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CAN FRUIT COLOR, MATURATION CYCLE, AND RESISTANCE TO RUST INFLUENCE BEVERAGE QUALITY IN ARABICA COFFEE?

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ABSTRACT: Several factors can improve the quality of the coffee drink and are important for recommending coffee cultivars. The goal of this study was to compare the sensory quality of the beverage of 19 Arabica coffee cultivars, individually and using groups concerning the period of fruit maturation, susceptibility to coffee rust, and color of fruits, in the Geographical Indication Region Mountain of Espírito Santo. Fruits were harvested manually when 80% were ripe, submitted to the adequate post-harvest process, and submitted to sensory analysis after 60 days. The cultivars Acauã Novo, Catucaí 785/15, IBC Palma II, and Yellow Bourbon presented the highest scores associated with sensory quality. Very early and early cycles' cultivars had the best sensory performance; red and yellow fruit of Arabica coffee cultivars showed similar beverage quality; the degree of rust resistance of the different groups did not influence the quality of the beverage. It was pointed out that the new Arabica coffee cultivars are resistant to rust and have red or yellow skin, which did not affect the quality of the beverage. This information is important to aggregate the quality of coffee production. Specialty coffee producers may increase the value of their products using the right Arabica coffee cultivar in their region. By combining cultivars of different maturation cycles, coffee farmers may rip mature coffee for a longer time, improving the use of all processes in the farm, and increasing the volume of specialty coffee produced.

KEYWORDS: *Coffea arabica*. Coffee Quality. Genotypes. Maturation Cycle.

RESUMO-Vários fatores podem melhorar a qualidade da bebida de café e são importantes para a recomendação de cultivares de café. O objetivo deste estudo foi comparar a qualidade sensorial da bebida de 19 cultivares de café arábica, individualmente e por grupos quanto ao período de maturação dos frutos, suscetibilidade à ferrugem e coloração dos frutos, na Região de Indicação Geográfica Montanhas do Espírito Santo. Os frutos foram colhidos manualmente quando 80% estavam maduros, submetidos ao processo de pós-colheita adequado e submetidos à análise sensorial após 60 dias. As cultivares Acauã Novo, Catucaí 785/15, IBC Palma II e Yellow Bourbon apresentaram as maiores pontuações associadas à qualidade sensorial. As cultivares de ciclos muito precoce e precoce apresentaram o melhor desempenho sensorial; os frutos vermelhos e amarelos das cultivares de café arábica apresentaram qualidade de bebida semelhante; o grau de resistência à ferrugem dos diferentes grupos não influenciou na qualidade da bebida. Foi destacado que as novas cultivares de café arábica resistentes à ferrugem e com casca vermelha ou amarela não afetou a qualidade da bebida. Essas informações são importantes para agregar qualidade à produção de café. Produtores de café especial podem aumentar o valor de seus produtos usando a cultivar de café arábica certa em sua região. Ao combinar cultivares de diferentes ciclos de maturação, os cafeicultores podem colher café maduro por mais tempo, melhorando o uso de todos os processos na propriedade, aumentando o volume de café especial produzido.

PALAVRAS-CHAVE: Ciclo de Maturação. *Coffea arábica*. Genótipos. Qualidade do Café.

1 INTRODUCTION

Coffee is a globally appreciated beverage with a volume of over 500 billion cups consumed per year. Coffee is the second largest commodity in market value with a global production of over 9 million tons (CARVALHO NETO et al., 2018). In Brazil, coffee farming is an activity that has great socioeconomic relevance, with about 46.9 million bags of processed coffee, spread over about 1.8 million hectares. Two species of coffee are produced in Brazil and Arabica coffee represents about 68% of the total production, while the conilon/robusta contributes with 32% (CONAB, 2023). Despite the advances in the international coffee market, it has undergone important changes or 'waves' related to the commercialization, valuation, philosophies, and purposes of its consumption. These changes have initiated a new market configuration and different consumer profiles have emerged, among them consumers of specialty coffees (GUIMARÃES et al., 2019). Specialty coffees constitute a growing market in Brazil stimulated by events, research, and the opening of specialized stores (SANTOS et al., 2021). The state of Espírito Santo is Brazil's second largest coffee producer and occupies a prominent position in the production of specialty coffees. The cultivation of coffee in the family farming system, combined with favorable environmental characteristics to produce specialty coffees, has resulted in superior quality coffees recognized for their high acidity and fruity sensory notes (COSTA, 2020; KROHLING et al., 2021).

In the period called "quality indifference", the main objective of breeding programs was to produce cultivars that were highly productive and resistant to the main pests and diseases of this crop, leaving the quality of the beverage a seldom considered characteristic. An example of this was the significant investment made to develop coffee cultivars resistant to leaf rust (*Hemileia vastatrix*), such as those originating from the Catimor cultivar. However, the beverage quality of these genetic materials has been repeatedly questioned by the market, hindering their insertion in the specialty coffee scenario (MONTAGNON et al., 2012; DIAS et al., 2021). However, with the increasing demand for higher quality coffees, in recent years coffee breeders have directed their efforts to follow these changes in the market and new coffee cultivars have been associated with the improvement of the coffee beverage (LEROY et al., 2006; ADANE; BEWKET, 2021). Another aspect that must be taken into consideration in the optimization of the specialty coffee production process is the maturation cycle presented by the genetic materials grown commercially. The uniformity of fruit maturation has been a frequent concern in coffee growing and one of the main factors to be considered in coffee improvement (SANTIN et al., 2019). The possible occurrence of this heterogeneity can compromise the harvest and result in impacts on the final quality of the beans. Another factor questioned by the productive sector refers to the interference of the coloration of the fruit epidermis related to the quality of the beverage. These effects can be even more significant in the case of specialty coffee production, since the labor force in this activity, especially in the State of Espírito Santo, Brazil is predominantly family-owned. Thus, the availability of cultivars with superior cup quality and different maturation cycles can contribute to the staggering of harvesting for family

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coffee growers, resulting in reduced costs and improved income for farms. The objective of this study was to evaluate the sensorial quality of the beverage of 19 Arabica coffee cultivars and compare them individually and among the groups they form in relation to the maturation period of the beans, susceptibility to coffee rust, and fruit color.

