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Productivity and physical quality of grains from *Coffea arabica* L. in a tropical high-altitude climate in Brazil

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ABSTRACT

The coffee plant is extremely important for Brazilian agribusiness as it generates foreign exchange earnings and employment throughout the production chain. In this study, we evaluated the production and parameters related to the quality of 18 *Coffea arabica* L. cultivars grafted onto the Apoatã IAC 2258 cultivar, in seven consecutive harvests. The experiment was installed in 2014 and carried out for seven harvests, in Fazenda Recreio in the municipality of Vera Cruz, state of São Paulo, Brazil. We used a randomised block design (DBC), with three experimental replications, which were conducted in 54 plots. We analysed productivity, yield, and grain size parameters. The data were evaluated by the analysisof variance (ANOVA) and the mean values were used to conduct the Scott-Knott and Tukey test. The results showed that in all the cycles, the characteristics evaluated showed significant differences among thecultivars. The ratio between the residual mean squares of the analysis of variance was less than 7:1 for all the characteristics evaluated, which allowed us to compare the seven harvests witheach other. The cultivars IPR 100, Obatã IAC 1669–20, IPR 107 and IAC 125 RN performed the best,as determined by the parameters evaluated, and thus, we recommend these cultivars for growing coffee tropical high-altitude climate in Brazil.

Key words: Arabica coffee; cultivars; regionalisation; coffee growing.

1 INTRODUCTION

Brazil is the largest coffee producer in the world, with around 52,900 sacks (60 kg) processed in the 2021/22 harvest. Of this, approximately 64% is Arabica coffee (*Coffea arabica* L.). The state of São Paulo produces 14% of the total arabica coffee in Brazil across an area of 199,800 ha. (Companhia Nacional de Abastecimento - CONAB, 2023).

The state of São Paulo occupies an important place in the economic dynamics of coffee;two regions, Alta Mogiana and the Midwest of São Paulo, are especially important. The top10 micro-regions for producing coffee in the state include Franca, São João da Boa Vista, Marília, Ourinhos, Bragança Paulista, Jaú, Avaré, Ribeirão Preto, Orlândia, and Tupã. The amount of coffee produced in the state of São Paulo in 2021, according to the Institute of AgriculturalEconomics (Instituto de Economia Agrícola - IEA, 2023), was worth BRL 4,021.75 billion, which was equivalent to 4.049 million sacks, representing an increase of 4.11% in the value of production and a decrease of 36.36% in production compared to that recorded in 2020.

Regionalisation of genetic materials directly affects theproductivity of coffee plants, as well as, the quality of the final product. Although an increase in genetic diversity is possible and advisable, only a few varieties of coffee plants are cultivated in Brazil a very small number (Guerreiro-Filho; Fazuoli; Gonçalves, 2013; Carvalho et al., 2017; Fernandes et al. 2020). New varieties released recently have favourable characteristics, suchas high production potential, better quality traits, and greater production stability. However, the adoption of these genetic materials has been very slow, probably due to a lack of agronomic and adaptive information (Carvalho et al., 2012; Pereira et al., 2019).

Cultivars adapted to a region respond positively to environmental characteristics, which are fundamental to regional recommendations. The selection of cultivars takes into consideration the productivity potential, grain quality, and tolerance to pests and diseases (Carvalho et al., 2017; Veiga et al., 2018).

Cultivars with high productivity potential that are adapted to regional production systems and environmental conditions are necessary for sustainable coffee production. Such increase the income of coffee farmers, which encourages them to continue growing coffee (Carvalho et al., 2017).

In this study, the productivity and physical quality of 18 cultivars of *Coffea arabica* L. were evaluated, across seven consecutive harvests, in the municipality of Vera Cruz, São Paulo (Brazil). This region has a humid subtropical climate.

2 MATERIAL AND METHODS

The experiment began in 2014 with the evaluation of seven harvests (from 2015/2016 to 2021/2022), in Fazenda Recreio in the municipality of Vera Cruz, state of São Paulo. The study site was at an altitude of 645 m (22°7’ S and 49°29’ W). The soil in the experimental field was typical eutrophic latosol with a medium texture (16 –25% of clay). According to the Koeppen climate classification, the region has a Cwa climate, i.e., a tropical climate with rain in summer and drought in winter; the average temperature of the hottest month exceeds 22 °C. This region has a humid subtropical climate.

Eighteen *Coffea arabica* L. cultivars were evaluated, grafted onto the Apoatã IAC 2258 cultivar (Table 1). The experiment was conducted using a randomised block design (DBC), with three replications across 54 plots. Each experimental plot consisted of 60 plants, distributed in two rows of 30 plants, spaced 0.65 m x 3.30 m (n = 4,662 plants per hectare). The plants were managed via drip irrigation.

Table 1: Cultivars of Arabica coffee.

