra y variedad Colombia, respectivamente. **Conclusiones:** El modelo desarrollado con lógica difusa validado con información de otras fincas presentó un error menor al 2% en la estimación de la taza en función de la composición de los estados de maduración del café variedad Caturra y Colombia.

Palabras clave: *Coffea arabica*, beneficio húmedo, estados de maduración del fruto, cafés especiales, lógica difusa.

INTRODUCTION

Traditionally coffee has been one of highest contributors to Colombia's gross domestic product and an important source of employment and rural development, because of this condition any variation that negatively affects the market, generates a social impact due to its incidence on the coffee grower's competitiveness.

Scientific knowledge about the cultivation, processing, exploitation and use of coffee has advanced in the last 25 years. Aroma and flavor (sensory characteristics) are the main reason for its high acceptability and enjoyment, besides giving it recognition as a high quality product as specialty coffee (1). Specialty coffees are those valued by consumers for having consistent, verifiable and sustainable attributes and for which they are willing to pay premium prices, which results in greater well-being for producers. In addition, it is estimated that the specialty coffee market represents approximately 13% of global consumption (2). The Specialty Coffee Association of America - SCAA, establish a protocol where, a cupping panel evaluates various attributes (3).

The intrinsic conditions of coffee quality acquired from the moment the variety to be planted is selected, crop management, climate and soil environment, geographic position and altitude, cause the plants to develop fruits in different stages of ripening, due to the numerous blooms that occur in the year, which leads to several rounds of picking. This process requires a task of picking only mature fruits, which implies a manual harvesting given the maturity variability in the cluster and the high slope conditions of the crops (4, 5).

Initially 8 maturation stages have been identified in the physiological development of the coffee variety Colombia, according to the time in days after flowering, (daf) and the dominant coloring for 50% of the fruits. These states range from immature green (182 daf), to mature red (217 daf), up to a dry state (231 daf). It has also been identified that the chemical property that best describes ripening is the soluble solids content expressed in degrees °Brix, which increases as the fruit continues to

develop (6). The optical properties were analyzed through the chromaticity coordinates color in the epicarp of the variety Colombian coffee fruits during ripening; finding differences in the luminosity L★ of the fruits, in the chromatic coordinate a★ and b★ according to the days after the anthesis (daa) (7).

When the harvesting activity is completed in the field, a proper handling of the harvested fruits should take place, given that the fermentation process has already been initiated due to their high sugar content (4). After the pulping, it is necessary to classify the pulped coffee in a grain sieve to remove pulp residues, foreign elements and fruits that were not pulped (8).

In the pulped beans the process of mucilage fermentation begins, during which different biochemical processes occur (9). As a result of the mucilage degradation, it detaches itself from the parchment and is subsequently removed by washing. Taking advantage of the apparent density changes between pulped and washed coffee, the "fermaestro" method uses a device that helps determine the coffee beans optimal washing point (10).

After the washing process, wet parchment coffee with a moisture content of 50 to 52% on wet basis is obtained; which must be reduced through solar or mechanical drying to a range between 10 and 12% (4). The moisture value of 12% corresponds to a water activity (a_w) of 0.67, which is a safe value to prevent any deterioration caused by the growth of fungi, such as the *Aspergillus ochraceus* which produces mycotoxins, that are harmful to consumers' health (11).

Grain quality evaluations obtained with immature coffee fruits between 0.5 and 15% in the harvested mass, processed by wet processing method with pulping without water, with 14 hours of natural fermentation or mechanical removal of mucilage, washing and drying in the sun, showed that starting from 2.5% of immature coffee, 30% of the cups are rejected for defects such as taints, ferment, stinker, earthy and unpleasant flavors (12). The type of fruit harvested has a direct impact on the final quality of the product, which was observed when evaluating the relation between the ripening stage of the coffee fruit with the yield in the processing and cup quality, finding that the presence of immature fruits contributes to produce defective cups and the presence of semi-ripe, ripe and overripe fruits contributes to obtaining good quality cups (6).