2 METHODOLOGY

The experiment was carried out from September 2016 to December 2017, in the municipality of Marechal Floriano, Espírito Santo state (ES), Brazil in the Atlantic Forest biome (lat 20° 26' 32.8" S, long 40° 46' 46.4" W, alt 715 m asl) in a randomized block design with 19 Arabica coffee cultivars ‘Catucaí 785/15’, ‘Siriema Amarelo’, ‘Bourbon Amarelo IAC J2’, ‘Maracatiá’, ‘Catucaí Amarelo 2 SL’, ‘Sabiá cv. 398’, ‘Catucaí Vermelho 20/15-479’, ‘IBC-Palma II’, ‘Mundo Novo 379-19’, ‘Topázio MG 1190’, ‘Rubi MG 1192’, ‘Arara’, ‘Japi’, ‘Catuaí Vermelho IAC-44’, ‘Catuaí Amarelo IAC-39’, ‘Catuaí Amarelo IAC-62’, ‘Catuaí Vermelho IAC-81’, ‘Acauã cv. 02’, ‘Acauã cv. 08’ (Table 1), and four repetitions. The plots were composed of eight plants, with six useful plants, planted in March 2002 with spacing of 2.5 × 0.70 m, with 5,714 plants per hectare, harvested in 2014 and trained with 02 stems per plant. One harvest was performed in each plot and the ripe cherry fruits of the plants in the experimental plots were used (10 L/plot). The fruits were harvested according to their ripening period (Table 1), manually when 80% of them were ripe. The post-harvest processing of the coffee beans was done wet on the same day of harvesting. In this processing, the cherry beans were separated from impurities and from the other beans that could be separated. After removal of the husk, the beans were immersed in water for 12 h to remove the mucilage. The drying of these cherry beans was done in a suspended plastic covered terrace, with the beans being well spread so as not to overlap; the fruits were stirred manually in 1 h intervals, from 7:00 am to 5:00 pm. The coffee samples were removed from the terrace when they presented 12% b.w. (ALIXANDRE et al., 2020). This process was done at different times of the year, respecting the maturation cycle of the beans. After 60 days of rest, the samples were submitted to sensory analysis. All this process was carried out so that each cultivar could express its drinking potential in the growing conditions adopted in the experiment.

Table 1 – Harvest time of the 19 Coffea arabica genotypes used in the field experiment.

Coffee cultivar	Month									
	April		May		June		July		August	
	1	2	1	2	1	2	1	2	1	2
1. Catucaí 785/15 (sel. CAK)		■								
2. Siriema Amarelo			■							
3. Bourbon Amarelo IAC J2			■							
4. Maracatiá			■							
5. Catucaí 2SL (sel. CAK)					■	■				
6. Sabiá cv 398					■	■				
7. Catuaí Vermelho 20/15 cv 479					■	■				
8. IBC Palma II					■	■				
9. Mundo Novo IAC 379-19					■	■				
10. Topázio MG 1190					■	■				
11. Rubi MG 1192					■	■				
12. Arara							■	■		
13. Japi							■	■		
14. Catuaí Vermelho IAC-44							■	■		
15. Catuaí Amarelo IAC-39							■	■		
16. Catuaí Amarelo IAC-62							■	■		
17. Catuaí Vermelho IAC-81							■	■		
18. Acauã cv 02 (sel. CAK)									■	■
19. Acauã cv 08 (sel. CAK)									■	■

*1 = 1st half of the month; 2 = 2nd half of the month.

2.1 Preparation of samples for sensorial analysis

The coffee samples were duly prepared according to the standard procedure adopted by SCA (2022) in the Specialty Coffee Research Center (CECAFES), in Venda Nova do Imigrante, ES, Brazil. The sensory evaluation process was also performed following the SCA (2022) methodology. Roasting was conducted using the Agtron-SCAA disc set as reference, and the roasting point of these samples was standardized by disc #60, from eight to ten minutes. A TP2 Probat® roaster was used, also following the SCA (2022) recommendation, 24 hours in advance. The roasted coffee beans were ground at the time of evaluation.

2.2 Sensory analysis method

The sensory quality of the coffees was evaluated according to the Protocol for Sensory Analysis of Coffee Methodology of the Specialty Coffee Association of America (SCAA 2022). expressed by a numerical centesimal scale. The sensory analyses were performed by 5 coffee tasters. The tasting form provides the possibility of evaluating the following 11 sensory attributes for coffee: fragrance/flavor, taste, acidity, body, finish, uniformity, absence of defects (clean cup), sweetness, equilibrium/balance, defects, and overall score (SCA, 2008).

2.3 Statistical Analysis

To compare the final score of the 20 Arabica coffee cultivars, analysis of variance was performed and the means were compared by the Scott-Knott test. Mean and mean group contrasts were compared by the Scheffé test (p< 5%).

The data were submitted to Lilliefors tests, to verify the normality of the errors and the Cochran and Bartlett tests were used to verify the homogeneity of the variances, before performing the Analysis of Variance (ANOVA) of the variables. The data of the variables were submitted to ANOVA, and the means compared by the Scott-Knott test (p < 5%).