Cultivar	Genealogy	Main features
IAC 125 RN	Villa Sarchi x Timor Hybrid CIFC 832/2	Early maturing, high yield potential, resistant to *Hemileia vastatrix,* resistant to *M. exigua* and *M.incognita* race 1, demanding on nutrition, sensitive to drought
Tupi IAC 4093	Progeny of the Sarchimor group	Early to medium maturity, high yield potential, large grains, *Hemileia vastatrix* tolerant.
IAPAR 59	Villa Sarchi CIFC 971/10 x Timor Hybrid 832/2	Early maturing, high yield potential, resistant to *Hemileia vastatrix* and to *M. exigua*, partially resistant to *Pseudomonas syringae* pv. *garcae*, suitable for thick plantings.
IPR 98	Villa Sarchi CIFC 971/10 x Timor Hybrid CIFC 832/2	Early to medium maturity, high yield potential, resistant to *Hemileia vastatrix* and *Phoma costaricensis*, susceptible to nematodes, demanding on nutrition, sensitive to branch drought, suitable for denser plantings.
IPR 107	IAPAR 59 x Mundo Novo IAC376–4	Medium maturity, high yield potential, resistant to *Hemileia vastatrix*, suitable for denser plantings and at higher altitudes.
IAC Ouro VerdeH5010–05	Yellow Catuaí IAC H2077–2–12–70 x Mundo Novo IAC 515–20	Medium maturity, high yield potential, susceptible to *Hemileia vastatrix* and nematodes, suitable for situations similar to Catuaí IAC 81.
Topázio MG 1190	Yellow Catuaí x Mundo Novo	Medium maturity, high yield potential, susceptible to *Hemileia vastatrix* and nematodes, demanding on nutrition, sensitive to cold.
Yellow Catuaí IAC 62	Yellow Caturra IAC 476–11 xMundo Novo IAC 374–19	Medium maturity, high yield potential, susceptible to *Hemileia vastatrix* and nematodes.
IAC Ouro Verde	Yellow Catuaí IAC H2077–2–12–70 x Mundo Novo IAC 515–20.	Medium to late maturity, susceptible to *Hemileia vastatrix* and nematodes, high yield potential, sensory quality of the drink similar to Catuaí.
Red Catuaí IAC 144	Yellow Caturra IAC 476–11 xMundo Novo IAC 374–19	Medium maturity, high yield potential, susceptible to *Hemileia vastatrix* and nematodes.
IAC Ouro Amarelo	Yellow Catuaí IAC H2077–2–12–70 x Mundo Novo IAC 515–20	Medium maturity, high yield potential, susceptible to *Hemileia vastatrix* and nematodes, suitable forsituations similar to Catuaí.
IPR 102	Red Catuaí IAC 99 x Low Height Icatu	Late maturity (medium), high yield potential, resistant to *Hemileia vastatrix*, resistant to *Pseudomonas syringae* pv. *garcae* and *Phoma costaricensis* demanding on nutrition.
IPR 103	Red Catuaí IAC 99 x Low Height Icatu	Late maturity (medium), very high yield potential, partially resistant to *Hemileia vastatrix*, partially resistant *Pseudomonas syringae* pv. *garcae* and *Phoma costaricensis*, good tolerance to heat and drought and greater tolerance to soils with low fertility levels.
Obatã IAC 1669–20	(Villa Sarchi x Timor Hybrid CIFC 832/2) x red Catuaí	Late maturing, high yield potential, resistant to Hemileia vastatrix, demanding on nutrition, suitable for irrigated and densified plantations.
IPR 99	Villa Sarchi, CIFC 971/10 x Timor Hybrid CIFC 832/2 (with probable hybridisation with Red Catuaí)	Late maturing, high yield potential, resistant to Hemileia vastatrix, moderate resistance Coffee ringspot virus – CoRSV, demanding in terms of nutrition, sensitive to branch drought, suitable for thick plantations.
IPR 100	Red Catuaí IAC 81 x progeny of the cross-breeding between Red Catuaí IAC 81 x IAC 1110–8 (BA- 10)	Late maturity, very high yield potential, susceptible to Hemileia vastatrix, resistant to most populations of M. paranaensis, M. incognita and M. exigua, demanding on nutrition, good drought tolerance.

Continue.

Table 1: Continuation.

IPR 106	Selected from the Icatu IAC 925	Late maturity, average yield potential, susceptible to Hemileia vastatrix, resistant to most populations of M. paranaenses and M. incognita, partially resistant to Pseudomonas syringae pv. garcae, Coffee ringspot virus – CoRSV and Mycosphaerella coffeicola increased yield potential in warmer regions, greater tolerance to soils with low fertility levels, fruit not very attached to the plants.
Araponga, MG	Yellow Catuaí IAC 86 x Timor Hybrid UFV 446–08	Medium maturity (late), medium yield potential, resistant to Hemileia vastatrix, susceptible to nematodes.
Apoatã IAC 2258 (rootstock)	*Coffea canephora*	Resistant to *Meloidogyne exigua* and *M. incognita*

Sources: adapted from Sera et al. (2017); Fazuoli et al. (2018); Sera, Sera and Fazuoli (2017); Fazuoli et al. (2021); Sera and Sera (2013).

