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Solar irradiance in the emergence and the initial development of arabica coffee seedlings in the south of Goiás

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Abstract

The photosynthesis is considered the greatest physiological process of growth, being essential to the supply of raw material for the development of plants. This work was developed with the objective of evaluating shading meshes (35%, 50%, 80% light retention mesh and in full sun), in the emergence and development of Arabica coffee seedlings (Acaiá do Cerrado, Catuaí Amarelo and Mundo Novo), with three replications, totaling 36 experimental units. The plot consisted of 4 plants, totaling 144 plants. Initially, the percentage of seedling emergence and the emergence speed index (IVE) were evaluated. At 180 days, the plant height, stem diameter of the seedlings, leaf area index of the first fully expanded pair of leaves, root length and number of leaf pairs were evaluated, as well as dry and fresh root and shoot. It was concluded that the 35% shading mesh was the one that best favored the IVE of coffee seedlings. There was no significant difference between the shading grids and between the cultivars in relation to the percentage of seedling emergence and the initial development of seedlings for any of the characteristics evaluated. The production of coffee seedlings in full sun is not recommended in the southern region of the state of Goiás.

Keywords: *Coffea arabica* L.; Cultivars; Coffee Propagation; Shading Mesh; Seedling nursery.

Introduction

Coffee has great historical and economic importance for Brazil. According to Fao (2022), the country is the world's largest producer of coffee—with 3,700,231 tons produced in 2020—followed by Vietnam, Colombia, Indonesia, and Ethiopia. In this context, Arabica coffee (*Coffea arabica* L.) stands out, with 2,829,680 tons produced in the same year, being the main cultivated species, followed by the Conilon coffee (*Coffea canephora* L.), with 870,551 tons. Thus, seedling production is essential to keep Brazil ahead of world production.

Every nurseryman's main objective is to produce seedlings with morphological, physiological, and phytosanitary quality (HOFFMANN; NACHTTIGAL; FACHINELLO, 2005). Regarding coffee plants, seedlings must meet current technical and regulatory standards, highlighting characteristics such as production in registered nurseries, seedlings from three to six pairs of definitive leaves, normal development, acclimatization for at least 30 days, absence of diseases (such as cercosporiosis, rhizoctoniose, and nematodes), and a maximum of 5% of "*pião torto*" (crooked tap roots) (MESQUITA et al., 2016).

The propagation of coffee plants can occur in two distinct forms: by using seeds (sexual) or vegetative structures of plants, such as cuttings or branch fractions (asexual). The seedlings' production is perfectly feasible and viable by small, medium, or large coffee growers. When produced at the place where they will be used, acquisition, production, and transportation costs decrease (BERGO et al., 2002). Seed propagation is still widely used (ROSA et al., 2007).

Several factors can influence the development of seedlings while they are in the nursery phase, such as container size, substrate composition,

and seedling location, among others (VALLONE et al., 2010). Some growers and producers use the production technique of coffee seedlings in full sunlight to improve the adaptation of plants under field conditions and economy in the structure of the nursery (PAIVA et al., 2003); however, scientific work is still necessary to confirm and properly use this method, since the results obtained and the forms of use have, in most cases, only practical observations as a basis (TATAGIBA et al., 2010a).

Adequate development, seedlings' vigor, and a shorter time to obtain them are highly desirable characteristics, considering the establishment of the stand and the reduction of the replanting percentage (ROSA et al., 2007). Some producers use production techniques with shading; the formation of seedlings with 50% shading is the predominant one. Since it is a C_3 species— which, according to Taiz et al. (2017) is the species whose first stable product of carbon fixation is composed of three carbons— coffee is a shading environment plant, having physiological and morphological adaptations for such, also being, however, a species that adapted satisfactorily under full sunlight (PAIVA et al., 2003). The use of black screening is widely adopted in the seedlings' production of various crops (HENRIQUE et al., 2011b). Considered neutral, the black mesh does not alter the light spectrum, only reducing solar irradiance (HENRIQUE et al., 2011a).

However, the literature lacks information regarding the shading and production of coffee seedlings in full sunlight, which is often performed empirically and without the proper scientific basis. Therefore, this study aimed to evaluate the effects of shading on seedling emergence and on the initial development of seedlings of different Arabica coffee cultivars in the south of Goiás.

Material and methods

Experimental conduction site

The experiment was carried out in the city of Goiatuba, in the south of Goiás state, in the coordinates of 27°48'S latitude and 50°19'W longitude, with average altitude of 810 m. The predominant climate in the region is Aw, according to the Köppen classification, defined as tropical with two well-defined seasons throughout the year, winter and summer, and rainfall concentrated during the summer (AMARAL et al., 2016).