Contrasts used to compare beverage quality for coffee cultivars of different maturation times, color, and rust resistance were the following: $C_1 = 3\widehat{m_1} - \widehat{m_2} - \widehat{m_3} - \widehat{m_{4;}}$ to compare times of very early and early maturation of coffee fruits; $C_2 = 7\widehat{m_1} - \widehat{m_5} - \widehat{m_6} - \widehat{m_7} - \widehat{m_8} - \widehat{m_9} - \widehat{m_{10}} - \widehat{m_{11}}$; to compare times of very early and medium maturation of coffee fruits; $C_3 = 6\widehat{m_1} - \widehat{m_{12}} - \widehat{m_{13}} - \widehat{m_{14}} - \widehat{m_{15}} - \widehat{m_{16}} - \widehat{m_{17}}$; to compare times of very early and late maturation of coffee fruits; $C_4 = 2\widehat{m_1} - \widehat{m_{18}} - \widehat{m_{19}}$; to compare times of very early and very late maturation of coffee fruits; $C_5 = 7\widehat{m_2} + 7\widehat{m_3} + 7\widehat{m_4} - 3\widehat{m_5} - 3\widehat{m_6} - 3\widehat{m_7} - 3\widehat{m_8} - 3\widehat{m_9} - 3\widehat{m_{10}} - \widehat{3m_{11}}$; to compare times of early and medium maturation of coffee fruits; $C_6 = 6\widehat{m_2} + 6\widehat{m_3} + 6\widehat{m_4} - 3\widehat{m_{12}} - 3\widehat{m_{13}} - 3\widehat{m_{14}} - 3\widehat{m_{15}} - 3\widehat{m_{16}} - 3\widehat{m_{17}}$; to compare times of early and late maturation of coffee fruits; $C_7 = 2\widehat{m_2} + 2\widehat{m_3} + 2\widehat{m_4} - 3\widehat{m_{18}} - 3\widehat{m_{19}}$; to compare the times of early and very late maturation of coffee fruits; $C_8 = 6\widehat{m_5} + 6\widehat{m_6} + 6\widehat{m_7} + 6\widehat{m_8} + 6\widehat{m_9} + 6\widehat{m_{10}} + 6\widehat{m_{11}} - 7\widehat{m_{12}} - 7\widehat{m_{13}} - 7\widehat{m_{14}} - 7\widehat{m_{15}} - 7\widehat{m_{16}} - 7\widehat{m_{17}}$; to compare the times of medium and late maturation of coffee fruits; $C_9 = 2\widehat{m_5} + 2\widehat{m_6} + 2\widehat{m_7} + 2\widehat{m_8} + 2\widehat{m_9} + 2\widehat{m_{10}} + 2\widehat{m_{11}} - 7\widehat{m_{18}} - 7\widehat{m_{19}}$; to compare the times of medium and very late maturation of coffee fruits; $C_{10} = \widehat{m_{12}} + \widehat{m_{13}} + \widehat{m_{14}} + \widehat{m_{15}} + \widehat{m_{16}} + \widehat{m_{17}} - 3\widehat{m_{18}} - 3\widehat{m_{19}}$; to compare the times of late and very late maturation of coffee fruits; $C_{11} = 7\widehat{m_1} + 7\widehat{m_4} + 7\widehat{m_6} + 7\widehat{m_7} + 7\widehat{m_8} + 7\widehat{m_9} + 7\widehat{m_{11}} + 7\widehat{m_{13}} + 7\widehat{m_{14}} + 7\widehat{m_{17}} + 7\widehat{m_{18}} + 7\widehat{m_{19}} - 12\widehat{m_2} - 12\widehat{m_3} - 12\widehat{m_5} - 12\widehat{m_{10}} - 12\widehat{m_{12}} - 12\widehat{m_{15}} - 12\widehat{m_{16}}$; to compare coffee cultivars with red and yellow fruits; $C_{12} = 7\widehat{m_3} + 7\widehat{m_4} + 7\widehat{m_9} + 7\widehat{m_{10}} + 7\widehat{m_{11}} + 7\widehat{m_{14}} + 7\widehat{m_{15}} + 7\widehat{m_{16}} + 7\widehat{m_{17}} - 9\widehat{m_1} - 9\widehat{m_2} - 9\widehat{m_5} - 9\widehat{m_6} - 9\widehat{m_7} - 9\widehat{m_8} - 9\widehat{m_{13}}$; to compare susceptible and moderately resistant coffee cultivars to coffee rust; $C_{13} =$

$3\widehat{m_3} + 3\widehat{m_4} + 3\widehat{m_9} + 3\widehat{m_{10}} + 3\widehat{m_{11}} + 3\widehat{m_{14}} + 3\widehat{m_{15}} + 3\widehat{m_{16}} + 3\widehat{m_{17}} - 9\widehat{m_{12}} - 9\widehat{m_{18}} - 9\widehat{m_{19}}$; to compare susceptible and high resistant coffee cultivars to coffee rust; $C_{14} = +3\widehat{m_1} + 3\widehat{m_2} + 3\widehat{m_5} + 3\widehat{m_6} + 3\widehat{m_7} + 3\widehat{m_8} + 3\widehat{m_{13}} - 7\widehat{m_{12}} - 7\widehat{m_{18}} - 7\widehat{m_{19}}$; to compare moderately and high resistant coffee cultivars to coffee rust. The principal component analysis was used to group the 20 coffee cultivars regarding the characteristics studied by means of a visual examination of their graphic dispersions.

For statistical analysis the Past version 4.10 (Hammer et al., 2001) and the R (R Core Team 2023) programs was used.

3 RESULTS AND DISCUSSION

It was observed that all 19 cultivars used reached scores higher than 81 points and presented characteristics of specialty coffees (Table 2). The cultivars Acauã cv 08 (Sel. CAK) (86.80), Catucaí 785/15 (Sel. CAK) (86.28), IBC Palma II (85.66), and Bourbon Amarelo IAC-J2 (85.32) had the highest scores, with no statistically significant difference among them. Neither was any difference observed in the final score (84.00 to 85.04) of the cultivars Maracatiá, Sabiá 398, Catucaí V.20/15 - 479, Mundo Novo 379-19, and Catuaí V. IAC-44.

To group the 19 cultivars regarding sensory characteristics, the first two principal components (dimensions) were used to compose equations 1 and 2:

CP1(DIM1) = 0.76FR + 0.93FL + 0.93AF + 0.90AC + 0.83BO + 0.85BA + 0.91OV + 0.99FS (1)

CP2(DIM2) = 0.62FR - 0.03FL - 0.12AF - 0.01AC - 0.41BO - 0.18BA + 0.15V + 0.03FS (2)

According to equation (1) and Figure 1A, in principal component #1, all variables influenced the formation of the groups of cultivars. According to equation (2) and Figure 1A, in principal component #2, the variables fragrance and balance stood out. Strong correlations were also observed among all variables, conforming to the acute angles formed among them. The results presented in Figure 1A confirm the results obtained (Table 2), that is, the further to the right of the principal component #1, the better were the final scores of the coffees.

