COFFEE SCIENCE
ISSN: 1984-3909

eISSN: 1984-3909
Coffee Science, e192259, 2024

Doi: https://doi.org/10.25186/.v19i.2259

Yield and beverage quality of thirty-one *Coffea canephora* clones shaded by *Hevea brasiliensis*

José Altino Machado Filho[1], Poliana Rangel Costa[1], Lúcio de Oliveira Arantes[1], Weverton Pereira Rodrigues[2], Jeane Crasque[3], Sara Dousseau-Arantes[3]

[1]Instituto Capixaba de Pesquisa Assistência Técnica e Extensão Rural, Linhares, ES, Brasil
[2]Universidade Estadual da Região Tocantins do Maranhão Centro de Ciências Agrárias, Naturais e Letras, Imperatriz, MA, Brasil
[3]Universidade Federal do Espírito Santo – Departamento de Ciências Biológicas, Vitória, ES, Brasil
Contact authors: altino@incaper.es.gov.br; drapolianarangelcosta@gmail.com; lucio.arantes@incaper.es.gov.br; brasil.weverton.rodrigues@uemasul.edu.br; jeanecrasker@gmail.com; saradousseau@gmail.com
Received in July 30, 2024 and approved in November 8, 2024

ABSTRACT

Coffea canephora is predominantly grown in monoculture in Brazil, particularly in areas with full sunlight. However, adverse climatic conditions, such as prolonged droughts and rising temperatures, are increasingly affecting the major coffee-producing regions. The objective of this study was to evaluate the influence of rubber tree shading on the productivity and cup quality of 31 clones of C. *canephora*, cultivated in the northern region of Espírito Santo state. Thirty-one *C. canephora* clones were evaluated under three shading conditions: full sunlight, morning shade, and afternoon shade. The parameters analyzed included thousand-seed weight, quantity of beneficiated green coffee beans, yield, the number of ripe fruits required to produce a 60 kg bag of green coffee beans, and sensory analysis. The results showed that coffee clones grown in afternoon shade had a reduced yield per plant but produced heavier beans and better beverage quality. Clones 02, 03, 16, 19, 31, 99, 120, and 143 stood out with the highest yields, while clones 46 and 106 exhibited the lowest. Additionally, the yield analysis revealed that the production of green grains was significantly affected by the growing conditions, with the most productive clones thriving under full sunlight. The afternoon shade may reduce yield, but it improves grain weight and beverage quality, making it a viable strategy for *C. canephora* clones. Selection should prioritize yield and quality in shaded environments.

Key words: Consortium; conilon; rubber tree.

1 INTRODUCTION

Brazil is the world's largest coffee producer and *Coffea canephora* (Conilon/Robusta) is the second most produced species (27.8%) (Companhia Nacional de Abastecimento -CONAB, 2024). Cultivation primarily occurs at low to medium altitudes (100 to 600 m) and thrives in hot climates with annual precipitation exceeding 1200 mm (Montagnon; Cubry; Leroy, 2012; Martins et al., 2019). The state of Espírito Santo accounts for 65,6% of national *C. canephora* production (CONAB, 2024). However, research indicates that environmental variances are becoming increasingly common, affecting key coffee-producing regions (Magrach; Ghazoul, 2015).

Despite the robustness and heat tolerance characteristics of *C. canephora*, productivity and quality have been threatened by prolonged periods of drought, irregular precipitation, and heat throughout the year (Venancio et al., 2020; Rodrigues et al., 2016; Vilas-Boas et al., 2023). Additionally, most coffee cultivation is carried out in full sunlight (Koutouleas et al., 2022).

Shading coffee plantations has been proposed to mitigate the effects of climate fluctuations by reducing soil and leaf temperatures, as well as air thermal amplitude (Ricci; Cocheto Júnior; Almeida 2013). Agroforestry systems improve soil quality and efficiency of its use, and support pest control through the promotion of natural enemies (Koutouleas et al., 2022). Additionally, cultivating coffee alongside fruit and/or timber trees reduces labor costs and increases profitability for producers (Jonsson et al., 2015; Koutouleas et al., 2022).

However, challenges remain, such as tree selection and density in coffee consortiums, which can reduce *C. canephora* productivity, as observed by Bezerra et al. (2024) and Alves et al. (2018). Furthermore, due to its plasticity, coffee plants exhibit anatomical, morphological, photosynthetic, and biochemical responses to radiation levels (Meylan et al., 2017). In shaded coffee, orthotropic and plagiotropic branches show etiolation (Partelli et al., 2014). Excessive shade increases leaf area in *C. canephora*, making them thinner and more susceptible to self-shading, potentially attracting diseases like rust and impairing flower formation, consequently reducing productivity (Venancio et al., 2019; Rigal et al., 2020; Koutouleas et al., 2022).

