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ORIGINAL ARTICLE

Physiology and production of colored bell pepper cultivars in a semi-hydroponic system[1]

Fisiologia e produção de cultivares de pimentão colorido em cultivo semi-hidropônico

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HIGHLIGHTS:
The cultivar Spinel presented greater chlorophyll contents in the semi-hydroponic system.
Bell peppers of the cultivar Fulgor presented greater length, diameter, weight, and pH.
The smallest fruit lengths were found for the cultivars Bachata and Red Jet.

ABSTRACT: Semi-hydroponic systems are an alternative for vegetable production, combining inert substrates and nutrient solutions and requiring less water. Bell pepper (*Capsicum annuum* L.) is a vegetable species of the Solanaceae family that is mainly grown in protected environments, which provide several financial and agronomic advantages for their management. Advancements in research and the need for high-quality productions have significantly contributed to this horticultural crop through the selection of productive cultivars with high economic yields and adapted to favorable conditions. The objective of this study was to evaluate growth, physiological, and production characteristics of colored bell pepper cultivars in a semi-hydroponic system. The experiment was conducted in a completely randomized design, using four colored pepper cultivars (Spinel, Bachata, Fulgor, and Red Jet), five evaluation times (7, 14, 21, 28, and 35 days after transplanting - DAT) for growth variables, and evaluations at two developmental stages (45 and 95 DAT) for physiological variables. Production and post-harvest variables were not evaluated in different times, considering only the cultivar factor, with five replications, each plot consisting of two plants. Chlorophyll *a* and *b*, maximum fluorescence, and water use efficiency were greater in bell pepper plants of the cultivar Spinel. The sweetest fruits were those of the cultivar Bachata. The cultivar Fulgor was the most suitable for growth under the studied conditions due to its greater fruit length and diameter and total fruit weight.

Key words: *Capsicum annuum* L., Solanaceae, fertigation

RESUMO: O sistema semi-hidropônico é uma alternativa para a produção de hortaliças, pois combina substrato inerte e solução nutritiva, necessitando de menos água. O pimentão é uma hortaliça da família Solanaceae, principalmente produzida em ambiente protegido, apresentando diversas vantagens financeiras e agronômicas no seu manejo. Com os avanços nas pesquisas e a necessidade de uma produção de qualidade, selecionar cultivares produtivas e com alto rendimento econômico, adaptadas às condições favoráveis, torna-se um grande avanço para esta cultura hortícola. O objetivo deste estudo foi avaliar o crescimento, características fisiológicas e produtivas das cultivares Red Jet, Spinel, Bachata e Fulgor em sistema semi-hidropônico. O delineamento experimental foi inteiramente casualizado com quatro cultivares de pimentão colorido (Spinel, Bachata, Fulgor e Red Jet) subdivididas em cinco épocas de avaliação (7, 14, 21, 28 e 35 dias após transplantio - DAT) para as variáveis de crescimento e duas épocas (45 e 95 DAT) de avaliação para fisiologia. As variáveis produtivas e pós-colheita não foram subdivididas no tempo, levando-se em consideração apenas o fator cultivar para estas variáveis, com cinco repetições, sendo cada parcela composta por duas plantas. Os índices de clorofila a e b, fluorescência máxima e eficiência no uso da água foram maiores nas plantas de pimentão da cultivar Spinel. Os frutos mais doces foram obtidos com a cultivar Bachata. A cultivar Fulgor foi a mais indicada para cultivo nas condições estudadas devido ao maior comprimento, diâmetro e peso médio dos frutos.

Palavras-chave: *Capsicum annuum* L., Solanaceae, fertigação

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Introduction

Growing bell pepper (*Capsicum annuum* L.) crops in semiarid regions is challenging, mainly due to the limitation of water supply for agriculture; therefore, semi-hydroponic systems can be an alternative for growing this crop, as it reduces the need for water during the crop cycle (Santos et al., 2019).

Bell pepper has a significant economic importance in the Brazilian market, standing out for its organoleptic qualities such as color, shape, and flavor, as well as its high contents of bioactive compounds such as carotenoids, anthocyanins, flavonols, total phenolics, and ascorbic acid (Garcia et al., 2021). Bell pepper production in Brazil reached 224,000 Mg in 2020; the state of Paraiba contributed with 3,519 Mg, accounting for 1.56% of this production (IBGE, 2021). This small production is attributed to limiting factors, such as water scarcity and high temperatures (Silva et al., 2023), making semi-hydroponic systems an alternative method for growing this vegetable.

Bell peppers often cannot be grown in open fields due to hot summer months and high solar radiation, which negatively affects plant growth and fruit production, causing sunburn on fruits and significant yield losses in terms of fruit quality (Jadama et al., 2021). However, growing colored bell peppers in protected environments reduces risks of fruit damage due to exposure to adverse environmental conditions, thus minimizing fruit yield and quality losses; additionally, it contributes to increasing the added value of the product by up to five times (Lang et al., 2020).