The graphic (Figure 1A) shows the dispersion of the 19 cultivars (Table 2) regarding sensorial characteristics, and it can be observed that the dispersion based on the coordinates relative to the first two principal components, CP1 and CP2 (Dimensions), formed three distinct groups and that the two components accounted for 87.09% of the variation existing in the original characteristics, being CP1 (Dimension #1) with 79.29% and CP2 (Dimension #2) with 7.80%.

Three groups were formed and these results confirm the data expressed in Table 2. Group A (yellow color) was formed by the cultivars Acauã 08 (Sel. CAK), Catucaí 785/15 (Sel. CAK) and IBC Palma II, with final scores of 86.80, 86.28 and 85.66 points, respectively. Group B (green color) was formed by the cultivars Bourbon Amarelo, Catuaí V. 20/15-479, Maracatiá, Mundo Novo 379-19, Catuaí V. IAC-44 and Sabiá cv. 398, with final scores ranging from 85.32 to 84. 00, and C (blue color) with the cultivars Siriema Amarelo, Acauã cv 02, Topágio MG 1190, Catucaí Amarelo 2SL, Catuaí Amarelo IAC-62, Arara, Japi, Catuaí Vermelho IAC-81, Rubi MG 1192, and Catuaí Amarelo IAC-39, with final scores ranging from 83.20 to 81.14 (Figure 1A).

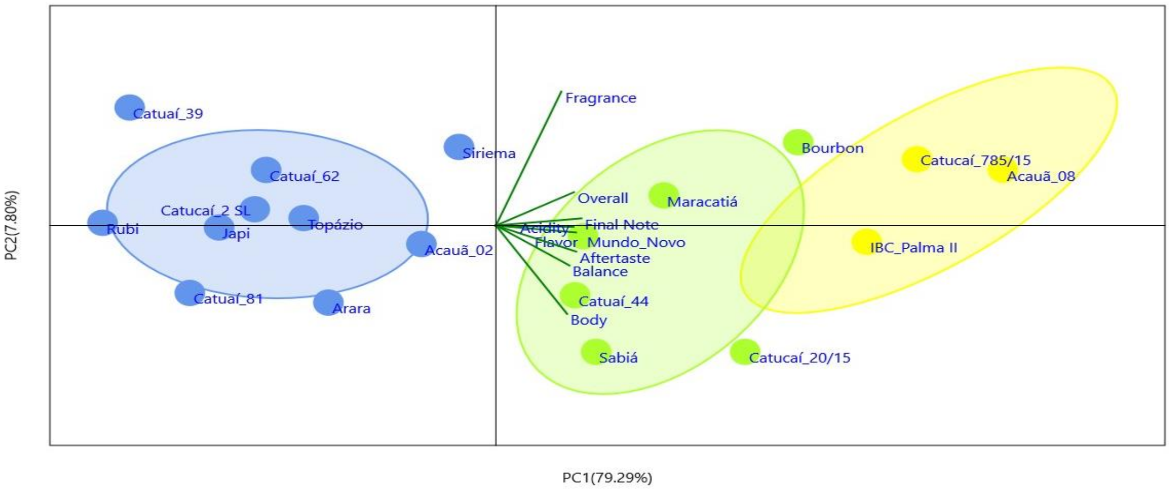
Table 2. Final score average of sensory analysis of individual arabica coffee cultivar related to fruit skin coloration, ripening cycle and rust resistance of 19 *Coffea arabica* genotypes.

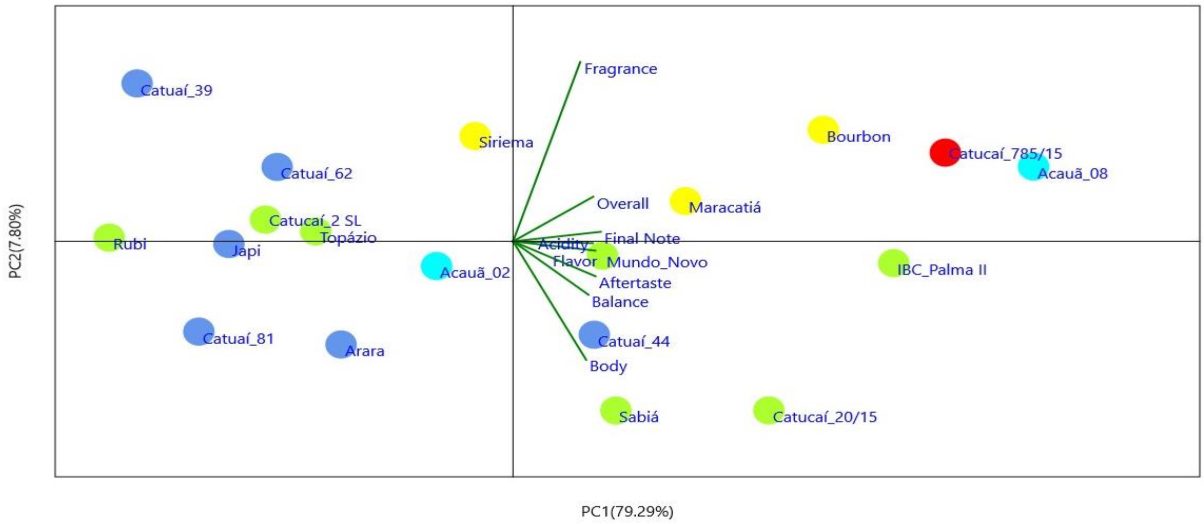
Cultivar	# order	Final score		Fruit color	Maturation cycle	Resistance to rust
Catucaí 785/15 (sel. CAK)	1	86.28	a	red	very early	moderate
Siriema Amarelo	2	83.20	c	yellow	early	moderate
Bourbon Amarelo IAC J2	3	85.32	a	yellow	early	susceptible
Maracatiá	4	84.40	b	red	early	susceptible
Catucaí Amarelo 2 SL (sel. CAK)	5	81.76	c	yellow	medium	moderate
Sabiá cv. 398	6	84.00	b	red	medium	moderate
Catucaí Vermelho 20/15 - 479	7	85.04	b	red	medium	moderate
IBC-Palma II	8	85.66	a	red	medium	moderate
Mundo Novo 379-19	9	84.06	b	red	medium	susceptible
Topázio MG 1190	10	82.54	c	yellow	medium	susceptible
Rubi MG 1192	11	81.26	c	red	medium	susceptible
Arara	12	81.64	c	yellow	late	high
Japi	13	81.50	c	red	late	moderate
Catuaí Vermelho IAC-44	14	84.00	b	red	late	susceptible
Catuaí Amarelo IAC-39	15	81.14	c	yellow	late	susceptible
Catuaí Amarelo IAC-62	16	81.76	c	yellow	late	susceptible
Catuaí Vermelho IAC-81	17	81.48	c	red	late	susceptible
Acauã cv. 02 (sel. CAK)	18	82.70	c	red	very late	high
Acauã cv. 08 (sel. CAK)	19	86.80	a	red	very late	high
AVERAGE		83.67				
CV (%)		1.50				

