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Morphological analysis and chlorophyll index of bell pepper cultivars under protected cultivation

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Abstract

Bell pepper is one of the vegetables that most contributes to the horticultural economy of the state of Para, Brazil, although the state has a low production of this vegetable. The objective of this study was to evaluate the adaptability of bell pepper (*Capsicum annuum* L.) cultivars grown in protected cultivation under the edaphoclimatic conditions of southeastern state of Para. The experiment was conducted at the Federal Rural University of Amazonia. A randomized block experimental design was used, with four replications. The treatments consisted of 9 bell pepper cultivars: Itapua 501, Yolo Wonder, Chapeu de Bispo Cambuci, Proveito, Amarelo SF 134, Rubi Gigante, Amarelo Alegria, All Big, and Amarelo Satrapo Sais. The parameters analyzed were: plant height (cm); number of fruits per plant; fruit weight (g); transversal (mm) and longitudinal diameters of fruits (mm); leaf area (cm²), width (cm), length (cm), perimeter (cm), and ratio (cm); and chlorophyll *a*, chlorophyll *b*, and total chlorophyll. The cultivar Amarelo Satrapo showed greater adaptability to cultivation in the studied region, presenting higher fruit weight, yield, and transversal diameter, leaf area and length, and good morphophysiological development. The cultivars Itapua 501, Amarelo SF 134, and Rubi Gigante showed good performances for morphophysiological parameters. The cultivars that presented the highest chlorophyll indices were Proveito, Itapua 501, All Big, and Amarelo Satrapo. The cultivar Amarelo Satrapo presented the highest adaptation to the climate conditions of southeastern Para.

Keywords: *Capsicum annuum* L. FCI, Production parameters, Vegetative parameters

Introduction

Bell pepper (*Capsicum annuum* L.) is a vegetable species native to Latin and Central Americas, where it was domesticated. It has great socioeconomic importance in Brazil, where it is among the most grown vegetables. The plant is an annual species that presents bushy growth and produces berries in different colors and shapes, with a smooth and shiny epicarp, containing 2 to 4 hollow loci (Ceasa, 2023). The state of Para has a low bell pepper production, which makes it a major buyer of peppers from other Brazilian producing states to supply its demand.

In 2017, bell pepper crops covered an area of 11,188 hectares in the country (Alencar, 2019), making the vegetable's production chain one of the most profitable for growers operating in the horticultural sector. Its nutritional value is due to presence of great contents of vitamins C, A, and E, in addition to minerals and nutrients essential to the human diet (Reifschneider, 2000). The market demand for bell peppers in colors other than green has increased (Sediyama et al., 2014.) due to the popularity of healthier and more colorful diets, in addition to have greater added value compared to the green fruits.

Bell peppers crops are highly demanding in nutritional levels (Chagas et al., 2019). They are mostly grown directly in the soil, but also in protected environments, combined with use of substrates to maintain the nutrients required for the plant development and production. In addition, the cultivation in protected environments ensures the production and quality of fruits and is an indispensable technology for regions with high rainfall depths, such as the state of Para.

Considering the great demand for these fruits in the North region of Brazil, the objective of this work was to evaluate different bell pepper cultivars to identify those that better adapt to the soil and climate conditions of

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the region.

Material and methods

The experiment was conducted at the Federal Rural University of Amazonia, in Paragominas, in the southeastern mesoregion of the state of Para, Brazil (03°00'00"S and 47°21'30"W), in a greenhouse (6×20 m) covered with 150-micron plastic and with open sides for ventilation. The analyses were performed in the multifunctional laboratory of the university.

The climate of the region is Awi, rainy tropical with an important dry season, according to the Köppen classification; and BlwA'a', humid tropical with an expressive water deficit, according to the Thornthwaite classification (Bastos et al., 2005); its annual mean air temperature and relative humidity are 26.6 °C and 81%, respectively (INMET, 2020). The predominant soil in the region was classified as Typic Hapludox (Latossolo Amarelo) of clay texture (Rodrigues et al., 2003).

The maximum and minimum temperatures during the experimental period were 27.5 °C and 21.5 °C, respectively, according to the Brazilian National Institute of Meteorology - INMET (INMET, 2020). The maximum and minimum wind speeds were 2.39 m/s and 0.96 m/s; maximum and minimum radiations were 1391.55 kJ/m² and 698/61 kJ/m²; and maximum and minimum air relative humidity were 83.5% and 63.7%, respectively.

