

Research Article

Effect of shading and growing season on the agronomic performance of jambu[1]

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ABSTRACT

The jambu (*Acmella oleracea*) production can be influenced by the growing season and light available for metabolic processes. This study aimed to assess the agronomic and physiological performance of two jambu varieties, under different shading levels, during the winter and summer of the Brazilian Amazon. Two random block experiments were conducted, in a 2 x 4 factorial scheme, consisting of two jambu varieties (yellow and purple flower) and four shading levels (0, 30, 50 and 70 %), with four replications. Physiological, growth and yield traits were assessed. There was no significant interaction between treatments and growing seasons (Amazon winter and summer) for growth or yield traits, nor between treatments for the physiological characteristics. The cultivation without shading screen can increase the shoot dry weight of both varieties; the yellow flower variety exhibited early-onset flowering regardless of the shading screen used; the "Amazon summer" growing season increased the jambu yield by 33 %, while the 70 % shading reduced the net photosynthetic rate, consequently not favoring the vegetative development of the jambu plants. As such, it is recommended that the yellow and purple flower jambu varieties be grown without shading screen in the Amazon summer.

KEYWORDS: *Acmella oleracea* [L.] R. K. Jansen, unconventional food plant, Amazon.

RESUMO

Sombreamento e época de cultivo
no desempenho agronômico de jambu

A produção de jambu pode ser influenciada pela época de cultivo e luminosidade disponível para processos metabólicos. Objetivou-se avaliar o desempenho agronômico e fisiológico de variedades de jambu, em diferentes níveis de sombreamento, no inverno e verão amazônicos. Foram realizados dois ensaios no delineamento de blocos ao acaso, em esquema fatorial 2 x 4, sendo duas variedades de jambu (flor amarela e roxa) e quatro níveis de sombreamento (0, 30, 50 e 70 %), com quatro repetições. Foram avaliadas características de crescimento, produção e fisiológicas. Não houve interação significativa entre os tratamentos e as épocas de cultivo (inverno e verão amazônicos) para as características de crescimento e produção. Para as fisiológicas, também não houve interação entre os tratamentos. O cultivo sem tela pode aumentar a massa seca da parte aérea em ambas as variedades; a variedade flor amarela apresentou precocidade para o início do florescimento, independentemente da tela utilizada; e a época do ano "verão amazônico" proporcionou aumento de 33 % para a produção de plantas de jambu, enquanto o nível de 70 % de sombreamento diminuiu a taxa fotossintética líquida, não favorecendo o desenvolvimento vegetativo do jambu. Assim, recomenda-se o cultivo das variedades de jambu flor roxa e amarela em ambiente sem tela no verão amazônico.

PALAVRAS-CHAVE: *Acmella oleracea* [L.] R. K. Jansen, planta alimentícia não convencional, Amazônia.

INTRODUCTION

Greenhouses are an alternative for horticulturists to modify the growing environment; however, it is important to understand the effect of these changes on plant development. Formisano et al. (2021) observed an increase in leaf area in greenhouse-grown lettuce, whereas Hirata et al. (2017) reported a decrease in fresh and dry weight in spring onion (*Allium fistulosum*) grown under 50 % shading screen, when compared to full sun.

Despite the importance of understanding the plant performance dynamics, field management is little studied for some groups, including unconventional food plants. Their adaptation to local climate and soil conditions make them economically important to food security in certain regions, but unrecognized in others, due to their competition with conventional leaf

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vegetables, low availability and limited nutritional information (Biondo et al. 2018).

Acmella oleracea [L.] R. K. Jansen, a leaf vegetable from the Asteraceae family and commonly known as jambu, is part of this group and widely used in different locations of the Amazon region (Gusmão & Gusmão 2013). It contains several bioactive compounds, including spilanthol, used commercially as an anti-inflammatory, for mouth and throat treatments and as an anesthetic (Rondanelli et al. 2020). Additionally, Grymel et al. (2022) reported that spilanthol inhibits subcutaneous muscle contraction, enabling its application in cosmetics.

