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Effect of culture conditions, the chemical characteristics of soil and grain handling in the sensory attributes of coffee (*Coffea arabica* L.) in cup

Efecto de las condiciones de cultivo, las características químicas del suelo y el manejo de grano en los atributos sensoriales de café (*Coffea arabica* L.) en taza

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Abstract

In the Municipalities of Suaza and Timana (Department of Huila, Colombia) 54 farms cultivated with coffee (*Coffea arabica* L.) in different altitude ranges, crop management conditions and coffee processing were selected to evaluate the relationship of those variables of cropping and managing with the sensory attributes of brew. The statistical method used was Multiple Correspondence Analysis (MCA) and Partial Least Square (PLS) analysis to determine the relationship among the sensory attributes and the soil characteristics and crop management. Through multivariate analysis of variance using Hotelling test, significant differences ($P < 0,001$) for pH, Ca, Mg, Na, base saturation (BS), Al, P, Zn were found, also, significant differences ($P < 0,001$) for K, Mn, OM and B were observed among the soil types. The cups were half-length, with some acidic and intermediate representative sensory attributes. Cup quality Q3 was associated to sensory attributes as a body, sweetness, balance, flavor, acidity, and these variables with crop management such as plant density (Ds), age, height and chemicals with Sulfur (S). Q2 was affected by the fermentation time (hours) and chemical characteristics such as pH, BS, Ca, Mg as well as shade management which depends on the altitude of the farm. Q1 that had low scores on the sensory attributes was associated to soil characteristics such as Al and Fe.

Key words: Agronomic management, benefit, multivariate statistics, altitudinal ranges.

Resumen

En 54 fincas cultivadas con café (*Coffea arabica* L.) en rangos altitudinales, características de plantación y formas de beneficio del fruto diferentes, en los municipios de Suaza y Timaná (Departamento del Huila), Colombia, se evaluaron la relación entre estas variables de cultivo y manejo con los atributos sensoriales en taza. Para el estudio fueron utilizados el método estadístico Análisis de Correspondencias Múltiples (ACM) y Partial Least Square (PLS) para determinar la relación entre los atributos sensoriales y las características del suelo y de manejo de la plantación. A través del análisis de varianza multivariado mediante la prueba de Hotelling se encontraron diferencias ($P < 0.001$) para pH, Ca, Mg, Na, saturación de bases (SB), Al, P, Zn, así mismo, se observaron diferencias ($P < 0.01$) para K, Mn, M.O y B entre los tipos de suelos. En general, el perfil de las tazas fueron de cuerpo medio, algunas ácidas e intermedias con atributos sensoriales representativos. La calidad de taza Q3 se relacionó con atributos sensoriales como cuerpo, dulzor, balance, sabor, acidez y estos con variables de características de la plantación como densidad de siembra (Ds), edad, altura y elementos químicos con azufre (S). Q2 fue una taza afectada por el tiempo de la fermentación (horas) y por variables químicas como pH, SB, Ca, Mg además variables de manejo como sombra, la cual depende de la altura del sitio en el cual se encuentra el cultivo. Q1, que presentó baja calificación en los atributos sensoriales, se relacionó con variables del suelo como Al y Fe.

Palabras clave: Manejo agronómico, beneficio, estadística multivariada, rangos altitudinales.

Introduction

The cup quality of coffee (*Coffea arabica* L.) is the result of sensorial attributes that depend on factors such as genotype, variety, soil type, agroecological qualities, agronomical practices, harvesting and post-harvesting activities, roasting, crop characteristics and, processing (Fajardo and Sanz, 2003; Griffin, 2001), together with soil characteristics (Cofenac, 2003). Avelino *et al.* (2002) demonstrated the effects of multiple factors, among them, altitude, precipitation, soil acidity, shade, productivity and granulometric parameters of the roasted and grounded coffee.