The initial seven harvests were analysed, with the harvest being carried out according to the maturity of the fruits of each cultivar and the following characteristics were evaluated: *Productivity*: a total 10 plants were harvested per plot, with five plants in each line. The total volume of fruit was converted into 60 kg sacks of processed coffee, considering the total number of plants per hectare and the income (after drying on a suspended terrace) of each cultivar. *Yield*: Coffee samples (2 kg) collected from the field were dried on a suspended patio. When the beans reached 11% humidity, 300 g of sub-samples of dried coco coffee were processed. The beans were weighed on a precision scale and the yield (%) was calculated. *Grain size*: The samples used to calculate the yield were passed through a set of specific sieves; the percentage of beans sieved through sieves 16 and above was determined.

Data were submitted to analysis of variance (ANOVA), and averages were submitted to the Scott Knott cluster test, aiming to compare cultivars within the same cycle and the Tukey test of averages, to compare production cycles. The characteristics were compared through joint analysis and between the cycles, when the ratios between the residual mean squares of individual analyses of variance of each cycle did not exceed 7:1, as proposed by Banzatto and Kronka (2006).

3 RESULTS

The results showed that in all cycles, the evaluated characteristics differed significantly among the cultivars, and the ratio between the residual mean squares of the analysis of variance was less than 7:1 for all the characteristics evaluated. This allowed us to compare the seven harvests with each other.

Over the seven harvests, the IPR 100 cultivar was the most productive, with an average of 64.9 sacks per hectare (Table 2).

The average productivity of Obatã IAC 1669–20, IPR 107, IAC 125 RN and IAPAR 59 cultivars ranked second (58.7, 59.9, 57.8, and 57.0 sacks ha^{-1}, respectively) (Table 2), based on the average of the seven harvests.

Ouro Verde IAC H5010–05 was the only cultivar that had average productivity lower than 50 sacks ha^{-1} (49.3 sacks ha^{-1}); however, its productivity was not significantly different from that of the cultivars Tupi IAC 4093, Topázio MG 1190, IPR 99, Yellow Catuaí IAC 62, Red Catuaí IAC 144, IAC Ouro Amarelo, and IPR 98, which showed average productivities of 52.6, 52.4, 52.0, 51.3, 54.6, 51.47, 50.1, and 51.2 sacks ha^{-1} per hectare.

Among the seven harvests, we found that the 2019/2020 harvest was the most productive (average: 84.5 sacks ha^{-1}), followed by the 2021/2022 harvest (average: 64.5 sacks ha^{-1}) (Table 2). The lowest harvest was recorded in 2018/2019 (average: 30.1 sacks ha^{-1}). Various factors can affect the productivity of coffee plants, including their biennial characteristics, plant age, and climatic conditions. In this study, the seasonality of production mainly occurred in the 2017/18, 2019/20, and 2021/22 harvests; these years also had the highest productivity, owing to the biennial characteristics of the coffee plant (Table 2).

Productivity in the first cycle (2015/16) was relatively low (48.3 sacks ha^{-1}), probably due to the incomplete physiological maturity of the plants, since this was the cultivars first commercial harvest (Table 2).

The IPR 106 cultivar had the lowest amplitude and best stability of average production associated with bienniality; it had the lowest productivity in the 2021/22 harvest (40.2 sacks ha^{-1}) and the highest in the 2019/20 harvest (70.0 sacks ha^{-1}). The average productivity for the seven harvests was 55.3 sacks ha^{-1}, which indicated that this cultivar was well-adapted to this region (Table 2).

The varieties IAC 125 RN, Tupi IAC 4093, and IPR 99 showed a high variation in the average yield with prominent biennial behaviour (Table 2). For these three cultivars, the lowest yield was recorded in the 2018/19 harvest, with 24.5, 14.5, and 17.3 sacks ha^{-1}, respectively; the highest yield was recorded in the 2019/20 harvest, with 98.2, 96.4, and 89.6 sacks ha^{-1}, respectively.

Table 2: Productivity (sacks ha^{-1}) of 18 *Coffea arabica* cultivars across seven harvests (from 2015/16 to 2021/22) in Vera Cruz, SP, Brazil.

