Selection Strategy For The Beverage Sensory Characterization In A Large Arabica Coffee Germplasm Bank

Denis H. S. Nadaleti

Instituto Nacional de Ciência e Tecnologia do Café

Juliana C. de R. Abrahão (✉ julianacosta@epamig.br)

EPAMIG Sul, Campus Universitário UFLA <https://orcid.org/0000-0002-6026-7634>

Vinícius T. Andrade

EPAMIG Sul, Campus Universitário UFLA

Marcelo R. Malta

EPAMIG Sul, Campus Universitário UFLA

Cesar E. Botelho

EPAMIG Sul, Campus Universitário UFLA

Gladyston R. Carvalho

EPAMIG Sul, Campus Universitário UFLA

Research Article

Keywords: Coffea arabica, Genetic inheritance, Breeding program, Specialty coffee.

Posted Date: September 27th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-897631/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

**Selection strategy for the beverage sensory characterization in a large arabica coffee
germplasm bank**

Denis H. S. Nadaleti^a, Juliana C. de R. Abrahão^{b*}, Vinícius T. Andrade^c, Marcelo R. Malta^b,
Cesar E. Botelho^b, Gladyston R. Carvalho^b

^a Denis H. S. Nadaleti Instituto Nacional de Ciência e Tecnologia do Café – INCT Café/ EPAMIG Sul, Campus Universitário UFLA, P. O. Box 176, Lavras, MG CEP 37200-000, Brazil; ^b Juliana C. de R. Abrahão, Marcelo R. Malta, Cesar E. Botelho, Gladyston R. Carvalho EPAMIG Sul, Campus Universitário UFLA, P. O. Box 176, Lavras, MG CEP 37200-000, Brazil; ^c Vinícius T. Andrade Consórcio Pesquisa Café/ EPAMIG Sul, Campus Universitário UFLA, P. O. Box 176, Lavras, MG CEP 37200-000, Brazil.

*Corresponding Author:
e-mail: julianacosta@epamig.br Phone number: +55 35 38216244

Funding

The authors would like to thank EPAMIG, for making infrastructure and equipment available; CNPq, for the productivity (GRC) grant and financial support (grant number 425088/2018-9); INCT Café/CNPq and Consorcio Pesquisa Café, for the industrial technological development grants (DHSN), CAPES for doctoral (DHSN) grant and INCT Café, CNPq, Fapemig and Consórcio Pesquisa Café, for the financial support for the project.

Conflict of Interest: The authors declare that they have no conflict of interest.

Availability of data and material (data transparency) Available on submission

Code availability 'Not applicable'

Authors' contributions

31 All authors contributed to the study conception and design. Material preparation, data collection
32 and analysis were performed by Denis H. S. Nadaleti, Vinícius T. Andrade, Marcelo R. Malta, Cesar E.
33 Botelho and Gladyston R. Carvalho. The first draft of the manuscript was written by Juliana C. de R.
34 Abrahão and all authors commented on previous versions of the manuscript. All authors read and
35 approved the final manuscript.

36

Selection strategy for the beverage sensory characterization in a large arabica coffee germplasm bank

Abstract

This study proposes a selection strategy to be applied to a large number of coffee accessions, which can be useful when exploring many genotypes in breeding programs for beverage quality. Over three consecutive years, 270 Arabica coffee accessions from the Germplasm Bank of Minas Gerais, Brazil, were sensorially characterized. At the end of this period, the 20 genotypes with the greatest potential for specialty coffee production were selected, which were subjected to a second sensory characterization. Additionally, we determined the genetic correlations between the attributes that make up the final beverage score. We did not identify an attribute that was more important than the others in the organoleptic performance of the studied accessions. Through the proposed method, we identified genetic variation in our original population and selected five accessions with beverage quality considered excellent according to the SCA classification. These accessions were planted in field conditions of highly specialized farms to study their interaction with the cultivation environment and to promote the increase in production of such coffees. Additionally, the five selected accessions are being used in crosses with elite cultivars create new segregating populations. We conclude that estimation of the heritable variation of each accession, the use over the years of common check cultivars with known performance, and extremely care of experimental precision in the entire processes warrant fair comparisons.

Keywords: *Coffea arabica*, Genetic inheritance, Breeding program, Specialty coffee.

Introduction

Due to the growing appreciation for and consumption of specialty coffees, the production of this type of bean has become a strategy to maintain and possibly enhance the economic viability of the crop. The coffee farms have been adapted to meet this market demand, which has led researchers to emphasize the beverage quality of the development of new cultivars.

The quality of the coffee beverage is basically governed by postharvest processing, cultivation environment, plant health, and the genetic constitution of the plants (Leroy et al. 2006). Some varieties, exotic or cultivated, are more likely to produce coffees with better sensory quality and thus higher scores,

which leads to a greater demand for these varieties by the buyers of these coffees (Illy and Viani 2005). However, little is known about the genetic influence of sensory traits. To fill this knowledge gap, two questions need to be answered. The first question is whether beverage quality is genetically controlled, so heritable. The second question is whether phenotypic superiority can be passed on to the offspring during the selection process performed by the breeders. If so, it is also necessary to estimate the crop's genetic progress through selection gain. The first question has been addressed by previous researchers, but with other plant genotypes in the multilocation trials (Barbosa et al. 2020) and different evaluation methods (Agwanda et al. 2003).

The evaluation of the quality of coffee is performed by physical classification and sensory analysis called cupping, in which professional tasters evaluate and score various attributes of a coffee and provide a description of its nuances (Lingle and Menon 2017). Some researchers use the phenotypic data from this evaluation to perform the selection, considering the traits as fixed effects and without estimating the genetic variance or heritability of the phenotypic variation (Silva et al. 2014; Figueiredo et al. 2015; Nadaleti et al. 2018; Donfrancesco et al. 2019). However, this strategy may not be effective because this procedure does not consider how much of the phenotype is due to the genotype, which does not allow us to predict whether the selected superiority will hold up in the future, such as when the factors under study have random effects (Smith et al. 2007; Resende et al. 2016). Understanding the genetic inheritance of quality traits is essential to benefit these programs (Tran et al. 2016). Because quality traits are affected by many factors, information on the association between various attributes of organoleptic quality can also benefit the breeding process.