Studies demonstrate that moderate shading can maintain productivity (Partelli et al., 2014; Venancio et al., 2019). Alves et al. (2018) concluded that *C. canephora* grown under rubber tree shade produced cup quality inferior to that of plants grown in full sun, which was specific to the study location. However, cup quality seems to be genotype-related (Koutouleas et al., 2022). Nevertheless, there are gaps in understanding how *C. canephora* responds in agroforestry systems, particularly concerning cup quality (Meylan et al., 2017).

Shading requires further evaluation to ensure there is no reduction in productivity and sensory quality of the beverage. Furthermore, the literature dedicated to the effects of shade on

cup quality is limited (Koutouleas et al., 2022) and often does not consider genotype variability. Therefore, it is essential to study the response of different *C. canephora* clones to various shading levels to enhance management practices. The objective of this study was to evaluate the influence of rubber tree shading on the productivity and cup quality of 31 clones of C. *canephora*, cultivated in the northern region of Espírito Santo state.

2 MATERIAL AND METHODS

2.1 Study Area

The study was conducted at the Experimental Farm of the Capixaba Institute of Research, Technical Assistance, and Rural Extension (INCAPER), located in the municipality of Sooretama, Espírito Santo, Brazil (19°06'41.3" S, 40°04'41.2" W, and 49 m altitude). Thirty-one clones of *Coffea canephora* cv. Kouillou were grown in consortium with rubber trees (*Hevea brasiliensis*). The consortium was established in 1999, while the evaluations for the current study were carried out between 2006 and 2011.

The experimental area was rainfed, and general cultural treatments (weeding, fertilization, and liming) followed crop-specific agronomic standards (citation). Climatic conditions were gathered through the automatic weather station of the National Institute of Meteorology (INMET). Average, minimum, and maximum temperatures (°C) and monthly accumulated precipitation (mm) were the climatic variables examined during the assessment periods.

Figure 1A shows that the years with the highest rainfall were 2007 and 2008, with a total accumulated precipitation exceeding 1200 mm. Precipitation did not surpass 69 mm throughout the dry months of may through september. Except for august 2009, these were the periods with the lowest average temperatures and maximum temperatures below 30 °C (Figure 1C). Minimum temperatures stayed between 15 and 20 °C, except in june, july, and august, when they fell below 15 °C in 2006, 2007, and 2010 (Figure 1B).

The coffee clones used in the study included clones 02, 03, 07, 11, 14, 16, 19, 26, 29, 31, 36, 45, 46, 49, 99, 100, 104a, 104b, 106, 110a, 110b, 109a, 116, 120, 128, 132, 139, 201, 143, 153, and 154. These clones were cultivated in an east-west orientation in rows, with one clone per row (Figure 2). The spacing between rows was 2.5 m, and the distance between plants was 1.0 m.

Rubber tree seddlings were planted (cultivars RRIM 600 and FX 3864) in double rows perpendicular to the coffee rows in the north-south direction. The distance between double rows was 3.0 meters, while the space between plants was 2.5 meters. The rubber trees stood 7 meters tall in 2006, the first year of evaluation.

2.2 Evaluated parameters

We determined the green bean yield (kg) per plant of the 31 *C. canephora* clones from 2006 to 2010. Weight of a thousand beans were obtained from the 2011 harvest.

The harvest was conducted according to the maturation cycle of each clone (early, intermediate, and late). Floating fruits and impurities were removed, and 2 kg samples of fruits from each plant were separated, weighed, and dried in a forced-air circulation oven at 40°C until they reached a moisture content of 13%, evaluated with a Gehaka grain moisture meter (G600). The fruits were then peeled to obtain the processed beans (kg). The yield was estimated by the weight reduction observed during the drying process, calculated as the ratio between the weight of dried and peeled cherry coffee and the weight of coffee from the farm: Equation 1.

$$\text{Yield} = 100 * \frac{\text{Ripe fruit weight}}{\text{weight of the processed coffee beans}} \quad (1)$$

The quantity of ripe fruits needed to produce a 60 kg bag of green coffee beans was calculated by the following equation: Equation 2.

$$\text{Ripe fruits per 60 kg bag} = \text{Yield} * 60 \quad (2)$$

In addition, the weight of a thousand seeds (green beans) was calculated according to the Seed Analysis Rules (Brasil, 2009).

Sensory analysis was performed during the 2011 harvest, following the Coffee Quality Institute (CQI) protocol. Sweetness, bitterness, astringency, and acidity were among the traits assessed. Scores for these attributes were assigned on a scale of 6 to 10, with 0.25 intervals.