[1] Means followed by at least one same lower-case letter in the column do not differ by the Scott-Knott test (p<0.05).

The maturation period influenced the final beverage quality (Figure 1B), only for the following groups of cultivars: i.) the group formed by very early cultivars had better drink quality than the group of late cultivars (C3); ii.) the group formed by early cultivars had better performance than the group of late cultivars (C6); iii.) the group formed by very late cultivars was better than the group formed by late cultivars (C10) (Table 3).

Figure 1. Diagram of dispersion in relation to the first two principal components obtained from sensorial characteristics: (A) of 19 Arabica coffee cultivars; (B) regarding the time of maturation of the fruits of 19 Arabica coffee cultivars.





No difference was found between the groups formed by cultivars with red colored beans and the group of yellow-colored fruits (C11) (Table 3). Also, no difference was observed in the final beverage quality among the groups of cultivars with different levels of resistance to coffee leaf rust (C12, C13, C14) (Table 3).

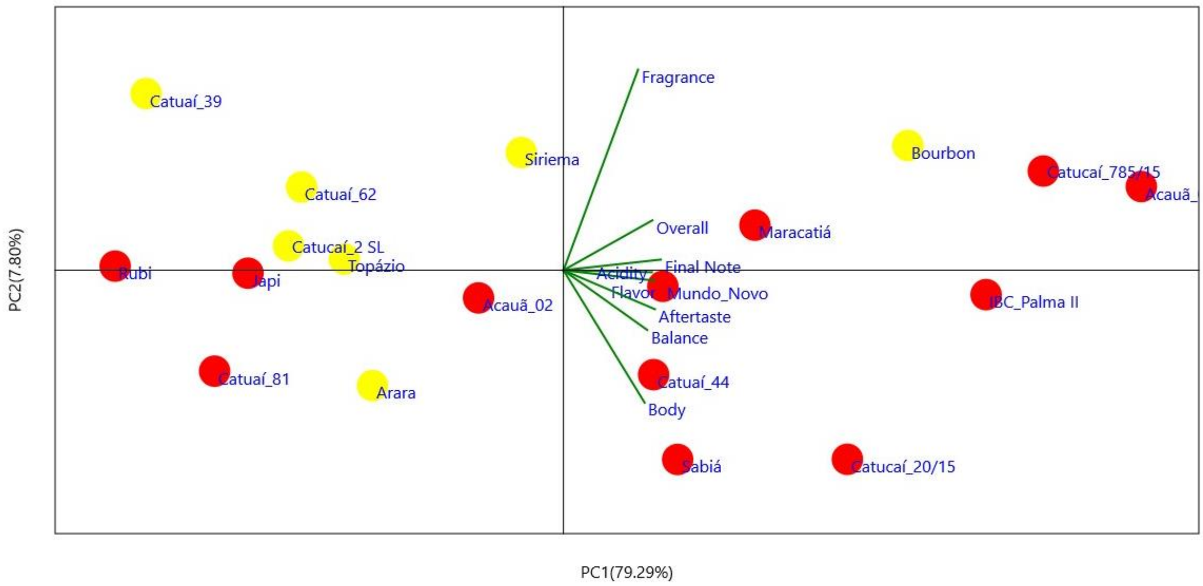
Table 3. Comparison of groups of means by contrast.