Currently, studies on the dynamic of solar radiation in forestry arrays and their interaction with coffee quality are known. In this sense, Bosselmann *et al.* (2009), Vaast *et al.* (2006) and Muschler (2001) did research to associate the shade characteristics with the quality of the coffee grains. However, it has not been possible to establish a significant relationship between radiation and the different variables that affect the sensorial attributes of this fruit. The benefits of the shade are mainly explained by a reduction in the water stress caused by exposition to radiation; likely, they give optimal conditions for a good maturation (Vaast *et al.*, 2006; Muschler, 2001). Avelino *et al.* (2005) and Figueroa (2000) found a positive effect in the cup quality as result of slow grain maturation, caused by the reduction in atmospheric temperature as the altitude is increased; opposite to what is reported by Bosselmann *et al.* (2009) who found a negative influence of shade on the sensorial attributes. The objective of this research was to analyze the relation between the soil chemical characteristics, crop management conditions, altitude over the level of the sea and shade level with the sensorial attributes related to cup quality (Q) in coffee (*Coffea arabica* L.).

Materials and methods

For this study 54 farms belonging to the Association of Agricultural Producers of the south of the Department of Huila (Colombia) were selected, farms were located in the municipalities of Suaza and Timaná for a 310 Km^2 as area of influence of this study and including different altitudinal ranges, crop characteristics and processing of coffee (Figure 1). The variables evaluated in situ and the data collected from surveys with farmers are included in Table 1.

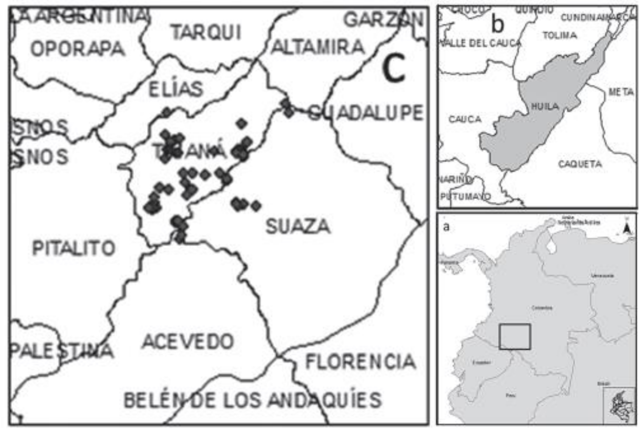

Figure 1. Location of the farms of the study. South of the Department of Huila, Colombia.

Table 1. Variables to describe the conditions of the coffee plots in farms at the south of the Department of Huila, Colombia.

Type of variable	Variable	Unit	Abrev. or symbol
Cup quality	Score by sensorial analysis	–	Q
Soil	Potential of hydrogen	–	pH
	Potassium	Cmol(+)/kg	K
	Calcium		Ca
	Magnesium		Mg
	Sodium		Na
	Base saturation	%	BS
	Aluminum	Cmol(+)/kg	Al
	Phosphorus	mg/kg	P
	Iron		Fe
	Copper		Cu
	Manganese		Mn
	Zinc		Zn
	Organic matter		OM
	Nitrogen		N
	Sulphur		S
	Boron		B
Crop characteristics	Variety	–	Var.
	Coffee plant density per hectare	Plants/ha	Plan/ha
	Tree coverage	%	%CA
	Coffee crop age	Years	Age
	Fermentation hours	Hours	Hours
	Altitude	m	Alt.

Soil management was characterized by implementation of technologies recommended by the National Federation of Coffee Growers and are consistent in the application of nitrogen as urea, diammonium phosphate (DAP) and potassium chloride (KCl) according to the scheme proposed by Sadeghian and Gonzales (2012) for crops under production. In each one of the farms one coffee plot that was under agroforestry array was selected, one soil sample up to 15 cm depth was taken and also, a cherry coffee sample following the methodology proposed by Banegas (2009) and Lara (2005) was collected to perform the analysis of attributes of the cup quality.

Cup quality (Q)

To control the effect of the type of processing, the processing of each one of the samples was done using the Becolsub technology, in which the pulping of cherry is done directly with the elimination of honey vs. the traditional system where the fermentation time and the processing steps are controlled.