This crop thrives in the year-round high temperatures and relative humidity of the Amazon, whose seasons are known locally as "Amazon winter and summer" (Andrade et al. 2017). As such, techniques may be needed to ensure a better development for leaf vegetables grown in this region, depending on their physiological requirements.

Neves et al. (2013) studied the jambu development under full sun and in a shaded environment and recorded higher fresh and dry weight (226.67 and 90 g plant^{-1}, respectively) under a 30 % shading screen. Gusmão & Gusmão (2013) reported that, despite being known for its growth under high temperatures, jambu also develops well in partially shaded environments.

Demonstrating that different seasons can affect plant development, Mendes et al. (2020) observed that the number of lettuce leaves decreased or increased depending on the cultivar and growing season (fall/winter or spring/summer). According to the authors, the environment, photoperiod and temperature influence this trait, changing the speed of biochemical reactions and photoassimilate translocation.

Thus, it is evident that growing and crop management can influence yield and performance. However further research on jambu is needed to understand its development under different levels of light and produce knowledge on phytotechnical management. As such, the present study aimed to assess the agronomic and physiological performance of two jambu varieties (yellow and purple flower) under different shading levels during the summer and winter of the Brazilian Amazon.

MATERIAL AND METHODS

The study was conducted at the experimental area of the Universidade Federal Rural da Amazônia (UFRA), in Capanema, Pará state, Brazil (01º11'45''S and 47º10'51''W). The climate in the region is classified as Am, according to the Köppen's classification, with average annual temperature and rainfall of 26 ºC and 1,750-2,500 mm, respectively. The soil in the area is classified as Latossolo Amarelo (Embrapa 2018) or Ferralsol (FAO 2015), which is highly weathered with low base and high aluminum saturation (Andrade et al. 2017).

Two experiments were carried out in two growing seasons: one from February to April 2020, popularly known as the "Amazon winter", characterized by high rainfall, and another from August to September 2020, in the so-called "Amazon summer", with low rainfall. A randomized block design was used in both experiments, with a 2 x 4 factorial scheme, consisting of two jambu varieties (yellow and purple flower) and four shading levels (0, 30, 50 and 70 %), with four replications.

Prior to the experiments, soil was collected from the site during the growing seasons at a depth of 0-20 cm, for chemical analysis in a laboratory, showing the following characteristics: pH (H_2O) = 5.6; organic matter = 28 g kg^{-1}; K^+ = 23.3 mg dm^{-3}; P = 23 mg dm^{-3}; Ca^{2+} = 2.3 cmol$_c$ dm^{-3}; Mg^{2+} = 0.58 cmol$_c$ dm^{-3}; B = 0.18 mg dm^{-3}; Cu = 0.4 mg dm^{-3}; Fe = 100 mg dm^{-3}; Mn = 4.9 mg dm^{-3}; Zn = 1.5 of mg dm^{-3}. Based on the results, fertilization was carried out in line with the recommendations of Brasil et al. (2020), using 555 g m^{-2} of single superphosphate (18 % of P_2O_5), 196 g m^{-2} of urea (45 % of N) and 200 g m^{-2} of potassium chloride (60 % of K_2O). Urea and potassium chloride were split over three periods, with applications every seven days.

The seeds used for seedling production were from the germplasm bank of the UFRA teaching garden, in Belém, Pará state. The seeds were sown in 200-cell expanded polystyrene trays filled with commercial substrate containing organic compost, burned rice husk and coconut fiber, with the following chemical characteristics: pH in $CaCl_2$ of 5.75, 65.70 mg dm^{-3} of P and 1.60 mg dm^{-3} of K. After sowing, the trays were moved to a nursery under a 30 % shading screen and irrigated daily as needed. Two seeds were planted per cell and thinning was performed at seven days after germination, leaving one seedling per cell.

Four plots measuring 1 m wide, 10 m long and 0.2 m high were constructed in the experimental area. In both experiments, the seedlings were transplanted at 31 days after sowing (DAS), when they had four pairs of true leaves. The spacing between plants and rows was 0.20 x 0.20 m, totaling 20 plants, with the five center plants considered as the study area.