Individual scores for each primary attribute were added together, based on a total scoring table, to determine the overall score. Defects were then subtracted from thisoverall score. The quality of the coffee was then defined using the following score ranges: exceptional coffee (100 to 95 points), specialty coffee (94.75 to 80 points), very good coffee (79.75 to 75 points), and decent coffee (74.75 to 65 points).

Post-harvest activities that did not interfere with the treatments used in the study were disregarded.

2.3 Statistical analysis

A randomized block experimental design was adopted, with four replications of three plants per plot. Thirty-one *C. canephora* clones were evaluated in three different cultivation conditions determined by the shading position of the *H. brasiliensis* trees over *C. canephora* throughout the day: east side (morning shading), middle of the row (full sun) and the west side (afternoon shading). The data were subjected to analysis of variance, and means were compared by the Scott-Knott test at a 5% significance level. The data were analyzed using the statistical software ASSISTAT 7.7 beta.

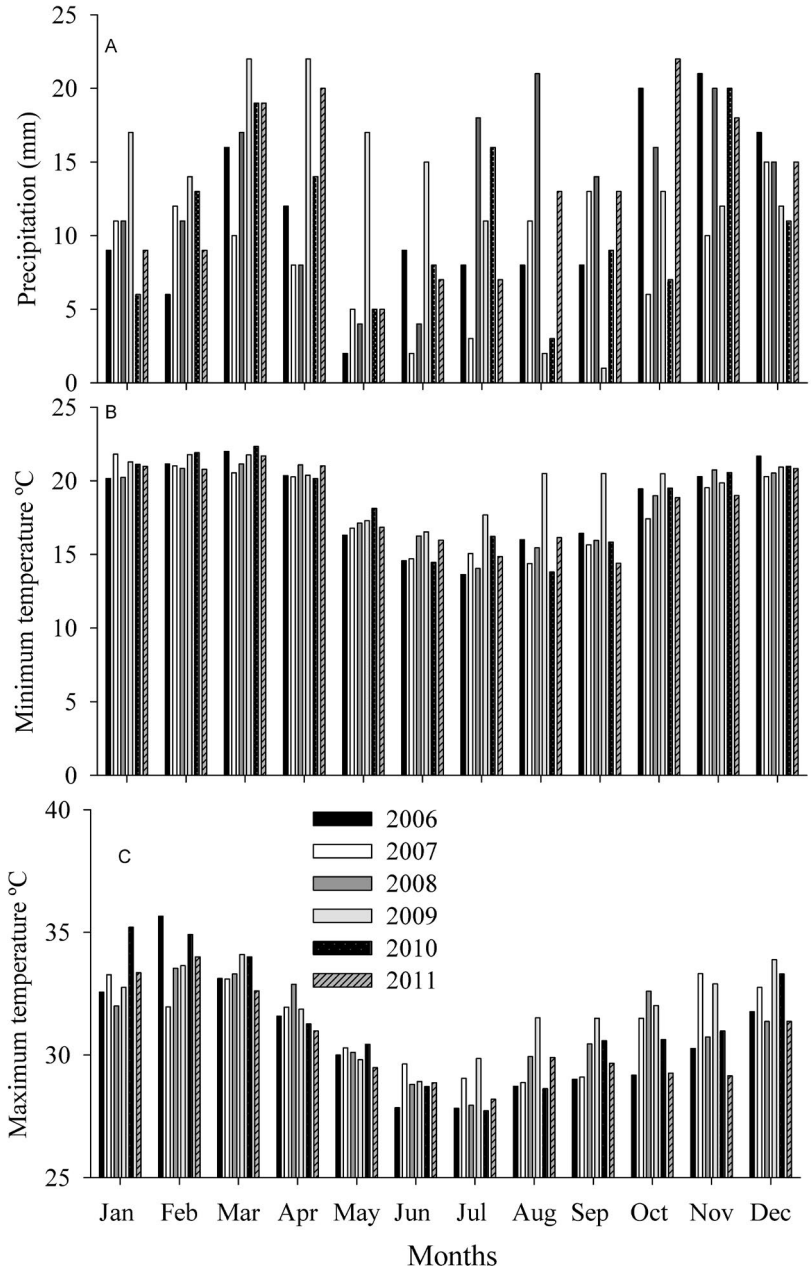

Figure 1: Accumulated precipitation (A), average minimum temperature (B), and average maximum temperature (C) in the municipality of Sooretama-ES, Brazil, from 2006 to 2011.

3 RESULTS

Coffee plants cultivated in the afternoon shade yielded fewer processed grains per plant (Table 1). Clones 02, 03, 16, 19, 31, 99, 120, and 143 exhibited the highest yield.