Containers and substrate preparation

Sowing was performed in plastic bags with dimensions of 11 × 22 cm, perforated to drain excess water, and the substrate was made based on the methodology of Paiva et al. (2003) and considered standard for the production of coffee seedlings. The following proportions were used: 70% of sifted soil, in which soil analysis was performed, and 30% of tanned and sifted corral manure, with nutrient analysis. We also added 5 kg of simple superphosphate and 0.5 kg of potassium chloride were added for every 1,000 L of soil + manure mixture. Table 1 shows the chemical analysis of the soil used in the experiment (considered clayey texture).

Table 1. Results of soil chemical analysis. Goiatuba, GO, 2021.

Soil	Sand	Silt	Clay	Ca^{2+}	Mg^{2+}	Al^{3+}	H+AL	SB	CEC	V
Unit		%		---------- $cmol_c\ dm^{-3}$ ----------						%
	53	11	36	1.6	0.8	0.0	4.0	2.5	6.5	38.9
	pH			P		S		K		MO
Unit	$CaCl_2$			---------- $mg\ dm^{-3}$ ----------						$g\ kg^{-1}$
	4.9			2.6		3.1		46.9		13.4

Table 2. Results of the chemical analysis of the sifted bovine manure. Goiatuba, GO, 2021.

Bovine Manure	Humidity	N	P_2O_5	K_2O	S	Ca
Unit			%			
	2.00	0.90	3.8	1.10	0.80	1.80
	Mg	B	Cu	Fe	Mn	Zn
Unit			%			
	0.60	0.11	0.86	13.00	2.4	0.96

Table 2 shows the result of the chemical analysis of bovine manure, in which the sample presents the macro and micronutrient contents.

The seeds were acquired from coffee growers in the region of Monte Carmelo/MG. The coffee fruits were harvested in their cherry stage and pulped under running water. Later, the seeds were left in water for four hours for degumming (mucilage removal), then rinsed and left at room temperature for drying forfour more hours.

Two seeds were placed per container with an average depth of 2 cm. After counting the germinated seedlings, the excess ones were thinned, which started approximately 90 days after sowing, remaining only one seedling per container for evaluation of its development. The phytosanitary management adopted was standardized for all blocks and treatments and the application was made at 122 and 156 days after sowing the commercial product Calpik, based on Bordeaux mixture, at a dose of 10 mL L^{-1}, aiming to protect plants against cercosporiosis, caused by the fungus *Cercospora coffeicola* Berk & Cooke, since a few lesions were observed on leaves in the lower third of some plants. Bordeaux mixture was applied due to the presence of copper and lime in its composition, since together they act against fungi in the control of diseases, including coffee plants, according to Carvalho et al. (2012).

Experimental design

A randomized block design was used in a factorial scheme of 4 × 3, with 12 treatments and three replications, with each experimental plot containing four seedlings, totaling 144.

Three Arabica coffee cultivars were evaluated: Acaiá do Cerrado, Catuaí Amarelo, and Mundo Novo with bronze sprouting; with three levels of shading, composed of meshes of 35%, 50%, 80%, and in full sunlight (Table 3).

The nurseries were arranged with spacing of 1.5 m to avoid overlap, which could interfere with development factors, such as luminosity. The nurseries were 3.41 m long, 1.21 m wide, and 1.50 m high.

The seedlings were accommodated on pallets, thus avoiding direct contact with the soil. The irrigation system by micro sprinkler was used to wet the plants twice a day—in the morning and in the late afternoon—throughout the experimental development period.

Table 3. Treatments evaluated in the experimental conduction. Goiatuba, GO, 2021.

	Treatments
1	Full sunlight *vs.* Acaiá do Cerrado
2	35% shading *vs.* Acaiá do Cerrado
3	50% shading *vs.* Acaiá do Cerrado
4	80% shading *vs.* Acaiá do Cerrado
5	Full sunlight *vs.* Catuaí Amarelo
6	35% shading *vs.* Catuaí Amarelo
7	50% shading *vs.* Catuaí Amarelo
8	80% shading *vs.* Catuaí Amarelo
9	Full sunlight *vs.* Mundo Novo
10	35% shading *vs.* Mundo Novo
11	50% shading *vs.* Mundo Novo
12	80% shading *vs.* Mundo Novo

After sowing, the containers were arranged immediately under the meshes, according to their respective level of shading.

Evaluated characteristics

The experiment was divided into two stages. First, two seeds were placed per container, totaling 384 seeds, to evaluate the seedling emergence index for 180 days. Then, the percentage of seedlings that emerged was evaluated and the results of the daily counts were submitted to the calculation of the emergence velocity index (EVI) according to Maguire (1962), following the formula:

$$EVI = \frac{P_1}{N_1} + \frac{P_2}{N_2} + \ldots + \frac{P_n}{N_n}$$

In which
P_1, P_2, P_n = number of seedlings emerged and verified on the day of counting; the first, second, and last count, respectively.
N_1, N_2, N_n = number of sowing days in the first, second, and last count, respectively.