In both growing seasons, the treatment differentiation occurred at 7 days after transplanting (DAT), with the installation of a shading screen measuring 1.30 x 1.0 m, ensuring that the plots were fully covered. The screen was stapled to bamboo arches, forming a low tunnel 0.8 m high from the top of the arch to the base of the plot, with two approximately 0.3-m-high side openings.

Crop treatments such as manual weeding were performed as needed, and the seedlings irrigated twice a day with a watering can, only during the dry period. For pest control, 10 mL of neem oil per liter of water and a solution of water with 2 % neutral detergent were applied every 7 and 15 days, respectively, in the early morning or late afternoon (milder temperatures), using a sprayer.

Days to flowering (DTF) were assessed during the experiments, obtained by counting the number of days from transplanting until the onset of inflorescence emergence in plants in the study area of each plot, which were monitored daily.

The point of harvest was established when 50 % of the plants in the crop were flowering. Harvesting was performed manually in both growing seasons. Next, the plants were sent to the laboratory to assess the following parameters: shoot length, measured from the base of the main stem to the beginning of the inflorescences, using a measuring tape; number of branches, determined by counting the total number of secondary branches per plant; number of leaves, by counting the total number of leaves per plant; shoot fresh weight, obtained after harvesting by weighing the plants (stems and leaves); and shoot dry weight, by weighing the plants after drying in a forced-air oven at 65 ºC, for 48 h.

Yield was estimated based on average shoot fresh weight in 1 m^2 of plot and expressed in kg m^{-2} (Ferreira et al. 2021), and performance in bunches m^{-2} based on the ratio between yield and the average weight of a commercial jambu bunch (300 g), under a conventional production system.

In the 'Amazon summer', gas exchange was assessed at 38 DAT (full vegetative development), between 9 and 11 a.m., using a portable infrared gas analyzer (IRGA - ADC BioScientific®) and measuring the net photosynthetic rate (A; µmol CO_2 m^{-2} s^{-1}), stomatal conductance (gS; mol H_2O m^{-2} s^{-1}), transpiration (E; mmol H_2O m^{-2} s^{-1}), internal CO_2 concentration (Ci; µmol CO_2 mol^{-1}) and internal to ambient CO_2 concentration ratio (Ci/Ca). The device was programmed to use ambient CO_2, and the photosynthetically active radiation (PAR) was determined using data obtained with an Accupar LP-80 ceptometer (no shading - 1,800 µmol m^{-2} s^{-1}; 30 % - 1,261 µmol m^{-2} s^{-1}; 50 % - 1,095 µmol m^{-2} s^{-1}; 70 % - 1,007 µmol m^{-2} s^{-1}). The aforementioned data were obtained on the second pair of recently matured leaves counted from the tip of the main stem (Sampaio et al. 2021).

Initially, Anova assumptions and the presence of outliers were evaluated individually for each growing season, using the RVAidemoire, car, *mclust*, *rstatix* and *psych* packages. Based on assumptions being met, individual Anova was performed in the *ExpDes.pt* package to assess the relationship between the mean squares of the two tests for homogeneity of variance.

Joint analysis was performed to compare the treatments in the different growing seasons, followed by the Scott-Knott test at 5 % of probability, in the *easyanova* package (Arnhold 2013). It should be noted that the growing seasons were not compared in physiological analyses because this was only done in the Amazon summer. All analyses were performed in the R software, version 4.1.0.

RESULTS AND DISCUSSION

The average temperature and total rainfall in the first growing season, in the Amazon winter (Figure 1A), were 26.32 ºC and 670 mm, respectively (rainfall of 12.81 mm day^{-1}), and 28.13 ºC and 144 mm (3.13 mm da^{-1}) (Figure 1B) during the Amazon summer.

The sources of variation analysis showed no significant interaction between the treatments and growing seasons for the growth traits studied, and, as such, the factors were analyzed separately (Table 1).