Cultivars (C)	Productivity (sacks ha^{-1})							
	Harvests (S)							Average
	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2015/2022
IAC 125 RN	62.7 aC	28.1 eE	83.0 aB	24.5 cE	98.2 aA	38.2 bD	69.7 dC	57.8 b
Tupi IAC 4093	61.5 aC	27.6 eD	64.6 bC	14.5 dE	96.4 aA	20.2 cE	83.4 bB	52.6 d
IAPAR 59	36.8 dE	54.4 bC	69.7 bB	45.8 aD	81.1 bA	54.7 aC	56.7 eC	57.0 b
IPR 98	36.6 dC	36.0 dC	64.2 bB	30.1 cD	76.5 bA	40.5 bC	74.8 cA	51.2 d
IPR 107	47.9 bC	52.0 bC	65.9 bB	31.2 cD	81.5 bA	53.1 aC	88.0 bA	59.9 b
Ouro Verde IAC H5010 –05	53.1 bB	44.0 cB	48.0 dB	34.8 bC	75.6 bA	50.0 aB	39.6 fC	49.3 d
Topázio MG 1190	52.7 bB	44.9 cC	44.0 dC	25.0 cD	92.9 aA	49.8 aC	57.6 eB	52.4 d
Yellow Catuaí IAC 62	50.1 bC	39.8 dD	50.0 dC	25.7 cE	75.6 bA	50.7 aC	67.0 dB	51.3 d
IAC Ouro Verde	48.3 bC	48.2 cC	47.1 dC	28.7 cD	94.9 aA	59.6 aB	55.6 eB	54.6 c
Red Catuaí IAC 144	47.2 bC	36.3 dD	54.9 cB	31.0 cD	74.3 bA	55.3 aB	61.4 eB	51.5 d
IAC Ouro Amarelo	43.3 cC	50.8 bB	44.1 dC	32.0 cD	71.5 bA	52.6 aB	56.2 eB	50.1 d
IPR 102	32.1 dF	41.6 dE	66.7 bC	31.1 cF	88.9 aA	54.8 aD	75.9 cB	55.9 c
IPR 103	43.1 cC	50.9 bB	55.6 cB	37.7 bC	71.6 bA	54.6 aB	69.6 dA	54.7 c
Obatã IAC 1669–20	52.6 bC	36.6 dD	70.2 bB	21.6 dE	95.3 aA	58.1 aC	76.1 cB	58.7 b
IPR 99	52.5 bB	39.9 dC	50.2 dB	17.3 dE	89.6 aA	27.6 cD	86.9 bA	52.0 d
IPR 100	53.5 bC	45.8 cD	68.8 bB	45.4 aD	97.9 aA	43.7 bD	99.2 aA	64.9 a
IPR 106	46.4 bC	62.9 aB	55.4 cB	51.4 aC	70.0 bA	61.1 aB	40.2 fD	55.3 c
Araponga MG1	50.7 bC	53.1 bC	68.3 bB	13.2 dE	89.7 aA	35.6 bD	74.9 cB	55.1 c
Average (S)	48.3 D	44.1 E	59.5 C	30.1 F	84.5 A	47.8 D	68.5 B	
F_C	10.20**	12.27**	24.21**	18.69**	12.14**	17.96**	36.16**	13.55**
Fs				1231.88**				
Fc x S				19.54**				
CV_C (%)	8.96	10.43	6.53	13.95	6.00	9.67	6.72	9.01
CVs (%)				6.83				
$CV_{c \times S}$ (%)				8.06				

[1]Averages followed by equal lowercase letters in the column do not differ at 5% probability by the Scott-Knott test.
[2]Averages followed by equal uppercase letters in the row do not differ at 5% probability by the Tukey test.

We found considerable differences in the productive potential of the cultivars studied, as well as, the change in behaviour over the period evaluated (details in Table 2). In the 2015/16 harvest, the cultivars IAC 125 RN and Tupi IAC 4093 were the most productive (62.7 and 61.5 sacks ha^{-1}, respectively); the difference in productivity between them was not significant. The cultivars IAPAR 59, IPR 98, and IPR 102 were the least productive (36.8, 36.6, and 32.1 sacks ha^{-1}, respectively). In this harvest, the difference between the most productive and least productive cultivars was 27 sacks ha^{-1}. In the 2016/17 harvest, the IPR 106 cultivar was the most productive with an average of 62.9 sacks ha^{-1}, whereas the IAC 125 RN and IAC Tupi 4093 cultivars were the least productive with averages of 28.1 and 27.6 sacks ha^{-1}, respectively, indicating the prominent biennial behaviour of these two cultivars (Table 2).

In the 2017/18 harvest, the IAC 125 RN cultivar was the most productive (83.0 sacks ha^{-1}). The cultivars Ouro Verde IAC H5010 - 05, Topázio MG 1190, IPR 99, Yellow Catuaí IAC 62, IAC Ouro Verde, and IAC Ouro Amarelo were the least productive (48.0, 44.0, 50.2, 50.0, 47.1, and 44.1 sacks ha^{-1}, respectively) (Table 2).