The brew sensorial characteristics were analyzed by a taste panel composed of three 'Q grader' professionals from the Coffee Quality Institute® in the Laboratory of Coffee Quality in the South Colombian Center for Management and Sustainable Development of the National Service for Learning SENA, Pitalito. The coffee beans samples (250 g) coming from each plot were roasted 11 minutes at 200 °C till reaching the yellow reddish standard color. Each cup was prepared using 11 g of grinded coffee in 150 ml of boiling distilled water, medium grinding was used with 500 µm size particles. The panel was prepared in five replications and two attributes were classified using the 1 to 10 scale by the methodology proposed by Specialty Coffee Association of America (Lingle, 2001) for tasting. The evaluated variables in each one of the cups were: fragrance, aroma, acidity, taste, body, sweetness and preference, to obtain a final score and accept and define the cup quality (Q).

Chemical parameters of the soil

Chemical parameters determined were: $pH_{1:2}$, exchangeable aluminum by difference of the titrable acidity and exchangeable hydrogen, organic matter (OM), total Nitrogen (N) by Kjeldahl, assimilable P by Bray II. Nutrients such as exchangeable calcium (Ca), magnesium (Mg) and potassium (K) were determined with extraction method by ammonium acetate lixiviation and atomic absorption. Iron (Fe), copper (Cu), zinc (Zn) and magnesium (Mn) by the DTPA extraction method and atomic absorption.

Relations among the crop characteristics

These observations were done by a survey performed among the producers of each farm to know from each selected plot the yield/area (kg/ha), the grown variety, the plant density/ha, tree coverage, coffee crop age; similarly, the post-harvest activities as grain processing and fermenting hours.

Statistical analysis of data

To evaluate the cup quality (Q) descriptive statistic tests were done for the soil analysis and cup sensorial test results. Similarly, contingency table were built and quantitative variables were transformed to qualitative ones in order to apply the Multiple Correspondence Analysis (MCA) using the free software R v. 2.15 (R Development Core Team, 2012) by the independent platform for statistical analysis R commander (Fox, 2005) based on the FactoMineR package (Husson *et al.*, 2012) for multivariate exploratory analysis. To create each one of the typologies per characteristic the methodology proposed by Deheuvels *et al.* (2012), Avelino *et al.* (2009) and Avelino *et al.* (2006) was used. The MCA is an exploratory technique that allows graphic representation of columns and files of contingency table (Lebart *et al.*, 1984). The MCA technique is also an important tool to analyze text data where contingency tables are associated with the use of several words among different texts in each variable. The MCA can be interpreted as a complementary technique and, sometimes, supplementary to the use of log-lineal models for the analytical study of the relationships contained on a contingency table. This analysis allows graphic exploration of these relationships (Balzarini *et al.,* 2008). To identify differences between soil typology (Su) in each one of the chemical varieties a multivariate analysis of variance was performed checking the differences by the Hotelling test. Then, a Partial Least Square (PLS) analysis was done to determine the relationship between the matrix of soil chemical variables and the sensorial attributes to determine the cup quality of coffee (Q).

Results and discussion

In the multivariate analysis of variance differences were detected ($P < 0.001$) for pH, Ca, Mg, Na, BS, Al, P, Zn and for K, Mn, OM and B between soil types ($P < 0.001$) (Table 2). The cup quality (Q) showed differences at three levels in attributes such as acidity, balance, body and score, where Q1 and Q3 were the groups with lower and higher scores, respectively (Figure 2).

Table 2. Correlation coefficient (P < 0.05) between soil characteristics and sensorial attributes in the coffee cup in farms at the south of the Department of Huila, Colombia.