In an evaluation of several types of pectolytic enzymes for the removal of mucilage in red variety Colombia coffee fruits in stages of ripe, semi-ripe and without sorting, the latter were characterized by 3% green fruits, 22.1% semi-ripe, 44.3% ripe, 21.1% overripe and 12.6% raisin, using natural fermentation without water as a control to compare the effect of the enzymes with the evaluation of the quality of the beverage, no statistical differences were found between the treatments with the enzymes and the control sample; establishing that the aroma of the coffee without sorting reached the highest grade with respect to the other degrees of ripeness (13).

The sensory evaluation of food is clearly an example of the ambiguity of human thought, due to the differences between the individual perception of a product in a group of panelists (14). For the sensory analysis of coffee, it is necessary to have previously trained personnel, standardized methods of analysis and experience in the interpretation of results in order to reduce errors inherent to human judgments (15). Fuzzy logic makes it possible for the phenomenon of uncertainty to be consider mathematically (14). This technique uses the human experience to generate a reasoning that enables the decision-making. The principles of fuzzy or multi-valued logic allow to allocate different degrees of certainty, where the numeric values of the input variables are assigned a degree of membership in respect to a fuzzy set or membership function previously defined. Then the inference process is determined in a decision-making that defines the fuzzy outputs, on the basis of decisions based on linguistic rules. The defuzzification of the outputs consists in obtaining a numerical value for each of the model responses from the fuzzy sets to which they belong. The defuzzification interface is responsible for generating the scalar, which is the value generated at the simulation output after the resolution of the formulated rules of inference (16).

In this study the influence of the composition of the harvested coffee (*Coffea arabica* L.) on the properties of cup quality for the varieties Colombia and Caturra was evaluated. Development stages of coffee fruits were characterized in order to configure four treatments. The mathematical models were validated with information from other farms in the coffee growing area of the department of Antioquia under the same conditions of cultivated variety and bean processing.

MATERIALS AND METHODS

Location

The investigation was carried out in two farms of the Municipality of Ciudad Bolivar, located to the southwest of the department of Antioquia; The Montenegro Vuelta Bonita farm, located in the Vereda Remolino Arriba, in an experimental field of variety Caturra coffee with a full solar exposure growing system, 6.5 years old at an altitude of 2020 m.a.s.l., and the Lorica farm, located in the Vereda Hondura, at an altitude of 1480 m.a.s.l., in a 2-year-old plot of variety Colombia coffee with a shaded growing system. The average climatic information of the zone for the last year registered an ambient temperature of 19 °C, relative humidity of 79% and mean annual precipitation of 1477 mm.

Materials

Coffee fruits (*Coffea arabica* L.), were used, which were initially classified using the ripening scale developed by (6). Plastic containers of different sizes, fermaestro equipment to determine the washing point of each sample, and plastic bags for the storage of dried parchment coffee (DPC) samples were used.

Procedure for the characterization of the ripening stages of coffee fruits

In order to identify the developmental stages: ripe, overripe, semi-ripe and unripe, 100 fruits from each stage of each variety were taken; the coordinates for each fruit were determined for the CIEL★a★b★ color system achromatic L★, and chromatic a★ and b★ (6). Measurements were performed on a *Konica Minolta*© model C-400 portable colorimeter with standard illuminant D65, 2° observer angle (of measurement) and pre-calibration with flat plate (white color, coordinates Y = 87.1, x = 0.3184, and y= 0.3357), using the *SpectraMagic* NX software for downloading and copying data. On the surface of the epicarp of each fruit, coordinates were recorded three times in the equatorial area in different positions in 360° using the methodology developed by (17). Similarly, on 100 fruits the detachment force was measured with an *Extech*© model 475040 digital dynamometer (50N capacity). In addition, the concentration of mucilage sugars (°Brix) was evaluated for 100 fruits in three ripening stages (ripe, overripe and semi-ripe), pulping

them by hand and extracting one drop, placing it in a *Hanna Instruments*© model HI86801 digital refractometer with a resolution of 0.1°Brix.

The mean values, and confidence intervals for the color variables, °Brix and detachment force (N) were calculated. With them a ripening scale was constructed (Tables 2 and 3), and used as a tool to classify the fruits in the four ripening states during the trials.

The different ripening stages unripe, semi-ripe, ripe and overripe, as classified by the operators were verified, by using the portable colorimeter and the *SpectraMagic* NX software to compare the color differences (ΔE), of the values of the previously defined pattern, with the data measured in 100 fruits and verified. In the same way, in 50 fruits already classified for the development stages ripe, overripe and semi-ripe, the total soluble solids (°Brix) were measured, in order to contrast the results to analyze values and differences with those previously established in the ripening scale.