The commercial production of colored bell peppers, the several cultivars available in the market, and limited information on the nutritional requirements of this vegetable crop restrict the selection of genotypes targeted at specific production niches (Oliveira Filho et al., 2018). Therefore, the objective of this study was to evaluate the growth and physiological and production characteristics of colored bell pepper cultivars (Red Jet, Spinel, Bachata, and Fulgor) grown in a semi-hydroponic system.

Material and Methods

The experiment was conducted from January to June 2021 in a protected environment (greenhouse) at the Hortaliças da Serra company, in Areia, microregion of Brejo Paraibano, Paraiba, Brazil (06° 57' 30" S, 35° 45" 33.8" W, altitude of 560 m). The region's climate is As, tropical semi-humid, with dry summers, according to the Köppen-Geiger classification, with annual average rainfall depth and temperature of 1,500 mm and 23 °C, respectively (Alvares et al., 2013).

Daily data of maximum, average, and minimum temperatures and relative air humidity inside the greenhouse were collected throughout the experimental period (Figure 1).

A completely randomized experimental design was adopted, using four colored pepper cultivars (Spinel, Bachata, Fulgor, and Red Jet), with five evaluation times (7, 14, 21, 28, and 35 days after transplanting - DAT) for growth variables, and evaluations at two developmental stages (beginning of flowering, 45 DAT; and fruiting, 95 DAT) for physiological

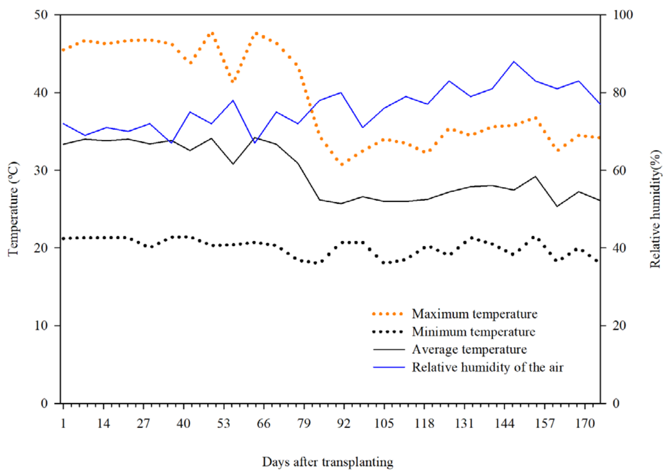


Figure 1. Maximum, minimum, and average air temperature (°C) and relative humidity (%) in the experimental area during the experimental period (January 1 to June 22, 2021)

variables. Growth parameters were measured up to 35 DAT, as an apical pruning was carried out at 40 DAT when the plants were beginning to emit flowers. Production and post-harvest variables were not evaluated in different times, considering only the cultivar factor for evaluation, with five replications and each plot consisting of two plants.

A semi-hydroponic system was tested in the experiment. Each plant was placed in a 5 dm^3 plastic pot containing an inert substrate composed of coconut fiber. A layer of 5-cm of crushed stones (9.5 to 19 mm) was placed at the bottom of the pot and covered with a polyethylene sheet to keep the substrate separate, promoting drainage of excess solution.

Seedlings of the bell pepper cultivars were purchased from the Ebnnezer Company and transplanted at 35 days after sowing when they had two pairs of true leaves and height of 15 cm. Branch breakage after transplanting was prevented through staking using raffia strings to attach each plant branch; this activity was carried out continuously until harvest. Plants were pruned at 20 DAT, leaving only two branches per plant at the first fork. The plant was then let to grow freely until reaching the fourth fork when it was subjected to topping (apex removal) at 40 DAT. Additionally, the first fruit was removed when the first floral buds appeared in all materials for reducing competition between these organs and achieving uniformity, earliness, and productivity.

Fertigation was performed using the nutrient solution recommended by Trani et al. (2011) for growing bell pepper crops. The fertilizer quantities for 1,000 L of solution were 650 g of calcium nitrate, 500 g of potassium nitrate, 170 g of monopotassium phosphate, 250 g of magnesium sulfate, 50 g of magnesium nitrate, 1 L of iron - EDTA, 16.7 mg L^{-1} boric acid, 15 mg L^{-1} manganese chloride, 0.82 mg L^{-1} copper chloride, 0.33 mg L^{-1} molybdenum oxide, and 2.62 mg L^{-1} zinc sulfate. This solution was used for fertigation at 50% concentration in the first 15 days after transplanting, increasing the nutrient supply according to the crop phenophases (Trani et al., 2011).

