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Relationship between the sensory attributes and the quality of coffee in different environments

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In order to understand the relationship between the sensory attributes of coffee (including factors such as acidity, flavor, and aftertaste), and given the possible influences of genetic factors on coffee quality, we evaluated the sensory quality of 10 commercial cultivars of *Coffea arabica* in three important coffee regions of Minas Gerais, Brazil, and examined, via path analysis, the interactions of the attributes that determine coffee quality. The experiments were conducted in three cities (Lavras, Patrocínio, and Turmalina) in three separate regions of cultivation in Brazil. Beverage quality was evaluated by assessing the sensory attributes of the cultivars Oeiras MG 6851, Catiguá MG 1, Sacramento MG 1, Catiguá MG 2, Araponga MG 1, Paraíso MG H419-1, Pau Brasil MG 1, Catiguá MG3, Topázio MG1190, and Bourbon Amarelo LCJ10, the last of which was used as the control cultivar. Experiments were designed in a randomized block consisting of 3.5 m × 0.7 m plots containing 10 plants of the various cultivars, with three replicates of each plot. We concluded that cultivation environment greatly influences the quality of the coffee produced by the cultivars. The cultivars Bourbon LCJ10, Araponga MG1, Paraíso MG H419-1, Sacramento MG1, Oeiras MG6851, and Catiguá MG2 exhibiting high potential for cultivation in the regions of Lavras, Patrocínio, and Turmalina.

Key words: *Coffea arabica*, sensory analysis, path analysis, genotype-environment interactions.

INTRODUCTION

Interest in unique cultivars for the production of specialty coffees has increased significantly in recent years due to the increasing global demand for high-quality coffee, leading researchers to focus not only on productivity factors but also the beverage quality produced by these new varieties (Figueiredo et al., 2013).

Environmental factors, dictated by altitude and latitude, and beverage quality are closely intertwined. Coffee is grown throughout the state of Minas Gerais, Brazil, accounting for 70% of *Coffea arabica* production in Brazil and 25% of global production (CONAB, 2016). Due to the quantity and diversity of coffee cultures, genotypicenvironmental interactions greatly influence the quality of the final product (Pereira et al., 2010; Sobreira et al., 2015th, 2015b).

Southern Minas Gerais is largely mountainous, with altitudes ranging from 700 to 1,255 m, and features a climate that falls somewhere between the B2 and B3 types (wet) prevalent in most parts of the region (Silva et al., 2008). Cerrados, an area within Minas Gerais, is located on a plateau where altitudes range between 820 and 1,110 m, and experiences a type B1 (wet) climate, factors that potentially favor the production of high-quality coffee (Barbosa et al., 2012). This region is Brazil's first region to have a geographical demarcation internationally recognized; it also has a certificate of origin, traceability, and a sustainability program (Barbosa et al., 2010). Specifically the region of Jequitinhonha Valley has relatively non-humid climate and great potential for quality coffee production (Farnezi et al., 2010).

Evaluation of coffee quality in Brazil is performed by coffee cupping sessions, in which professional coffee tasters ascribe grades to several attributes, with the sum of the grades providing the final score (Chalfoun et al., 2013). This coffee cupping session can detect whether the coffees from different cultivars have special nuances, generally related to chocolaty, caramelly, fruity and flowery tastes (Sobreira et al., 2015a).

Our goal here was to gain a better understanding of the relationship between these sensory attributes and the influence of genetic factors on coffee quality by evaluating the sensory quality of 10 commercial cultivars of *C. arabica* grown in three prominent coffee regions of Minas Gerais state, and using path analysis to examine the interactions between these attributes and how they affect the coffee-beverage quality.

MATERIALS AND METHODS

Description of the experimental area

Experiments were conducted in January 2006 in three significant coffee regions of Minas Gerais state, consisting of Lavras (Experimental Campus of Federal University of Lavras, southern Minas Gerais), Patrocínio (Experimental Farm of the Agricultural Research Company of Minas Gerais, in Alto Paranaíba), and Turmalina (Capão da Estiva Farm, in the Jequitinhonha Valley). The average altitude of these three municipalities are 966, 920, and 820 m, respectively; soils in all three locations are classified as dark red latosols, as they have low saturation (V < 50%) and a Fe_2O_3 (for H_2SO_4) content among 180 and 360 g·kg^{-1}, which mostly occurs in the topmost 100 cm of the B horizon (Santos, 2006).