Defining the coffee fruit treatments

From preliminary samplings in 50 coffee growing farms of the department of Antioquia, where the harvested coffee that arrived in the receiving hopper was characterized, an analysis of the percentage ranges of the most common ripening stages was made, which allowed the treatments for M2 and M3 to be define. M1 was defined as the treatment corresponding to a selective harvesting (100% ripe fruits) and M4 corresponded to the control treatment, meaning as the harvested coffee fruits arrives to the receiving hopper on the farm, which was characterized in each trial in order to determine its composition in relation to the different stages of development of the fruit. The defined treatments are shown in Table 1.

Table 1. Treatments for the harvest mass defined for the experiment.

Treatment	Ripening stages (%)			
	R	*OV*	*SR*	*UR*
M1	100	0	0	0
M2	80	13	7	0
M3	60	26	12	2
M4	Control	Control	Control	Control

Experimental design

An arrangement on blocks were defined for each of the 3 rounds of pickings in each farm,

where a minimum of 80 kg of coffee was collected in order to classify the fruits by ripening stages and to elaborate the experimental unit of 10 kg of coffee fruit, where the four treatments (mixtures of ripening stages) were applied to obtain a total of 12 samples per farm.

Procedure for the wet processing and drying of the coffee samples

A wet processing was conducted for each treatment sample (manual sorting of floaters, pulping without water, classification of pulped coffee in grain sieve, fermentation with fermaestro, classification of floaters in washed coffee and mechanical drying in gas fuelled grain dryer with heat exchanger). Samples of 2 kg of dry parchment coffee obtained in each treatment and repetition with a humidity of 10 to 12%, determined by the Gravimet method (18), were coded and stored between 45 and 60 days (19) at a relative humidity close to 65% and an average temperature of 15 °C.

Sensory quality of the drink

The sensory quality evaluation of the coffee drink was made with a cupping panel of 5 Q Grader tasters who evaluated: fragrance, aroma, flavor, aftertaste, acidity, body, balance, uniformity, clean cup, sweetness, defects and overall impression, assigning positive quality scores with values ranging from 0 to 10 and negative scores denoting unpleasant flavor sensations with the same range of values. The sum of the attributes including the negative values of the defects, generates a score on a scale of 0 up to 100 points, when the score is equal to or greater than 85 it is considered as a specialty coffee (3).

Development of the mathematical model

In order to explain the behavior of the cup quality response variable from a data set of independent variables, two modeling techniques were used; one using least-squares multivariate regression, and another called fuzzy logic, for this case a methodology was developed in the elaboration of the model similar to the one defined by (14) using the Fuzzy Logic application of the Matlab® v. 7.0 program in the following steps:

- The fuzzy inference system was defined based on fuzzy sets with trapezoidal-shaped membership functions.
- The scale and the measurement range of the input variables (percentage of fruits R, OV, SR and UR) with linguistic terminology were established in 5 levels: Very low, low, medium, high and very high.
- The output variable "cup quality" was defined in linguistic terms for 5 levels: Very low, low, medium, high and very high, which defined the values of the fuzzy sets, in this way the lowest values in cup were grouped into: "Very low", and the higher values into "High" and "Very high". The centroid method was used in the defuzzification of the outputs.
- Heuristic rules that integrated the inference system were established. A total of 625 rules were defined by making all possible combinations of the 5 linguistic levels in the input and output variables. The fuzzy implication method of minimum operation or *mamdani* was used for the solution of the rules of inference.
- Validation of the model based on data from the AOCE project of the main harvest of 2014 and the minor harvest of 2015 (20), 13 farms for variety Caturra and 19 for variety Colombia with characterization of the ripening stages and wet processing similar to the one developed in the experiment.

RESULTS

Characterization of the ripening stages of coffee fruits

Table 2 shows the ripening scale for the variety Caturra, indicating the coordinates L★a★b★, the median and the confidence intervals of the detachment force, and the concentration of mucilage sugars for the four ripening stages.

For variety Colombia the ripening scale (Table 3) shows similar results in the behavior of physical, optical and chemical properties. For the two varieties, we observed the decreasing behavior of the detachment force value as the fruit development progresses, while the concentration value of °Brix increases.