In the 2018/19 harvest, the IPR 100, IPR 106, and IAPAR 59 cultivars were the most productive (45.4, 51.4, and 45.8 sacks ha^{-1}, respectively). August and September (2018) were marked by very low minimum temperatures in Vera Cruz, São Paulo - Brazil, which negatively affected the flowering of coffee plants, causing a sharpdrop in the 2018/19 harvest. Our results suggested that the yield of these three varieties showed some tolerance to regional climatic problems. The Tupi IAC 4093, Obatã IAC 1669–20, IPR 99, and Araponga MG1 cultivars were the least productive (14.5, 21.6, 17.3, and 13.2 sacks ha^{-1}, respectively). In the 2018/19 harvest, the difference between the most and least productive varieties was 30.9 sacks ha^{-1} (Table 2).

The 2019/20 harvest showed the most stable production. Only two distinct classes of variation in the yield between the cultivars were found by statistically analysing the data. On average, the most productive cultivars produced 20% more coffee than the least productive cultivars. The average yield of the 18 cultivars was 84.5 sacks ha^{-1} (Table 2). The climatic factor along with the high harvest factor of the biennial plants and the physiological maturity of the plants promoted the different cultivars to express their best productive potential.

The 2020/21 harvest also showed stable production among the cultivars. The Tupi IAC 4093 and IPR 99 cultivars showed the lowest yields of 20.2 and 27.6 sacks ha^{-1}, respectively. The IPR 106 cultivar showed the highest yield of 61.1 sacks ha^{-1}; the difference in yield among the other 11 cultivars was not significant (details in Table 2).

The 2021/22 harvest was affected by low temperatures in the winter of 2021, followed by high temperatures and scarce rainfall in early spring. Despite the bad weather, the average yield of the cultivars was 68.5 sacks ha^{-1}. The IPR 100 cultivar was the least affected and yielded 99.2 sacks ha^{-1} (Table 2).

Coffee yield (%) is the ratio between the weight of processed coffee and that of dried coconut coffee (in percentage) (Fernandes et al., 2020).

The average yield of the cultivars from the first harvest (2015/16) was the highest (54.9%), and that of the 2017/18 harvest was the lowest (42.5%) among all seven harvests evaluated (Table 3).

Among the seven harvests evaluated, the Tupi IAC 4093 cultivar had the lowest yield (42.1%), followed by the IAC 125 RN cultivar (45.3%). The IPR 106 (54.4%) and IPR 107 (53.4%) cultivars had the highest yield (Table 3).

In the first three harvests (2015/16 to 2017/18), the Tupi IAC 4093 cultivar had the lowest yield (45.8%, 39.7%, and 36.9%, respectively), and in the following two harvests (2018/19 and 2019/20), the IAC 125 RN cultivar had the lowest yield (Table 3).

Regarding the size of the coffee bean, in the average of seven harvests, the cultivars IPR 100, Obatã IAC 1669–20, IPR 99, and IPR 107 were evaluated with 83.9%, 81.2%, 83.2%, and 83.8%, respectively, being the best in terms of producing the larger grains (sieve 16 and above). The IPR 102 cultivar presented the lowest average, with 62.9% (Table 4).

These results indicated that the grain size is affected by regional conditions (climate and cultivation), although the genetic component also plays an important role.

In the 2018/19 harvest, the average number of grains sifted through sieve 16 and above decreased significantly, coinciding with a substantial decrease in productivity. However, the results (Tables 2 and 4) did not indicate a strong relationship between these two parameters since this behaviour was not observed in all the harvests.

The 2021/22 harvest had the lowest average size of the coffee grain, as determined by using sifting sieve 16 and above (65.5%), which differentiated it from other harvests. In the 2021/22 harvest, the cultivars Tupi IAC 4093, IPR 98, and IPR 102 had the lowest average grain size (41.6%, 37.6%, and 43.0%, respectively).

4 DISCUSSION

Sera et al. (2017) evaluated the yield of the IPR 100 cultivar in Paraná and obtained an average yield of 58.79 sacks ha^{-1}, which was lower than the average yield recorded in this study (64.9 sacks ha^{-1}) (Table 2). Rodrigues et al. (2014) conducted a study in Rio de Janeiro and obtained an average yield of 89.93 sacks ha^{-1} per biennium in the 2009/10 to 2011/12 harvests. These results indicate the variability in the behaviour of this cultivar according to the location of cultivation.

Studies conducted by Paiva et al. (2010) in Varginha (MG), Carvalho et al. (2012) in the coffee-growing region of Minas Gerais, and Morello et al. (2020), Alves, Coelho, and Lemos (2021) in Jaboticabal (SP) recorded lower average yields for the Obatã IAC 1669-20 cultivar than that recorded in this study (58.7 sacks ha^{-1}, Table 2). These findings indicated that this cultivar was adapted to our study region.