Simultaneously with the evaluations, thinning was performed, remaining only one seedling per container, aiming to avoid losses due to competition between seedlings for resources of the environment.

In the second stage, after 180 days of sowing, the following characteristics were evaluated: seedlings' height (cm), measured from the stem basis to the apex with the aid of a measuring tape; stem diameter (mm), measured in the region of the plant's collar with the aid of a pachymeter; leaf area (cm^2), in which the width and length of the constant leaves were measured in the first pair of leaves completely expanded from the apex of the plant, and then obtained by the following formula, according to the methodology of Paiva et al. (2003):

$$LA = \{[(length \times width) \times 0{,}667] \times 2\}$$

In which
LA = leaf area.

At the end of these evaluations, the two plants were collected in the center of the plot to determine root development by root length (cm), fresh mass (g), and dry mass (g) of root and aerial part. For weighing, the roots were washed to remove substrate residues and then separated from the aerial part in the region of the collar.

Statistical analysis

The data were submitted to the Shapiro-Wilk tests for normality of the residues, Levene for homogeneity of variances, and Durbin-Watson for the independence of the residues. Then, they were submitted to the F test, with 0.05 significance, and the means were compared by the Tukey test, also with 0.05 significance, using the Software R (R CORE TEAM, 2021).

Results and discussion

There was no emergence and no development of seedlings in full sunlight; thus, we disregarded this treatment for statistical analysis purposes, and we do not recommend its use in the climatic conditions in which the study was conducted. Thus, the factorial studied became 3 × 3, with three environments (shading of 35%, shading of 50%, and shading of 80%) and three coffee cultivars (Acaiá do Cerrado, Catuaí Amarelo, and Mundo Novo), with three replications. Since there was no interaction of shading levels with cultivars, we studied the factors separately.

Based on the results obtained, we found a significant difference only for the EVI. Regarding other characteristics, we observed no significant differences between treatments, both for meshes and cultivars, indicating a uniform development of seedlings, regardless of the environment or genotype in question, as the analysis of Table 4 shows.

According to Paiva et al. (2003), some producers have opted for the formation of coffee seedlings in full sunlight, aiming mainly

Table 4. Means of the parameters evaluated on different shadings in the three cultivars evaluated. Goiatuba, GO, 2021.

Shad.	EVI	Diam.	Height	Leaf area	DMAP
35	0.074 a	3.75 a	17.48 a	257.3 a	2.52 a
50	0.039 b	3.89 a	17.67 a	265.80 a	2.85 a
80	0.018 b	2.57 a	11.02 a	194.33 a	1.43 a
Cultivar					
Acaiá	0.037 a	3.44 a	17.11 a	193.08 a	2.29 a
Catuaí	0.052 a	3.67 a	13.26 a	309.34 a	2.49 a
Mundo Novo	0.042 a	3.10 a	15.80 a	215.04 a	2.02 a
CV%	45.89	30.24	42.55	51.58	61.98
	W = 0.94; **L** = 1.78; **DW** = 2.67	**W** = 0.94; **L** = 2.23; **DW** = 2.65	**W** = 0.96; **L** = 0.56; **DW** = 2.38	**W** = 0.95; **L** = 0.94; **DW** = 2.37	**W** = 0.94; **L** = 0.63; **DW** = 2.52

Shad.	RDM	FMAP	FRM	Root length	Pairs leaves	% emerg.
35	1.07 A	9.22 A	7.73 A	20.12 A	6.28 A	44.44 A
50	1.20 A	10.52 A	9.05 A	20.52 A	6.44 A	26.39 A
80	0.43 a	6.28 A	4.92 A	15.32 A	4.67 a	23.61 a
Cultivar						
Acaiá	1.02 A	8.53 A	7.87 A	16.63 a	5.78 A	26.39 A
Catuaí	1.0 a	9.71 A	7.54 A	20.14 A	5.72 A	37.50 A
Mundo Novo	0.69 A	7.78 A	6.29 A	19.17 A	5.89 A	30.56 A
CV%	61.68	56.14	53.56	27.99	26.39	66.62
	W = 0.95; **L** = 0.32; **DW** = 2.55	**W** = 0.94; **L** = 0.61; **DW** = 2.49	**W** = 0.96; **L** = 0.40; **DW** = 2.67	**W** = 0.95; **L** = 0.37; **DW** = 2.46	**W** = 0.98; **L** = 1.88; **DW** = 2.74	**W** = 0.98; **L** = 1.47; **DW** = 2.95

