

Divergence among arabica coffee genotypes for sensory quality

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Abstract

The production of specialty coffees is the main criterion to add value to the product. However, there is a lack of information regarding genetic variability of *C. arabica* for quality improvement. The aim of this study was to analyze the genetic divergence among *Coffea arabica* genotypes regarding the potential cup quality, possible limitations and their potential use in breeding programs to improve quality. We evaluated 101 coffee genotypes from the Germplasm Active Bank of Empresa de Pesquisa Agropecuária de Minas Gerais, covering different groups of genealogical origin. A randomized block design was used with two replications. Sensory analysis of the beverage was performed by two tasters per sample (repetition), using the Cup of Excellence methodology enhanced by the Brazilian Specialty Coffee Association. The attributes assessed were clean cup, sweetness, acidity, body, flavor, aftertaste, balance, overall and final score. K-means and Ward clustering methods were used to study the genotypes divergence. Based on sensory scores, the formed clusters differed with regards to all sensory characteristics ($P \leq 0.01$). Three K-means clusters were formed among 40, 45 and 16 genotypes, with final average scores of 80.11, 83.17 and 87.56 points, respectively. Ninety percent of the genotypes evaluated have the genetic potential to produce specialty coffees. The observed divergence indicates the potential of genetic gains for quality and the Híbrido de Timor germplasm can be used for this purpose.

Keywords: Híbrido de Timor, genetic resources, specialty coffee, bourbon, caturra.

Abbreviations: ACI_Acidity; AFT_Aftertaste; ASS_Average Sieve Size; BOD_Body; EPAMIG_Empresa de Pesquisa Agropecuária de Minas Gerais; FLA_Flavor; FSC_Final Score; HT_Híbrido de Timor; PBE_peaberry percentage; SWE_Sweetness.

Introduction

The production of specialty coffees is the main criterion to add value to the product, support the increase of production costs and meet the coffee market demands (ICO, 2014). Environments and post-harvest technologies that favor coffee quality are known (Vaast et al., 2006, Bertrand et al., 2012, Borém et al., 2013). However, there is a lack of information regarding genetic variability of *C. arabica* for quality improvement (Leroy et al., 2006). In this context, coffee breeding programs around the world seek genetic resources, especially with respect to coffee sensory attributes to produce differentiated coffees aimed at the specialty coffee market. Several studies have shown the genetic variability in *C. arabica* germplasm (Lashermes et al., 1999 Aerts et al., 2013, Geleta et al., 2012, Setotaw et al., 2010), but due to intrinsic difficulties of a standardized assessment for sensory quality, few studies presented potential genetic resources to be used in this feature.

Tessema et al. (2011), studying the genetic diversity for quality among 21 arabica coffee genotypes, collected in six regions of southwestern Ethiopia, verified significant divergence both between and within regions of geographical

origin, suggesting the possibility of quality gains with the selection of promising parents. Similarly in Kenya Kathurima et al. (2009) assessed beverage quality of 42 elite genotypes of arabica coffee, verifying the formation of two sensory clusters with nearly 47% dissimilarity.

Although most of the *C. arabica* cultivars are genetically similar (Anthony et al., 2002, Setotaw et al., 2013), several authors found sensory diversity among cultivars in Southern and Southeastern Brazil. In these environments they identified modern (derived from Híbrido de Timor) and traditional cultivars as superior (Pereira et al., 2010, Kitzberger et al., 2011, Chalfoun et al., 2013, Scholz et al., 2013). However, it is not clear how distant these cultivars or accessions are from each other regarding their potential cup quality, it understood as the genotype higher score for quality in a given environment. Unaware of this information reduces the probability of gains in quality after a selection and recombination process. The aim of this study was to analyze the genetic divergence among *Coffea arabica* genotypes regarding the potential cup quality according to established protocols for the specialty coffee market.

Results and Discussion

K-means clusters

When applying the K-means procedure to study genetic divergence among accessions and cultivars, three distinct clusters were formed. This procedure (K-means) has commonly been applied by many authors (Sarkar et al., 2011; Hageman et al., 2012; Meirmans, 2012) in studies with large numbers of genotypes to form less heterogeneous clusters. The relative importance of characters affecting genetic divergence (Singh, 1981) was 24% for sweetness; 14% for body; 12.5% for flavor; 12.33% for overall; 11.23% for aftertaste; 9% for acidity; 7.68% for final score; 4.83% for balance; and 4% for clean cup. The formed clusters differed with regards to all sensory characteristics ($P \leq 0.01$), allowing for isolation of access sets as a potential quality. In the studied conditions, cluster 1 presented the lowest Final Score (80.11 points). However, among 40 genotypes only 12 did not produce specialty coffee (> 80 points) (BSCA, 2014). Cluster 2, with 45 genotypes, presented intermediate values (83.17 points) and cluster 3, with 16 genotypes, and presented a Final Score of 87.56 points.