Table 2. Ripening scale for variety Caturra coffee fruits.

Development stage	Fruit color pattern in the CIEL★a★b★ model	Detachment force (N)	°Brix
Unripe	L★=48.58dx a★= -12.78a b★= 36.16d ΔE★= 4.79	15.05d±2.98	--------
Semi-ripe	L★= 43.31c a★= 13.84b b★= 26.65c ΔE★= 7.89	13.23c ± 2.77	11.63a ± 1.61
Ripe	L★= 3466b a★= 29.84d b★= 14.74b ΔE★= 4.44	10.17b ± 2.40	13.96b ± 1.66
Overripe	L★= 28.16a a★= 19.04c b★= 6.53a ΔE★= 3.15	6.66a ± 2.23	17.19c ± 1.77

ˣ For the same variable in a column averages with different letter present statistically significant difference according to Duncan's test at 5%.

Table 3. Ripening scale for variety Colombia coffee fruits.

Condition	Fruit color pattern in the CIEL★a★b★ model	Detachment force (N)	°Brix
Unripe	L★= 45.04ax a★= -14.16a b★= 30.69a ΔE★= 3.74	10.60c ± 3.55	------
Semi-ripe	L★= 51.64b a★= 15.74b b★= 33.15b ΔE★= 11.09	9.78c ± 3.79	11.23a ± 1.87
Ripe	L★= 34.98c a★= 27.68c b★= 14.51c ΔE★= 5.39	8.10a ± 3.60	13.90b ± 2.42
Overripe	L★= 28.30d a★= 21.19d b★= 7.27d ΔE★= 4.15	6.04b ± 3.08	16.54c ± 2.31

ˣ Each variable with a different letter average presents statistically significant difference according to Duncan's test at 5%

Verification of color and sugars concentrations in the coffee fruits

Table 4 shows that for the color verification (success rate), in the ripening stages semi-ripe, ripe and overripe, the manual classification of these fruits, generated confusion among the workers, possibly due to variations in the lighting conditions at the site where the work was performed, fatigue and the difficulty in learning the identification using the ripening scale.

Table 4. Coffee fruits of varieties Caturra and Colombia in different ripeness stages verified with the colorimeter.

Variety Caturra				
Round of picking	% R	% OV	% SR	% UR
P1	74	48	49	68
P2	72	87	90	67
P3	93	95	95	85
Variety Colombia				
P1	73	82	92	33
P2	67	24	80	58
P3	74	63	87	76

Regarding the concentration of sugars (°Brix), statistical differences were observed in the development stages of the three fruits evaluated for both varieties of coffee, as shown in Figure 1, with slightly higher values than those recorded in the ripening scale of Tables 2 and 3.
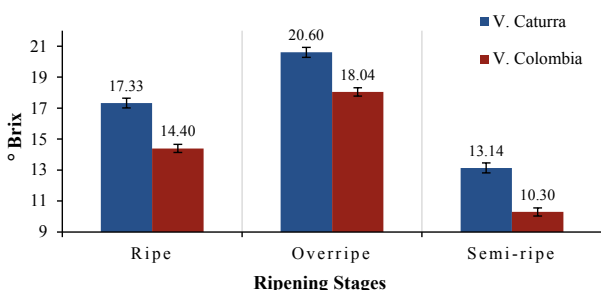

Figure 1. Sugar concentration in coffee fruits of the varieties Caturra and Colombia with different development stages.

Processing and analysis of sensory quality of the drink

Table 5 shows the composition of the control treatment M4 in each round of picking for the two varieties. In addition, high percentages of overripe fruits for the variety Caturra (third round), and semi-ripe and overripe fruits with similar values (24.24 and 23.38%) for the variety Colombia are seen in this table for the first round of picking, whereas a high percentage of semi-ripe and unripe fruits were observed for the third round, which is higher than the limit mentioned by (12) that could affect the cup quality.

Table 5. Harvested mass composition for the control treatment M4 in the evaluated varieties at each round of picking.