Experimental design and treatments

We evaluated 10 cultivars of *C. arabica* L.: Oeiras MG6851, Catiguá MG1, Sacramento MG1, Catiguá MG2, Araponga MG1, Paraíso MG H419-1, Pau Brasil MG1, Catiguá MG3, Topázio MG1190, and Bourbon Amarelo LCJ10, the last of which was used as the control cultivar, as it is known to produce high-quality beans for use in specialty coffees (Ferreira et al., 2012; Figueiredo et al., 2013.).

We used a randomized block design with three replicates, consisting of plots containing 10 plants, six of which composed the core plot. We used a spacing pattern of 3.5 m between rows and 0.70 m between plants, equivalent to 4,081 plants ha^{-1}.

Variables analyzed

Analyses of the sensory attributes were performed annually for the first three crops. After harvesting, fruits in the cherry and nut stages were separated via a water tank and a 3.0 mm × 3.0 mm wire-mesh-screen sieve. Separation of fruits in cherry from those still in green, which remained in the sample, was performed using a coffee peeler, ensuring that only ripe fruits were peeled; in total, seven gallons of peeled cherries was obtained. These samples were equally distributed in sieves of 1 m² (composed of a wooden frame and a 2.00 mm × 1.00 mm screen mesh, manufactured with polyethylene yarn) and turned 12 times daily until the coffee grains attained levels of approximately 11 to 12% water content (wb). After drying, the samples were processed and prepared for use in the sensory analyses.

Sensory analysis was performed by members of the Brazilian Specialty Coffee Association (BSCA), and followed established BSCA procedures. Attributes consisted of clean cup (Ccp), sweetness (Swt), acidity (Acd), body (Bod), flavor (Fla), aftertaste (Aft), balance (Bln), and overall impression (Ove), with each attribute assigned a score ranging from 0 to 8 based on the intensity of the sample, thus ensuring greater objectivity than conventional "cup tests". The sum of the scores was considered to be the final score (Fsc) of the beverage, from which was determined the final classification. Each sample was given a baseline score of 36 points, which was incorporated into the scoring of each attribute; specialty coffees were those for which final scores exceeded a value of 80 (BSCA, 2014).

Statistical analysis

The averages of the quality attributes of the first three crops were used in the statistical analyses. The data obtained were adjusted to the following linear mixed model (Smith et al., 2005):

$$y_{ijk} = \mu + c_i + b_{j(k)} + a_k + ca_{ik} + \epsilon_{ijk},$$

where y_{ijk} is the observed value of the variable response related to the *i*th cultivar of the *j*th block in the *k*th environment; μ is a constant inherent to all observations; c_i is the effect of the *i*th cultivar (expressed as i = 1, ..., 10); $b_{j(k)}$ is the effect of the *j*th block within *k*th environment (j = 1, 2, 3; $b_j \sim N(0, \sigma_b^2)$); a_k is the effect of the *k*th environment (where k = 1, 2, and 3); ca_{ik} is the effect of the interaction between the *i*th cultivar and the *k*th environment; and ε_{ijk} is the experimental error associated with the y_{ijk} observation ($\varepsilon_{ijk} \sim N(0, \sigma^2)$).