Analyzing the mean score of each sensory attribute indicated higher similarity between the clean cup and balance attributes (Fig 1). Clean cup refers to a lack of perceptible sensory defects in the beverage. Considering this description, null genetic effects were expected for this attribute, however statistical differences were observed among genotypes. For balance, genetic effects can be expected since it refers to an interaction relationship among other attributes, which may provide synergistic, complementary or contrasting effects (SCAA, 2015).

Difference among the clusters was greater for the others beverage attributes; especially Sweetness and Flavor, whose range of scores from the inferior to superior cluster were 5.1 to 6.7 and 5.2 to 7.0, respectively. This interval of about 1.8 points for these characteristics, 0.7 for Acidity and around 1.0 for body, aftertaste and overall, indicates the possibility of genetic gains by hybridization between superior and additional parents. In general, based on sensory quality data the accessions of similar genealogical origin were not allocated in the same cluster formed by the K-means procedure. Therefore, the Bourbon, Catimor, Sarchimor and Hybrid Timor accessions were dispersed among the three clusters. Scholz et al. (2013) also verified variability for sensory quality between genetically similar cultivars of the Sarchimor and Catucaí cluster (Catucaí x Icatu). These results allow for inferring that lower genetic variations, as expected among genotypes with similar background, could provide the observed dispersion for sensory quality. Thus, from the traditional arabic germplasm of lower genetic variability (Lashermes et al., 1999, Anthony et al., 2002), to a higher divergent germplasm, such as Híbrido de Timor (Setotaw et al., 2010), genetic gains in sensory quality may be achieved.

Hierarchical subclusters

Working with a limited number of genotypes (21), Tessema et al. (2011) satisfactorily used the hierarchical clustering methods in the study of genetic diversity for sensory quality. In this study, high dissimilarity among accessions was identified in each K-means cluster after applying the Ward hierarchical clustering method. In K-means cluster 1, containing the accessions with the lowest sensory average, three subclusters were formed with near 72% of dissimilarity (Fig 2). In subcluster 1, 16 accessions were allocated with different genealogic origins, whose average Final Score was 79.96 points. Subcluster 2, with 20 accessions and average of

80.64 points, included genotypes (Catucaí Vermelho IAC 144, Catimor, Sarchimor and Bourbon access) with slightly higher scores (0.5 points) for sweetness and flavor. Subcluster 3 presented the lowest mean for final score (78.06 points), and consisted of three Bourbon (cod. 7, 8 and 12) and one Caturra accessions (cod. 26) which presented scores below the minimum to be classified as a specialty coffee (BSCA, 2014). Some authors reported underperformance of Bourbon, Caturra and Catucaí genotypes in comparison with modern cultivars. Kitzberger et al. (2011), at an elevation of 700 m, verified that beverage quality of the HT derived cultivar (IPR 99) was superior to the Bourbon cultivar. Similarly, Pereira et al. (2010) verified that the Catiguá MG-2 cultivar (HT UFV 440-10 x Catucaí Amarelo IAC 86), presented for two consecutive years (elev. 900 m) sensory quality superior to traditional cultivars (Catucaí Amarelo IAC 62 and Bourbon Vermelho). However, at higher elevations (1200 - 1400 m), Bertrand et al. (2006) observed that there is generally no differences in quality of the beverage from arabica hybrids and traditional cultivars. Therefore, there is an indication that modern cultivars, which are less closely related to traditional cultivars, have higher homeostasis for quality (Bertrand et al., 2005, Bertrand et al., 2006, Setotaw et al., 2013).

The K-means cluster 2, with intermediate sensory scores compared to the other clusters, was divided into two subclusters (Fig 3), considering about 80% dissimilarity (Mojena, 1977). In subcluster 1, with 24 genotypes, scores lower than six points were allocated for all characteristics and final score between 81.5 and 83.5 points. This subcluster included Catucaí Vermelho IAC 99 (cod. 96), Mundo Novo MG 1222 and MG 1238 (cod. 90 and cod. 92), and Catiguá MG2 cultivars (cod. 94). In subcluster 2, composed of 21 genotypes, including the Catucaí Amarelo IAC 62 cultivar (cod. 95), the final score ranged from 83.0 to 85.5 points. The MG 0926 accession (cod. 66) (Caturra x S795) was isolated from the others because of its superior score for Aftertaste (7.0 points).