Attribute	Characteristic													
	pH	MO	N	P	K		Mg	Ca		Al		Na		S	Fe
Body	0.17	0.06	0.05	0.05	0.05		0.05	0.20		0.18		0.01		0.03	0.15
Acidity	0.05	0.03	0.04	0.05	0.03		0.01	0.28	0.0444	0.03		0.04		0.01	0.13
Balance	0.06	0.10	0.10	0.04	0.003		0.01	0.14		0.10		0.09		0.08	0.04
Taste	0.09	0.03	0.03	0.04	0.12		0.01	0.21		0.06		0.02		0.04	0.16
Residual taste	0.14	0.01	0.02	0.03	0.06		0.04	0.20		0.13		0.06		0.03	0.12
Fragance/aroma	0.25	0.04	0.04	0.22	0.30	0.0308	0.14	0.18		0.29	0.0338	0.28	0.0461	0.03	0.16
Sweetness	0.13	0.02	0.03	0.07	0.02		0.24	0.16		0.13		0.12		0.07	0.15

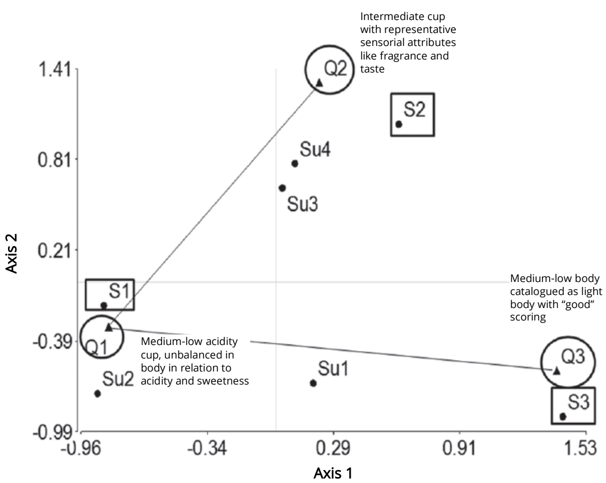

Figure 2. Analysis of correspondence based on the contingency tables between sensorial attributes and coffee cup quality. Farms at the South of the Department of Huila, Colombia.

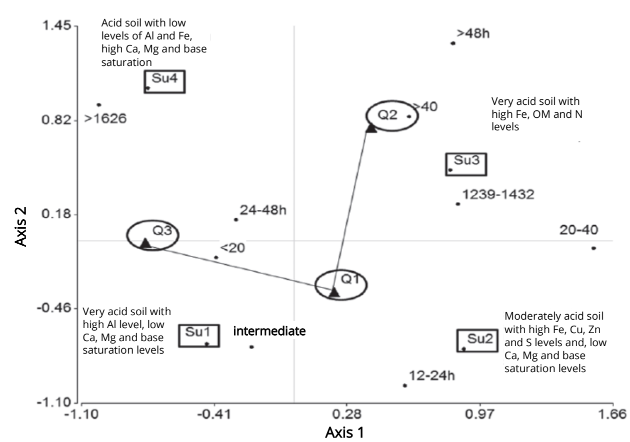

Figure 3. Analysis of correspondence based on the contingency tables of soil characterisitics (Su) and coffee quality (Q). Farms at the South of the Department of Huila, Colombia.

In the Figure 3 are shown the relationships between soil type and coffee quality, where it is observed a relationship between a very acid soil type with high Al, low Ca, Mg and BS and the Q3 cup quality. Moderately acid soil with high Fe, Cu, Zn and S and low level of Ca, Mg and BS were associated with Q1 cup quality. Very acid soils with high Fe, OM and N are associated with Q2 cup quality. The farms under study were found at low altitudes with tree coverage (%CA) lower than 20%, sowing densities between 4000 and 5200 trees/ha and grain fermentation times between 24 and 48 hours. These management and crop conditions affect the sensorial attributes as demonstrated with the relationship between Q3 and plots located higher than 1626 MASL and shade coverage lower than 20% (Figure 3).