Clones 46 and 106 showed reduced productivity per plant in both cultivation environments. Furthermore, clones 99, 120, and 104a exhibited lower yield per plant when grown in the afternoon shade. Additionally, clones 99, 120, and 104a also exhibited lower yield per plant when grown under afternoon shade. Among the 31 evaluated clones of *C. canephora* in each environment, the highest yields per plant under full sunlight were observed in clones 02, 03, 07, 11, 14, 16, 19, 31, 46, 99, 116, 120, 143, and 104a. Regarding morning shade, the best performances were recorded for clones 02, 03, 16, 19, 26, 31, 46, 99, 100, 116, 120, 143, 154, 104a, and 109a. For afternoon shade, the most outstanding results were observed in clones 03, 14, 16, 19, 26, 31, 46, 99, 100, 116, 120, 143, 154, 104a, and 109a.

The yield analysis determines the weight of mature fruits necessary to produce 1 kg of green beans. As shown in Table 1, cultivation under afternoon shade resulted in a lower yield of green coffee beans.

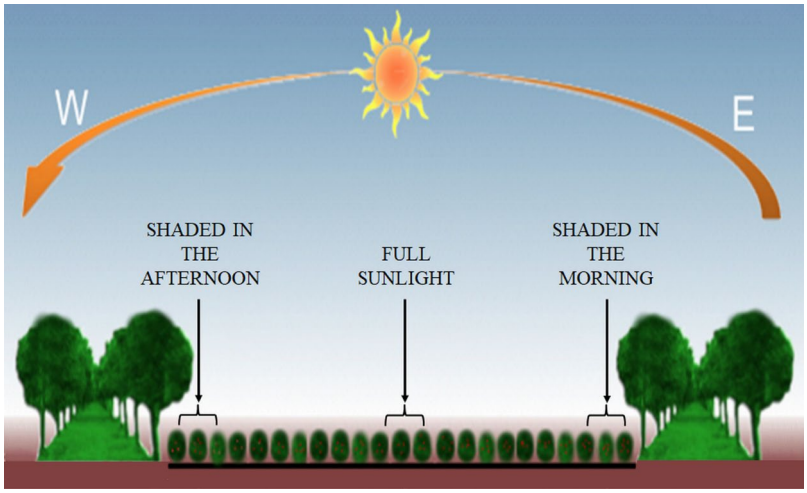

Figure 2: Representation of the consortium area with *Coffea canephora* and *Hevea brasiliensis*. Arrows indicate the plants that were examined. The plants in the center of the *H. brasiliensis* row were cultivated in full sunlight, while those to the east and west received morning and afternoon shade, respectively.

Clone 128 recorded the highest average yield, followed by clones 03, 14, 16, 19, 36, 139, 109a, and 110a, which showed no significant differences among themselves. Regardless of the growing conditions, the remaining clones had the lowest average green bean yields (Table 2).

The average amount of ripe fruits required to produce 1 kg of green beans ranged from 235.8 kg to 376.2 kg for clones 104 to 128 when cultivated in full sunlight. Clones 128 and 247 had an average of 396 kg and 247 kg, respectively, when shaded in the morning. In the afternoon shade, clone 128 averaged 310 kg, and clone 02 averaged 226.2 kg.

All clones reached their highest output under full sunlight (Table 2). The yield of clones 03, 120, 128, and 110a was lower in the afternoon shade, while clone 19 was less productive in the morning and afternoon shade conditions. When comparing the clones within the individual growing environments, we found significant differences only in the environment with full sunlight. In this setting, clones 02, 07, 11, 16, 26, 29, 31, 45, 46, 49, 99, 100, 106, 116, 120, 132, 143, 153, 154, 201, 104a, and 104b exhibited the highest productivities.

The shading conditions resulted in higher seed weight values (Table 3). Clones 02, 11, 19, 26, 46, 100, 132, and 153 produced heavier seeds, regardless of the growing conditions. Clones 36, 49, 139, 104a, and 104b had lower seed weights.

Table 3 shows that clones 36, 45, 46, 132, 201, 132, and 153 had a lower grain weight when grown in full sunlight, while clones 132 and 153 exhibited the lowest values under afternoon shading. Cultivation in full sun favored the formation of heavier seeds in clones 02, 03, 07, 11, 14, 16, 19, 31, 45, 99, 100, 106, 120, 132, 143, 153, 109a, 110a, and 110b, while clone 36 produced the lightest seeds. Clones with the highest seed weight under morning shading were 11, 14, 19, 26, 49, 100, 132, and 153, whereas clones with the highest seed weight per thousand seeds under afternoon shading were 02, 11, 19, 26, 45, and 46.

The afternoon shading environment outperformed all other sensory characteristics assessed (Table 4). The highest values of astringency and bitterness were observed under afternoon shading conditions. Clones cultivated in shaded areas scored highest in sweetness, acidity, and overall score of the beverages.