A fixed effects model is a statistical model were analyzed with a

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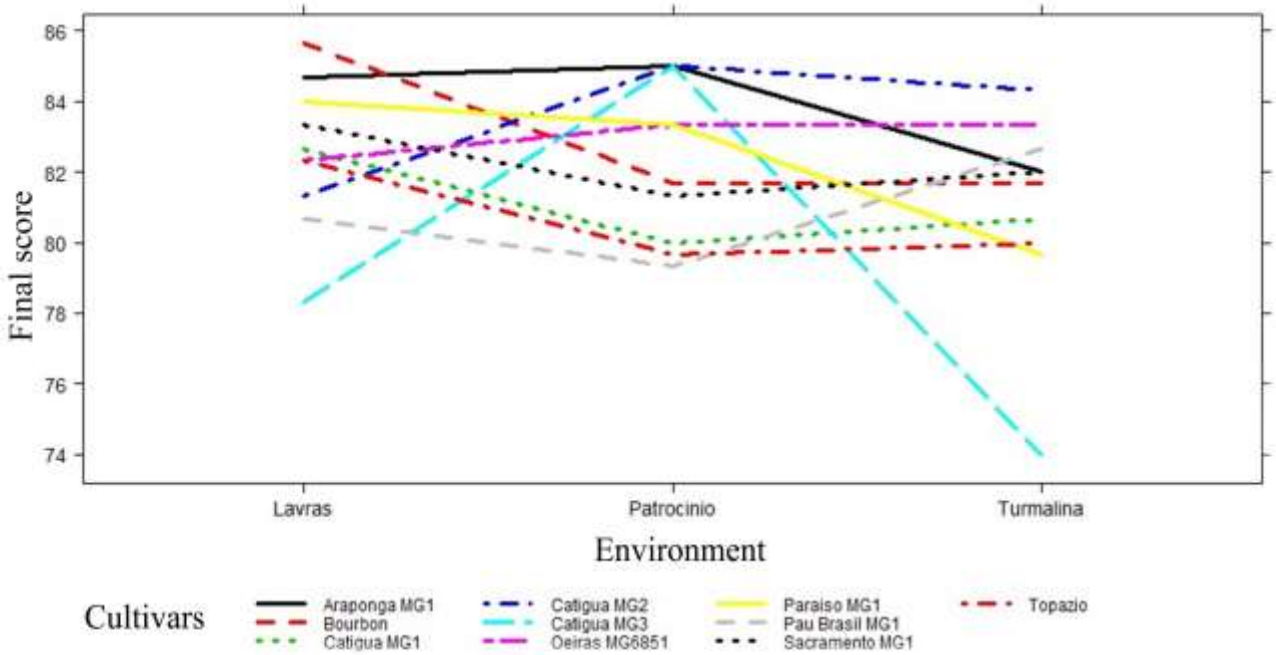

Figure 1. Cultivar performance relative to the final scores in the three cultivation regions of Lavras, Patrocínio, and Turmalina.

Wald type II test. For this study, the average performance of the cultivars was calculated as the adjusted means of the cultivars for each environment and their respective confidence intervals (95%), according to the statistical model described above, using the LSmeans procedure of the library "doBy" (Hojsgaard and Halekoh, 2014) in R (R Development Core Team, 2013).

Path analysis was used to examine both direct and indirect correlations between the quality attributes and the final score (Wright, 1921). The final score (Nsc) was considered to be the main variable, with the attributes Ccp, Swt, Acd, Bod, Fla, Aft, Bln, and Ove set as the explanatory variables.

Data were standardized by dividing the deviation of each observation between the averages of the attributes by the standard deviation for that attribute. Standardized observations were assigned an average of zero and a variance of one; in our analysis, Fsc was considered to be the basic variable (Y), with Ccp, Swt, Acd, Bod, Fla, Aft, Bln, and Ove as the primary factors. It was necessary to ensure that no multicollinearity existed among the explanatory variables in order to maximize reliability of the estimates of the direct and indirect effects obtained via the path analysis. As such, analysis of the correlation matrix between the explanatory variables model and the condition number of the matrix was obtained, that is, the relation between the largest and smallest self-value of the matrix. The condition number (CN) for the correlation matrix was CN = 17, indicative of a slight multicollinearity (CN < 100), but one too weak to pose a problem for path analysis (Montgomery; Peck, 1992). All statistical procedures were performed using R software (R Development Core Team, 2013).

RESULTS AND DISCUSSION

We detected a genotype × environment interaction effect (χ^2 91,440), indicating that beverage quality of the cultivars varies with environmental factors such as altitude, and the genetic diversity of the cultivated material-a result that accords with the findings of previous research (Mendonça et al., 2005; Pereira et al., 2010; Ferreira et al., 2012; Chalfoun et al., 2013).