Fazuoli et al. (2018) found crop yields slightly higher than those recorded in this study (Table 2). In that study, the average yield of five harvests of the cultivar IAC 125 RN in Patrocínio, MG, was 66.0 sacks ha^{-1}, indicating that the cultivar might have high productive potential in favourable environments.

The average yield of IPR 107 obtained in this study (59.9 sacks ha^{-1}) was lower than that found by Sera and Sera (2013), who recorded a yield of 72.54 sacks ha^{-1} in the state of Paraná. These findings showed that although the cultivar showed satisfactory results, the environmental characteristics of Vera Cruz, SP prevented the full productive potential of this cultivar from being expressed. The ripening cycle of this cultivar, described as medium in other studies, was classified as early in our study site, probably because of climatic reasons.

Sera and Sera (2013) evaluated the IAPAR 59 cultivar in Paraná and recorded an average yield of 59.28 sacks ha^{-1}, which was similar to that found in this study (57.0 sacks ha^{-1}, Table 2). Carvalho et al. (2012) conducted a study in Minas Gerais and obtained an average of 28.8 sacks ha^{-1}. These findings indicated that this cultivar could not adapt to Minas Gerais, since its yield was considerably below expectations.

Table 3: Yield (%) of 18 coffee cultivars from 2015 to 2022 in Vera Cruz, SP., Brazil.

Cultivars (C)	Yield (%)							
	Harvests (S)							Average
	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2015/2022
IAC 125 RN	50.4 bA	44.7 cB	40.1 cC	46.8 dB	47.2 dB	46.7 dB	41.3 eC	45.3 d
Tupi IAC 4093	45.8 bA	39.7 dC	36.9 dC	45.1 dA	46.4 dA	42.4 eB	38.1 dC	42.1 e
IAPAR 59	54.8 aB	53.2 aB	42.5 bD	54.1 bB	52.3 bB	56.7 aA	45.7 cC	51.3 b
IPR 98	52.1 bA	49.7 bA	42.5 bC	51.4 cA	51.4 cA	53.3 cA	46.3 cB	49.5 c
IPR 107	56.1 aA	54.6 aB	43.1 bC	57.2 aA	53.0 bB	58.2 aA	51.8 aB	53.4 a
Ouro Verde IAC H5010 –05	57.1 aA	50.1 bB	41.4 cD	50.9 cB	49.6 cB	51.0 cB	46.2 cC	49.8 c
Topázio MG 1190	58.4 aA	47.9 bC	41.7 cD	50.7 cB	51.0 cB	52.1 cB	48.8 bC	50.1 c
Yellow Catuaí IAC 62	60.8 aA	48.6 bB	42.0 cC	51.2 cB	51.2 cB	51.4 cB	51.6 aB	51.0 b
IAC Ouro Verde	55.1 aA	50.0 bB	40.8 cC	54.0 bA	50.8 cB	52.8 cA	49.3 bB	50.4 c
Red Catuaí IAC 144	54.2 aA	49.3 bB	43.0 bC	53.9 bA	51.3 cB	54.6 bA	49.4 bB	50.8 b
IAC Ouro Amarelo	57.3 aA	48.8 bB	41.5 cD	51.6 cB	51.2 cB	50.8 cB	47.0 cC	49.7 c
IPR 102	49.2 bB	50.8 bB	41.4 cC	52.9 bA	52.8 bA	54.7 bA	47.8 cB	49.9 c
IPR 103	56.1 aA	50.5 bC	43.8 bD	51.1 cC	53.4 bB	52.5 cB	49.7 bC	51.0 b
Obatã IAC 1669–20	56.7 aA	47.9 bC	44.9 aD	54.6 bA	56.2 aA	52.4 cB	50.2 bC	51.8 b
IPR 99	55.8 aA	49.3 bC	43.5 bD	52.1 cB	55.9 aA	48.7 dC	48.8 bC	50.6 b
IPR 100	52.8 bB	49.5 bC	44.3 aD	53.2 bB	56.2 aA	50.1 cC	49.9 bC	50.8 b
IPR 106	60.7 aA	54.2 aC	46.2 aD	54.6 bC	57.5 aB	54.5 bC	53.0 aC	54.4 a
Araponga MG1	54.1 aA	48.8 bB	44.9 aC	50.2 cB	50.0 cB	50.3 cB	49.3 bB	49.7 c
Average (S)	54.9 A	49.3 C	42.5 E	52.0B	50.1B	51.8B	48.0 D	
F_C	5.30**	28.01**	9.91**	10.94**	21.27**	13.76**	13.42**	55.09**
Fs				407.58**				
Fc x S				3.84**				
CV_C (%)	5.22	2.23	2.74	2.86	2.16	3.27	3.59	3.35
CVs (%)				2.91				
$CV_{c\ x\ S}$(%)				3.39				

[1]Averages followed by equal lowercase letters in the column do not differ at 5% probability by the Scott-Knott test.
[2]Averages followed by equal uppercase letters in the row do not differ at 5% probability by the Tukey test.