In K-means cluster 3, due to the discrepancy in quality of the two genotypes, we opted for the formation of three subclusters for about 35% of the maximum dissimilarity (Fig 4). Subcluster 1, with Final Score of 87.52 points, was composed of the Híbridos de Timor (cod. 34, 35 and 39), Bourbon (cod. 1) and Catimor accessions (cod. 75), the H419-6-2-3-4 progeny (cód. 98) and the HT derived cultivars (Sarchimor) Obatã 1669-20 (cód. 73) and Paraíso MG H419-1 (cod. 101). Subcluster 2, averaging 85.55 points, was composed of one Híbrido de Timor (MG 0338 - cod. 37) and one Mundo Novo accession (MG 1256 - cod. 93), and the Icatu Amarelo IAC 2944 cultivar (cod.86) derived from natural crossing between Icatu Vermelho (*C. canephora* – robusta X *C. arabica* – Bourbon) and Mundo Novo Amarelo. In subcluster 3, with final score of 92.75 points, the Pau Brasil MG 1 cultivar (Catucaí Vermelho IAC 141 x HT UFV 442-34) (cod. 100) and H419-6-2-5-2 advanced progeny (Catucaí Amarelo IAC 30 x HT UFV445-46) (cod. 99) were highlighted, where both genotypes have rust resistance (*Hemileia vastatrix*) and are recent products from a breeding program based on genetic resistance of Híbrido de Timor germplasm (Setotaw et al., 2010 Setotaw et al., 2013). The predominance of accessions with recent introgression of *C. canephora* alleles in the superior cluster for sensory quality, besides endorsing previous information that the insertion of genes which confer resistance to rust does not affect the beverage quality of these cultivars (Bertrand et al., 2003), indicated quality gains with the incorporation of these Robusta coffee genes.

Table 1. Code and description of coffee accessions, cultivars and progenies of the Active Germplasm Bank of Epamig, evaluated for sensory quality of the beverage.

Code	Accessions	Description	Code	Accessions	Description
1	MG0009	Bourbon Amarelo	48	MG0545	Bourbon N 39 x Híbrido Timor
2	MG0011	Bourbon Vermelho	49	MG0554	Bourbon N 39 x Híbrido Timor
3	MG0012	Bourbon Amarelo	50	MG0558	Bourbon N 197 x Híbrido Timor
4	MG0014	Bourbon Vermelho	51	MG0563	Bourbon N 197 x Híbrido Timor
5	MG0016	Bourbon Vermelho	52	MG0571	S 4 Agaro x Híbrido Timor
6	MG0025	Bourbon Vermelho	53	MG0576	S 4 Agaro x Híbrido Timor
7	MG0027	Bourbon Vermelho	54	MG0587	Dilla & Alge x Híbrido Timor
8	MG0036	Bourbon Amarelo	55	MG0597	KP 423 UFV 163-04
9	MG0041	Bourbon Amarelo	56	MG0603	K 7 IAC 1151-2 c1003 UFV 165-04
10	MG0043	Bourbon Amarelo	57	MG0608	KP 423 UFV 182-04
11	MG0064	Bourbon Vermelho	58	MG0651	Caturra Vermelho x DK 1/ 6
12	MG0066	Bourbon Vermelho	59	MG0654	Caturra Vermelho x DK 1/ 6
13	MG0126	Bourbon Amarelo	60	MG0692	Caturra Amarelo x CIFIC H358/5
14	MG0130	Sumatrão Ponta Roxa	61	MG0694	Caturra Amarelo x CIFIC H358/5
15	MG0133	Sumatrão Ponta Roxa	62	MG0851	CIFIC H 310/1 x Mundo Novo
16	MG0134	Sumatra Palma	63	MG0891	Bourbon 43/7 x RP13 x CIFIC H 264
17	MG0138	Mundo Novo Purpuracens	64	MG0896	Caturra Vermelho x S 333
18	MG0139	Mundo Novo Amarelo	65	MG0899	Caturra Vermelho x S 333
19	MG0145	Planta Desconhecida	66	MG0926	Caturra Vermelho x S 795
20	MG0151	Icatu Amarelo IAC 3282	67	MG0932	Catuai SH2 SH3
21	MG0154	Café Brasil	68	MG1032	Mundo Novo x CIFIC H 288/4
22	MG0165	Maragogipe Amarelo	69	MG1034	Mundo Novo x CIFIC H 288/4
23	MG0173	Maragogipe Vermelho	70	MG1038	Sarchimor UFV 349-04
24	MG0187	Caturra Vermelho	71	MG1045	Sarchimor UFV 349-77
25	MG0193	Caturra Amarelo	72	MG1054	Sarchimor UFV 350-39
26	MG0194	Caturra Amarelo Colombiano	73	MG1059	Sarchimor UFV 350-98
27	MG0212	Caturra Amarelo	74	MG1060	Obatã IAC 1669-20
28	MG0213	Caturra Vermelho	75	MG1079	Cavimor UFV 357-04
29	MG0223	Pacamara	76	MG1083	Cavimor UFV 357-08
30	MG0245	Obatã Tardio	77	MG1085	Cavimor UFV 357-22
31	MG0248	Obatã Amarelo	78	MG1108	Catimor UFV 355-18
32	MG0277	Híbrido de Timor UFV 376-52	79	MG1126	Catimor UFV 390-52
33	MG0289	Híbrido de Timor UFV 376-01	80	MG1140	Catimor UFV 395-02
34	MG0304	Híbrido de Timor UFV 427-15	81	MG1156	Catimor MS
35	MG0313	Híbrido de Timor UFV 428-04	82	MG1157	Catimor PI 09
36	MG0333	Híbrido de Timor UFV 437-10	83	MG1158	Catimor PI 04
37	MG0338	Híbrido de Timor UFV 439-02	84	MG1159	Catimor PI 07
38	MG0339	Híbrido de Timor UFV 439-03	85	MG1160	Catimor PI 11
39	MG0357	Híbrido de Timor UFV 441-04	86	MG1188	Icatu Amarelo IAC 2944
40	MG0369	Híbrido de Timor UFV 443-03	87	MG1206	Bourbon Vermelho
41	MG0420	Mundo Novo x S795 UFV 315-04	88	MG1209	Amarelo de Botucatu
42	MG0438	Mundo Novo x S795 UFV 335-04	89	MG1218	Sumatra Fruto Alaranjado
43	MG0494	K 7 x Híbrido Timor UFV 452-30	90	MG1222	Mundo Novo Amarelo
44	MG0530	H 66 x Híbrido Timor UFV 372-11	91	MG1230	Mundo Novo I MP 376-4
45	MG0534	BE 5 Wush-Wush x Híbrido Timor	92	MG1238	Mundo Novo I LCP 379-19
46	MG0536	BE 5 Wush-Wush x Híbrido Timor	93	MG1256	Mundo Novo II CP 388-17-16
47	MG0540	BE 5 Wush-Wush x Híbrido Timor			
Genotypes used as a control					
94	Catiguá-MG 2		98	H419-6-2-3-4 amarelo	
95	Catuai Amarelo IAC 62		99	H419-6-2-5-2 vermelho	
96	Catuai Vermelho IAC 99		100	Pau-Brasil MG 1	
97	Catuai Vermelho IAC 144		101	Paraíso MG H419-1	