The Germplasm Bank of Minas Gerais (BAG-MG) contains considerable genetic variability, consisting of sources of resistance to the main coffee diseases and accessions that produce coffee with superior beverage quality (Malta et al. 2020; Sobreira et al. 2015). Based on the sensory profile of the different accessions, crosses and selections have aimed to harness the potential of parents carrying alleles favorable to the breeding of coffee to produce specialty coffees (Van der Vossen et al. 2015). To explore new genetic variability for sensory characteristics it is important to do a wide survey in germplasm collection because there are a lot of untested genotypes. However, given the great number of accessions evaluating all of them is difficult in one year harvest. So, a procedure that allows a careful assessment of sensory traits is of utmost necessity.

Given the above, the first objective of this study was to determine whether there is genetic variability and heritability in the sensory quality of the coffee beverage. The possibility of generating coffee plants with higher quality potential is extremely important, but the success of this strategy depends on the existence of genetic variation in the studied trait, consequently a heritability value. The second objective was to determine the genetic correlations between the attributes that make up the final beverage score. This correlation will help assess whether the selection gain is indirectly greater in each of these attributes. The third objective was to assess the efficiency of the selection process in a large number of accessions from BAG-MG evaluated over three consecutive years. The proposed method can be useful when exploring many genotypes in breeding programs. At the end of the line, the focuses are immediate use of the selected accesses by producers and cross them with elite cultivars to develop segregating populations.

Materials and Methods

The BAG-MG is located in the Alto Paranaíba region, at 18°59'26" south latitude and 48°58'9.5" west longitude, with altitude of approximately 1,000 meters. The soil is a dystrophic red-yellow Latosol. The topography is flat with a slight slope. The average annual temperature is 20.61°C, with maximum of 27.06°C, minimum of 15.95°C, and an average annual precipitation of approximately 1900 mm. The climate is subtropical temperate (mesothermal), with summer rains, dry winters, and hot summers (Wca according to Köppen). The BAG-MG was implemented in 2005 in a randomized block design, with two replicates composed of 10 plants and a spacing of 3.5 m × 1.0 m. The implementation and maintenance of the BAG-MG were in accordance with the technical recommendations for the coffee crop.

A total of 49 accessions in the 2014/2015 harvest, 113 accessions in the 2015/2016 harvest, and 108 accessions in the 2016/2017 harvest were evaluated for sensory quality, totaling 270 accessions at the end of three consecutive harvests. This accessions have been chosen according to their yield and/or beverage quality and/or resistance to the main pests and diseases of economic importance.

Ten liters of ripe fruit were selected per experimental replicate. These fruits were washed for removal of impurities and dried in a thin layer (14 liters/m²) under full sun in sieves suspended 1 m from the ground to favor air circulation through the fruit mass until the grains reached 11% water content.

After drying, the samples were placed in double-layer Kraft paper bags, covered with a plastic bag, and stored for 30 days in a cold chamber with a constant temperature of 16 °C to standardize the water content in the grains.

For the sensory analyses, the samples were standardized on high mesh size, and we selected the grains free of intrinsic and extrinsic defects. The grains were toasted according to the protocol proposed by the Specialty Coffee Association - SCA (Lingle 2011), which recommends color 55# to 65# on the Agtron color scale for whole grains, in addition to a roasting time of 8-12 minutes. These analyses were performed in five cups per sample by three accredited and calibrated Q-graders using the same protocol, which consists of 10 sensory attributes: flavor, acidity, balance, aftertaste, body, aroma, and overall (which are evaluated with scores from 6 to 10 points each) and the attributes uniformity, sweetness, and clean cup (to which are assigned 2 points per cup that is free of defects, that is uniform, and that has a minimum sweetness equivalent to the concentration of 0.5% w/v of sucrose). The final score was calculated considering the sum of the 10 sensory attributes cited, and coffees with a final score equal to or greater than 80 points were considered specialty coffees.

To compare the mean final score of the different accessions in the three harvests, the mean of the control common to all experiments was used with the estimator $\pm_{iz} = Y_{iz} - (T_z - T)$, where $\pm_{iz}$ is the adjusted final mean score of accession i at harvest z , Y_{iz} is the mean final score of accession i at harvest z , T_z is the mean yield of the control at harvest z , and T is the overall final score of the controls in all experiments (Guerreiro Filho et al. 2018). The accessions MG0224 Pacamara and MG0233 Obatã Amarelo were used as controls in the three harvests. The data for the final sensory score of the three evaluation years obtained by the estimator were subjected to statistical analysis and estimates of genotypic values and heritability for each accession, using the Selegen REML/BLUP software (Resende 2016). The model $y = Xr + Zg + e$ was used, where y is the data vector, r is the vector of the repetition effects (assumed to be fixed) added to the overall mean, g is the vector of the genotypic effects (assumed to be random), and e is the vector of (random) errors or residuals. X and Z represent the incidence matrices for these effects. Heritability values range from 0 to 1 (0 to 100%). When heritability is $\leq 50\%$, this represents a low correlation between the genotype and phenotype, and heritability is considered low. In this work, moderate heritability was considered between 50% and 70%, and high greater than or equal to 70%.

The 27 accessions that had the highest predicted additive values were subjected to new sensory evaluation in the 2019/2020 harvest, and their genetic parameters were estimated by the model $y = Xr + Zg + Wi + e$, where i is the vector of the genotype $\times$ environment interaction effect (random), and W represents the incidence matrix for this effect. In 2018, there was no harvest due to a negative biennial cycle, so there was not enough production of plants to obtain a sample.

The genetic correlations between the attributes that make up the final beverage score of the accessions evaluated in the 2019/2020 harvest were analyzed using the software Genes (Cruz 2013). The sensory attributes uniformity, sweetness, and clean cup were not statistically evaluated, since all samples were given a score of 10 on these attributes.

Results

The studied population had great genotypic variability in the traits that make up beverage quality (Supplemental Table S1). The predicted additive values ranged from 75.87 to 85.53, and heritability ranged from 0.69% (accession MG 0253) to 100% (83 accessions) among the 270 accessions studied. We selected the top 10% of this population (27 accessions) by predicted genotypic value for further study (Figure 1). The estimate of heritability was of medium magnitude at the plot level, indicating that it is a trait with lower genetic determinism. However, the estimated heritability at the mean accession level was satisfactory for accurate selection for the sensory score of the beverage.