Carvalho et al. (2017) evaluated 10 *Coffea arabica* cultivars in Minas Gerais and recorded lower yields for the cultivars Topázio MG 1190 (41.8 sacks ha^{-1}) and Red Catuaí IAC 144 (26.8 sacks ha^{-1}). Fazuoli et al. (2018) also obtained a lower average yield for the cultivar Red Catuaí IAC 144 under irrigated conditions in Minas Gerais (40.0 sacks ha^{-1}). Lower average yields were also obtained in a study conducted by Carvalho et al. (2012) in Minas Gerais for the cultivars Topázio MG 1190 (41.5 sacks ha-1), IPR 99 (41.4 sacks ha^{-1}), and IPR 98 (31.6 sacks ha^{-1}). This showed that these cultivars are better adapted to a humid subtropical climate.

The IPR 106, a good regional adaptation performance was observed in terms of productivity (Table 2), compared with the results obtained by Sera et al. (2020) in a study conducted in the State of Paraná; the authors reported an average productivity of 52.6 sacks ha^{-1}. Paiva et al. (2010) obtained a two-year average yield of 36.7 sacks ha^{-1} for the variety Tupi IAC 4093 in a trial conducted at Varginha, MG, from 2001/02 to 2006/07.

In the 2018/19 harvest, the IPR 100, IPR 106, and IAPAR 59 cultivars were the most productive (45.4, 51.4, and 45.8 sacks ha^{-1}, respectively). The temperatures in August and September (2018) were very low in Vera Cruz, SP, which adversely affected the flowering of the coffee trees and led to a sharp decline in the 2018/19 harvest. The varieties IPR 100, IPR 106, and IAPAR 59 had the highest yield in this harvest (Table 2) and showed some tolerance to regional climatic problems.

Fernandes et al. (2020), in a study conducted in Monte Carmelo, MG, evaluated the 2018/19 harvest and obtained a yield of 50.8% for the IAC 125 RN cultivar and 56.6% for the Topázio MG 1190 cultivar; these values were higher than those recorded in this study (46.8% and 50.7%, respectively; Table 3).

Table 4: Sieve 16 and above (%) of 18 coffee cultivars from 2016 to 2022 in Vera Cruz, SP, Brazil.

Cultivars (C)	Sieve 16–23 (%)							
	Harvests (S)							Average
	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2015/2022
IAC 125 RN	89.0 aA	89.0 aA	83.5 bB	79.3 bB	87.9 aA	80.6 aB	67.1 bC	82.4 b
Tupi IAC 4093	82.6 bA	71.9 eC	87.4 aA	64.2 dD	79.2 bB	72.2 bC	41.6 dE	71.3 e
IAPAR 59	91.5 aA	81.7 cB	78.0 cB	72.5 cC	77.4 bB	68.9 bC	51.0 cD	74.4 d
IPR 98	80.6 cA	68.8 eB	76.3 cA	58.2 eC	73.6 cB	72.7 bB	37.6 dD	66.8 g
IPR 107	93.1 aA	90.7 aA	83.2 bB	82.8 aB	86.6 aB	78.3 aC	71.9 aD	83.8 a
Ouro Verde IAC H5010–05	91.1 aA	85.8 bA	75.1 cC	71.5 cC	78.5 bB	80.0 aB	74.8 aC	79.6 c
Topázio MG 1190	85.5 bA	77.8 dB	76.5 cB	47.7 fD	61.3 eC	72.4 bB	60.5 bC	68.8 f
Yellow Catuaí IAC 62	91.5 aA	82.6 cB	80.2 cB	64.8 dD	74.6 cC	79.6 aB	73.0 aC	78.1 c
IAC Ouro Verde	90.7 aA	81.8 cB	79.1 cC	70.6 cC	74.8 cC	73.3 bC	75.1 aC	77.9 c
Red Catuaí IAC 144	92.8 aA	78.3 dC	82.7 bB	72.8 cC	83.7 aB	86.2 aB	78.7 aC	82.2 b
IAC Ouro Amarelo	84.9 bA	72.8 eB	79.5 cA	43.5 gD	61.1 eC	63.2 bC	56.6 cC	65.9 g
IPR 102	78.3 cA	77.0 dA	81.5 cA	59.5 eC	67.7 dB	33.3 cE	43.0 dD	62.9 h
IPR 103	92.0 aA	89.7 aA	84.8 bB	75.2 bC	70.8 cC	84.9 aB	71.9 aC	81.3 b
Obatã IAC 1669–20	92.1 aA	92.9 aA	89.3 aA	74.0 cC	84.7 aB	82.9 aB	73.7 aC	81.2 a
IPR 99	91.4 aA	91.7 aA	84.2 bB	77.8 bC	78.5 bC	82.4 aB	76.2 aC	83.2 a
IPR 100	91.4 aA	93.2 aA	91.6 aA	76.5 bC	81.6 bB	82.3 aB	70.4 aD	83.9 a
IPR 106	94.3 aA	86.9 bB	82.5 bB	73.4 cC	71.4 cC	88.5 aB	82.7 aB	82.8 b
Araponga MG1	92.3 aA	84.5 bB	83.7 bB	72.0 cC	65.7 dD	81.9 aB	73.8 aC	79.1 c
Average (S)	89.2 A	83.2B	82.2B	68.7 D	75.5 C	75.8 C	65.5 E	
F_C	17.75**	30.28**	4.50**	61.93**	16.38**	20.29**	23.32**	129.3.0**
Fs				231.78**				
Fc x S				10.50**				
CV_C (%)	2.16	2.85	4.43	3.39	4.58	6.33	7.55	3.66
CVs (%)				5.22				
$CV_{c\,x\,S}$ (%)				4.72				