In general, beverage quality varied for all cultivars among the three regions included in this experiment (Figure 1), a result that supports recommendations that coffee production be concentrated in specific regions. According to the BSCA methodology, final scores must be higher than 80 for classification as specialty coffee (Chalfoun et al., 2013). Scores between 71 and 75 were assigned to hard beverage, 75 to 79 for only soft drink, 80 to 84 for soft drink, and above 85 for strictly soft drink (Martinez et al., 2014). The Bourbon LCJ10 cultivar, a genotype with good potential for specialty coffee production, had final average scores of 85.67 in Lavras and 81.67 in Patrocínio and Turmalina.

The Catiguá MG3 cultivar exhibited the greatest degree of variation in response to different environmental conditions. This cultivar scored high (85) in Patrocínio and was thus classified as a specialty coffee in that region, but scored considerably lower in both Lavras (78.33) and Turmalina (74).

Overall, the averages of the final scores of the 10 cultivars were very similar among the three municipalities, ranging from 82.36 in Patrocínio to 82.53 in Lavras to 81.03 in Turmalina. The latter site is at a much lower elevation than the other two locations-an indication that beverage quality tends to improve with increasing elevation (Bertrand et al., 2012). The cultivar Bourbon had the highest final score of all in Lavras, with

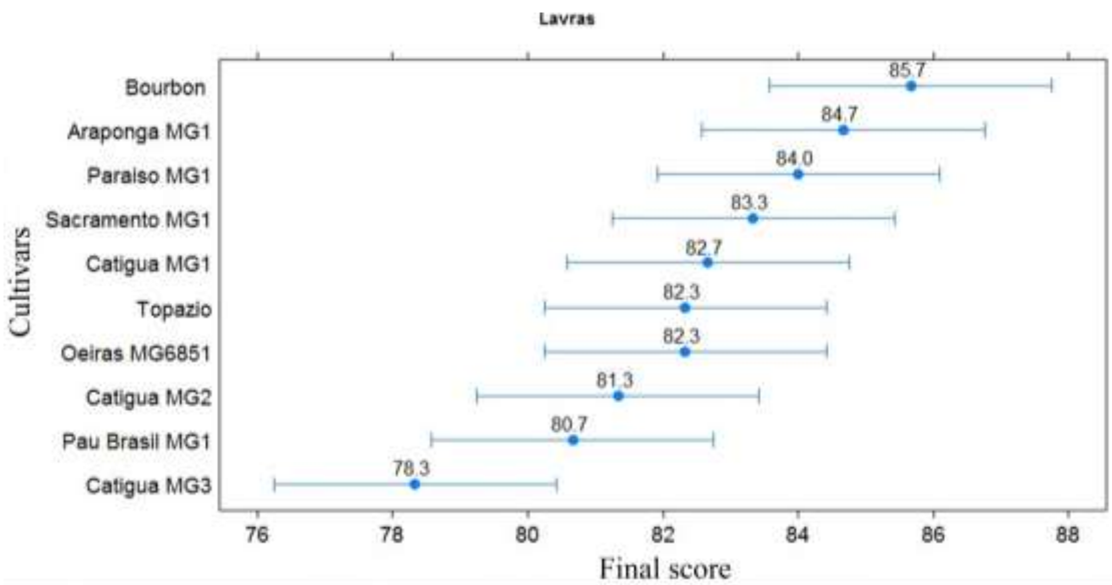

Figure 2. Averages of the final scores of the coffee cultivars in Lavras.