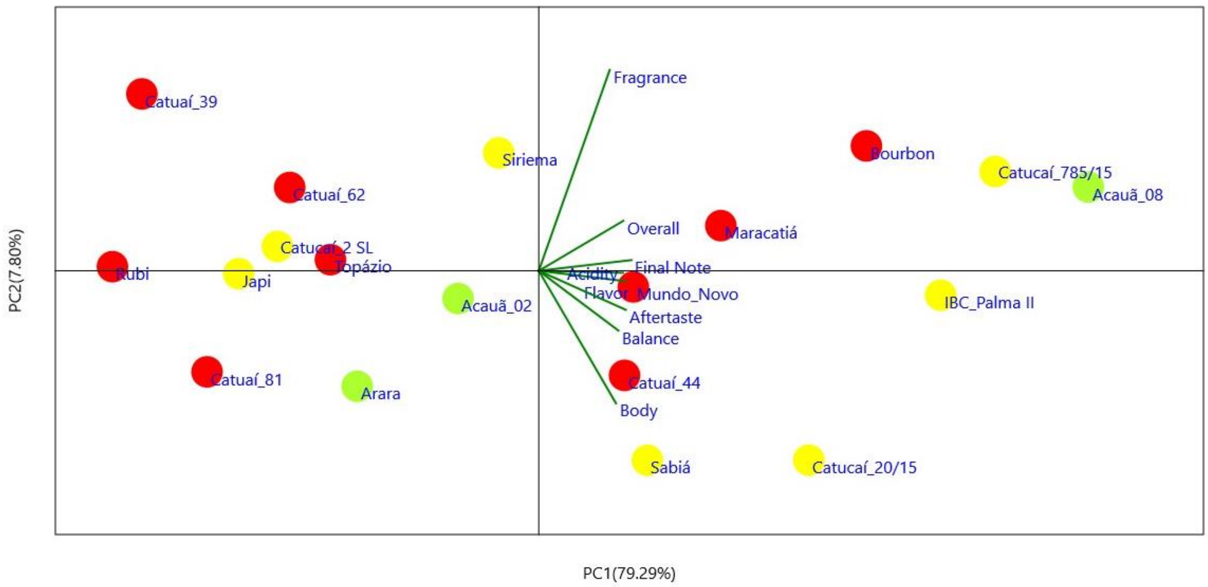
Contrasts	
$C_1 = 3\widehat{m}_1 - \widehat{m}_2 - \widehat{m}_3 - \widehat{m}_4$	5.92ns
$C_2 = 7\widehat{m}_1 - \widehat{m}_5 - \widehat{m}_6 - \widehat{m}_7 - \widehat{m}_8 - \widehat{m}_9 - \widehat{m}_{10} - \widehat{m}_{11}$	19.64ns
$C_3 = 6\widehat{m}_1 - \widehat{m}_{12} - \widehat{m}_{13} - \widehat{m}_{14} - \widehat{m}_{15} - \widehat{m}_{16} - \widehat{m}_{17}$	26.16*
$C_4 = 2\widehat{m}_1 - \widehat{m}_{18} - \widehat{m}_{19}$	3.06ns
$C_5 = 7\widehat{m}_2 + 7\widehat{m}_3 + 7\widehat{m}_4 - 3\widehat{m}_5 - 3\widehat{m}_6 - 3\widehat{m}_7 - 3\widehat{m}_8 - 3\widehat{m}_9 - 3\widehat{m}_{10} - \widehat{3m_{11}}$	17.48ns
$C_6 = 6\widehat{m}_2 + 6\widehat{m}_3 + 6\widehat{m}_4 - 3\widehat{m}_{12} - 3\widehat{m}_{13} - 3\widehat{m}_{14} - 3\widehat{m}_{15} - 3\widehat{m}_{16} - 3\widehat{m}_{17}$	42.96*
$C_7 = 2\widehat{m}_2 + 2\widehat{m}_3 + 2\widehat{m}_4 - 3\widehat{m}_{18} - 3\widehat{m}_{19}$	-2.66ns
$C_8 = 6\widehat{m}_5 + 6\widehat{m}_6 + 6\widehat{m}_7 + 6\widehat{m}_8 + 6\widehat{m}_9 + 6\widehat{m}_{10} + 6\widehat{m}_{11} - 7\widehat{m}_{12} - 7\widehat{m}_{13} - 7\widehat{m}_{14} - 7\widehat{m}_{15} - 7\widehat{m}_{16} - 7\widehat{m}_{17}$	65.28ns
$C_9 = 2\widehat{m}_5 + 2\widehat{m}_6 + 2\widehat{m}_7 + 2\widehat{m}_8 + 2\widehat{m}_9 + 2\widehat{m}_{10} + 2\widehat{m}_{11} - 7\widehat{m}_{18} - 7\widehat{m}_{19}$	-17.86ns
$C_{10} = \widehat{m}_{12} + \widehat{m}_{13} + \widehat{m}_{14} + \widehat{m}_{15} + \widehat{m}_{16} + \widehat{m}_{17} - 3\widehat{m}_{18} - 3\widehat{m}_{19}$	-16.98*
$C_{11} = 7\widehat{m}_1 + 7\widehat{m}_4 + 7\widehat{m}_6 + 7\widehat{m}_7 + 7\widehat{m}_8 + 7\widehat{m}_9 + 7\widehat{m}_{11} + 7\widehat{m}_{13} + 7\widehat{m}_{14} + 7\widehat{m}_{17} + 7\widehat{m}_{18} + 7\widehat{m}_{19} - 12\widehat{m}_2 - 12\widehat{m}_3 - 12\widehat{m}_5 - 12\widehat{m}_{10} - 12\widehat{m}_{12} - 12\widehat{m}_{15} - 12\widehat{m}_{16}$	121.94ns
$C_{12} = 7\widehat{m}_3 + 7\widehat{m}_4 + 7\widehat{m}_9 + 7\widehat{m}_{10} + 7\widehat{m}_{11} + 7\widehat{m}_{14} + 7\widehat{m}_{15} + 7\widehat{m}_{16} + 7\widehat{m}_{17} - 9\widehat{m}_1 - 9\widehat{m}_2 - 9\widehat{m}_5 - 9\widehat{m}_6 - 9\widehat{m}_7 - 9\widehat{m}_8 - 9\widehat{m}_{13}$	-65.24ns
$C_{13} = 3\widehat{m}_3 + 3\widehat{m}_4 + 3\widehat{m}_9 + 3\widehat{m}_{10} + 3\widehat{m}_{11} + 3\widehat{m}_{14} + 3\widehat{m}_{15} + 3\widehat{m}_{16} + 3\widehat{m}_{17} - 9\widehat{m}_{12} - 9\widehat{m}_{18} - 9\widehat{m}_{19}$	-22.38ns
$C_{14} = +3\widehat{m}_1 + 3\widehat{m}_2 + 3\widehat{m}_5 + 3\widehat{m}_6 + 3\widehat{m}_7 + 3\widehat{m}_8 + 3\widehat{m}_{13} - 7\widehat{m}_{12} - 7\widehat{m}_{18} - 7\widehat{m}_{19}$	4.34ns

*****Significant at $p<0.05$, [ns] not significant, by the Scheffé test.

The group formed by the coffee cultivars moderately resistant to coffee leaf rust showed better results. There was no difference in the performances regarding the final beverage quality of the groups formed by the highly rust-resistant cultivars when compared with the group of susceptible cultivars (C13) and with the group of moderately resistant cultivars (C14) (Figure 2).

Figure 2. Dispersion diagram in relation to the first two principal components, obtained from sensorial characteristics regarding: (A) fruit color (red and yellow) of 19 Arabica coffee cultivars; (B) rust resistance of 19 Arabica coffee cultivars. Color: Red - susceptible; yellow - moderately resistant and green - highly resistant.