The predicted additive genetic values ranged from 85.53 to 83.16. Twenty of the 27 accessions studied showed high heritability. The accessions MG 364, MG 1197, MG 1059, MG 161, MG 291, MG 043, and MG 016 had low to moderate heritability, ranging from 11 to 69%. The selection gain was 2.11%, and the prediction error variance (PEV) of the genotypic values was 1.31, indicating precision in the estimated values.

To prove the efficiency of the applied selection process, the 20 accessions with high individual heritability were subjected to a new evaluation of sensory quality in the 2019/2020 harvest (Figure 2). The individual heritability of the selected accessions ranged from 61 to 99%, and the predicted additive value ranged from 84.44 to 87.10. Considering a selection intensity of 25% (five accessions), an SG of 1.63% was observed in the selection of accessions MG 159, MG 1011, MG 171, MG 1007, and MG 155. The new predicted mean with the selection of these five accessions was 86.42.

Aiming to identify heritable associations to guide breeding programs for beverage quality, the genetic parameters of the attributes that make up the final quality score and the correlations between them and the final score were estimated (Table 1). The correlations between all traits studied were positive, significant. Of high magnitude, ranging from 0.73 to 0.95, indicating that all attributes of organoleptic quality contributed to the classification of genotypes and the final score, as expected.

When evaluating the genetic parameters, all the traits studied were strongly influenced by the environment. The individual broad sense heritability values were low, ranging from 16 to 32%, so it can be inferred that the studied accessions tend to have lower stability of expression of these characteristics in the face of environmental changes. The relative coefficient of variation showed medium-magnitude values for the acidity, body, and overall traits and high-magnitude values for the other traits, revealing that the selection of the best progenies will enable an increase in the genetic value of the population regarding aroma, flavor, aftertaste, balance, and final score (Bernardo, 2011). The sensory attributes uniformity, sweetness, and clean cup were not statistically evaluated, since a score of 10 was assigned to these attributes in all samples, while the other attributes had a mean score between 7.59 and 7.95 points.

Discussion

After a few years of hard work, we were able to identify genotypes with high sensory beverage quality in the germplasm bank of the State of Minas Gerais. Analyzing the past, we realize that the strategy worked. Heritability for the evaluated trait was achieved, it was noticed that using a common control through the harvests, different genotypes could be evaluated without losing the precision of the answers, and it was still possible to install field experiments to commercially test the identified genetic superiority.

There is a strong need to develop low-cost and high-yield evaluation strategies for classical breeding programs, especially for perennial crops such as coffee. Basically, our study sought to clarify whether the selection of coffee plants for beverage quality is efficient by studying different accessions in each year. After evaluating 270 accessions over three consecutive years and comparing them to commonly used controls, we initially selected a population of 20 accessions. New evaluations indicated gains in sensory quality for this population, with a new mean of 85.03 points, three points higher than the mean of the 270 accessions evaluated. A final score above 85 points is considered excellent, making a

bean a specialty coffee (SCAA 2015). Thus, the method used in the present study was efficient in selecting accessions.

Several accessions had predicted genetic values and heritability values higher than the accessions used as references: Pacamara (Donnet et al. 2007) and Obatã Amarelo (Fazuoli et al. 2018). The classification by genotypic values (Supplemental Table S1) showed accession 224, Pacamara, in 10th place (Figure 1) and Obatã Amarelo in 30th place among the 270 accessions studied. These data confirm the beverage quality potential of the accessions studied, a potential already observed by other authors (Fassio et al. 2020; Malta et al. 2020; Sobreira et al. 2015).

Most of the 270 accessions studied scored 80 points or higher and were thus classified as specialty by the SCA scale (Lingle 2011). The two exceptions were the MG 132 and MG 253 accessions. However, selection without considering the heritability of each accession may not be ideal and may lead to inefficient breeding programs for beverage quality because through this estimate, we seek to minimize environmental effects (Bernardo 2011). Of the 270 accessions studied, 184 showed high heritability, indicating that cupping is a highly heritable trait and may be underlain by weak environmental effects when the appropriate accession is selected. Such accessions, with high heritability, will keep their phenotypic behavior of beverage quality as constant as possible over time, making the results repeatable. Therefore, crosses of plants with high beverage quality should be used to develop other traits of interest.

According to the evaluation method, the five accessions selected for beverage quality were MG 159 (Maragogipe Híbrido F1), MG 1011 (Dilla & Alghe × S333 UFV 329-02), MG 171 (Maragogipe Vermelho Pl 02), MG 155 (Geisha × S288/23 UFV 328-62), and MG 1188 (Maragogipe Amarelo) (Figure 2). Maragogipe is a mutant that has seeds, fruits, leaves, and plant sizes larger than the usual standards for coffee cultivars (Guedes et al. 2013a). The xanthocarpa form is called Maragogipe Amarelo, which likely arose from natural hybridization between Maragogipe Vermelho and Amarelo de Botucatu (typical variety, xanthocarpa form). Dilla & Alghe was introduced from Ethiopia and is resistant to *Pseudomonas syringae* pv. *garcae* (causal agent of coffee halo blight) and some breeds of *H. vastatrix* (carrier of the resistance gene HS₁) (Guedes et al. 2013b). S333 is a selection of material from India resistant to many rust breeds, probably originating from natural hybridization between *C. arabica* and *C. liberica* (Medina Filho et al. 2007). The Geisha variety was first discovered in the forested mountains of Western Ethiopia in the 1930s in the provinces of Maji and Goldija (Boot 2013), and it displays unique flavor profiles, larger beans, and resistance to coffee leaf rust (*Hemileia vastatrix*). S288/23 carries the

rust resistance genes SH₃ and SH₅ (Wellman and Echandi 1980). Thus, efficient selection can be achieved in the crosses between these parents, which have favorable values of cupping, since the presence of these resistance genes has no pleiotropic effects on beverage quality (Leroy et al. 2011).

We found correlations between all sensory attributes, corroborating other authors (Pereira et al. 2017; Gamboa Becerra et al. 2019; Tariku and Ayano 2018). Due to their polygenic nature, the inheritance of quality components is complex and must have a high broad-sense heritability value to ensure that desirable characteristics can be selected with minimal influence. However, all the attributes that make up the final score were grouped under a low heritability range (Table 1), indicating that there is no single attribute that is particularly important to the organoleptic performance of the studied accessions. These findings suggest that the selection should be performed through the final score since the correlations were of high magnitude.