Sweeter-tasting beverages scored higher, while bitter and astringent beverages scored lower (Table 5). The overall score considered the sweetness, bitterness, astringency, and acidity evaluations. Irrespective of the growing environment, clones 19, 26, 29, 31, 45, 46, 49, and 128 achieved the highest overall scores.

The growth environment influenced the overall scores of clones 02, 07, 14, 16, 26, 106, and 104a (Table 5). When grown in full sun, the clones had no significant differences in their overall scores. Among plants grown in the morning shade, clones 02, 03, 11, 14, 19, 26, 29, 31, 45, 46, 49, 100, 106, 116, 128, 139, 143, 153, 201, 104a, 104b, 109a, and 110a showed the highest overall scores. Under afternoon shading, the standout clones were 02, 07, 16, 19, 26, 31, 45, 46, 49, 106, 120, 128, 153, 154, 201, and 104a. Based on the reported overall scores, these clones demonstrated good beverage quality, with 16, 26, 31, and 201 scoring around 80 when grown under afternoon shading.

4 DISCUSSION

In general, we observed decreased agricultural output per plant in *C. canephora* clones cultivated in the afternoon shade. Previous studies have shown that growing coffee in artificial shade or among trees reduces productivity (Moreira et al., 2018; Araújo et al., 2016; Jaramillo-Botero et al., 2010; Vaast et al., 2005). This decrease in yield in shaded environments has been

linked to effects on coffee plant physiology, such as longer internodes, fewer fruiting nodes, and reduced floral induction, all of which result in a reduction in fruit load (Rigal et al., 2020; Venâncio et al., 2019).However, only five of the 31 clones evaluated (46, 99, 106, 120, and 104a) showed decreased yield per plant when grown in at least one of the shaded environments.

Partelli et al. (2021) evaluated the productivity of 43 *C. canephora*genotypes under typical full-sun cultivation conditions and observed yields ranging from 294.01 to 439.72 liters per 60-kg bag of green coffee. Our results were similar, with clones 104 and 128 weighing 235.8 kg and 396 kg under full sun and morning shade conditions, respectively. Moreover, the lower ratio between the weight of ripe fruit and the weight of processed dry seed in clone 03 observed under afternoon shading was likely due to branch etiolation, accompanied by reduced growth of plagiotropic branches and node emission (Venancio et al., 2019).

Table 1: Processed grains (kg) per plant for the 31 clones of *C. canephora* grown in full sunlight, morning shade, and afternoon shade. The values are the average of the five harvests (2006-2010).

	Environments			
Clones	Full Sunlight	Morning shade	Afternoon shade	Average of clones
2	0.75 aA	0.79 aA	0.73 aA	0.76 a
3	0.81 aA	0.88 aA	0.83 aA	0.84 a
7	0.79 aA	0.65 aB	0.62 aB	0.68 b
11	0.72 aA	0.64 aB	0.73 aA	0.69 b
14	0.78 aA	0.71 aA	0.58 aB	0.69 b
16	0.82 aA	0.79 aA	0.77 aA	0.79 a
19	0.85 aA	0.85 aA	0.65 aA	0.78 a
26	0.60 aB	0.72 aA	0.59 aB	0.64 b
29	0.49 aB	0.42 aC	0.47 aB	0.46 c
31	0.92 aA	0.75 aA	0.74 aA	0.80 a
36	0.50 aB	0.56 aB	0.53 aB	0.53 c
45	0.50 aB	0.51 aB	0.64 aA	0.55 c
46	0.91 aA	0.68 bA	0.53 bB	0.71 b
49	0.28 aC	0.27 aC	0.28 aB	0.28 d
99	0.89 aA	0.83 aA	0.59 bB	0.77 a
100	0.62 aB	0.74 aA	0.68 aA	0.68 b
106	0.67 aB	0.40 bC	0.41 bB	0.49 c
116	0.73 aA	0.75 aA	0.59 aB	0.69 b
120	0.97 aA	0.98 aA	0.73 bA	0.90 a
128	0.59 aB	0.61 aB	0.42 aB	0.54 c
132	0.61 aB	0.54 aB	0.42 aB	0.52 c
139	0.35 aC	0.41 aC	0.46 aB	0.40 d
143	0.83 aA	0.89 aA	0.95 aA	0.89 a
153	0.69 aA	0.58 aB	0.49 aB	0.59 c
154	0.56 aB	0.73 aA	0.60 aB	0.63 b
201	0.63 aB	0.60 aB	0.60 aB	0.61 c
104a	0.71 aA	0.87 aA	0.53 bB	0.71 b
104b	0.60 aB	0.53 aB	0.60 aB	0.58 c
109a	0.65 aB	0.67 aA	0.67 aA	0.66 b
110a	0.45 aC	0.51 aB	0.49 aB	0.48 c
110b	0.53 aB	0.51 aB	0.47 aB	0.50 c
Average environments	0.67 A	0.66 A	0.59 B	

According to the Scott-Knott test, the mean values followed by the same letter, lowercase in rows and uppercase in columns, do not differ significantly ($p > 0.05$). CV = 24.65%.