Variety	Control sample	Ripening stage (%)			
		R	OV	SR	UR
Caturra	M4P1	51.92	36.83	10.08	1.17
	M4P2	48.03	39.19	12.30	0.49
	M4P3	30.87	54.09	13.68	1.36
Colombia★	M4P1	52.10	24.24	23.38	0.20
	M4P3	38.85	14.00	43.74	3.41

★ The replica of the M4 treatment in the 2 round (P2) was not reported due to the small amount of coffee harvested.

Sensory quality of the drink

Tables 6 and 7 show the results of the cup scores for the different treatments (compositions) evaluated in the varieties Caturra and Colombia, respectively. The total score ranged between 82.48 and 83.65 for Caturra and between 80.35 and 82.07 for Colombia. The attributes: uniformity, clean cup and sweetness, reported the highest score (10 points) in all treatments for both varieties of coffee evaluated. The cupping panel did not perceive statistically significant differences between the treatments for the variety Caturra, whereas in the variety Colombia there were significant differences favoring treatments M1 and M3 (Table 7), finding that M3 in this composition of 60% ripe fruits, 26% of over-ripe, 12% of semi-ripe and 2% of unripe and with the processing method used in the experiment, led to similar results in sensor quality than those obtained when processing an ideal coffee sample of 100% ripe fruits (Treatment M1).

Treatments (M1 and M3) with overripe fruits and a percentage higher than 26%, and less than 12% of semi-ripe in the harvested coffee mass, led to the best cup quality in the variety Colombia; On the contrary, the presence of a value > 20% of semi-ripe fruits and <25% of overripe (M4 control treatment) for the 2 rounds of picking, and higher than 3% of unripe in the third round (Table 5), caused an astringent and coarse taste in the sensory analysis of the drink, and consequently the cupping panel assigned lower scores.

Table 6. Cup score and main attributes of the variety Caturra.

Mixture	Cup	CV (%)	Aroma	Flavor	Aftertaste	Acidity	Body	Balance	Cupper score
M1	82.98a★	1.35	7.80a	7.73a	7.38a	7.58a	7.40a	7.52a	7.57a
M2	82.95a	1.42	7.92a	7.68a	7.47a	7.50a	7.42a	7.45a	7.52a
M3	83.65a	2.05	7.92a	7.72a	7.57a	7.65a	7.58a	7.58a	7.63a
M4	82.48a	4.92	7.82a	7.68a	7.53a	7.57a	7.58a	7.57a	7.57a

★ In a column, averages with different letter present statistically significant difference according to Duncan's test at 5%.

Table 7. Cup score and main attributes of the variety Colombia.

Mixture	Cup	CV (%)	Aroma	Flavor	Aftertaste	Acidity	Body	Balance	Cupper score
M1	82.07a★	1.31	7.83a	7.58a	7.27ab	7.43a	7.25ab	7.32ac	7.38ac
M2	80.35b	1.54	7.57b	7.22b	7.13ac	7.08b	7.12a	7.10b	7.13bc
M3	82.02a	1.07	7.70ab	7.53ac	7.32b	7.38ac	7.30b	7.37a	7.42ab
M4	81.05b	1.36	7.67ab	7.42c	7.10c	7.25c	7.17ab	7.22cb	7.23c

★ In a column, averages with different letter present statistically significant difference according to Duncan's test at 5%.

For treatments M1 and M3 that obtained the best cup scores for the variety Colombia, most of the panel assigned for the aroma attribute, the descriptors caramel and red fruit; for the flavor attribute; chocolate and sweet; for the aftertaste, it was sweet; and for acidity, citric. Whereas for treatments M2 and M4 the aftertaste was described as astringent and dry, and for the body they qualified it mainly as course.

The sensory analysis enabled the coffee to be classified, according to cup average values of 5 cuppers per sample evaluated, as specialty coffee – very good (80 – 84.99) (3) for all treatments, as shown in the Tables 6 and 7.

Results of the mathematical model

The nonlinear least squares multiple regression model for varieties Caturra and Colombia, made it possible to obtain the coefficients of determination R^2 of 0.687 and 0.423, respectively, which were considered imprecise in order to estimate the response variable.