A randomized block experimental design was used, with 9 treatments and four replications. The treatments consisted of 9 different bell pepper cultivars: Itapua 501 (ISLA®), Yolo Wonder (ISLA®), Chapeu de Bispo Cambuci (ISLA®), Proveito (ISLA®), Amarelo SF 134 (Feltrin®), Rubi Gigante (Feltrin®), Amarelo Alegria (ISLA®), All Big (ISLA®), and Amarelo Satrapo Sais (ISLA®). The cultivars were chosen according to the demands of the regional market.

The seedlings used in the experiment were produced in expanded polystyrene trays with 128 cells, using a substrate consisting of black soil and rice straw (60% and 40%, respectively), enriched with limestone (15g $tray^{-1}$), simple superphosphate (10 g $tray^{-1}$), potassium chloride (5 g $tray^{-1}$), and urea (5 g $tray^{-1}$); one seed was sown per cell.

The trays were kept in a protected environment with dimensions of 4×12 m, ceiling height of 3 m, and covered with a 70% shade screen, where they were arranged on wooden benches of 60×220 cm with height of 70 cm. These benches had a gap galvanized wire support with a 5 cm clearance to allow air circulation under the trays. Irrigation was performed manually twice a day using a watering can. A solution containing NPK (10-28-20 formulation with nitrogen, phosphorus, and potassium, respectively, diluted in 2 L water) was applied 23 days after sowing.

The plant stand was randomly arranged for transplanting of seedlings 30 days after sowing into four 20-meter beds with 50 cm spacing between rows and 30 cm spacing between plants. Each replication consisted of eight plants, and six plants per plot were evaluated.

Ten soil subsamples were collected, using a Dutch auger, to form a composite sample, which was subjected to chemical analysis in the laboratory for determining nutrient contents and acidity and fertility levels (**Table 1**).

The soil was prepared by applying simple superphosphate (50 g m^{-2}) and lime (100 g m^{-2}), which were broadcasted over the soil in the beds. Seedlings with 4 to 5 leaves were transplanted 30 days after sowing to a protected experimental area (12.5 m long, 6.27 m wide, and 5 m high) covered with transparent plastic (150-micron thick) and with open sides.

Regarding cultural practices used in the experimental area, drip irrigation was carried out with one dripper per plant, flow rate of 2.7 L h^{-1}, and daily irrigation shift of 2 hours (one hour in the morning and one hour in the evening) for 5.4 L $plant^{-1}$ day^{-1}. Weeds were controlled by weeding whenever necessary. A

Table 1. Result of the chemical analysis of the soil located in the experimental area of UFRA, Paragominas campus 2019

O.M	TOC	P	Mn	Zn	S	B	Cu	Fe
	g dm^{-3}			mg dm^{-3}				
25	15	3,8	46,1	2,9	21	0,59	0,6	230
K	Ca	Mg	Na	H° + Al ³	Al ³	H°	B.S	C.E.C
		mmolc dm^{-3}						
2.3	23	8	0.3	51	0	51	33.6	84.6
K na CEC	Ca naCEC	Mg naCEC	Na naCEC	Al naCEC	H na CEC	H+AL naCEC	V%	m%
				%				
2.7	27.2	9.5	0.4	0	60.3	60.3	40	0
Ca/K		Ca/Mg		Mg/K		pH		pH
10		2.9		3.5		4.6		5.83

O.M.: organic matter; TOC: total organic carbon; P: phosphorus; Mn: manganese; Zn: zinc; S: sulfur; B: boron; Cu: copper; Fe: iron; K: potassium; Ca: calcium; Mg: magnesium; Na: sodium; H: hydrogen; Al: aluminum; B.S.: base sum; CEC: cation exchange capacity; V%: base saturation; m%: aluminum saturation. Source: Brazilian Institute of Analyses - IBRA, 2018.

Bordeaux mixture and urea were mixed and applied for prevent fungus infestation. Soil fertilization management consisted of weekly applications of NPK solution (10-28-20 formulation), prepared with 10 g of the formulation diluted in 2 L of water; approximately 100 mL were supplied per plant every 15 days. Micronutrients were supplied 45 days after transplanting the seedlings to the experimental area, using a commercial fertilizer (Mover; Stoller do Brazil, Cosmopolis, Brazil) composed of nitrogen (5%), boron (4%), copper (0.17%), molybdenum (0.015%), and zinc (3%); the mixture was prepared using 12 mL of fertilizer diluted in 3 L of water and applied using a backpack sprayer.