For the different varieties (yellow and purple flower) and shading levels (0, 30, 50 and 70 %), a significant effect was observed (Table 2) for days to

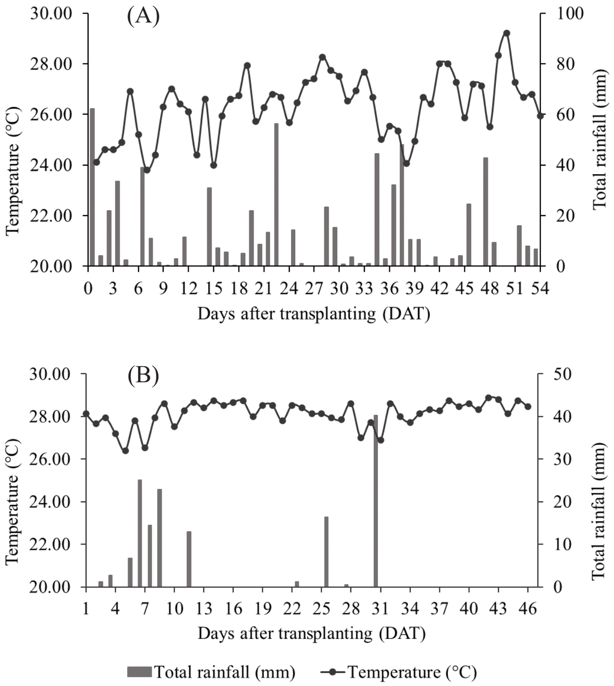

Figure 1. Average daily temperature and total daily rainfall in the Amazon winter (A) and summer (B) as a function of days after transplanting. Source: Brasil (2020).

flowering, number of leaves and shoot dry weight, whereas shoot length, number of branches, shoot fresh weight, yield and performance showed no significant difference between treatments.

For days to flowering, the reproductive stage of the yellow flower variety began at 28 DAT (Table 2). Depending on the commercial goal of producers, this result may influence their decision (commercialization of the plant or flower). In this respect, if this leaf vegetable is grown for seed production, it may signal early seed maturation, allowing the plant to reach early physiological maturity. Additionally, Dias et al. (2012) extracted spilanthol from jambu flowers, leaves and stems and concluded that the flowers are rich in this substance, enabling a greater anti-inflammatory activity and validating them for pharmaceutical/medicinal purposes.

For both varieties, plants grown under a 70 % shading screen displayed fewer leaves (Table 2), while the shoot dry weight (Table 2) differed in the treatment without shading for both the yellow and purple flower varieties, with average values of 12.8 and 12.5 g, respectively. This is because, in jambu plants, shading can influence the net photosynthetic rate (Figure 3D) and, consequently, the photoassimilate production, which are important for energy production and plant development.

With respect to the growing seasons (Figure 2), there was a significant delay in flowering in the Amazon summer (Figure 2A), with average of 32 days. This may be related to the effect of the climate conditions on the plants during the wet season, whereby the large number of cloudy days may have reduced the amount of solar radiation in the different environments, prolonging the vegetative stage.

As such, the precocity observed in the Amazon summer demonstrates that this growing season is the best suited to inflorescence production, since the flowers are the main component of spirits such as cachaça and liqueurs (Sampaio et al. 2022), due to their higher spilanthol content, when compared to the other plant parts (leaves and stem) (Monroe et al. 2016).

Superior results were also obtained in this season for shoot length (Figure 2B) and number of branches (Figure 2C), with average values of 36 cm and 13 branches plant^{-1}, respectively, possibly

Table 1. Summary of joint analysis for the agronomic data on the treatments (variety x shading levels) and growing seasons (Amazon winter and summer) and interaction between treatments and growing seasons.