For the variety Caturra, the response surface of the coffee cup as a function of the proportion of ripe and unripe fruits is presented in Figure 2. For the case of proportions higher than 40% and 80% of ripe fruits, when the values of unripe fruits do not exceed 1% and semi-ripes less than 5%, the estimated cup score exceeds 84 points. In the case of variety Colombia, Figure 3 shows that with ripe fruits higher than 40% and with semi-ripe fruits less than 25%, it reported a cup quality of more than 80 points, and with 60% and less than 10% the cup

quality increased to 82.5 points. For both varieties, the increase of the unripe fruits above 2.5% and of semi-ripe fruits higher than 15% affects the quality of the drink, as shown by the behavior of the response surfaces of the model.
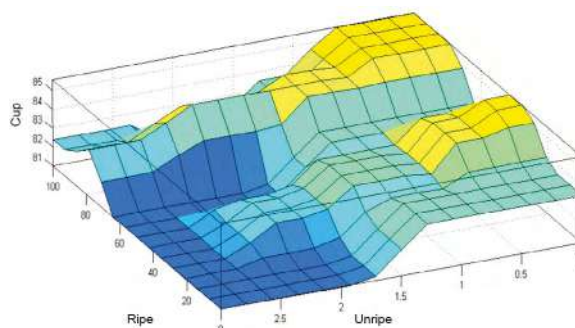

Figure 2. Response surface of the cup for the interaction of proportions of ripe and unripe fruits in variety Caturra.
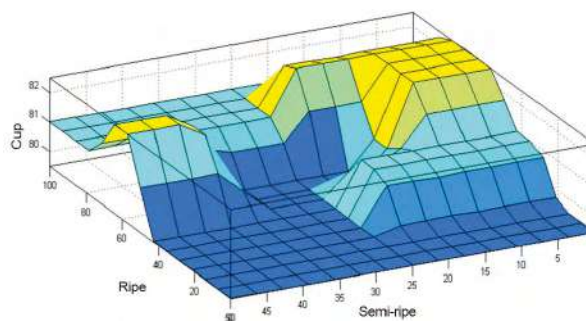

Figure 3. Response surface of the cup for the interaction of proportions of ripe and semi-ripe fruits in variety Colombia.

The fuzzy logic model led to a more accurate estimation of the cup for both coffee varieties (Figures 4 and 6), with an error of 1.40% and an R^2 of 0.46 for the variety Caturra (Figure 5), and an error of 1.03% and an R^2 of 0.852 for variety Colombia (Figure 7).
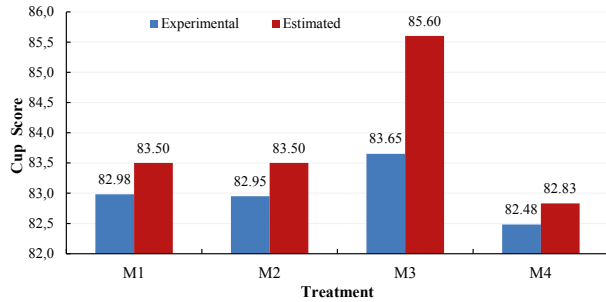

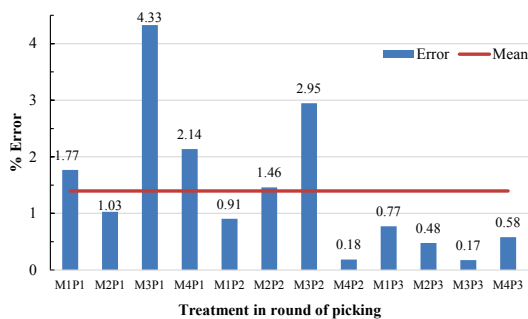**Figure 4.** Experimental and estimated values of variety Caturra coffee cup with fuzzy logic.

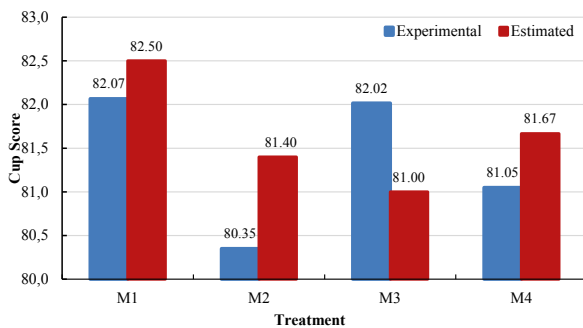**Figure 5.** Error of the quality estimate in cup for variety Caturra with the fuzzy logic model.