As the altitude over the level of the sea increases the temperature decreases, which favors the duration of the maturation process of the cherry coffee, and in turn, favors a better filling and weight of grain, a higher production and a better quality of the brew (Vaast *et al.*, 2005b; Wintgens, 2004). On the other hand, higher levels of cloudiness during the day in higher altitudes caused an additional reduction in the use of radiation, for this reason it is common that the tree coverage levels in the agroforestry arrays of coffee are reduced with increases in the altitude over the level of the sea. The physical and organoleptic characteristics of coffee are modified as altitude increases affecting, therefore, the cup quality (Vaast and Bertrand, 2005; Vaast *et al.*, 2005a; Figueroa *et al.*, 2000; Buenaventura and Castaño, 2002; Salazar *et al.*, 2000), therefore a higher altitude develops positive attributes as acidity and aroma, which defines a better taste and quality in the drink (Vaast *et al.*, 2005a) (Figure 3).

In the Figure 4 is observed the relationship between cup quality vs. management and processing characteristics of grain and crop variety. The level of correspondence between the variety and the cup quality Q was high (P < 0.001). The lower score (Q1) was for the samples obtained in the Castillo variety, in compa-

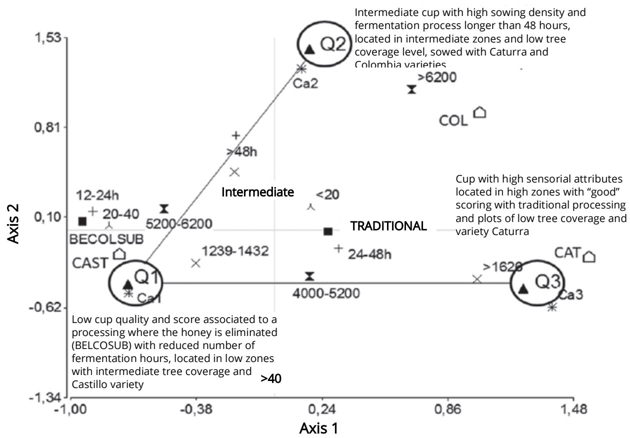

Figure 4. Analysis of correspondence based on the contingency tables of coffee quality (Q) and crop management characteristics. Farms at the South of the Department of Huila, Colombia.

rison with Colombia and Caturra varieties that are associated with Q2 and Q3, that belong to intermediate and high sensorial attributes, respectively. In this sense Kumar *et al.* (2013) state that Caturra variety is associated to cup of better body, taste and acidity which are characteristics found in Q3. It is possible that low cup quality is affected during the processing by variables like fermentation time associated with the removal of mucilage by the Becolsub technology which eliminates the fermentation and reduces the wet processing of coffee.

75.2% of the variability was explained when correlating the variables for sensorial attributes with the matrix composed of 21 variables associated with soil chemistry, characteristics of the crop and coffee production, finding a direct relationship between Q3 coffee quality and the sensorial attributes of acidity, body, residual taste, taste and balance. The Q1 cup quality was associated mainly with variables of crop characteristics such as sowing density (Ds) and tree coverage (%CA) that are directly dependent on the altitude range where the crop is located, affecting negatively the grain sensorial attributes (Figure 5).

In the Table 3 are shown the coefficients

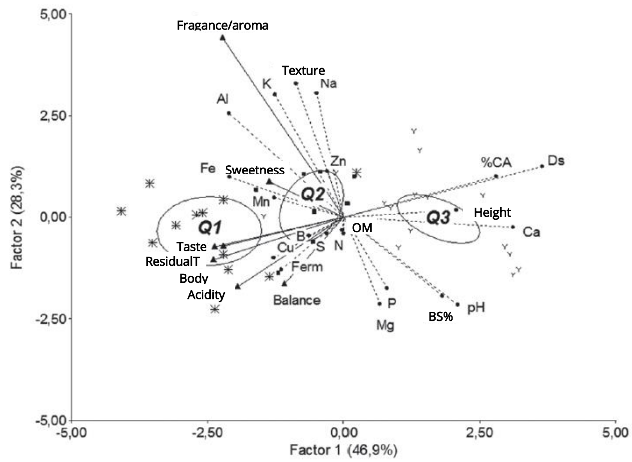

Figure 5. Triplot of the correlation between the matrix of interaction among the sensorial attributes variables vs. matrix of 21 coffee crop and production management variables. Q3 to Q1 is good to bad quality coffee. Farms at the South of the Department of Huila, Colombia.