Source of variation	DF	Mean square							
		DTF	SL (cm)	NB	NL	SFW (g)	SDW (g)	Yield (kg m^{-2})	Performance (bunch m^{-2})
Blocks	6	32.64*	61.83^{ns}	8.62^{ns}	621.20^{ns}	3,112.98**	30.28*	1.69**	19.23**
Treatments (T)	7	18.72*	40.27^{ns}	7.95^{ns}	942.70*	1,143.79^{ns}	37.45**	0.61^{ns}	6.79^{ns}
Growing seasons (GS)	1	375.79*	163.40*	110.48**	23,712.24**	36,616.30**	392.69**	23.70**	265.02**
T x GS	7	4.84^{ns}	60.63^{ns}	3.69^{ns}	290.49^{ns}	487.55^{ns}	11.84^{ns}	0.37^{ns}	3.85^{ns}
Coefficient of variation (%)		7.60	15.92	17.85	21.44	26.44	31.13	25.89	26.73

*, ** and ^{ns}: significant at 5 and 1 % and not significant, respectively, according to the F test. DF: degrees of freedom; DTF: days to flowering; SL: shoot length; NB: number of branches; NL: number of leaves; SFW: shoot fresh weight; SDW: shoot dry weight.

Table 2. Average values for days to flowering (DTF), shoot length (SL), number of branches (NB), number of leaves (NL), shoot fresh weight (SFW), shoot dry weight (SDW), yield and performance for the two jambu varieties [yellow (YF) and purple (PF) flower] under different shading levels (0, 30, 50 and 70 %).

Treatment	DTF	SL (cm)	NB	NL	SFW (g)	SDW (g)	Yield (kg m^{-2})	Performance (bunch m^{-2})
YF + no screen	29.3 b*	31.3	12.0	106.6 a	118.1	12.8 a	2.9	9.7
YF + 30 % shading screen	27.7 b	34.3	10.5	77.0 b	84.3	7.7 b	2.2	7.3
YF + 50 % shading screen	29.0 b	32.6	12.8	98.0 a	95.7	8.5 b	2.3	7.8
YF + 70 % shading screen	28.5 b	35.7	11.8	86.0 b	90.9	7.6 b	2.3	7.3
PF + no screen	32.1 a	34.9	13.9	104.6 a	103.1	12.5 a	2.5	8.4
PF + 30 % shading screen	31.1 a	34.5	11.9	91.9 a	88.0	8.1 b	2.2	7.4
PF + 50 % shading screen	31.3 a	38.5	13.0	96.6 a	82.7	8.3 b	2.1	7.0
PF + 70 % shading screen	30.6 a	36.6	12.0	80.2 b	85.9	7.9 b	2.1	7.1
Standard error	0.7	1.2	0.5	4.1	4.5	0.5	0.1	0.4
Overall mean	29.93	35.10	12.22	92.6	93.6	9.2	2.3	7.8

* Means followed by the same letter do not differ according to the Scott-Knott test.

because of the lower rainfall in the summer (144 mm), in relation to the Amazon winter (670 mm). Similar findings were reported by Gaia et al. (2020), who studied the effect of different irrigation depths (9.61, 35.69, 172.68, 508.18 and 748.50 mm) on jambu growth and production and observed the greatest response for shoot length under 172 mm of water. The functional balance between plant water absorption and shoot photosynthesis, whereby the shoot continues to grow until root water absorption begins, is a limiting factor (Taiz et al. 2017).

A significantly superior performance was also observed for number of leaves (Figure 2D) in the summer season, with average of 112 leaves, which contributed to shoot fresh (Figure 2E) and dry weight, with average of 11.65 g plant^{-1} (Figure 2F). By contrast, Silva et al. (2020) studied jambu plants under different growing seasons and systems and recorded the highest average number of leaves (215 leaves) for plants grown in soil during the rainy season.

The higher number of leaves reflected on yield (Figure 2G) and bunches performance (Figure 2H), which obtained significant results in the Amazon summer, at 2.93 kg m^{-2} and 9.78 bunches m^{-2}, respectively. Sampaio et al. (2018) reported an average yield of 4 kg m^{-2} and a lack of standardization regarding bunch size (the main way for jambu commercialization); however, the average weight of bunches sold at markets and fresh produce stalls varies from 140 to 180 g.