Table 2. Average of beverage sensory characters and beans of 16 *C. arabica* genotypes belonging to the superior cluster (3) for sensory quality.

Code	Accessions	Beverage ¹ and beans ² characteristics							
		SWE	ACI	BOD	FLA	AFT	FSC	ASS	PBE
1	MG 0009	7.00 a	6.63 a	6.50 a	6.63 a	6.50 a	87.75 b	17.03 a	8.50 e
17	MG 0138	7.00 a	6.00 b	6.00 b	7.00 a	6.50 a	86.50 c	14.99 f	11.00 d
34	MG 0304	7.00 a	6.00 b	7.00 a	7.00 a	7.00 a	88.00 b	16.79 b	9.00 e
35	MG 0313	7.00 a	6.00 b	7.00 a	7.00 a	6.00 b	87.00 b	16.13 c	9.00 e
37	MG 0338	6.00 b	6.50 a	6.50 a	6.50 b	6.25 b	85.75 c	15.90 d	10.50 d
39	MG 0357	7.00 a	7.00 a	6.50 a	7.00 a	6.75 a	88.50 b	15.45 e	18.00 c
49	MG 0554	6.00 b	6.00 b	6.00 b	7.00 a	7.00 a	86.00 c	16.70 b	12.00 d
59	MG 0654	6.50 a	6.00 b	6.00 b	7.00 a	6.00 b	85.50 c	16.77 b	9.00 e
73	MG 1059	7.00 a	6.25 b	6.25 b	7.00 a	6.00 b	86.50 c	16.85 b	12.50 d
75	MG 1079	6.75 a	7.00 a	6.00 b	7.00 a	6.75 a	87.50 b	15.84 d	6.00 e
86	MG 1188	6.38 b	6.38 a	6.00 b	6.50 b	6.25 b	85.50 c	17.07 a	14.00 c
93	MG 1256	6.00 b	6.00 b	6.00 b	7.00 a	6.00 b	85.00 c	15.84 d	12.00 d
98	H 419-6-2-3-4	6.50 a	6.75 a	7.00 a	6.75 a	6.00 b	87.50 b	16.19 c	16.00 c
99	H 419-6-2-5-2	7.00 a	7.00 a	7.00 a	7.00 a	7.00 a	92.00 a	16.27 c	10.00 d
100	Pau-Brasil MG1	7.00 a	7.00 a	7.00 a	8.00 a	7.50 a	93.50 a	16.12 c	30.00 a
101	Paraíso MG H 419-1	7.00 a	6.75 a	6.75 a	7.00 a	6.00 b	88.50 b	16.31 c	21.00 b
Standard deviation		0.41	0.42	0.44	0.33	0.48	2.31	0.58	5.93
Average		6.70	6.45	6.47	6.96	6.47	87.56	16.27	13.03

Means followed by the same letter in the column do not differ according to the Scott & Knott test at 5% probability, ¹ Beverage characteristics: Sweetness (SWE), acidity (ACI), Body (BOD), Flavor (FLA) Aftertaste (AFT), Final Score (FSC), ² Beans characteristics: average sieve size (ASS), peaberry percentage (PBE).