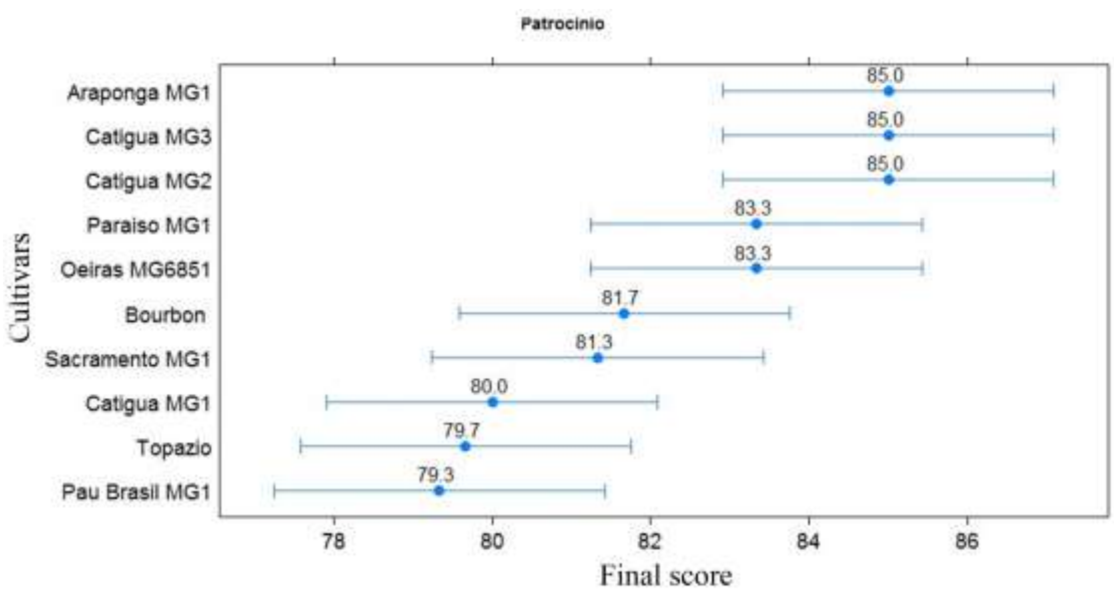

Figure 3. Averages of the final scores of the coffee cultivars in Patrocínio.

no overlap with the confidence intervals of the cultivars Catiguá MG2, Pau Brasil MG1, and Catiguá MG3, indicating a clearly superior performance of Bourbon over the others (Figure 2). Similarly, Araponga MG 1, the final score of which was only a single point below the Bourbon control, overcame the Catiguá MG3 cultivar, highlighting the potential of this cultivar for producing high-quality coffee. Most of the cultivars assessed in Lavras scored higher than 80, with the exception of Catiguá MG3. These results corroborate those of Barbosa et al. (2012), who suggested that many of the environmental conditions prevalent in southern Minas Gerais, including average temperatures, precipitation levels, and elevation, are ideal for the production of high-quality coffee.

In the Alto Paranaíba region, represented by the city of Patrocínio, the cultivars Araponga MG1, Catiguá MG3, and Catiguá MG2 scored higher than the cultivars Catiguá MG1, Topázio MG1190, and Pau Brasil MG1 (Figure 3). Moreover, the cultivars Araponga MG1, Catiguá MG3, Catiguá MG2, Paraíso MG H419-1, and