This study proposed a selection strategy for a large number of coffee accessions that can be useful when exploring many genotypes in breeding programs for beverage quality. Through the proposed method, we identified genetic variation in our original population and selected five accessions with excellent beverage quality according to the SCA classification. These accessions were planted in field conditions of highly specialized farms to study their interaction with the cultivation environment and to promote the increase in the production of such coffees. The five selected accessions are being used in crosses with elite cultivars to create new segregating populations. We conclude that the optimization of selection requires estimating the heritable variation of each accession studied. Also, the use over the years of common check cultivars with known performance and extremely care of experimental precision in the entire process warrant fair comparisons.

References

Agwanda CO, Baradat P, Eskes AB, Cilas C, Charrier A (2003). Selection for bean and liquor qualities within related hybrids of Arabica coffee in multilocal field trials. *Euphytica* 131:1–14. doi: 10.1023/A:1023071815109

Barbosa IP, Oliveira ACB, Rosado RDS, Sakiyama NS, Cruz CD, Pereira AA (2020). Sensory analysis of arabica coffee: cultivars of rust resistance with potential for the specialty coffee market. *Euphytica* 216:165. doi: 10.1007/s10681-020-02704-9

Bernardo R (2010) *Breeding for Quantitative Traits in Plants*. 2nd Edition, Stemma Press, Woodbury.

Boot W (2013). Exploring the holy grail: Geisha Coffee, 10 years on. *Roast Magazine*, May/June 2013: 39 – 49.

Cruz CD (2013) GENES: a software package for analysis in experimental statistics and quantitative genetics. *Acta Sci. Agron.*: 35 (3) 271-276 doi: 10.4025/actasciagron.v35i3.21251

Donfrancesco Bdi, Guzman NG, Chambers E (2019). Similarities and differences in sensory properties of high quality Arabica coffee in a small region of Colombia. *Food Res. Int.* 116: 645-651 doi: 10.1016/j.foodres.2018.08.090

Donnet ML, Weatherspoon DD, Hoehn JP (2007). What adds value in specialty coffee? Managerial implications from hedonic price analysis of Central and South American e-auctions. *Int. Food Agribus. Manag. Rev* 10: 1-18. doi: 10.22004/ag.econ.8162

Fassio LO, Malta MR, Liska GR, Carvalho GR, Botelho CE, Pereira AA, Pereira RGFA (2020). Performance of arabica coffee accessions from the active germplasm bank of Minas Gerais – Brazil as a function of dry and wet processing: a sensory approach. *Aust. J. Crop Sci.* 14(06): 1011-1018 doi: 10.21475/ajcs.20.14.06.p2528

Fazuoli LC, Braghini MT, Silvarolla MB, Gonçalves W, Mistro JC, Gallo PB, Guerreiro Filho O (2018). IAC Obatã 4739 - dwarf arabic coffee cultivar with yellow fruits and resistant to leaf rust. *Crop Breed. Appl. Biotechnol.* 18(3): 330-333 doi: 10.1590/1984-70332018v18n3c49.

298 Figueiredo LP, Borém FM, Ribeiro FC, Giomo GS, Taveira JHS, Malta MR (2015). Fatty acid profiles
 299 and parameters of quality of specialty coffees produced in different Brazilian regions. *Afr. J. Agric. Res.*
 300 10(35): 3484-3493 doi: 10.5897/AJAR2015.9697
 301
 302 Gamboa-Becerra R, Hernández-Hernández, MC, González-Ríos Ó, Suárez-Quiroz ML, Gálvez-Ponce E,
 303 Ordaz-Ortiz JJ, Winkler R (2019). Metabolomic Markers for the Early Selection of *Coffea canephora*
 304 Plants with Desirable Cup Quality Traits. *Metabolites* 9: 214 doi: 10.3390/metabo9100214
 305
 306 Guedes JM, Vilela DJM, Rezende JC, Silva FL, Botelho CE, Carvalho SP (2013a). Divergência genética
 307 entre cafeeiros do germoplasma Maragogipe. *Bragantia* 72(2): 127-132 doi: 10.1590/S0006-
 308 87052013000200003
 309
 310 Guedes JM, Rezende JC, Andrade JMR, Carvalho SP, Pereira AA, Carvalho AM (2013b). Genetic
 311 Divergence among Progenies Resulting from the Crossing of Groups Coffee Timor Hybrid and Dilla &
 312 Alge. *J. Agric. Sci. Technol.* 3(12): 865-872
 313
 314 Guerreiro Filho O, Ramalho MAP, Andrade VT (2018). Alcides Carvalho and the selection of Catuaí
 315 cultivar: interpreting the past and drawing lessons for the future. *Crop Breed. Appl. Biotechnol.* 18: 460-
 316 466 doi: 10.1590/1984-70332018v18n4p69
 317
 318 Illy A, Viani R (2005). *Espresso coffee: the science of quality*, 2nd ed. Academic Press, London
 319
 320 Leroy T, Ribeyre F, Bertrand B, Charmetant P, Dufour M, Montagnon C, Marraccini, Pot D (2006).
 321 Genetics of coffee quality. *Braz. J. Plant Physiol* 18(1): 229-242 doi: 10.1590/S1677-
 322 04202006000100016
 323
 324 Leroy T, De Bellis F, Legnate H, Kananura E, Gonzales G, Pereira LF, Andrade AC, Charmetant P,
 325 Montagnon C, Cubry P, Marraccini P, Pot D, de Kochko A (2011). Improving the quality of African
 326 robustas: QTLs for yield- and quality-related traits in *Coffea canephora* . *Tree Genet. Genomes* 7: 781–
 327 798 doi: 10.1007/s11295-011-0374-6

328

329 Lingle TR, Menon SN (2017). Cupping and Grading—Discovering Character and Quality. The Craft and
330 Science of Coffee 181–203 doi:10.1016/b978-0-12-803520-7.00008-6

331

332 Lingle TR (2011). The coffee cupper's handbook: a systematic guide to the sensory evaluation of coffee's
333 flavor. Long Beach, CA: Specialty Coffee Association of America.

334

335 Malta MR, Fassio LO, Liska GR, Carvalho GR, Pereira AA, Botelho CE, Ferraz VP, Silva AD, Pedrosa
336 AW, Alvaro LN, Pereira RGFA (2020). Discrimination of genotypes coffee by chemical composition of
337 the beans: Potential markers in natural coffees. Food Res. Int 134
338 <https://doi.org/10.1016/j.foodres.2020.109219>.