The analysis of the growing seasons indicated better results for shoot length, number of leaves, number of branches, shoot fresh weight, shoot dry weight, yield and performance in the Amazon summer (Figure 2). Additionally, there was no significant difference for the interaction between variety and shading level for stomatal conductance (gS), net photosynthetic rate (A), internal CO_2 concentration (C_i) and internal to ambient CO_2 concentration (Ci/Ca) (Table 3).

Thus, given the results described in Figure 2 and Table 3, only the Amazon summer growing season and the shading level factor were considered to evaluate the gas exchange parameters transpiration

Table 3. Summary of Anova for the physiological data on the factors variety and shading level during the Amazon summer.

Source of variation	DF	Mean square				Ci/Ca
		E	gS	A	Ci	
Blocks	3	0.31^{ns}	0.07**	122.54*	878.33^{ns}	0.00^{ns}
Variety (V)	1	0.13^{ns}	0.01^{ns}	1.15^{ns}	1,433.90**	0.01^{ns}
Shading level (SL)	3	3.11**	0.02^{ns}	124.46*	1,847.37*	0.00*
V x SL	3	0.60**	0.01^{ns}	7.68^{ns}	232.33^{ns}	0.00^{ns}
Coefficient of variation (%)		6.72	15.92	13.30	10.47	10.47

*, ** and ^{ns}: significant at 5 and 1% and not significant, respectively, by the F test. DF: degrees of freedom; E: transpiration; gS: stomatal conductance; A: net photosynthetic rate; Ci: internal CO_2 concentration; Ci/Ca: internal to ambient CO_2 concentration.