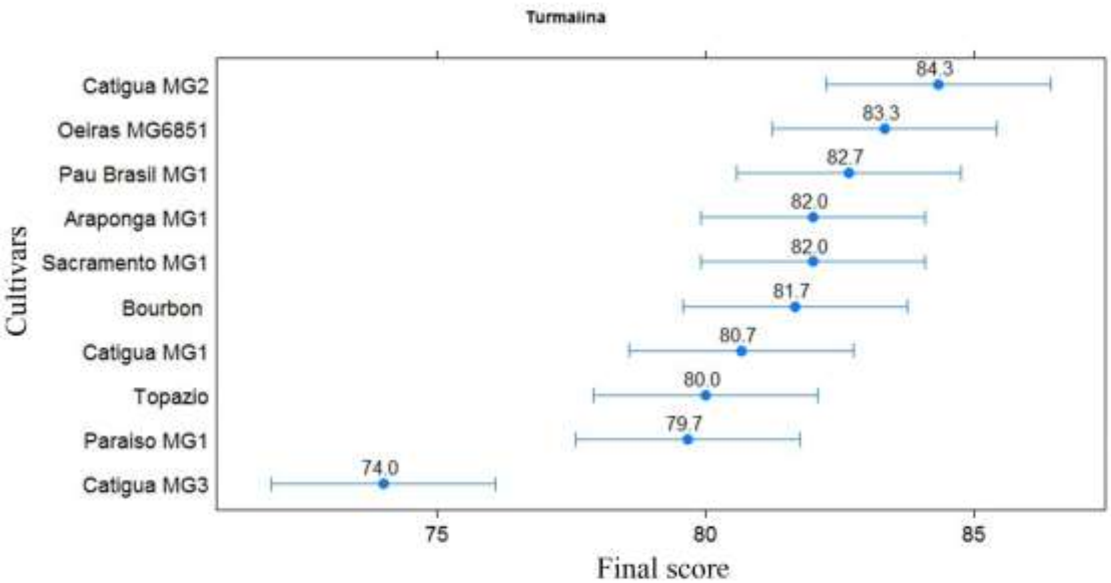

Figure 4. Averages of the final scores of the coffee cultivars in Turmalina.

Oeiras MG6851 had final scores higher than the control Bourbon cultivar, demonstrating that the combination of genetic and environmental factors affects the chemical composition of coffee, corroborating the findings of other authors (Ferreira et al., 2012; Figueiredo et al., 2013, 2015). In this location, only Topázio MG1190 and Pau Brasil MG1 failed to attain the minimum score for classification as specialty coffees. The experiment was performed at 820 m of altitude.

In Turmalina, the cultivar Catiguá MG3 was graded as having little potential for specialty coffee production compared to the other cultivars, with a final score of 74 and no overlap between the confidence intervals for this cultivar and the other nine cultivars (Figure 4). This result shows the influence of the environmental conditions in the Turmalina region on the qualitative characteristics of this cultivar whereas 'Catiguá MG3' had the highest score in Patrocínio. The cultivars Catiguá MG2, Oeiras MG6851, Araponga MG1, Sacramento MG1, Bourbon, and Catiguá MG1 also scored higher than 80, with final scores ranging from 80.7 to 85.

In addition to the Bourbon control, the cultivars Araponga MG1, Paraíso MG H419-1, Sacramento MG1, Oeiras MG6851, Catiguá MG2, and Catiguá MG1 scored the highest in all three regions, which allows us to infer that genetics has a more dominant influence than environmental conditions in these cultivars. It is worth noting here that all cultivars, with the exception of the control, derive from crosses between the cultivars Timor Hibryd and Catuaí, which are widely used in the specialty coffee market (Kitzberger et al., 2011; Scholz et al., 2013).

The quality of these cultivars has been reported elsewhere. Pereira et al. (2010) showed that Catiguá MG2 had sensory quality scores superior to the Bourbon cultivar at an altitude of 900 m for two consecutive years, as did the Sacramento MG1 and Catiguá MG1 cultivars, results similar to those presented by Chalfoun et al. (2013). Fassio et al. (2016), while assessing these same cultivars in Lavras and Patrocínio, gave Catiguá MG2, Paraíso MG H419-1, and Araponga MG1 the highest sensory scores, and Sobreira et al. (2015b) found that cultivars deriving from Timor Hybrid de scored higher than traditional and Bourbon cultivars.

Simple correlations between the explanatory variables (Ccp, Swt, Acd, Fla, Bod, Aft, Bln, Ove) and the Fsc were performed in order to better understand the relationships between the various attributes, which could then be used to guide sensory analyses (Table 1). The Fla attribute had the strongest positive correlation with Fsc (0.80), followed by Ccp and Swt (0.74). Whereas the final grade is obtained by determining the sum of the individual characteristics, these correlation analyses indicated that improvement in the quality of the other sensory attributes could be obtained via selection for these three factors.

The attribute of flavor represents the intensity, quality, and complexity of the combination of all of the attributes, whereas Ccp refers to the absence of negative impressions during ingestion and Swt refers to the pleasantness of the taste, which is the result of the presence of certain carbohydrates. Bitterness (or "green" flavor) in this context is the opposite of Swt (SCAA, 2014). Such terms are commonly used by both professional coffee tasters and researchers involved in analyses of the sensory qualities of coffee (Kitzberger et al., 2011; Gamboa et al., 2013). All of the correlations both between the main variable and the explanatory variables and among the various explanatory variables were positive, indicating that all of the sensory attributes

Table 1. Correlations between the sensory characteristics of coffee cultivars in the three regions of Minas Gerais assessed in this study.