Fertigation and irrigation were provided to each pot through pressure-compensating drippers with a flow rate of 4 L h^{-1}, using a fertigation shift of 10 minutes day^{-1} divided into two steps (in the morning at 06:30 hours and in the afternoon at

15:00 hours), and an irrigation shift of 10 minutes, divided into two steps (in the morning at 10:00 hours and in the afternoon at 12:00 hours), totaling 1.33 L day^{-1} of water for each plant.

Phytosanitary control was carried out preventively twice a week, alternating between chemical insecticide (Actara 250 WG) and fungicide (Amistar WG) applied at concentration of 0.1 mL L^{-1}.

Plant height (cm) and stem diameter (mm) were measure using a tape measure and a digital caliper, respectively; the results were used to calculated the absolute and relative growth rates every 7 days up to 35 DAT, according to Benincasa (2003), using Eq. 1 and Eq. 2. No subsequent measurements were taken due to the beginning of emission of the first flowers and apical pruning of the plants.

$$AGR = \frac{(A_2 - A_1)}{t_2 - t_1} \quad (1)$$

where:

AGR - absolute growth rate;
A_2 - plant growth at time t_2;
A_1 - plant growth at time t_1; and
t_2 - t_1 - time difference between evaluations

$$RGR = \frac{(\ln A_2 - \ln A_1)}{t_2 - t_1} \quad (2)$$

where:

RGR - relative growth rate;
A_2 - plant growth at time t_2;
A_1 - plant growth at time t_1;
t_2 - t_1 - time difference between evaluations; and,
ln - natural logarithm.

Parameters of chlorophyll *a* fluorescence were assessed at the beginning of flowering (45 DAT) and at the beginning of the fruiting stage (95 DAT) through measurements on the middle of the second fully expanded leaf from the apex, in the mornings between 07:00 and 09:00 hours. The leaves were dark-adapted for 30 minutes before measurements. Initial fluorescence (F_0), maximum fluorescence (F_m), variable fluorescence (F_v), and potential quantum efficiency of photosystem II (F_v/F_m) were measured using a portable fluorometer (OS-30p+, Opti-Sciences, Hudson, USA).

Chlorophyll *a,* chlorophyll *b,* and chlorophyll total were measured at the beginning of flowering (45 DAT) and at the beginning of fruiting (95 DAT) using the third fully developed leaf from the apex. The measurements were taken in the morning between 07:00 and 09:00 hours, through the non-destructive method, on the middle third of the leaf blade, avoiding the central vein, using a portable electronic chlorophyll meter (ClorofiLOG®, model CFL 1030, Porto Alegre, Brazil). The mean of three measurements was considered; the results were expressed as Falker Chlorophyll Index (FCI).

CO_2 assimilation rate (μmol CO_2 m^{-2} s^{-1}), stomatal conductance (mol H_2O m^{-2} s^{-1}), intercellular CO_2 concentration (μmol CO_2 m^{-2-} s^{-1}), transpiration rate (mmol H_2O m^{-2} s^{-1}), water use efficiency [μmol CO_2(mmol H_2O m^{-2} s^{-1})$^{-1}$], intrinsic water use efficiency [μmol CO_2 m^{-2} s^{-1} (mol H_2O m^{-2} s^{-1})$^{-1}$], and intrinsic carboxylation efficiency [μmol CO_2 m^{-2} s^{-1} (μmol CO_2 m^{-2} s^{-1})$^{-1}$] were measured at 45 and 95 DAT using an infrared gas analyzer (LI-6400XT, LI-COR,, Lincoln, USA). Measurements were taken on the youngest fully expanded leaf in the mornings between 07:00 and 09:00 hours. The airflow rate was 300 mL min^{-1} and the photosynthetically active radiation was 1200 μmol m^{-2} s^{-1}.

Relative water content (RWC; %) was calculated according to the methodology described by Irigoyen et al. (1992). Leaf discs were taken at 45 and 95 DAT and weighed on a semi-analytical balance for determining fresh weight (mg). Then, the discs were submerged in distilled water for 24 hours for obtaining turgid weight (mg). Subsequently, they were dried in a forced air circulation oven at 65 °C for 24 hours for obtaining the dry weight (mg). RWC was calculated using Eq. 3:

$$RWC = \frac{(FW - DW)}{(TW - DW)} \times 100 \quad (3)$$

where:

FW - leaf fresh weight (g);
TW - leaf turgid weight (g); and
DW - leaf dry weight (g)

Electrolyte leakage (EL; %) was assessed at 45 and 95 DAT, as described by Lutts et al. (1996). Ten leaf discs of 10 mm diameter were taken, placed in test tubes with 10 mL of deionized water, and incubated in a water bath at 25 °C for 6 hours. Readings were taken using a conductivity meter to determine the electrical conductivity of the solutions (L_1) (dS m^{-1}). Subsequently, the tubes were again placed in a water bath at 100 °C for one hour, and new readings of electrical conductivity of the solutions (L_2) (dS m^{-1}) were taken. EL was calculated using Eq. 4:

$$EL = \frac{L_1}{L_2} \times 100 \quad (4)$$

where:

L_1 - initial electrical conductivity (dS m^{-1}); and
L_2 - final electrical conductivity (dS m^{-1}).