In addition, a trellising system was used 45 days after transplanting to prevent the plants from lodging: bamboo poles and string were used as supports to tie the seedlings. During the crop cycle, branches, and leaves below the first fork and the first flowers were removed from the plants to increase energy expenditure and ensure greater vigor, quality, and quantity of fruits.

The plants were monitored during the experiment period following the methodology of (Moura, 2015), through evaluations of occurrence of leaf tip deformations such as downward wrinkling of the leaf blade and veins, petiole expansion, and others symptoms associated with broad mite (*Polyphagotarsonemus latus*) infestation (Pereira et al., 2007); sulfur solution (2 gL^{-1}) was applied for pest control.

The harvest was performed 120 days after sowing, when most of the fruits presented size and color suitable to the marketing standards (CEASA, 2023).

The following parameters were evaluated: plant height (cm), measured from the base of the stem to the tip, using a measuring tape; number of fruits per plant; fruit weight (g), weighed on an analytical precision balance; fruit transversal and longitudinal diameters (mm), measured with a digital caliper; leaf area (cm^2), width (cm), length (cm), and perimeter (cm), and leaf ratio (width to length ratio; cm) were measured in two leaves per plant for a total of six plants per treatment, using a portable device (AM350 Portable Leaf Area Meter; ADC BioScientific Ltd., Hoddesdon, UK); chlorophyll *a*, chlorophyll *b*, and total chlorophyll were determined using a chlorophyll meter device (ChlorophiLOG CFL1030; Falker, Porto Alegre, Brazil) that expresses results in ICF (Falker chlorophyll index).

The data collection started with the appearance of the first fruits, approximately 100 days after sowing, with measurement of plant height as previously described. After harvesting, the fruits were counted and taken to the laboratory for determining the weight of each fruit, fruit transversal and longitudinal diameters, and leaf parameters.

The data were subjected to analysis of variance (F test) and the means were compared by the Tukey's test at 5% probability, using the software SISVAR® (Ferreira, 2011).

Results and discussion

The F test was significant and the Tukey's test at 5% probability was applied for the characteristics: plant height, number of fruits per plant, fruit weight, fruit transversal and longitudinal diameters, and leaf area, width, length, and ratio.

Regarding fruit weight, the bell pepper cultivar Amarelo Satrapo showed higher results than the other cultivars, presenting 143.09 g (**Table 2**). (Casais et al., 2018) evaluated morphological and production parameters of the cultivars Ikeda and Rubi Gigante grown under the edaphoclimatic conditions of Paragominas and found 31.57 and 29.08 g, respectively. (Aviz et al., 2020) evaluated chili peppers grown under the edaphoclimatic conditions of Paragominas and found fruit weight ranging from 19.95 g to 23.37g.

Thus, the production of bell peppers in a protected environment is more appropriate for the region of Paragominas, as the use of protected cultivation decreases the leaching of nutrients from the soil, enables better control of pests and diseases, and protects against bad weather (Oliveira & Luz, 1998), providing, mainly, milder temperatures and lower incidence of solar radiation for Amazon conditions.

The fruit weight results found in the present study are in accordance with those of (Sousa, 2018), who found 147.6 to 155.1 g in an experiment under protected environment. However, despite these results are higher than those reported in other studies, the mean fruit weight found is below the reference for the cultivar: 230 to 250 g under ideal conditions (Isla, 2021). Moreover, the yellow bell pepper cultivar Amarelo Satrapo is a hybrid, which makes it more efficient than the other cultivars, mainly when its hybrid vigor is efficiently used. Contrastingly, the cultivar Chapeu de Bispo presented the lowest fruit weight, 15.07 g (Table 2), which can be explained by the cultivar characteristics, as its fruit size is usually 6×4 cm, according to the seed manufacturer (FELTRIN, 2021).