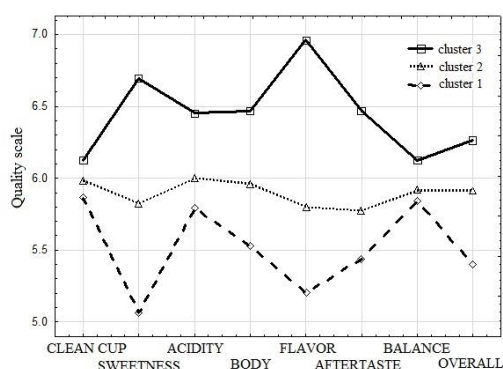


Fig 1. Average scores for the sensory characteristics of the beverage for the genotype clusters formed according to the K-means method.

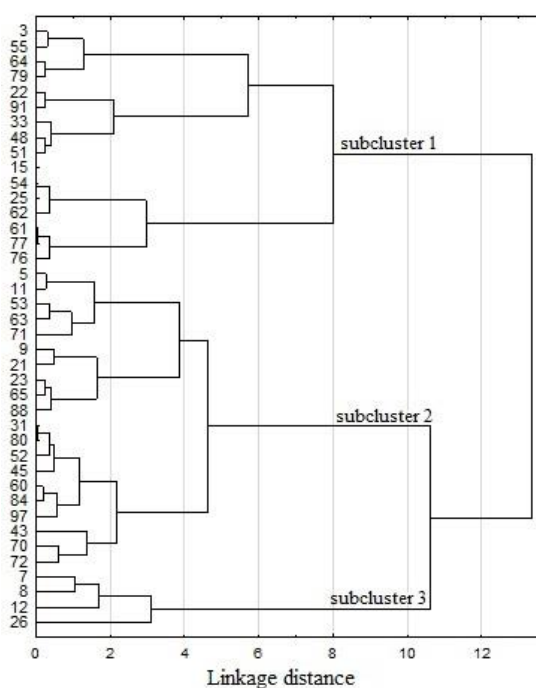


Fig 2. Dendrogram of 40 genotypes belonging to cluster one (K-means method) based on the sensory characteristics of the beverage, using the Mahalanobiss generalized distance and Ward clustering (numbers refer to accession codes in Table 1).

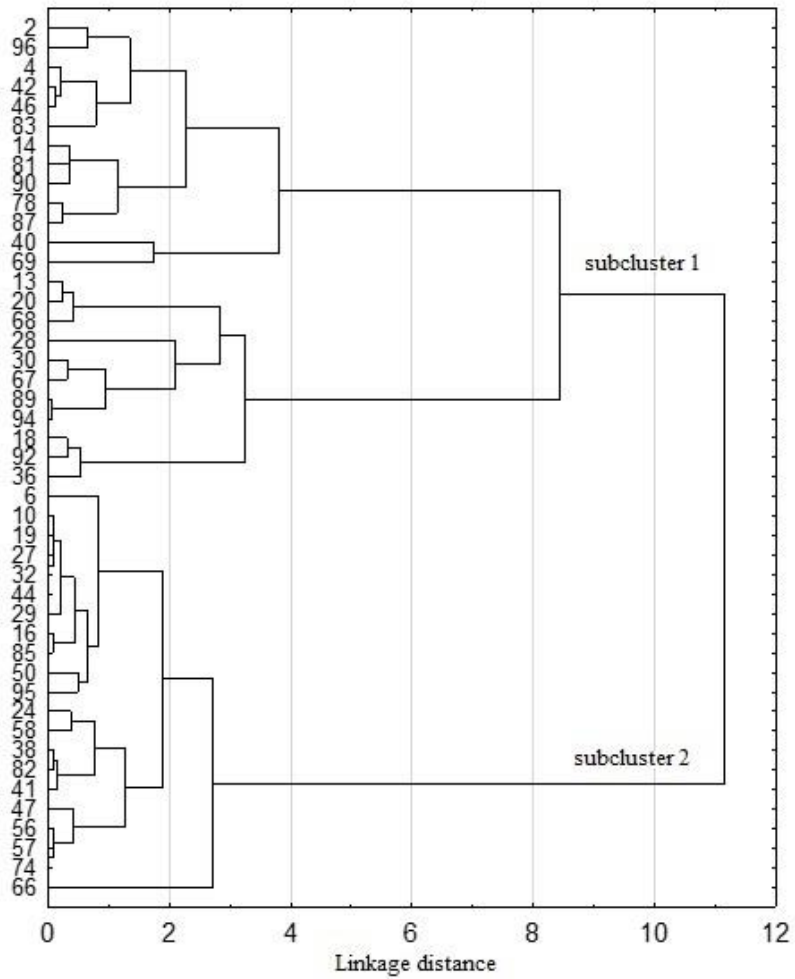


Fig 3. Dendrogram of 45 genotypes belonging to cluster two (K-means method) based on the sensory characteristics of the beverage, using the Mahalanobiss generalized distance and Ward clustering (numbers refer to accession codes in Table 1).