339

340 Medina-Filho HP, Maluf MP, Bordignon R, Guerreiro-Filho O, Fazuoli LC (2007). Traditional breeding
341 and modern genomics: a summary of tools and developments to exploit biodiversity for the benefit of the
342 coffee agroindustrial chain. Acta Horticulturae 745: 351–368 doi:10.17660/actahortic.2007.745.21

343

344 Nadaleti DHS, Vilela DJM, Carvalho GR, Mendonça JMA, Botelho CE, Coelho LS, Fassio LO, Carvalho
345 JPF (2018). Productivity and sensory quality of arabica coffee in response to pruning type
346 “esqueletamento”. Journal of Agricultural Science 10(6): 207-216 doi: 10.5539/jas.v10n6p207

347

348 Pereira LL, Cardoso WS, Guarçoni RC, Fonseca AFA, Moreira TR, Caten CST (2017). The consistency
349 in the sensory analysis of coffees using Q-graders. Eur Food Res Technol. 243: 1545–1554
350 doi.org/10.1007/s00217-017-2863-9

351

352 Resende MDV (2016) Software Selegen-REML/BLUP: a useful tool for plant breeding. Crop Breed.

353 Appl. Biotechnol. 16: 330-339 doi: 10.1590/1984-70332016v16n4a49

354

355 SCAA (2015). SCAA Protocols - Cupping Specialty Coffee. Specialty Coffee Association of America.

356 <http://www.scaa.org/PDF/resources/cupping-protocols.pdf> (accessed 28 Jun. 2020).

357

Silva PA, Rabelo VM, Calixto JMR, Coelho PO, Gorski IC (2014). Quality assessment of coffee grown in Campos Gerais, Minas Gerais State, Brazil. Acta Sci. Technol. 36(4): 739-744 doi: 10.4025/actascitechnol.v36i4.19765

Smith AB, Stringer JK, Wei X, Cullis BR (2007) Varietal selection for perennial crops where data relate to multiple harvests from a series of field trials. Euphytica 157: 253–266 doi: 10.1007/s10681-007-9418-2

Sobreira FM, Oliveira ACB de, Pereira AA, Sobreira MFC, Sakyama NS (2015). Sensory quality of arabica coffee (*Coffea arabica*) genealogic groups using the sensogram and content analysis. Aust. J. Crop Sci. 9: 486-493.

Tariku A, Ayano A (2018). Genetic variability analysis of some coffee germplasms (*Coffea arabica* L.) based on organoleptic quality traits in Ethiopia. International Journal of Agriculture and Biosciences 7 (3): 164-167

Tran HT, Lee LS, Furtado A, Smyth H, Henry RJ (2016). Advances in genomics for the improvement of quality in coffee. J Sci Food Agric. 96(10): 3300-3312 doi:10.1002/jsfa.7692

van der Vossen H, Bertrand B, Charrier A (2015). Next generation variety development for sustainable production of arabica coffee (*Coffea arabica* L.): a review. Euphytica 204, 243–256. doi: org/10.1007/s10681-015-1398-z

Wellman FL, Echandi E (1980). The coffee rust situation in Latin America in 1980 Phytopathology (EUA) 71(9): 968-971.

Fig 1 Estimates of predicted additive values ($u+g$), individual heritability per accession (h^2), genetic parameters, and overall mean and estimated gain for the sensory score of the beverage of the 27 accessions selected among the 270 accessions studied. * Accession used as control. h^2_i : heritability at the plot level; h^2_m : heritability at the mean progeny level. PEV: prediction error variance of the genotypic values, assuming no loss of plots. M_o : phenotypic mean of the 270 accessions before selection. M_s : mean of the 27 accessions selected. SG: selection gain

Fig 2 Estimates of the genotypic values ($u+g$), individual heritability per accession, genetic parameters and overall mean for the sensory score of the beverage of 20 accessions evaluated in the 2019/2020 harvest and estimated gain with the selection of the five best accessions.* Accession used as control. h^2_i : heritability at the plot level; h^2_m : heritability at the mean progeny level. PEV: prediction error variance of the genotypic values, assuming no loss of plots. M_o : phenotypic mean of the 270 accessions before selection. M_s : mean of the 27 accessions selected. SG: selection gain

the genotypic values, assuming no loss of plots. M_O : phenotypic mean of the original population before selection. SG: selection gain

Table 1 Coefficients of genotypic correlations and estimates of genetic parameters among the sensory attributes of the beverage evaluated in coffee accessions in the 2018/2019 harvest

	Aroma	Flavor	Acidity	Body	Afterta	Balan	Overall	Final
Aroma		0.78**	0.92**	0.73**	0.84**	0.85**	0.93**	0.92**
Flavor			0.83**	0.85**	0.91**	0.85**	0.83**	0.92**
Acidity				0.8**	0.89**	0.8**	0.94**	0.95**
Body					0.86**	0.77**	0.79**	0.89**
Aftertaste						0.83**	0.87**	0.95**
Balance							0.85**	0.91**
Overall								0.95**
h_a^2	0.31	0.19	0.18	0.19	0.35	0.30	0.16	0.32
h_{mg}	0.47*	0.32	0.30	0.33	0.52*	0.46*	0.27	0.48*
CV_r	0.90	0.75	0.65	0.61	1.03	0.90	0.61	1.01
Mean	7.59	7.95	7.76	7.90	7.79	7.58	7.64	84.20

** Significant at 1% by Student's t-test. * Significant at 5% by the likelihood ratio test. h_a^2 : broad-sense

heritability of individual plots. h_{mg} : heritability of the mean genotype. CV_r : relative coefficient of variation.

Supplemental Table S1. Estimates of the genotypic values (u+g), individual heritability by accession, and classification by genotypic values for the 270 accessions evaluated over three years on the sensory characteristics of beverage quality.