Sensory diversity of the Arabica cultivars

The sensory results and the scatter diagram revealed significant variation among the 19 coffee genotypes, either in the scores or in the formation of groups obtained from the sensory characteristics. The results of this study suggest significant impact of the genetic factor on the sensory performance of the genotypes. This, despite the limiting factors commonly associated with Arabica coffee genetic gains, such as reproductive behavior (autogamy) and the narrow genetic base of cultivars used by breeding programs (ANTHONY et al., 2002). Sensory diversity among *C. arabica* genotypes have also been confirmed by some studies such as those conducted by Barbosa et al. (2019) and Kathurima et al. (2009).

The progenies from the Mundo Novo variety are among the most cultivated genetic materials in Brazil (COSTA, 2020). Fazuoli et al. (2000), studying the behavior of Mundo Novo progenies in different regions of São Paulo state, found that IAC 376-4 was among the best. The Mundo Novo cultivars correspond to a recombination resulting from a natural cross between the Sumatra and Bourbon Vermelho cultivars. Mundo Novo and Bourbon cultivars have been considered a reference for coffee quality around the world. Previous studies have observed a wide adaptability of these materials, obtaining good yields in almost all coffee growing regions of Brazil with an appropriate climate for the *C. arabica* species (CARVALHO et al., 2006). Besides the good productive capacity, the cultivars belonging to this variety have been selected to produce specialty coffees, due to the presence of desirable organoleptic characteristics (COSTA, 2020; RIBEIRO et al., 2020), corroborating the sensory results observed in this study. However, the cultivars of the Bourbon, Mundo Novo, and Catuaís groups were developed in genetic improvement programs by the IAC before the occurrence of coffee rust in Brazil. Due to the importance of this disease in the different Brazilian coffee growing regions, coffee growers have opted for cultivars that are resistant to rust due to the production costs associated with the use of fungicides, the difficulty of spraying in sloping areas and the availability of labor, especially in the highland region, and due to the need for environmental preservation and protection of rural workers' health.

The cultivars that stood out the most were ‘Acauã cv 08 (sel. CAK)’ with a final score of 86.80 points, ‘Catucaí 787/15 (sel. CAK)’ (86.28), and ‘IBC Palma II’ (85.66), genetic materials that are beginning to be disseminated and planted in different Brazilian regions. These cultivars have shown differentiated behavior in several Brazilian production regions. The cultivar Acauã cv 08 comes from the crossing of ‘Sarchimor 1668’ with ‘Mundo Novo’, whose cv 08 was selected after outstanding performance in vigor and productivity in cultivar competition trials (CARVALHO et al., 2012; KROHLING et al., 2018). ‘Catucaí 787/15’ originated from a natural cross between Catuaí and Icatu 785 and is characterized by rust tolerance, high productivity, and good beverage quality (MATIELLO et al., 2012). Thus, they are considered interesting genetic materials to produce specialty coffees.

In contrast, although the cultivars Bourbon Amarelo, Mundo Novo 379-19 and Catucaí Amarelo (IAC 62) are considered references in the production of quality coffees in other environments (PEREIRA et al., 2010; FIGUEIREDO et al., 2018; DOMINGHETTI et al., 2021), in this study these two cultivars presented intermediate grades when compared to the other cultivars tested. Specialty coffees, in general, differ from ordinary coffees by the absence of defects, management, and by the effect of the Genotype × Environment (G × E) interaction, which determines the intrinsic quality of the beans (BARBOSA et al., 2019). The usual definition of the G × E interaction implies the relative change in the performance of the same genotype when exposed to different environments (LEMI et al., 2018). Thus, finding cultivars that adapt to different environments and show stable and high-quality production has become a priority for breeders (DAMATTA et al., 2018). Therefore, it is necessary to evaluate how the G × E interaction affects the performance and sensory quality of beans, enabling new recommendations of cultivars based on each planting environment.

Influence of ripening cycle

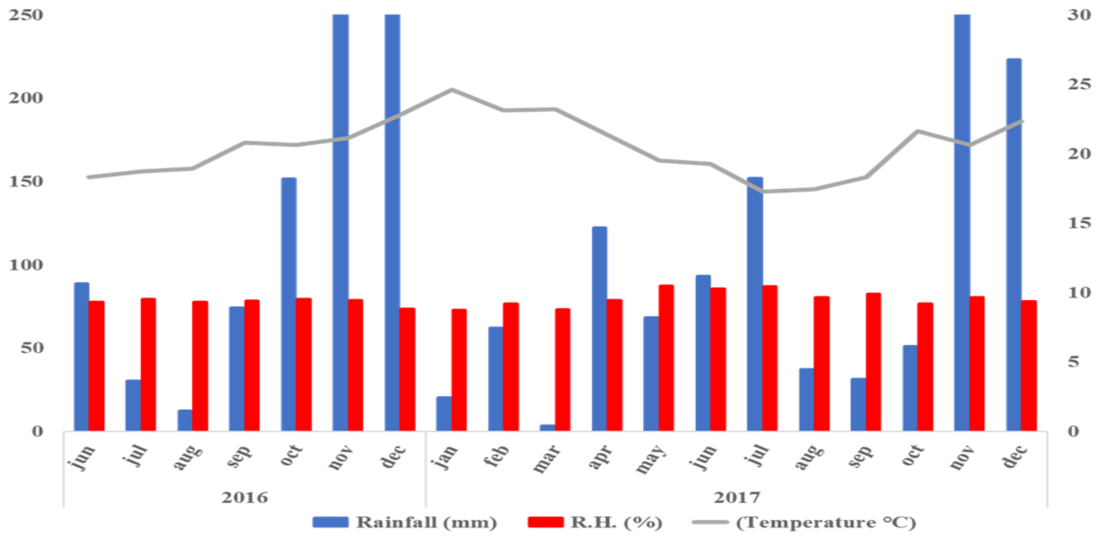
In addition to the sensory results, the evaluation of the contrasts between the averages of final scores regarding the ripening season suggests important correlations for the sensory quality of the cultivars. In this study, the contrasts revealed that on average, very early and early maturing cultivars showed higher final scores than late maturing cultivars, while very late maturing cultivars outperformed those of late maturing cultivars.