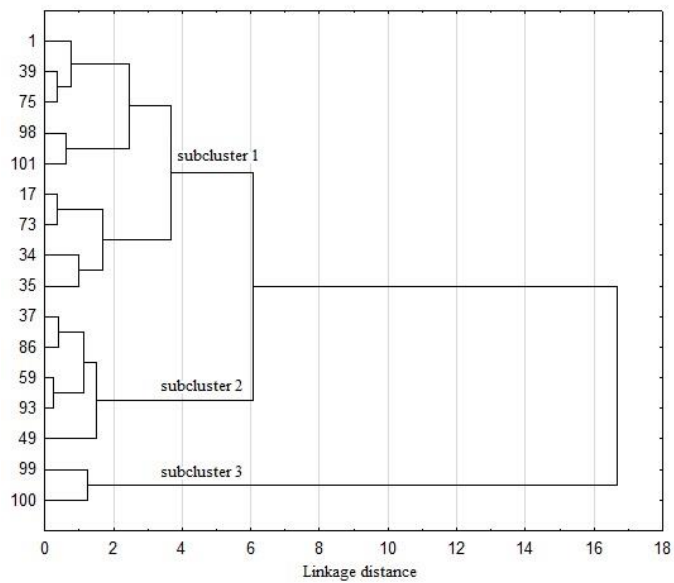


Fig 4. Dendrogram of 16 genotypes belonging to cluster three (K-means method) based on the sensory characteristics of the beverage, using the Mahalanobiss generalized distance and Ward clustering (numbers refer to accession codes in Table 1).

Promising genotypes for quality

When comparing the higher quality genotypes (Cluster 3) in each sensory attribute there was no difference regarding the overall characteristic (6.0 points), and for Clean Cup and Balance only two genotypes (H 419 6-2-5-2 and Pau-Brasil MG1), averaging 7.0 points, were superior to the others (6.0 points). To simplify the visualization of data these variables were not presented (Table 2), and to assist in the breakdown of potential parents, information was included on bean quality (size and shape). Since the correlation between physical characteristics of beans and sensory characteristics of the beverage is low to null (Dessalegn et al., 2008, Kathurima et al., 2009), the selection of genotypes, considering the size and shape of the beans, does not influence the sensory beverage quality of the progenies.

Regarding the sensory characteristics, the H 419-6-2-5-2 progeny and Pau-Brasil MG 1 cultivar were superior to the others, receiving an outstanding classification level for specialty coffee (SCAA, 2015). However, because these genotypes present similar sensory profiles (Fig 3), the H 419-6-2-5-2 progeny stands out in terms of quality due to the lower percentage of peaberry beans (10%). In a distinct subcluster of these genotypes the MG 0009 bourbon accession, due to a larger average sieve size (17.03) and low percentage of peaberry beans (8.50%), also stood out as a promising source of alleles. The three cited genotypes received the following comments from the tasters:

- H 419-6-2-5-2: "Excellent coffee, sweet aroma, brown sugar, velvety body, refreshing, present and lasting, vibrant acidity, very sweet and pleasant aftertaste";
- Pau-Brasil MG 1: "It is an exceptional coffee, exotic, fragrant aroma, roses, jasmine, refreshing acidity, adorable aftertaste, delicious coffee";
- MG 0009: "Excellent coffee, floral aroma, honey taste, luscious, velvety body, soft, elegant, extremely sweet, sweet acidity and refreshing aftertaste."

Materials and Methods

Evaluated genotypes

We evaluated 101 *Coffea arabica* genotypes, in the adult production stage (4 years old), from the Germplasm Active Bank of Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), located in Patrocínio-MG (18° 54' S; 46° 50' W, 975 m elevation) (Table 1). The region has a Cwa type climate according to Koppen's classification, with annual average temperature and precipitation of 21.6°C and 1643.1 mm, respectively.

Sample preparation

Thirty liters of fresh coffee fruits were selectively handpicked at the "cherry" stage from each accession plot. They were then mechanically pulped (depulper Pinhalense model DPM-02 n° 928) four hours after harvest. Sequentially, the samples were packaged in plastic pots (20 L) to be desmucilage by natural fermentation for 24 h. The water was replaced when the temperature approached 40° C. After fermentation, the bean parchments were manually washed under clean running water. For drying, the sample was spread onto sieves with dimensions of 1 m², according to the process of Borém (2008). Samples were then processed (Palini & Alves equipment, PA-AMO/30 Model, Serial No. 387), packaged in waterproof plastic bags and maintained in coolers until the time of assessment.