Table 2: Yield (kg/kg) and average yield in liters of mature coffee per 60 kg bag of 31 *C. canephora* clones cultivated under different growing conditions (full sun, morning shade, and afternoon shade).

Environments							
Clones	Full Sunlight		Morning Shade		Afternoon Shade		
	Yield	Ripe coffee per 60-kg bag	Yield	Ripe coffee per 60-kg bag	Yield	Ripe coffee per 60-kg bag	Average of clones
02	4.77 aB	286.2	4.50 aA	270	3.77 aA	226.2	4.34 c
03	5.63 aA	337.8	5.03 aA	301.8	3.97 bA	238.2	4.88 b
07	5.07 aB	304.2	4.30 aA	258	4.87 aA	292.2	4.74 c
11	5.07 aB	304.2	4.83 aA	289.8	4.53 aA	271.8	4.81 c
14	5.77 aA	346.2	4.67 aA	280.2	4.80 aA	288.0	5.08 b
16	4.87 aB	292.2	5.67 aA	340.2	4.87 aA	292.2	5.13 b
19	5.73 aA	343.8	4.80 bA	288	4.33 bA	259.8	4.96 b
26	4.77 aB	286.2	4.43 aA	265.8	4.13 aA	247.8	4.44 c
29	3.83 aB	229.8	4.20 aA	252	3.93 aA	235.8	3.99 c
31	5.07 aB	304.2	4.30 aA	258	5.07 aA	304.2	4.81 c
36	5.47 aA	328.2	4.90 aA	294	4.73 aA	283.8	5.03 b
45	5.03 aB	301.8	4.20 aA	252	4.30 aA	258.0	4.51 c
46	4.30 aB	258.0	4.87 aA	292.2	4.90 aA	294.0	4.69 c
49	4.70 aB	282.0	4.57 aA	274.2	4.87 aA	292.2	4.71 c
99	4.87 aB	292.2	4.40 aA	264	4.30 aA	258.0	4.52 c
100	4.77 aB	286.2	4.83 aA	289.8	4.70 aA	282.0	4.77 c
106	4.83 aB	289.8	4.67aA	280.2	4.67 aA	280.2	4.72 c
116	4.87 aB	292.2	4.13 aA	247.8	4.10 aA	246.0	4.37 c
120	5.10 aB	306.0	4.87 aA	292.2	3.80 bA	228.0	4.59 c
128	6.27 aA	376.2	6.60 aA	396	5.17 bA	310.2	6.01 a
132	4.93 aB	295.8	4.70 aA	282	4.63 aA	277.8	4.76 c
139	5.43 aA	325.8	4.90 aA	294	4.57 aA	274.2	4.97 b
143	4.90 aB	294.0	4.97 aA	298.2	4.70 aA	282.0	4.86 c
153	4.33 aB	259.8	4.73 aA	283.8	4.57 aA	274.2	4.54 c
154	4.80 aB	288.0	4.97 aA	298.2	4.47 aA	268.2	4.74 c
201	4.23 aB	253.8	4.70 aA	282	4.97 aA	298.2	4.63 c
104a	3.93 aB	235.8	4.57 aA	274.2	4.57 aA	274.2	4.36 c
104b	4.00 aB	240.0	4.97 aA	298.2	4.60 aA	276.0	4.52 c
109a	5.57 aA	334.2	5.23 aA	313.8	4.53 aA	271.8	5.11 b
110a	5.50 aA	330.0	5.40 aA	324	4.20 bA	252.0	5.03 b
110b	5.27 aA	316.2	4.80 aA	288	4.27 aA	256.2	4.78 c
Average environments	4.96 A		4.80 A		4.51 B		

According to the Scott-Knott test, the means followed by the same letter, lowercase in rows and uppercase in columns, do not differ significantly ($p > 0.05$). CV = 13.78%.

Table 3: Weight of 1000 seeds from the 31 clones of *C. canephora* grown in variousshading conditions (full sun, morning shade, and afternoon shade).