[1]Averages followed by equal lowercase letters in the column do not differ at 5% probability by the Scott-Knott test.

[2]Averages followed by equal uppercase letters in the row do not differ at 5% probability by the Tukey test.

Paiva et al. (2010) conducted a study in Varginha, MG, and evaluated six consecutive harvests. In this study, the average yields of the cultivars Tupi IAC 4093, Obatã IAC 1669–20, and IAPAR 59 were 43.7%, 47.4%, and 50.7%, respectively, while in this study, the same cultivars had averages of 42.1%, 51.8%, and 51.3, respectively.

Morello et al. (2020) conducted a study in Jaboticabal and obtained yields of 46.25%, 51.01%, 49.06%, 46.96%, 49.60%, 45.88%, and 50.74% for the cultivars Yellow Catuaí IAC 62, IAC Ouro Verde, IAC Ouro Amarelo, Obatã IAC 1669–20, IPR 99, IPR 100, and IPR 103, respectively. These values were lower than those found in this study, except for the yield of the cultivar IAC Ouro Verde (Table 3).

In general, the relationship between dried coconut coffee to processed coffee is 2:1, that is, 50%.Values between 45% and 55% are considered adequate for this parameter, which is considered in classifying the quality of the beans and also in the profitability of the coffee plantation. However, these values can vary depending on the climatic conditions and handling methods, which can lead to shrivelled or poorly formed beans, reducing coffee yields. Genetic factors also influence this parameter (Morello et al., 2020; Matiello et al., 2010; Paiva etal., 2010). Based on these findings, all cultivars evaluated in this study showed favourable yields, over the seven harvests, except for the final yield of the Tupi IAC 4093 cultivar (42.15 sacks ha^{-1}) (Table 3). A good cultivar must present not only high productive potential, but also physical characteristic favourable to the quality of the beans, such as a high percentage of coffee beans in the larger sieves (from 16 to above), with greateruniformity in the final product (Pereira et al., 2019; Veiga et al., 2018; Ferreira et al., 2013; Ferreira et al., 2005).

Santos et al. (2018) showed that water deficiency affects plant nutrition, directly influencing fruit setting. Although the crops in this study were irrigated, the water deficiency that occurred in the spring of 2022, combined with very high temperatures, might have influenced fruit setting, especially in the Tupi IAC 4093, IPR 98, and IPR 102 cultivars (Table 4).

Rodrigues *et al*. (2014) also obtained high values for the IPR 99 and IPR 100 cultivars (87.0% and 82.66%, respectively) in a study conducted in Rio de Janeiro; their findings matched the results of this study. In a study conducted in Minas Gerais, Carvalho *et al*. (2012) obtained lower values across four harvests for the cultivars Obatã IAC 1669–20, IAPAR 59, IPR 98, IPR 99, IPR 103, and Topázio MG 1190 (average: 67.5%, 68.2%, 60.3%, 67.3%, 67.6%, and 62.6%, respectively).

Pereira et al. (2019) evaluated several cultivars in Monte Carmelo, MG, and obtained values of 75.0% and 84.5% for the Topázio MG 1190 and IAC 125 RN cultivars in the 2017/28 harvest, respectively, of grains with sieves 16 and above. Their results were similar to those found in this study for the same cultivars and the same harvest (i.e., 76.5% for the Topázio cultivar and 83.5% for the IAC 125 RN cultivar) (Table 4).

5 CONCLUSION

In this study, we presented alternative cultivars for producers and provided novel insights into the behaviour of each cultivar. The cultivars IPR 100, Obatã IAC 1669–20, IPR 107, and IAC 125 RN performed the best for the parameters evaluated and might be recommended for growing coffee in tropical high-altitude climate in Brazil.

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7 AUTHORS´ CONTRIBUTION

ANM wrote the manuscript and performed the experiment, PHNT supervised the experiment and co-work the manuscript; HSA review and approved the final version of the work; RF conducted all statistical analyses.

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