Figure 6. Experimental and estimated values of variety Colombia with fuzzy logic.
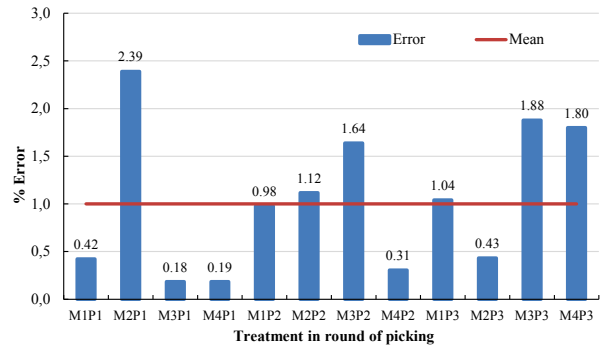

Figure 7. Error of the quality estimate in cup for variety Colombia with the fuzzy logic model.

The acceptable models obtained, in terms of the explanation of the phenomenon in a percentage higher than 80%, was validated with information from samplings carried out in other farms. Validation results for the variety Caturra are shown in Figures 8 and 9 with an average estimation error of 1.54%, and the cup quality estimated values were above the experimental data on 13 farms.
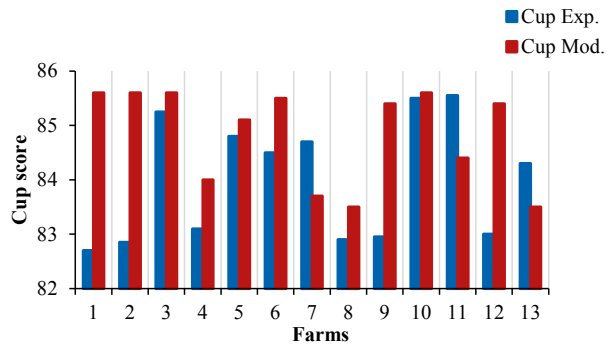

Figure 8. Validation of the fuzzy logic model in 13 farms with variety Caturra.
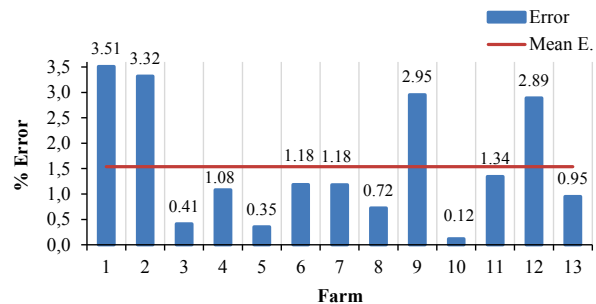

Figure 9. Error of the validated values with regards to the experimental ones of cup quality, for the 13 farms with variety Caturra.

Validation results for the variety Colombia are shown in Figures 10 and 11 with an average estimation error of 2.05% applied to 19 farms, resulting in a model with high predictive capacity, maintaining the conditions of wet processing and standardized drying of the grain.
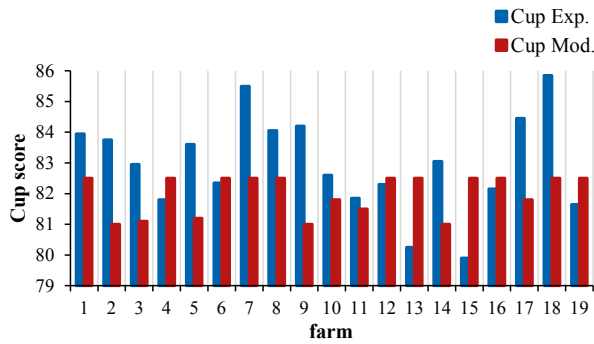

Figure 10. Validation of the fuzzy logic model in 19 farms with variety Colombia.
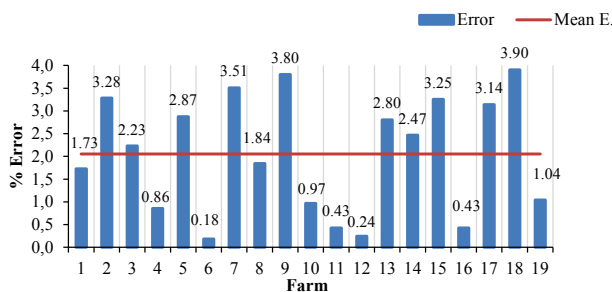

Figure 11. Error of the validated values with regards to the experimental ones of cup quality, for the 19 farms with variety Colombia.