	Sensory characteristics of beverage[1]								
	Fsc	**Ccp**	**Stw**	**Acd**	**Bod**	**Fla**	**Aft**	**Bln**	**Ove**
Fsc	1.00***								
Ccp	0.74***	1.00***							
Dcr	0.74***	0.60***	1.00***						
Acd	0.53***	0.22***	0.27***	1.00***					
Bod	0.61***	0.40***	0.40***	0.38***	1.00***				
Fla	0.80***	0.57***	0.64***	0.26***	0.31***	1.00***			
Aft	0.61***	0.26***	0.32***	0.22***	0.29***	0.41***	1.00***		
Bln	0.71***	0.69***	0.41***	0.24***	0.35***	0.57***	0.30***	1.00***	
Ove	0.73***	0.43***	0.40***	0.29***	0.44***	0.53***	0.40***	0.52***	1.00

[1]Final score (Fsc), clean cup (Ccp), sweetness (Stw), acidity (Acd), body (Bod), flavor (Fla), aftertaste (Aft), balance (Bln) e overall impression (Ove).**(value - $p < 0.05$) e ***(value - $p < 0.001$).

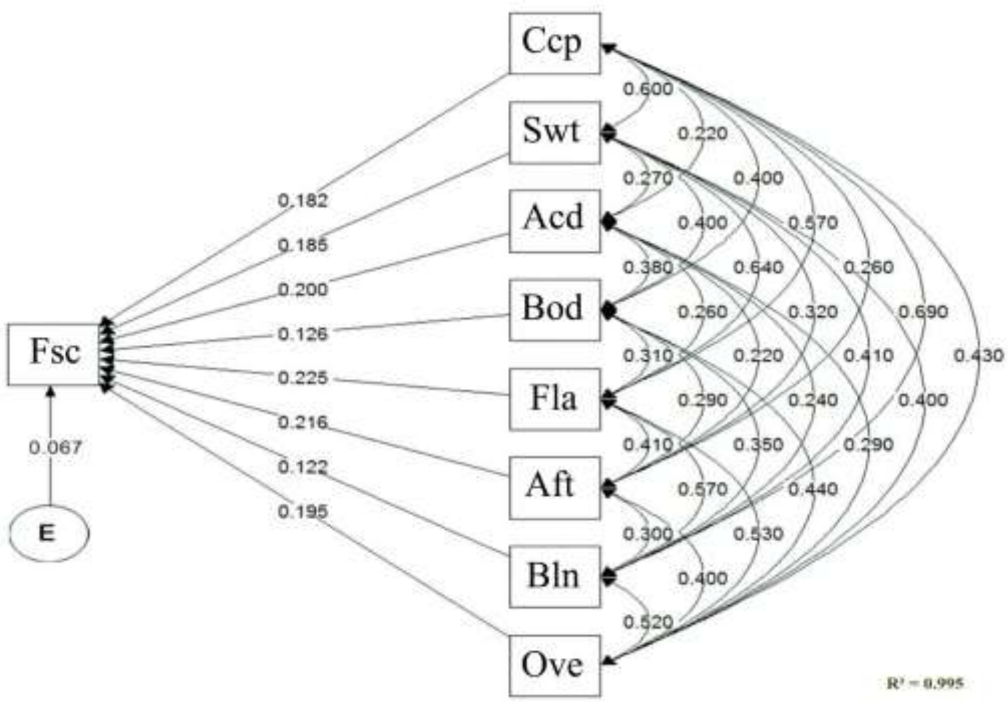

Figure 5. Graphical representation of direct and indirect effects of the sensory attributes on the final score of beverage quality, where: final score (Fsc), clean cup (Ccp), sweetness (Stw), acidity (Acd), body (Bod), flavor (Fla), aftertaste (Aft), balance (Bln) and overall impression (Ove).

are important components in determining beverage quality, corroborating the results of several other studies of *C. arabica* genotypes (Dessalegn et al., 2008; Kathurima et al., 2009; Sobreira et al., 2015). However, these correlations are only indicative of associations among the various attributes and do not reveal cause-and-effect relationships. For this, analysis of the direct and indirect effects among the variables is required, in order to identify the most effective selection criteria.