The correlation of coffee maturity cycles with beverage quality was reported by Machado et al. (2022), however, it is still poorly understood. Furthermore, while it is known that although the early maturation of the fruit is genetically controlled (CARVALHO et al., 1991), this characteristic is greatly influenced by the soil and climate conditions. Regional and interannual variations in the phenology of coffee cultivars may occur due to the differences in soil and climate conditions between growing regions (PETEK et al., 2009).

The limited sensory performance of late ripening cultivars observed in the sensory evaluation and shown in the analysis of contrasts can be partly explained by the climatic conditions present during the harvest period. The cultivars classified in this ripening cycle were harvested during the month of July 2017 (Table 1), which presented the highest average rainfall among all harvest months (from March to August) corresponding to the evaluated cultivars (Figure 1A), being higher than 150mm. In a study conducted by Kath et al. (2021) who tested and quantified the climatic impacts on coffee bean quality, they identified that the occurrence of high rainfall during harvest increased the risk (>75% probability) of above average coffee bean defects, compromising the final beverage quality. Several characteristic sub-components of coffee beans, such as insect damage, different bean sizes, and moldy beans resulting from high moisture content during the drying period were also examined and affected by a variety of rainfall predictors throughout the harvest season.

Although the higher occurrence of rainfall in the month of July is unusual for the locality of this study, as observed in the harvest conducted in 2017 (Figure 3), with this information, targeted risk management strategies such as the use of processing and drying techniques during the wet and cold harvest periods can be used to minimize the effect of weather conditions that increase the risk of defects and, in turn, improve the quality of the beans produced (SILVA et al., 2021).

Figure 3. Monthly rainfall (mm), relative humidity (%) and temperature (°C) from June 2016 to December 2017 at the experiment site, municipality of Marechal Floriano, Espírito Santo state, Brazil.



Influence of fruit color

Although there is little evidence on the sensorial superiority of coffees according to the color of the fruits, some points can be highlighted. The first of these is related to the stage of ripeness appropriate for harvesting. The full maturation of coffee fruits occurs when the fruits reach the cherry stage (BORGES et al., 2002). Although no difference was found between the groups of coffee cultivars formed by red-colored fruits and the yellow-colored group, red-colored fruits have an easier visualization of the cherry stage due to the whole extension of the fruit being pigmented in this coloration. Yellow-colored coffee fruits when they reach this same cherry stage can be confused with fruits in the verdigris maturation stage, which contribute to a decrease in the quality of the coffee beverage (PEREIRA et al., 2021b). Thus, the difficulty in identifying ripe fruits in yellow cultivars has been considered a limiting factor in the harvesting process of specialty coffees. Thus, it was found that the harvesting of the fruits in this research work was performed very adequately, at the exact point of maturation and respecting the phenology of the coffee fruits, according to their specific times of maturation for the region.

Another piece of evidence that could contribute to support sensory differences between red- and yellow-colored fruit cultivars is genetic. In a transcriptome study conducted to identify key regulatory genes of color, biosynthesis, and transcription pathways in coffee fruits, it was found that most genes involved in the anthocyanin biosynthetic pathway were significantly higher in red-fruit cultivars than in yellow-fruit cultivars (HU et al. 2022). There is evidence that higher levels of anthocyanins are related to improved flavor and aroma quality of coffees (SAHAMISHIRAZI et al., 2017; HUANG et al., 2021). In addition, it has been reported that the expression levels of genes involved in anthocyanin are generally higher in *C. arabica* than in *C. canephora*. This factor may have correlation in the composition of the contributing factors of the superior sensory quality of *C. arabica* (SAHAMISHIRAZI et al., 2017). Thus, future studies aimed at understanding the correlation of the coloration of *C. arabica* cultivars with beverage quality will be important for breeding purposes and in the production of specialty coffees.

Influence of rust resistance

Rust-resistant cultivars such as Catimor, Sarchimor and their derivatives (hybrids) have been grown worldwide on hundreds of thousands of hectares in different coffee-producing countries. These cultivars have been responsible for significant reductions in production costs (ECHEVERRIA-BEIRUTE et al., 2018; SETOTAW et al., 2020). However, some traditional representatives of the international coffee trade question these new cultivars due to the lack of flavor commonly found in traditional varieties such as Mundo Novo and Caturra (VAN DER VOSSEN, 2009). Therefore, to maintain commercial interest in resistant cultivars, breeding programs are concentrating efforts to select materials that present at least equivalent sensory quality compared to traditional cultivars (PEREIRA et al., 2021a).

In this study, no evidence was found that resistant cultivars tend to be sensorially inferior to cultivars susceptible to rust. These results suggest the need for further studies aimed at identifying materials that show superior performance in both factors, making them even more interesting for the purpose of selecting elite coffee cultivars for planting in different regions of Brazil.

4 CONCLUSIONS

A wide sensory diversity among *Coffea arabica* cultivars was pointed out, with scores ranging from 81.26 to 88.86 points;

The Arabica coffee cultivars Catucaí 785/15 (Sel. CAK), Acauã cv 08 (Sel. CAK), IBC Palma II and Bourbon Amarelo had the best sensorial performances for beverage quality;

Traditionally cultivated coffee cultivars such as Mundo Novo and cultivars from the Catuaí Vermelho group (IAC-44, 20/15-479, IAC-81) and Catuaí Amarelo (IAC-39, IAC-62) showed intermediate or lower final scores for beverage quality;

The groups composed by the very early and early maturing cultivars showed the best sensorial performances in relation to the late maturing cultivars;

The color of the fruit (red and yellow) of the two groups of cultivars had no influence on the quality of the coffee beverage;

The degree of resistance of cultivars to rust showed no influence on the sensorial quality of the coffee beverage;

Coffee cultivars of very early and early cycles, in general, seem to have been benefited to produce higher quality coffees by the more favorable climatic conditions at harvest time.

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