Weight of 1000 seeds				
Clones	Full Sunlight	Morning Shade	Afternoon Shade	Average of clones
02	113.87 aA	113.17 aB	120.23 aA	115.76 a
03	99.37 aA	93.67 aC	94.23 aC	95.76 c
07	103.17 aA	108.60 aB	104.47 aB	105.41 b
11	113.93 aA	123.50 aA	123.30 aA	120.24 a
14	101.77 aA	119.63 aA	110.07 aB	110.49 b
16	111.90 aA	93.03 aC	104.53 aB	103.16 b
19	111.80 aA	119.57 aA	124.20 aA	118.52 a
26	113.80 aB	143.50 aA	128.77 aA	128.69 a
29	85.73 aB	101.20 aC	96.60 aC	94.51 c
31	95.07 aA	105.00 aB	89.63 aC	96.57 c
36	54.70 bC	75.10 aD	85.63 aD	71.81 d
45	92.30 bB	116.60 aB	123.07 aA	110.66 b
46	99.20 bA	124.00 aA	132.90 aA	118.70 a
49	86.50 aB	86.20 aD	72.60 aD	81.77 d
99	95.73 aA	109.57 aB	106.10 aB	103.80 b
100	105.77 aA	124.00 aA	115.17 aB	114.98 a
106	96.47 aA	92.13 aC	92.13 aC	93.58 c
116	88.23 aB	94.10 aC	91.47 aC	91.27 c
120	98.60 aA	95.97 aC	93.73 aC	96.10 c
128	90.27 aB	96.70 aC	106.67 aB	97.88 c
132	102.63 bA	128.63 aA	113.53 bB	114.93 a
139	82.03 aB	85.90 aD	91.30 aC	86.41 d
143	104.10 aA	109.43 aB	106.83 aB	106.79 b
153	108.80 bA	128.83 aA	111.37 bB	116.33 a
154	85.03 aB	91.80 aC	95.30 aC	90.71 c
201	86.13 bB	110.50 aB	100.20 aC	98.94 c
104a	78.40 aB	78.83 aD	78.83 aD	78.69 d
104b	81.60 aB	78.20 aD	79.70 aD	79.83 d
109a	101.30 aA	98.83 aC	96.80 aC	98.98 c
110a	109.20 aA	107.60 aB	112.97 aB	109.92 b
110b	105.23 aA	108.73 aB	106.33 aB	106.77 b
Average environments	96.86 B	105.24 A	103.51 A	

According to the Scott-Knott test, the means followed by the same letter, lowercase in rows and uppercase in columns, do not differ significantly at a probability of 5%. CV = 10.22%.

Although Partelli et al. (2014) did not assess coffee cultivation under full-sun conditions, their study of the proximity between *C. canephora* and *H. brasiliensis* found no negative impact on productivity. This suggests that an important factor to consider in commercial plantations is the strategic positioning of clones. Aligning coffee rows with the rubber tree rows could optimize shading benefits, with shade-tolerant clones being planted under the canopy's projection to take full advantage of the moderated microclimate provided by the shade.

Table 4: Sensory analysis of drinks from *C. canephora* clones grown in full sunlight and shade in the morning and afternoon.

	Evaluated attributes (score)				
Environments	Sweetness	Bitterness	Astringency	Acidic	Global score
Full Sunlight	7.36 b	7.35 b	7.29 b	7.38 b	73.76 b
Morning shade	7.47 a	7.41 b	7.34 b	7.44 a	74.81 a
Afternoon Shade	7.55 a	7.47 a	7.40 a	7.49 a	75.49 a
CV (%)	4.20	3.51	3.29	2.46	4.17

Means followed by the same letter do not differ significantly,as determined by the Scott-Knott test (p > 0.05).

Table 5: Overall score of sensory analysis of the 31 clones of *C. canephora*cultivated under full sun, morning shade, and afternoon shade.