Means followed by lowercase distinct letters in the column differ from each other by the Tukey test at the significance level of 0.05; *CV*: coefficient of variation; *W*, *L, and DW*: statistics of the Shapiro-Wilk tests for normality of the residues, Levene for homogeneity of variances, and Durbin-Watson for waste independence, respectively. Bold values indicate normally distributed and independent residuals and homogeneous variances at the significance level of 0.05; [1] Square root transformation. Shad. = Shading; EVI = Emergence Velocity Index; Diam = Diameter in the Height of the Seedling Rootlet (mm); Height = Plant Height (cm); Leaf area = Leaf Area of the First Pair of Fully Expanded Leaves (cm^2); DMAP = Dry Mass of Aerial Parts (g); RDM = Root Dry Mass (g); FMAP = Fresh Mass of Aerial Parts (g); FRM = Fresh Root Mass (g); Root length = Root length (cm); Pairs leaves = Number of Pairs of Leaves; % emerg. = Percentage of Emerged Seedlings.

to improve the adaptation of plants to the conditions of the field and to save the resources for constructing the nursery. However, this practice was not favorable in this study, since no seedling emerged.

The lack of seedling emergence was possibly due to the high solar incidence, which favored higher temperatures in the surrounding area and an excessive increase in temperature in the substrate and container. The climatic conditions of the region (Aw, defined as tropical, with winter drought and high temperature) result in higher temperatures compared to other regions where studies have been conducted on the production of coffee seedlings. Paiva et al. (2003) and Tatagiba et al. (2010a) also conducted studies with coffee seedling production under shading, however, under Cwa climate conditions (subtropical dry winter climate and moderate temperature), according to Köppen classification.

In this seedling production system, with full sunlight and without nursery cover, the evapotranspiration of seedlings is much higher (TOMAZ et al., 2015). Dardengo et al. (2013) observed that Conilon coffee seedlings kept in full sunlight had lower quality than those obtained under shading levels.

According to Tatagiba et al. (2010a), both the conditions of direct exposure to solar radiation on seedlings produced in full sunlight and the excess shading provided by a mesh of 88% damaged the vegetative growth of seedlings of cultivar Catuaí Vermelho IAC 81, which is in accordance with the results in the full sunlight of this study. Paiva et al. (2001) also report that the seedlings of Arabica coffee produced in full sunlight were the ones that developed the least, with the shading that best favored the seedlings being50%, followed by 90%, and 30%.

In vegetatively propagated Conilon coffee seedlings, Braun et al. (2007) observed that the plants had higher vegetative growth under 75% shading compared to the other levels (30%, 50%). On the other hand, Tatagiba et al. (2010b) observed that Conilon coffee seedlings propagated vegetatively by cuttings had the highest vegetative growth when maintained at the level of 88% shading.

The luminosity retention meshes contributed to the satisfactory development of the seedlings, which developed and emerged homogeneously. The development of the aerial part and the root system of the seedlings was regular, indicating adequate quality in their formation.

Barbizan et al. (2002) recommend prioritizing, in the nursery phase, the growth with a balance between the aerial part and the root system of coffee seedlings, since the development of the root system is essentially important for the implementation of the coffee crop.

Based on the observed results, we recommend that the most indicated screen to produce coffee seedlings, ranging between 35 and 80% shading, would be the easiest one for producers to find and the easiest to acquire, as well as the one with the lower cost. Shading meshes, such as the one with 50% light retention, are already used in the production of coffee seedlings. According to Hoffmann et al. (2005), the type of shading screen that retains 50% luminosity has been the most used one, providing 50% shading of seedlings. Moreover, according to Toldrá et al. (2003), the 50% mesh is traditionally used in the formation of coffee seedlings. Tatagiba et al. (2010a) observed the formation of seedlings of cultivar Catuaí Vermelho IAC 81 with greater vigor and growth when produced in meshes of 22% and 50% of shading.

These results are similar to those from Paiva et al. (2003), who observed that the production of seedlings of cultivar Rubi MG 1192 produced under 50% shading had a better development since they accumulated higher values for height, number of leaf pairs, and leaf area.

The 35% shading mesh was the one that best favored the EVI, possibly due to the higher rate of solar radiation index inside the nursery, increasing the temperature in the containers, which may have accelerated the germination and emergence of seedlings. Adequate temperature is essential for seed germination, as well as the availability of environmental factors, such as water and oxygen (TAIZ et al., 2017). Moreover, according to Rena and Maestri (1986), some factors, such as the presence of the endocarp in seeds and low temperatures, delay seed germination of coffee.

Conclusions

The 35% shading mesh was the one that best favored the emergence velocity of coffee seedlings.

Shading meshes and cultivars did not affect seedling emergence percentage and initial development of Arabica coffee seedlings.

We do not recommend the production of coffee seedlings in full sunlight in the south of the state of Goiás.

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