DISCUSSION

In the fruit detachment force, values close to those found by (7) for variety Colombia are observed with differences mainly between ripe, semi-ripe and unripe fruits. Sugar concentrations (°Brix) in the mucilage differ in the three development stages evaluated, confirming what was found by (6), by concluding that this is an important chemical property for the identification of ripening stages in coffee fruits. The °Brix value for ripe fruit in the variety Caturra is higher than that reported by (20) in this same variety under a full solar exposure growing system. It was observed that, the luminosity values (L$\star$) are closer to those reported by (18) with variety Colombia, while the chromatic coordinates a$\star$ and b$\star$ of that study vary considerably from those obtained in the present investigation.

For variety Colombia the sugar concentration values were lower than those reported by (6). According to the results, the sugar concentration, °Brix of the mucilage is a criterion that enables the differentiation of developmental states, whereas the color generates imprecisions in the fruit selection process, possibly due to variations in the lighting conditions in the selection site and fatigue of the operators.

The use of the fuzzy logic model as a tool to predict, with a low estimation error, the sensory quality of the coffee in farms with defined cup profile, enables the conditioning of a methodical tool, based on the ripening stages of harvested coffee fruits. This could allow farms to standardize the harvesting process and the processing method in order to participate in differentiated markets that demand consistency and continuity of coffee quality, allowing them to be competitive.

The attributes uniformity, clean cup and sweetness reported the highest score, 10 points, in all treatments for the two varieties of coffee studied; corresponding to a score close to that found by (21) using wet processing in a harvested mass of ripe and unclassified fruits, where he scored good quality cups by describing the characteristic, balanced and estimated acidity of the drink, as well as the overall impression with the best assessment.

The errors presented by the models in both overestimation and underestimation in cup quality, considered relatively low, could be explained by the different climatic, edaphic and altitude conditions of the farms used for the validation in both varieties. The validation of the diffuse logic models led to a high predictive capacity of the cup quality based on different proportions of ripening stages of coffee. It also showed results close to those obtained by (22) who created a Fuzzy Neural Network (FNN) in order to estimate the sensory evaluation scores for coffee, from bean mixtures; finding that the FNN trained with16 learning data, showed greater precision in the estimation of the sensory evaluation scores, compared to the linear and polynomial equation models in response surface methods and multiple regression analysis.

Limitations of the study

Due to the logistic and financial constraints for the development of the research, it was carried out only in two farms, where the probabilistic model did not reliably explain the interaction of the inde-

pendent variables of the different ripening stages with respect to the cup quality. The development of the mathematical model based on fuzzy logic was constructed with data from the experiment and therefore applies to the condition of the two farms studied. Further work, can be improved from information about the characterization of the development stages in coffee fruits, for different coffee growing zones of the department of Antioquia and Colombia; even adding other variables that intervene in the climatic, edaphic, crop management conditions, and the wet processing.

CONCLUSIONS

The sugar concentration was the variable that enabled to differentiate more accurately the different ripening stages of the manually selected fruits, in comparison with the CIEL*a*b* color coordinates system.

For all treatments (ripening stages compositions) evaluated from coffee variety Caturra and Colombia, the sensory analysis led to the classification of the samples obtained as specialty coffee – very good, by scoring values between 80 - 84.99 according to the classification of the SCAA.

Similarity in the sensory quality of the drink from treatments M1 and M3, for variety Colombia, confirms the data found in other investigations about the fact that a proportion of less than 2.5% of unripe fruits in the harvested mass does not affect the quality of the drink.

The model developed with fuzzy logic and validated with information from other farms presented an error of less than 2% in the estimation of the cup quality based on the composition of ripening stages of the coffee varieties Caturra and Colombia.

CONFLICT OF INTEREST

The authors certify that there is no conflict of interest is this research.

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AUTHORS´ CONTRIBUTIONS

Víctor Manuel Martínez: conducting the experiments, reviewing the background, drafting the manuscript.

Iván Darío Aristizábal: statistical analysis, editing and proofreading of the manuscript.

Edilson León Moreno: fuzzy logic modeling, editing and proofreading of the manuscript.

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