The ranks, direct effects (pyx_i) of the explanatory variables (x_i) on the main variable (y), and correlations (r_{xixi}) among the explanatory variables are shown in Figure 5. The indirect effect of an explanatory variable (x_1) on the main variable (y) via a second explanatory variable (x_2) can be expressed as $pyx_2{*}r_{12}$. Note that the variables explained 99.50% of the total variation of the final scores, according to the determination coefficient (R^2). All estimates of the ranks of the direct effects were higher than the residual effect (0.067), indicating that all of the attributes are important and influence the final score, and corroborate the results shown in Table 1. Of the attributes, Fla was the most influential, followed by Aft, Acd, Ove, Swt, Ccp, Bod, and Bln.

The estimated rank for Fla was 0.225; estimates of the indirect effects of Fla on Fsc were higher than the residual effect for only five variables, of which the indirect effect of Fla via Swt was greatest (pyx_2*r_{12} = 0.185*0.640 = 0.1184), due to the highly positive correlation between flavor and sweetness (0.640), followed by indirect effects on Ccp (0.1038), Ove (0.1034), Aft (0.0885), and Bln (0.0693).

Aftertaste had a direct effect of 0.216 on Fsc, and indirect effects of 0.0924 on Fla and 0.0780 on Ove. Other indirect effects were lower than residual ones. Acidity had a direct effect of 0.2002 on Fsc, and no indirect effect was greater than the residual effect. As such, it would seem that Acd does not have any relationships with other attributes that may influence Fsc but exerts only a direct influence on the final score, which can be attributed to the low correlations between Acd and the other attributes (Figure 5).

Sobreira et al. (2015b) divides the acidity category into the three subcategories alive, sweet, and undefined/medium, flavor into chocolaty, fruity, and caramel, and aftertaste into long, refreshing, and pleasant. In this paper, these three categories – acidity, flavor, and aftertaste – were considered to be decisive in determining the final score of the beverage. Kathurima et al. (2009), in a study of 42 genotypes of *C. arabica* in Kenya, observed that aftertaste, acidity, and flavor correlated strongest with quality, a result similar to ours. Likewise, in a similar study, Sobreira et al. (2015a) observed that aftertaste and flavor correlated highly with quality for the germplasm Timor Hybrid.

The direct effect of Ove on the Fsc was 0.195, and the indirect effect of Ove via Fla was 0.119, the highest level of indirect effect on Ove of all attributes. Although the correlation between Ove and Bln (0.520) was similar to the correlation between Ove and Fla (0.530), the indirect effect of Ove via Bln was lower than the residual effect due to the direct effect of Bln being quite low (0.122) compared to the direct effect of Fla on the Fsc (0.225). Sweetness had a direct effect of 0.185 on the Fsc, with indirect effects of 0.109 via Ccp, 0.144 via Fla, 0.069 via Aft, and 0.078 via Ove, with the indirect effects via the other attributes lower than the residual. Clean cup had a direct effect of 0.1821 on the Fsc, and indirect effects of 0.111 via Swt, 0.128 via Fla, 0.084 via Bln, and 0.084 via Ove, all higher than the residual effect.

The attributes Bod and Bln had the least amount of influence on the Fsc, with estimated direct effects of 0.126 and 0.122, respectively. For both features, the effects of Swt, Fla, and Ccp were higher than the residual, and the effects of the latter two attributes were superior to the direct effect of Bln on the Fsc.

Conclusions

1. The cultivation environment greatly influences the quality of the beverage of coffee cultivars.
2. The cultivars Bourbon LCJ10, Araponga MG1, Paraíso MG H419-1, Sacramento MG1, Oeiras MG6851, and Catiguá MG2 exhibited potential for the production of high-quality coffee in the regions included in this study.
3. The attributes acidity, flavor, and aftertaste exert a strong influence on coffee quality.

Conflict of Interests

The authors have not declared any conflict of interests.

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