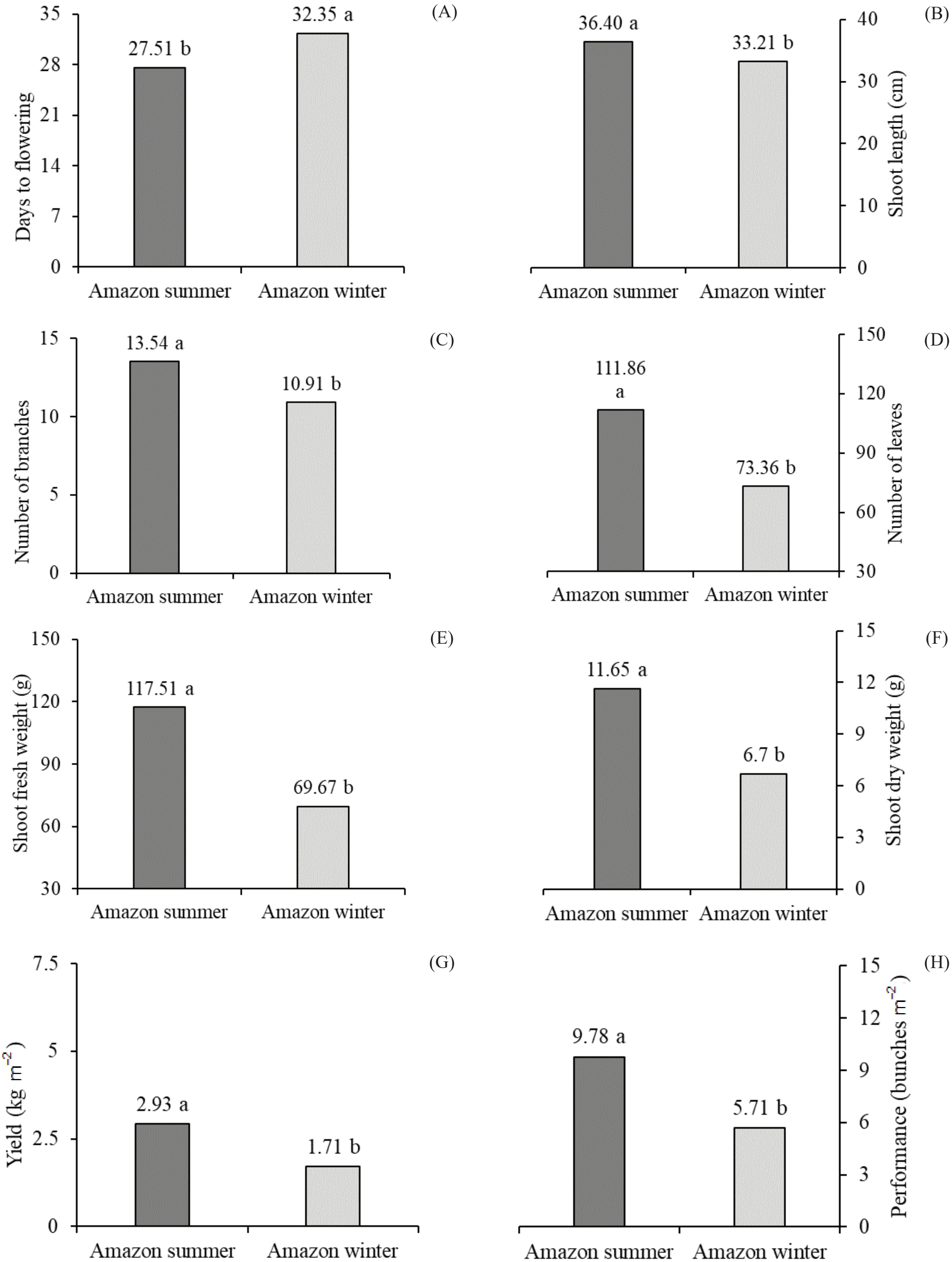

Figure 2. Comparative average values for the variables days to flowering (A), shoot length (B), number of branches (C), number of leaves (D), shoot fresh weight (E), shoot dry weight (F), yield (G) and performance (H) for the yellow and purple flower jambu varieties grown in the Amazon winter and summer.

(E), stomatal conductance (gS), net photosynthetic rate (A) and internal CO_2 concentration (C_i) in the purple and yellow flower jambu (Figure 3).

There was a significant difference between the treatments for C_i, with the 70 % shading screen producing the highest average value (221.10 µmol CO_2 mol^{-1}) and the largest Ci/Ca ratio (0.55) (Table 3). By contrast, Guerra et al. (2017) reported that the lower the Ci/Ca ratio, the more efficient the carbon fixation reactions.

Thus, despite the high C_i, a poor carbon fixation efficiency is directly related to the low net photosynthetic rate in the 70 % shading screen treatment (Figure 3D). Taiz et al. (2017) found that higher Ci levels in more shaded environments limit the net photosynthesis because of the reduced capacity of light reactions to generate nicotinamide adenine dinucleotide phosphate (NADPH) and adenosine triphosphate (ATP), which could restrict the crop yield.

No screen and the 30 % shading screen produced the highest average E values (Figure 3B) of 7.70 and 7.90 mmol of H_2O m^{-2} s^{-1}, respectively, with no shading also resulting in the maximum gS (0.65 mol H_2O m^{-2} s^{-1}) (Figure 3C).

These results may be due to the high solar radiation, temperature (average of 28.13 ºC) and average rainfall of 144 mm (3.13 mm day^{-1}) during the Amazon summer (Figure 1B). According to Taiz et al. (2017), heat stress increases the gS and, consequently, transpiration (E) that the plant performs to reduce the leaf surface temperature.

By contrast, the decrease in temperature caused by the 70 % shading screen microclimate reduced the E and gS (Figures 3B and 3C), when compared with no shading, favoring a high internal CO_2 concentration (Figure 3A).

The lowest average net photosynthetic rate (34.64) (Figure 3D) was recorded under the 70 % shading screen. Similar results were reported by Kitta & Katsoulas (2020) in hydroponic lettuce grown in a greenhouse (shaded environment), with an average photosynthetic rate of 9.51 µmol m^{-2} s^{-1}, when compared to the 14.50 µmol m^{-2} s^{-1} recorded in the control treatment (no screen), with a decrease of 34.41 %. The authors suggested that the low light levels due to shading may have limited the functioning of the photosystem I (Kitta & Katsoulas 2020).