Evaluated characteristics

Sensory analysis of the beverage was performed by two tasters per sample (repetition), using the Cup of Excellence (CoE) methodology, enhanced by the Brazilian Specialty Coffee Association (BSCA, 2014). The following attributes, rated in numeric values, were assessed: clean cup, sweetness (SWE), acidity (ACI), body (BOD), flavor (FLA), aftertaste (AFT), balance, overall and final score (FSC). Genotypes that presented more than 80 points in the final score were classified as Specialty Coffees. Each sample considered the average score among the tasters. The data related to beverage were obtained from beans which passed through a ≥16 size sieve. In genotypes that stood out with regards to sensory quality we evaluated the average sieve size (ASS) and the peaberry percentage (PBE). The first was obtained by the ratio between the sum of the mass of flat beans retained in each sieve (19, 18, 17, 16, 15 and 14/64ths of an inch) multiplied by the respective sieve number, divided by the total mass of beans (Krug, 1940). The second was determined by the summed percentages of peaberries retained in the 11, 10 and 9 sieve sizes. The bean shape and size was evaluated considering a processed sample of 300 grams.

Statistical analysis

Fruits were collected in the field and the beans analyzed in a randomized block design with two repetitions and plot size of ten plants. The data were standardized (unit variance) and clustered by the K-means (Hageman et al., 2012) using the squared Euclidean distance to cluster the similar genotypes. The ideal number of clusters was determined from the variance and the sum of the square of residues, assessing the interval of two to eight clusters. By the method of Singh (1981), the relative importance of characters affecting genetic divergence was determined. Genetic divergence among the clusters formed (intracluster K-means) was evaluated according to the Ward hierarchical clustering method based on the Mahalanobis generalized distance. The means of the superior genotypes for cup and bean quality (size and shape) were evaluated by the Scott Knott test at 5% probability. The analyses were performed using the Genes (Cruz, 2006) and Statistica programs (Hill and Lewicki, 2007).

Conclusion

Considering the quality evaluations, the genotypes which presented lower quality values should be re-evaluated to confirm a possible genetic limitation for quality, according to the concept adopted in the specialty coffee market. On the other hand, for the cluster of genotypes with the highest scores, their genetic potential to produce specialty coffees is clear. It is therefore noteworthy that quality below the potential can only occur due to environmental factors. The observed divergence among *C. arabica* genotypes indicated the possibility of genetic gain in breeding to improve beverage quality. The risk of a decline in sensory quality of modern cultivars caused by genetic factors is reduced since ninety percent of the 101 genotypes evaluated, regardless the genealogical origin, produced specialty coffees. Considering that all evaluated Híbrido de Timor accessions had specialty coffee quality, the exploration potential of this germplasm is evident, not only for resistance to pests and diseases, but also for genetic gains in quality. The genotypes identified as superior are promising for integration into coffee breeding programs focused on quality and should be selected by the