	Environments			
Clones	Full Sunlight	Morning Shade	Afternoon Shade	Average of clones
02	72.33 aA	75.00 aA	72.67 bA	73.33 b
03	72.33 aA	74.67 aA	74.33 aB	73.78 b
07	73.00 aA	69.00 bB	76.33 aA	72.78 b
11	70.67 aA	74.67 aA	74.33 aB	73.22 b
14	73.67 bA	78.33 aA	72.00 bB	74.67 b
16	72.33 bA	71.67 bB	80.00 aA	74.67 b
19	76.33 aA	76.33 aA	75.67 aA	76.11 a
26	72.33 bA	74.33 bA	80.00 aA	75.56 a
29	75.33 aA	77.00 aA	73.67 aB	75.33 a
31	78.67 aA	75.00 aA	80.33 aA	78.00 a
36	73.33 aA	69.67 aB	71.67 aB	71.56 b
45	73.67 aA	76.00 aA	76.67 aA	75.44 a
46	74.00 aA	77.00 aA	79.67 aA	76.89 a
49	76.00 aA	78.00 aA	79.00 aA	77.67 a
99	72.67 aA	72.00 aB	73.67 aB	72.78 b
100	76.67 aA	74.33 aA	73.00 aB	74.67 b
106	70.67 bA	76.67 aA	76.67 aA	74.67 b
116	73.00 aA	75.00 aA	72.33 aB	73.44 b
120	72.67 aA	73.33 aB	75.67 aA	73.89 b
128	74.00 aA	76.00 aA	75.67 aA	75.22 a
132	73.67 aA	71.67 aB	73.33 aB	72.89 b
139	73.00 aA	76.00 aA	75.00 aB	74.67 b
143	77.67 aA	76.00 aA	73.67 aB	75.78 a
153	73.33 aA	76.33 aA	78.33 aA	76.00 a
154	74.67aA	72.00 aB	76.67 aA	74.44 b
201	77.00 aA	76.33 aA	81.33 aA	78.22 a
104a	71.00 bA	77.00 aA	77.00 aA	75.00 b
104b	75.67 aA	75.33 aA	72.00 aB	74.33 b
109a	72.00 aA	76.00 aA	76.67 aA	74.89 b
110a	72.33 aA	74.67 aA	71.67 aB	72.89 b
110b	72.67 aA	73.67 aB	71.33 aB	72.56 b
Average environments	73.76 B	74.81 A	75.49 A	

According to the Scott-Knott test, the mean values followed by the same letter, lowercase in rows and uppercase in columns, do not differ significantly (p> 0.05). CV = 4.17%.

The results indicated that exposure to full sun increased yield, requiring fewer ripe fruits to yield one kilogram of green beans. However, afternoon or morning shade cultivation resulted in heavier seeds, increased dry matter accumulation, and higher overall sensory scores. Research indicates that cultivating coffee in shaded environments improves grain weight and the quality of the coffee beverage more than growing it in full sun (Moreira et al., 2018; Siles; Harmand; Vaast, 2010; Somporn et al., 2012; Souza et al., 2020; Vaast et al., 2005).

Although the ideal coffee productivity requires more than 1,200 mm of annual rainfall, Venancio et al. (2020) recorded an average rainfall of around 1,000 mm in the state of Espírito Santo. In this context, identifying productive genotypes adapted to rainfed cultivation systems, such as those evaluated in the present study, becomes essential.

In addition to understanding genotypes adapted to water-restricted conditions, agroforestry systems emerge as a promising adaptation strategy in response to future climate variability and changes associated with high temperatures and low rainfall (Venâncio et al., 2019). Shading helps minimize the negative effects of excessive solar radiation and heat on coffee development, while also improving beverage quality and increasing yield (Venâncio et al., 2020; Oliosi et al., 2016).

Regarding cup quality, clones 16, 26, 31, and 201 were positively influenced by the afternoon shade environment, producing distinctive coffee notes in these conditions. Shaded coffee plantations produce microclimatic changes that correlate with improved beverage quality. Other studies have also shown that shading delays fruit ripening, promotes the development of larger seeds, and increases the levels of acidity and sucrose, which are essential elements for aroma (Muschler, 2001; Silva Neto et al., 2018). Coffee cultivated in full sunlight contains higher quantities of chlorogenic acid and trigonelline, which cause increased astringency and bitterness in the beverage (Vaast et al., 2005). Our results emphasize the importance of understanding the optimal planting conditions for producers to meet financial demands and cater to various market niches.

5 CONCLUSION

The unique characteristics of each clone must be taken into account when establishing a consortium between rubber trees and *C. canephora*, as outcomes differ in yield, bean weight, and beverage quality.

Although afternoon shading may reduce overall yield, it offers advantages in terms of bean weight and beverage quality, particularly in clones 16, 26, 31, and 201, making it a viable strategy to enhance the performance of specific *C. canephora* clones targeted at the specialty coffee market. Therefore, the selection of clones for agroforestry systems should prioritize both yield potential and the improved quality associated with shaded environments to optimize overall productivity and profitability.

6 ACKNOWLEDGMENT

The authors thank the Consórcio Brasileiro de Pesquisa e Desenvolvimento do Café (CBP&D/Café) - Chamada 001/2006 PNP&D/Café and the Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural (INCAPER) for funding and support in the development of this project.

7 AUTHOR CONTRIBUTION STATEMENT

Conceptual Idea: Machado Filho, J. A.; Methodology design: Arantes, L. De O.; Dousseau–Arantes, S.; Machado Filho, J. A.; Data collection: Costa, P. R.; Data analysis and interpretation: Costa, P. R.; Crasque, J.; Machado Filho, J. A.; Rodrigues, W. P.; and Writing and editing: Crasque, J.; Rodrigues, W. P.; Machado Filho, J. A.

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