Regarding plant height (PH), Chapeu de Bispo and Itapua 501 showed significantly higher results than the other cultivars, reaching 83.75 and 83.00 cm, respectively (Table 2). Similarly, (Moreira, 2015) evaluated the cultivar Itapua 501 under the edaphoclimatic conditions of

Table 2. Results of variance analysis for the evaluated productive parameters in different Bell peppers cultivars produced in Paragominas – PA

Cultivars	Fruit weight (g)	Yield (g m^{-2})	Height (cm)	N° of fruits	Diameter L	Diameter T
Chapéu de bispo	15.07 f	90.44e	83.75 a	80.00 a	39.02 e	43.39 e
Amarelo sf 134	65.16d	390.92c	65.75 b	25.75 b	75.08 ab	45.31 de
Rubi gigante	53.29 e	319.74cd	60.44 bc	26.50 b	73.61 abc	44.16 de
Proveito	64.48 d	386.86c	65.75 b	29.25 b	83.91 a	53.35 bcd
Itapuã 501	64.59 d	387.52c	83.00 a	22.75 bc	75.83 ab	47.72 de
Amarelo alegria	133.16 b	816.84 a	55.17 bc	15.50 cd	60.58 cd	50.97 cde
Yolo wonder	83.72 c	502.27b	52.79 bc	15.25 d	58.83 d	62.00 ab
All big	83.74 c	502.46b	48.6 c	16.00 cd	55.76 d	59.22 abc
Amarelo satrapo	143.09 a	858.54 a	60.31 bc	9.25 d	66.90 bcd	65.23 a
Test F	**	**	**	**	**	**
CV (%)	6.88	6.88	10.93	11.42	8.32	7.89

Lowercase letters compare the means of the cultivars. Means followed by the same letter do not differ by the Tukey test at 5% probability

Table 3. Results of variance analysis for the parameters leaf area, width, length, ratio factor and leaf perimeter evaluated in the different Bell peppers cultivars produced in Paragominas - PA, 2019

Cultivars	Leaf area (cm^2)	Width (cm)	Length (cm)	*Ratio* (cm)	Perimeter (cm)
Chapéu de bispo	30.08 ab	5.21 ab	10.97 b	2.12 b	26.16 a
Amarelo sf 134	27.41 b	4.35 c	11.27 b	2.63 a	28.16 a
Rubi gigante	31.39 ab	4.58 bc	11.98 ab	2.63 a	27.43 a
Proveito	33.93 ab	5.21 ab	11.76 ab	2.39 ab	28.40 a
Itapuã 501	32.08 ab	5.46 a	11.67 ab	2.51 b	26.24 a
Amarelo alegria	29.05 ab	4.79 abc	10.92 b	2.31 ab	26.26 a
Yolo wonder	33.18 ab	4.80 abc	12.15 ab	2.53 a	27.13 a
All big	33.33 ab	4.91 abc	11.67 ab	2.38 ab	29.39 a
Amarelo satrapo	35.96 a	5.14 abc	13.03 a	2.48 ab	29.39 a
Test F	**	**	**	**	ns
CV (%)	8.91	6.71	5.57	6.26	9.93

Means followed by the same letter do not differ by Tukey's test at 5% probability.

Campo dos Goytacazes, in the northern region of the state of Rio de Janeiro, Brazil, and found a mean PH of 74.7 cm. The PH found for the cultivar Chapeu de Bispo is consistent with the reference data from the seed manufacturer: from 70 to 100 cm.

Considering the number of fruits, Chapeu de Bispo also showed better results than the other cultivars (Table 2), presenting 80 fruits per plant. (Gonçalves, 2011), evaluating the inheritance of agronomic traits and resistance to yellow mosaic in *Capsicum baccatum* var. pendulum in tunnel protected cultivation in the edaphoclimatic conditions of Campos dos Goytacazes, evaluated the agronomic traits of the Bispo Hat cultivar where he obtained the result of 51.61 fruits per plant, with values lower than those obtained by the cultivar in this trial.

The cultivar Proveito showed the largest fruit longitudinal diameter (83.91 mm), whereas Amarelo Satrapo showed the largest fruit transversal diameter (65.23 mm). These results can be attributed to their hybrid vigor, which is expressed mainly in yield components, such as fruit longitudinal and transversal diameters (Silva, 2002).