1	MG 159	Maragogipe Híbrido F1	85.53	1	136	MG 448	Mundo Novo × S 795 UFV 335-15	82.04	1
2	MG 1011	Dilla & Alghe × S 333 UFV 329-02	85.46	1	137	MG 260	Catuaí Vermelho PI 04	82.04	1
3	MG 171	Maragogipe Vermelho PI 02	85.11	1	138	MG 1230	Mundo Novo I MP 376-4	82.04	0.66
4	MG 1007	Geisha × S 288/23 UFV 328-62	84.46	0.77	139	MG 139	Mundo Novo Amarelo	82.01	0.92
5	MG 1059	Sarchimor UFV 350-98	84.42	0.58	140	MG 141	Mundo IAC 379-19	82.01	0.43
6	MG 161	Maragogipe	84.31	0.38	141	MG 338	Híbrido Timor UFV 439-02	82	0.23
7	MG 155	Maragogipe Amarelo	84.07	1	142	MG 154	Café Brasil	81.98	0.94
8	MG 1197	Híbrido Interespecífico	84.04	0.62	143	MG 205	Guatenano	81.98	1
9	MG 1188	Icatu Amarelo IAC 2944	83.81	0.87	144	MG 1243	Mundo Novo 25L LCMP 379-19	81.98	1
10	MG 224	Pacamara*	83.81	0.98	145	MG 1244	Mundo Novo 25L LCP 382-7	81.98	1
11	MG 291	Híbrido Timor UFV 379-07	83.47	0.4	146	MG 193	Caturra Amarelo	81.95	1
12	MG 128	Bourbon Amarelo	83.44	1	147	MG 201	Vila Lobos	81.94	0.92
13	MG 227	Sete Favas	83.44	1	148	MG 259	Catuaí Vermelho PI 05	81.93	1
14	MG 036	Bourbon Amarelo T8	83.34	0.81	149	MG 226	Polisperma	81.91	0.99
15	MG 294	Híbrido Timor UFV 408-01	83.33	0.99	150	MG 175	Caturra X H.T. IAC 2012	81.9	0.76
16	MG 133	Sumatirão Ponta Roxa	83.25	0.98	151	MG 1256	Mundo Novo II CP 388-17-16	81.9	0.76
17	MG 1006	Geisha × S 288/23 UFV 328-60	83.24	0.73	152	MG 143	Planta Roxa	81.9	0.66
18	MG 364	Híbrido Timor UFV 442-42	83.24	0.66	153	MG 027	Bourbon Vermelho T4	81.9	0.94
19	MG 186	Amphillo IAC 1167-19 MR 2-115	83.23	1	154	MG 248	Obatã Amarelo	81.9	1
20	MG 1046	Sarchimor UFV 349-85	83.23	1	155	MG 040	Bourbon Amarelo T12	81.89	0.34
21	MG 043	Bourbon Amarelo T15	83.21	0.11	156	MG 932	Catuaí S _H 2-S _H 3	81.89	0.34
22	MG 1165	Ouro Verde IAC 5010-5	83.19	0.8	157	MG 1092	Catimor UFV 343-48	81.89	0.43

23	MG 329	Híbrido Timor UFV 437-02	83.17	0.78	158	MG 209	Villa Sarchi Graúdo	81.87	1
24	MG 016	Bourbon Vermelho	83.16	0.69	159	MG 1048	Sarchimor UFV 350-01	81.86	1
25	MG 246	Obatã Alaranjado	83.16	1	160	MG 153	Acaiá Cerrado Pl. diferente	81.85	0.52
26	MG 625	BE 5 Wush-Wush UFV 406-06	83.16	1	161	MG 365	Híbrido Timor UFV 442-44	81.84	0.6
27	MG 865	Mundo Novo × CIFIC H 288/14 UFV 323-59	83.16	1	162	MG 198	San Ramon Alto	81.84	1
28	MG 277	Híbrido Timor UFV 376-52	83.16	1	163	MG 456	Mundo Novo × S 795 UFV 335-124	81.83	0.33
29	MG 007	Bourbon Amarelo	83.13	0.14	164	MG 1318	Mundo Novo X Mundo Novo LCH 6677	81.82	0.43
30	MG 233	Obatã Amarelo*	83.07	0.61	165	MG 216	Caturra Vermelho UFV 534 C83	81.81	0.56
31	MG 601	K7 IAC 1151-2 C1003 UFV 165-01	83.04	1	166	MG 278	Híbrido Timor UFV 376-37	81.81	0.26
32	MG 203	Pacas	83.02	1	167	MG 149	Iarana 1973-74 MS	81.8	0.97
33	MG 1238	Mundo Novo I LCP 379-19	83.02	1	168	MG 187	Caturra Vermelho	81.77	0.88
34	MG 336	Híbrido Timor UFV 438-49	83.01	0.81	169	MG 110	Bourbon Amarelo	81.77	1
35	MG 602	K 7 IAC 1151-2 C 1003 UFV 165-02	82.96	1	170	MG 167	Maragogipe Amarelo Pl 03	81.77	1
36	MG 357	Híbrido Timor UFV 441-04	82.95	0.29	171	MG 1207	Sumatra	81.77	1
37	MG 118	Bourbon Trigo	82.95	1	172	MG 134	Sumatra Palma	81.73	0.85
38	MG 182	UFV 3075 c. 241	82.95	1	173	MG 136	Sumatra	81.73	0.62
39	MG 009	Bourbon Amarelo	82.88	0.28	174	MG 142	Mundo Novo Ponta roxa	81.73	0.92
40	MG 176	Amphillo × H. Natural MR 36-349	82.85	0.96	175	MG 138	Mundo Novo Purpuracia	81.72	0.35
41	MG 212	Caturra Amarelo	82.82	0.32	176	MG 191	Caturra Amarelo	81.72	0.99
42	MG 292	Híbrido Timor UFV 380-05	82.82	1	177	MG 168	Maragogipe Amarelo Pl 04	81.71	0.46
43	MG 1277	Mundo Novo I RPP 474-6	82.81	1	178	MG 1053	Sarchimor UFV 350-19	81.7	1
44	MG 1340	Maragogipe Vermelho	82.81	1	179	MG 1211	Bourbon Vermelho	81.7	1
45	MG 1206	Bourbon Vermelho	82.79	0.71	180	MG 127	Carolino	81.63	0.81
46	MG 152	Icatu Precoce IAC 3282	82.79	0.52	181	MG 334	Híbrido Timor UFV 438-03	81.62	0.1