Table 3. Properties of soil from the farms under study. South of the Department of Huila, Colombia.

Property	Soil 1	Soil 2	Soil 3	Soil 4	P <
	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.	
pH	4.26±0.08a*	5.72±0.28d	4.65±0.07b	5.18±0.1c	<0.0001
K	1.57±0.31b	1.48±0.39ab	0.57±0.17a	0.56±0.2a	0.0178
Ca	2.81±0.42a	15.77±4.63c	2.97±0.56a	7.23±0.96b	<0.0001
Mg	0.78±0.17a	1.06±0.44ab	0.52±0.08a	2.27±0.37b	<0.0001
Na	0.24±0.01b	0.14±0.01ab	0.1±0.01a	0.13±0.01a	<0.0001
BS%	68.62±3.74a	98.99±0.59b	71.96±3.32b	94.88±1.02a	<0.0001
Al	2.08±0.24c	0.14±0.06ab	1.49±0.18b	0.48±0.1a	<0.0001
P	21.4±4.05ab	57.87±5.89c	32.27±6.14b	12.55±3.66a	0.0001
Fe	92.12±10.8ab	91.98±22.36c	113.18±15.93b	57.55±9.08a	0.05
Cu	0.98±0.25	2.1±0.5	2.19±0.9	1.1±0.24	0.2855
Mn	27.17±3.5b	13.83±4.62ab	26.3±4.91b	12.98±2.58a	0.0395
Zn	2.69±0.43b	6±1.2c	2.33±0.39ab	1.28±0.25a	0.0001
OM	3.99±0.24a	3.54±0.2ab	5.13±0.22b	3.88±0.47a	0.0054
N	0.2±0.01a	0.18±0.01ab	0.26±0.01b	0.19±0.02a	0.0051
S	8.6±1.34a	15.75±5.38b	6.07±0.62a	6.84±1.23a	0.0165
B	0.66±0.08	0.57±0.26	0.5±0.1	0.6±0.11	0.7039

* Values in the same row followed by different letters are statistically different according to the Hotelling test (P < 0.05).

and levels of probability for the relation between predictive and dependent variables in relation to the cup quality Q. Positive relationships were found between K ($P < 0.0308$), Na ($P < 0.0461$) and Al ($P < 0.0338$) with fragrance/aroma; which was not observed for Ca and cup acidity ($P < 0.0444$). Rosas *et al.* (2008) and Avelino *et al.* (2002) found similar relationships between Ca level and fragrance/aroma, indicating that low Ca in the soil affects coffee grain quality, however, these authors state that excess of Al negatively affects the coffee quality, which are opposite results to the ones found in this study.

The altitude effect on cup quality is attributed to the temperature and humidity changes. The altitude and temperature have negative correlations since for each 100 m in altitude the temperature decreases between 0.5 and 0.6 °C (Wintgens, 2004). Buenaventura and Castaño (2002) did not find a relation between the increase in altitude and the quality of coffee grains. On the other hand it is known that some elements have negative effects on the coffee cup quality, mainly nitrogen, potassium and calcium (Avelino *et al.*, 2002) and minor elements like boron, chloride, molybdenum, iron, among others (Bornemisza, 1988).

Conclusions

The relationship between the sensorial attributes on the coffee cup quality and the chemical characteristics of soil was high, in this sense, acid soils with high Fe and Al content provide cups of intermediate quality Q2 and high quality Q3. The cup quality Q1 (low) was associated to moderately acid soils with high levels of Cu, Zn, S and low of Ca and Mg.

A negative relationship between cup acidity with Ca content and a positive correlation between fragrance/aroma with K, Na and Al content in soil.

The coffee variety affected the cup quality in addition to the fermentation time.

The best scores for sensorial attributes in the coffee cup were obtained in areas of high altitude over the level of the sea and under shade, therefore it is required an adequate management of the tree coverage taking into account the altitude.

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