Regarding yield, the cultivars Amarelo Satrapo and Amarelo Alegria showed higher results (858.54 and 816.84 g m^{-2}, respectively) than the other cultivars (Table 2). Who evaluated the cultivar Amarelo Satrapo in field under the edaphoclimatic conditions of Capitao Poço, Para, and reported a mean yield of 830 g m^{-2}. (Araquam, 2013) evaluated bell pepper plants cultivated in environments covered with shade screens under the microclimate conditions of the Sao Francisco Valley region, Brazil, and found a mean commercial yield of 858.96 g m^{-2}.

The largest leaf area (35.96 cm^2) was found for the cultivar Amarelo Satrapo (**Table 3**). According to (Carvalho, 2011), leaf area is connected to the photosynthetic capacity of plants to intercept solar radiation and assimilate carbon dioxide; this results in a greater amount of energy available for the plant to perform its metabolic activities, such as growth and fruit production (Reis et al., 2013). This result corroborates the higher results found for fruit weight, yield, and transversal diameter found Amarelo Satrapo in the present study.

The largest leaf width (5.46 cm) was found for the cultivar Itapua 501, whereas the longest leaf length (13.03

Table 4. analysis of variance results for the parameters chlorophyll *a*, chlorophyll *b* and total chlorophyll contents in bell pepper leaves in Paragominas (2019)

Cultivars	Chlorophyll a	Chlorophyll b	Total Chlorophyll
Chapéu de bispo	34.68 abc	8.74 d	43.42 bc
Amarelo SF 134	36.06 ba	10.22 bcd	46.27 abc
Rubi gigante	34.76 abc	10.38 bcd	45.14 abc
Proveito	36.84 a	11.21 abc	48.05 a
Itapuã 501	36.85 a	10.40 bcd	47.25 a
Amarelo alegria	33.23 c	10.02 cd	43.25 c
Yolo wonder	33.85 bc	12.08 ab	45.92 abc
All big	36.66 a	10.05 cd	46.71 ab
Amarelo satrapo	34.24 abc	12.32 a	46.56 abc
Test F	**	**	**
CV (%)	3.26	7.52	3.09

Means followed by the same letter do not differ by Tukey's test at 5% probability.

cm) was found for Amarelo Satrapo. These results may be connected to the genetic characteristics of these cultivars.

The Ratio, in analysis of variance showed that the cultivars Amarelo SF 134, Rubi Gigante, and Yolo Wonder had the highest leaf ratio: 2.63 (SF 134 and Rubi Gigante) and 2.53 (Yolo Wonder). The cultivars presented no no significant difference for leaf perimeter (**Table 4**).

The cultivars Itapua 501, Proveito, and All Big showed the best results for chlorophyll *a*, and Amarelo Satrapo showed the best results for chlorophyll *b*. The cultivars Proveito and Itapua 501 presented the highest chlorophyll *a* and total chlorophyll, reaching 36.84 ICF, 36.85 ICF for chlorophyll *a* and 48.05 ICF and 47.25 ICF for total chlorophyll, respectively (Table 4). (Rocha et al., 2018) evaluated the efficiency of irrigation water depths in two periods and found 44.0 ICF for chlorophyll *a* and 26.8 ICF for chlorophyll *b*, which were higher than those found in the present study.

According to (Kaya et al., 2013), chlorophyll is strongly affected by environmental factors, as light, water, mineral nutrients, and stress conditions, which may have affected the chlorophyll results found in the present study. Similar results were found by (Silva et al., 2020) for *Spilanthes oleracea* plants grown in a protected hydroponic system in Paragominas: 31.02 ICF (chlorophyll *a*), 10.06 ICF (chlorophyll *b*), and 41.36 ICF (total chlorophyll); therefore, the higher values found in the present study indicate a strong adaptation of the cultivars to the local environment.

Conclusions

The bell pepper cultivar Amarelo Satrapo showed the highest yield under the climate conditions of southeastern state of Para, Brazil, standing out among the other bell pepper cultivars, considering the following parameters: fruit weight, yield, and transversal diameter. This cultivar also proved to be superior to the others regarding the vegetative parameters leaf area and length.

The cultivars Amarelo Satrapo, Itapua 501, Amarelo SF 134, and Rubi Gigante presented the best morphophysiological development. The cultivars Proveito, Itapua 501, All Big, and Amarelo Satrapo presented the highest chlorophyll index. The cultivar Amarelo Satrapo showed the best adaptation to the climate conditions of southeastern Para.

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