47	MG 545	Bourbon N39 × H.T. UFV 455-01	82.79	1	182	MG 022	Bourbon Alaranjado T6	81.57	0.23
48	MG 012	Bourbon Amarelo	82.78	0.38	183	MG 1079	Cavimor UFV 357-04	81.57	0.41
49	MG 192	Caturra Vermelho	82.74	0.23	184	MG 1363	Mundo Novo IAC 376-4	81.57	0.52
50	MG 217	Caturra Vermelho UFV 534 C80	82.74	0.99	185	MG 088	Bourbon Amarelo Pl 02	81.56	1
51	MG 245	Obatã Tardio	82.74	0.76	186	MG 160	Maragogipe	81.56	1
52	MG 035	Bourbon Vermelho	82.74	0.52	187	MG 204	Nanico da Guatemala	81.56	1
53	MG 311	Híbrido Timor UFV 428-02	82.74	1	188	MG 335	Híbrido Timor UFV 438-40	81.54	1
54	MG 367	Híbrido Timor UFV 442-108	82.72	0.22	189	MG 447	Mundo Novo × S 795 UFV 335-14	81.54	0.92
55	MG 207	Guatenano Colis	82.71	0.27	190	MG 458	Mundo Novo × S 795 UFV 409-01	81.54	1
56	MG 264	Catuaí Vermelho Pré lançamento	82.68	0.97	191	MG 1336	Mundo Novo tozan Monte Déste	81.54	0.14
57	MG 363	Híbrido Timor UFV 442-40	82.67	0.87	192	MG 150	Iarana 1973/74 IAC 1110	81.52	1
58	MG 215	Caturra Vermelho UFV 534 C64	82.67	1	193	MG 184	Planta considerada como Maragogipe	81.51	0.94
59	MG 1216	Caturra Amarelo	82.67	1	194	MG 220	Caturra Amarelo Matielo	81.5	1
60	MG 206	Guatemalenses	82.67	0.99	195	MG 164	Maragogipe UFV 3075	81.5	0.73
61	MG 1168	Palma I	82.64	1	196	MG 1368	Pacas	81.5	0.88
62	MG 280	Híbrido Timor UFV 376-14	82.64	0.23	197	MG 011	Bourbon Vermelho	81.49	0.19
63	MG 179	Ct. V. × Amphillo MR 2161	82.63	0.94	198	MG 109	Bourbon Amarelo IAC JC	81.47	1
64	MG 1060	Obatã IAC 1669-20	82.63	1	199	MG 252	Catuaí Amarelo 2SL	81.47	1
65	MG 859	CIFC H 288/13 × Caturra Vermelho UFV 322-38	82.62	1	200	MG 321	Híbrido Timor UFV 432-09	81.45	0.89
66	MG 170	Maragogipe Vermelho Pl 01	82.6	0.15	201	MG 185	Catuaí V. × Amphillo MR 2474	81.43	0.19
67	MG 225	IAPAR 59 polisperma	82.6	1	202	MG 454	Mundo Novo × S 795 UFV 335-104	81.43	0.88
68	MG 261	Catuaí Vermelho Pl 03	82.6	1	203	MG 1178	IPR 100	81.43	0.41
69	MG 1226	Mundo Novo	82.6	1	204	MG 1192	Mundo Novo 502-9	81.42	0.45
70	MG 117	Bourbon Limoeiro	82.59	0.41	205	MG 104	Bourbon Amarelo UFV 535	81.4	0.85
71	MG 169	Maragogipe Amarelo Pl 05	82.57	0.31	206	MG 337	Híbrido Timor UFV 439-01	81.36	0.73

72	MG 131	Sumatra	82.56	0.26	207	MG 1170	Acauã	81.36	0.73
73	MG 308	Híbrido Timor UFV 427-55	82.55	0.99	208	MG 081	Bourbon Vermelho Pl 19	81.35	1
74	MG 276	Híbrido Timor UFV 376-57	82.55	0.61	209	MG 119	Bourbon Italiano	81.35	1
75	MG 214	Caturra Amarelo	82.53	1	210	MG 1062	IAPAR 59	81.35	1
76	MG 156	Maragogipe Vermelho	82.53	0.73	211	MG 254	Catuaí Vermelho Pl 10	81.33	0.38
77	MG 1187	Catuaí Vermelho IAC 99	82.52	0.37	212	MG 326	Híbrido Timor UFV 435-03	81.33	0.97
78	MG 064	Bourbon Vermelho	82.51	0.71	213	MG 197	São Bernardo	81.31	0.69
79	MG 020	Bourbon Amarelo T7	82.51	0.81	214	MG 250	Catuaí Amarelo SL 6	81.3	0.32
80	MG 347	Híbrido Timor UFV 440-07	82.5	0.86	215	MG 258	Catuaí Vermelho Pl 06	81.3	0.24
81	MG 1294	Mundo Novo I MP 502-1	82.5	0.19	216	MG 257	Catuaí Vermelho Pl 07	81.28	1
82	MG 213	Caturra Vermelho	82.5	1	217	MG 1036	Sarchimor UFV 349-02	81.28	1
83	MG 174	Maragogipe Vermelho Pl 05	82.46	0.73	218	MG 295	Híbrido Timor UFV 408-10	81.26	0.69
84	MG 041	Bourbon Amarelo T13	82.46	0.66	219	MG 062	Bourbon Vermelho MS1 T1890	81.25	1
85	MG 166	Maragogipe Amarelo Pl 02	82.46	0.81	220	MG 348	Híbrido Timor UFV 440-10	81.22	0.88
86	MG 266	Híbrido Timor UFV377-51	82.46	1	221	MG 1321	Mundo Novo X Mundo Novo LCH 6682	81.22	0.99
87	MG 430	Mundo Novo x S 795 UFV 315-77	82.44	0.97	222	MG 178	Acaiá Comprido	81.21	0.8
88	MG 002	Típica UFV 536	82.43	1	223	MG 1332	Acauã	81.21	0.15
89	MG 023	Bourbon Amarelo T6	82.43	0.55	224	MG 231	Erecta	81.21	0.32
90	MG 1061	Obatã Amarelo IAC	82.43	0.92	225	MG 911	Caturra Vermelho x S 795 UFV 314-57	81.21	1
91	MG 1233	Mundo Novo I MP 376-4-36	82.43	0.92	226	MG 195	Caturra Amarelo Nº.52	81.2	0.76
92	MG 140	Mundo Novo Ponta Roxa	82.39	0.88	227	MG 319	Híbrido Timor UFV 432-04	81.19	0.7
93	MG 130	Sumatirão Ponta Roxa	82.37	0.08	228	MG 1008	Geisha x S 288/23 UFV 328-69	81.16	0.99
94	MG 172	Maragogipe Vermelho Pl 03	82.36	0.19	229	MG 1218	Sumatra fruto amarelo	81.16	0.86
95	MG 270	Híbrido Timor UFV 377-21	82.36	0.35	230	MG 318	Híbrido Timor UFV 432-02	81.15	0.48
96	MG 165	Maragogipe Amarelo Pl 01	82.33	0.58	231	MG 188	Caturra Amarelo	81.14	1
97	MG 158	Maragogipe	82.32	0.7	232	MG 083	Bourbon Vermelho T1890 Pl 32	81.13	0.42