Based on the obtained results, the smaller number of leaves produced in this environment (70 % shading screen) is another factor to be considered, with a 19.32-23.33 % decrease in relation to no shading (Table 2). This reduces the plant photosynthesis, since the leaves are the primary location for this process.

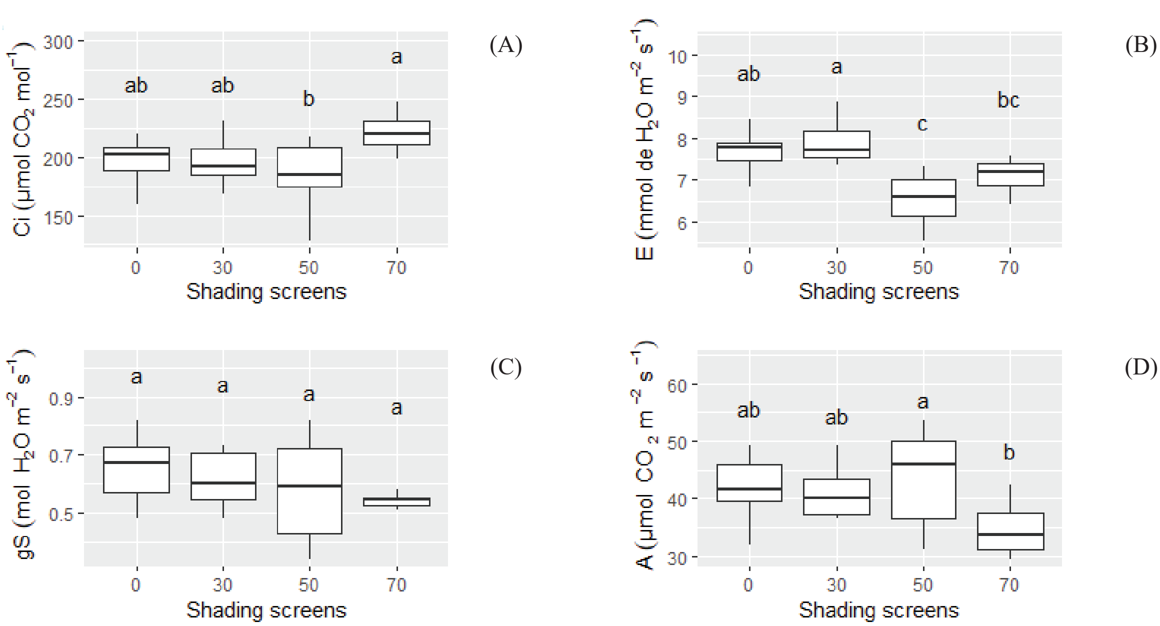

Figure 3. Average values for the physiological parameters internal CO_2 concentration (A), transpiration (B), stomatal conductance (C) and net photosynthetic rate (D) evaluated in yellow and purple flower jambu grown in the Amazon summer. Means followed by the same letter do not differ according to the Tukey test.

It is important to note that increased CO_2 rates within cells raise the photosynthetic rate (Dalastra et al. 2014). However, in the present study, with jambu plants grown under different shading levels, as the light level decreased, the Ci increased (Figures 3A and 3D) and the photosynthetic rate decreased. This variation in light intensity in the growing environments may influence production results and, as such, further research is needed to better understand the physiology of this agricultural crop.

CONCLUSIONS

1. Cultivation at full sunlight (no screen) may influence the vegetative traits of yellow and purple flower jambu plants by increasing the shoot dry weight;
2. The yellow flower variety exhibited an early-onset flowering, regardless of the shading screen used;
3. The Amazon summer growing season increased the jambu yield by 33 %;
4. The 70 % shading screen reduced the net photosynthesis and, therefore, does not favor the vegetative development of jambu plants;
5. It is recommended that yellow and purple flower jambu be grown without shading during the Amazon summer.

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