breeder in accordance with the recombination need for desired characteristics

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References

- Aerts R, Berecha G, Gijbels P, Hundera K, Glabeke SV, Vandepitte K, Muys B, Roldan-Ruiz I, Honnay O (2013) Genetic variation and risks of introgression in the wild *Coffea arabica* gene pool in south-western Ethiopian montane rainforests. *Evol Appl.* 6:1-10.
- Anthony F, Combes MC, Astorga C, Bertrand B, Graziosi G, Lashermes P (2002) The origin of cultivated *Coffea arabica* L. varieties revealed by AFLP and SSR markers. *Theor Appl Genet.* 104: 894-900.
- Bertrand B, Guyot B, Anthony F, Lashermes P (2003) Impact of the *Coffea canephora* gene introgression on beverage quality of *C. arabica*. *Theor Appl Genet.* 107:387-394.
- Bertrand B, Etienne H, Cilas C, Charrier A, Baradat P (2005) *Coffea arabica* hybrid performance for yield, fertility and bean weight. *Euphytica.* 141:255-262.
- Bertrand B, Vaast P, Alpizar E, Etienne H, Davrieux F, Charmetant P (2006) Comparison of bean biochemical composition and beverage quality of Arabica hybrids involving Sudanese-Ethiopian origins with traditional varieties at various elevations in Central America. *Tree Physiol.* 26:1239-1248.
- Bertrand B, Boulanger R, Dussert S, Ribeyre F, Berthiot L, Descroix F, Joet T (2012) Climatic factors directly impact the volatile organic compound fingerprint in green Arabica coffee bean as well as coffee beverage quality. *Food Chem.* 135:2575-2583.
- Borém FM (2008) Handbook of coffee post-harvest technology. Editora UFLA, Lavras, Brazil.
- Borém FM, Ribeiro FC, Figueiredo LP, Giomo GS, Fortunato VA, Isquierdo EP (2013) Evaluation of the sensory and color quality of coffee beans stored in hermetic packaging. *J Stored Prod Res.* 52:1-6.
- BSCA – Brazilian Specialty Coffee Association - Associação Brasileira de Cafés Especiais Available at: <www.bsca.com.br > Access in: June 20 2014.
- Chalfoun SM, Pereira MC, Carvalho GR, Pereira AA, Savian TV and Botelho DDS (2013) Sensorial characteristics of coffee (*Coffea arabica* L) varieties in the Alto Paranaíba Region. *Coffee Science.* 8:43-52.
- Cruz CD (2006) Programa Genes: Editora UFV, Viçosa.
- Dessalegn Y, Labuschagne MT, Osthoff G, Herselman L (2008) Genetic diversity and correlation of bean caffeine content with cup quality and green bean physical characteristics in coffee (*Coffea arabica* L). *J Sci Food Agr.* 88:1726-1730.
- Geleta M, Herrera I, Monzón A and Bryngelsson T (2012) Genetic diversity of arabica coffee (*Coffea arabica* L) in Nicaragua as estimated by simple sequence repeat markers. *Sci World J.* 2012:1-11.
- Hageman JA, Malosetti M, Van Eeuwijk FA (2012) Two-mode clustering of genotype by trait and genotype by environment data. *Euphytica.* 183:349-359.
- Hill T, Lewicki P (2007) Statistics: methods and applications. StatSoft, Tulsa.
- ICO (2014) International Coffee Organization Statistics on Coffee. Available at <<http://www.ico.org/historical/2010-19/PDF/TOTPRODUCTIONpdf>>. Access in: June 20 2014.
- Kathurima CW, Gichimu BM, Kenji GM, Muhoho SM, Boulanger R (2009) Evaluation of beverage quality and green bean physical characteristics of selected arabica coffee genotypes in Kenya. *Afr J Food Sci.* 3:365-371.
- Kitzberger CSG, Scholz MBS, Silva GD, Toledo JB, Benassi M (2011) Caracterização sensorial de cafés arábica de diferentes cultivares produzidos nas mesmas condições edafoclimáticas. *Braz J Food Technol.* 14:39-48.
- Krug CA (1940) O cálculo da peneira média na seleção do cafeeiro. *Revista Instituto Café.* 15:123-127.
- Lashermes P, Combes MC, Robert J, Trouslot P, D'Hont A, Anthony F, Charrier A (1999) Molecular characterization and origin of the *Coffea arabica* L genome. *Mol Gen Genet.* 261:259-266.
- Leroy T, Ribeyre F, Bertrand B, Charmetant P, Dufour M, Montagnos C, Marraccini P, Pot D (2006) Genetics of coffee quality. *Braz J Plant Physiol.* 18:229-242.
- Meirmans PG (2012) AMOVA-Based Clustering of Population Genetic Data. *J Hered.* 103:744-750.
- Mojena R (1977) Hierarchical grouping method and stopping rules: an evaluation. *Comput J.* 20:359-363.
- Pereira MC, Chalfoun SM, Carvalho GR, Savian TV (2010) Multivariate analysis of sensory characteristics of coffee grains (*Coffea arabica* L.) in the region of upper Paranaíba. *Acta Scientiarum.* 32:635-641.
- Sarkar RK, Rao AR, Wahi SD, Bhat KV (2011) A comparative performance of clustering procedures for mixture of qualitative and quantitative data—an application to black gram. *Plant Genet Resour.* 9:523-527.
- SCAA - Specialty Coffee Association of America (2015) SCAA Protocols - Cupping Specialty Coffee. SCAA, Santa Ana.
- Scholz MBS, Silva JVN, Figueiredo VRG, Kitzberger CSG (2013) Atributos sensoriais e características físico-químicas de bebida de cultivares de café do Iapar. *Coffee Science.* 8:6-16.
- Setotaw TA, Pena GF, Zambolin EM, Pereira AA, Sakiyama NS (2010) Breeding potential and genetic diversity of "Híbrido do Timor" coffee evaluated by molecular markers. *Crop Breed Appl Biot.* 10:298-304.
- Setotaw TA, Caixeta ET, Pereira AA, Oliveira ACB, Cruz CD, Zambolim EM, Zambolim L, Sakiyama NS (2013) Coefficient of parentage in *Coffea arabica* L cultivars grown in Brazil. *Crop Sci.* 53:1237-1247.
- Singh D (1981) The relative importance of characters affecting genetic divergence. *Indian J Genet Pl Br.* 41:237-245.
- Tessema A, Alamerew S, Kufa T and Garedew W (2011) Genetic Diversity Analysis for Quality Attributes of Some Promising *Coffea arabica* Germplasm Collections in Southwestern Ethiopia. *J Biol Sci.* 11:236-244.
- Vaast P, Bertrand B, Perriot JJ, Guyot B and Génard M (2006) Fruit thinning and shade improve bean characteristics and beverage quality of coffee (*Coffea arabica* L) under optimal conditions. *J Sci Food Agr.* 86:197-204.