98	MG 230	Catuaí Erecta	82.32	1	233	MG 223	Pacamara	81.11	0.81
99	MG 066	Bourbon Vermelho	82.32	1	234	MG 099	Bourbon Vermelho VD	81.09	1
100	MG 438	Mundo Novo × S 795 UFV 335-04	82.32	0.94	235	MG 151	Icatu Precoce IAC 3282	81.08	0.88
101	MG 330	Híbrido Timor UFV 437-03	82.31	0.61	236	MG 108	Bourbon Amarelo	81.02	0.73
102	MG 038	Bourbon Amarelo T10	82.29	0.85	237	MG 268	Híbrido Timor UFV 377-24	80.97	0.71
103	MG 354	Híbrido Timor UFV 441-01	82.28	0.19	238	MG 1327	Topázio MG 1190	80.95	1
104	MG 558	Bourbon N197 × H.T.UFV 403-19	82.28	0.99	239	MG 457	Mundo Novo × S 795 UFV 335-130	80.94	0.88
105	MG 485	Mundo Novo S _H 2-S _H 3	82.27	1	240	MG 008	Bourbon Amarelo	80.93	0.66
106	MG 317	Híbrido Timor UFV 430-20	82.26	0.2	241	MG 296	Híbrido Timor UFV 408-11	80.9	0.83
107	MG 255	Catuaí Vermelho Pl 09	82.26	1	242	MG 054	Bourbon Vermelho Pl 10	80.9	1
108	MG 200	Vila Lobos	82.25	0.88	243	MG 183	UFV 3075 c. 135	80.87	1
109	MG 006	Bourbon Amarelo	82.23	1	244	MG 194	Caturra Amarelo Colombiano	80.79	0.76
110	MG 079	Bourbon Vermelho Pl 16	82.22	0.55	245	MG 013	Bourbon Amarelo	80.79	1
111	MG 242	Goiaba	82.2	0.58	246	MG 1194	Acaiá Maragogipe	80.79	1
112	MG 355	Híbrido Timor UFV 441-02	82.2	0.46	247	MG 219	Caturra Amarelo	80.75	0.81
113	MG 157	Maragogipe Alaranjado	82.19	0.73	248	MG 094	Bourbon Vermelho	80.73	0.81
114	MG 189	Caturra Alaranjado	82.18	0.76	249	MG 856	CIFC H 288/13 × Caturra Vermelho UFV 322-15	80.73	1
115	MG 196	Caturra Amarelo Seb. Dornelas	82.18	1	250	MG 058	Bourbon Vermelho T1890 Pl 05	80.66	0.99
116	MG 1250	Mundo Novo I MP 388-6-13	82.18	0.81	251	MG 003	Típica da Guatemala	80.65	1
117	MG 346	Híbrido Timor UFV 440-04	82.18	0.61	252	MG 162	Acaiá Híbrido F3	80.63	0.85
118	MG 862	CIFC H 288/13 × Caturra Vermelho UFV 322-97	82.16	1	253	MG 315	Híbrido Timor UFV 430-13	80.62	0.05
119	MG 1169	Palma II	82.15	0.25	254	MG 221	Caturra Amarelo Nanição	80.61	0.17
120	MG 1228	Mundo Novo Broto Verde	82.15	0.97	255	MG 857	CIFC H 288/13 × Caturra Vermelho UFV 322-19	80.6	0.88
121	MG 218	Caturra Amarelo	82.14	1	256	MG 453	Mundo Novo × S 795 UFV 335-77	80.6	1

122	MG 289	Híbrido Timor UFV 376-01	82.14	1	257	MG 283	Híbrido Timor UFV 376-11	80.58	1
123	MG 303	Híbrido Timor UFV 427-09	82.14	1	258	MG 1229	Mundo Novo Broto Verde	80.51	0.99
124	MG 1005	Geisha × S 288/23 UFV 328-43	82.13	0.88	259	MG 262	Catuaí Vermelho Pl 02	80.51	1
125	MG 1283	Mundo Novo I LCP 480	82.13	0.99	260	MG 126	Bourbon Amarelo ou Vermelho	80.47	0.16
126	MG 648	Caturra Vermelho × DK 1/6 UFV 309-05	82.13	0.94	261	MG 235	Trifolia	80.46	0.71
127	MG 135	Sumatra	82.12	0.81	262	MG 1208	Maragogipe	80.44	1
128	MG 241	Glaucia	82.12	0.41	263	MG 146	Mundo Novo Ponta Roxa	80.42	0.31
129	MG 273	Híbrido Timor UFV 377-06	82.12	1	264	MG 076	Bourbon Vermelho T1890 Pl 13	80.25	0.41
130	MG 281	Híbrido Timor UFV 376-13	82.09	0.38	265	MG 177	Amphillo × H. Natural MR 36-352	80.18	0.52
131	MG 860	CIFC H 288/13 × Caturra Vermelho UFV 322-63	82.09	0.92	266	MG 1337	Piatã IAC 387 Planta 2	80.04	1
132	MG 025	Bourbon Alaranjado T5-2	82.08	0.77	267	MG 137	Sumatra Amarelo Pl 03 L6	78.84	1
133	MG 1166	Ouro Verde Amarelo IAC 4397	82.06	0.58	268	MG 550	Bourbon N39 × Híbrido Timor UFV 455-07	76.82	1
134	MG 181	UFV 3075 c. 319	82.05	0.93	269	MG 132	Sumatra Amarelo Pl 01	76.05	0.02
135	MG 228	Laurina	82.04	1	270	MG 253	Catuaí Amarelo 24/137	75.87	0.01

* Accessions used as controls

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementalTableS1.docx](#)