Harvesting started at 85 DAT, when the fruits reached commercial size and the characteristic bright yellow or red color of each colored pepper cultivar, extending until 175 DAT, according to fruit maturation.

The number of fruits per plant was determined based on the number of harvested fruits. The total fruit weight per plant was obtained by weighing all fruits per plant on a semi-analytical balance (kg per plant); fruit diameter (mm) was determined by measuring the diameter of the fruit or its greatest width using a digital caliper; fruit length (cm) was determined by measuring the greatest length of the fruit with a digital caliper.

The fruits were physiochemically evaluated after harvest (175 DAT) at the Food Laboratory of the Universidade Estadual da Paraíba (UEPB), campus II Lagoa-Seca.

Pulp pH was determined directly in the homogenized pulp using a digital pH meter calibrated with pH 4.0 and 7.0 buffer solutions. Titratable acidity was determined using 20 g of fruit pulp, which were crushed in 100 mL of distilled water, placed in a 150 mL beaker, and measured for volume; subsequently, three drops of 0.5% alcoholic phenolphthalein solution were added to 10 mL of the solution, and titration was carried out using 0.1 M sodium hydroxide (NaOH) solution until a pink color was obtained; the results were expressed as a percentage of malic acid (IAL, 2008). Soluble solids content was determined in liquid fruit extract using a digital refractometer with automatic temperature compensation; the result was expressed as °Brix (Bomfim et al., 2020).

The obtained data were subjected to normality (Shapiro-Wilk) and homogeneity (Bartlett) tests and then to analysis of variance at 0.05 and 0.01 probability levels, followed by the Tukey's test ($p \leq 0.05$) for cultivars and evaluation stages (physiological variables) and linear and quadratic regressions for evaluation times (growth variables). Statistical analyses were performed using the program R 3.6.3 with the ExpDes.pt package (Ferreira et al., 2018).

Results and Discussion

Relative and absolute growth rates in plant height and stem diameter of colored bell pepper cultivars were significantly affected ($p \leq 0.01$) by the interaction between the factors (evaluation time and cultivar), except absolute growth rate in plant height (Table 1).

All studied cultivars showed higher absolute growth rate in stem diameter at 35 days after transplanting (DAT), presenting 1.19 mm per day (Spinel), 1.18 mm per day (Fulgor), 1.20 mm per day (Bachata), and 1.21 mm per day (Red Jet) (Figure 2A), representing increases of 40.99%, 38.29%, 43.99%, and 46.77%, respectively, from 7 DAT to 35 DAT. Plants of all cultivars did not emit flowers until 35 DAT; however, all plants were at full flowering at 45 DAT. Therefore, growth was assessed up to 35 DAT, as pruning was performed from the onset of flowering, including apical pruning, as the plants continue to grow. This is because semi-hydroponic systems provide a more stable growing environment due to nutrient supply through the solution, allowing plants to grow more rapidly and with higher yields compared to conventional soil cultivation (Baiyin et al., 2023). All cultivars showed high absolute growth rates at 35 DAT, however, some of them had a higher growth rate in stem diameter depending on the evaluation time, such as Red Jet; this different pattern in cultivars can be attributed due to genotypic variation in response to the environment (Souza et al., 2022).

The interaction between the factors had no significant effect on absolute growth rate in plant height; however, the evaluation time had a significant effect, with an increase of 20.15% from 7 DAT (1.29 cm per day) to 35 DAT (1.55 cm per day) (Figure 2B). This increase may be because the plants were still at the vegetative growth period, directing photoassimilates to promote shoot growth (Oliveira Filho et al., 2018). Oliveira et al. (2015) found a higher absolute growth rate at 45 DAT for bell pepper plants (cultivar Magali) grown in open field. In the present study, however, the highest absolute growth rate in height was found at 35 DAT, as the plants began to emit flowers and reached an ideal size for apical pruning, resulting in no further significant increases in height after 35 DAT. Growth under protected environment conditions in a semi-hydroponic system may have promoted higher plant growth within a shorter time frame. Silva et al. (2023) evaluated pepper plants grown in a protected environment without semi-hydroponic system and found a plant height of 48 cm at 80 days after sowing, whereas the plants in the present study exhibited heights greater than 80 cm at 35 DAT (50 days after sowing).

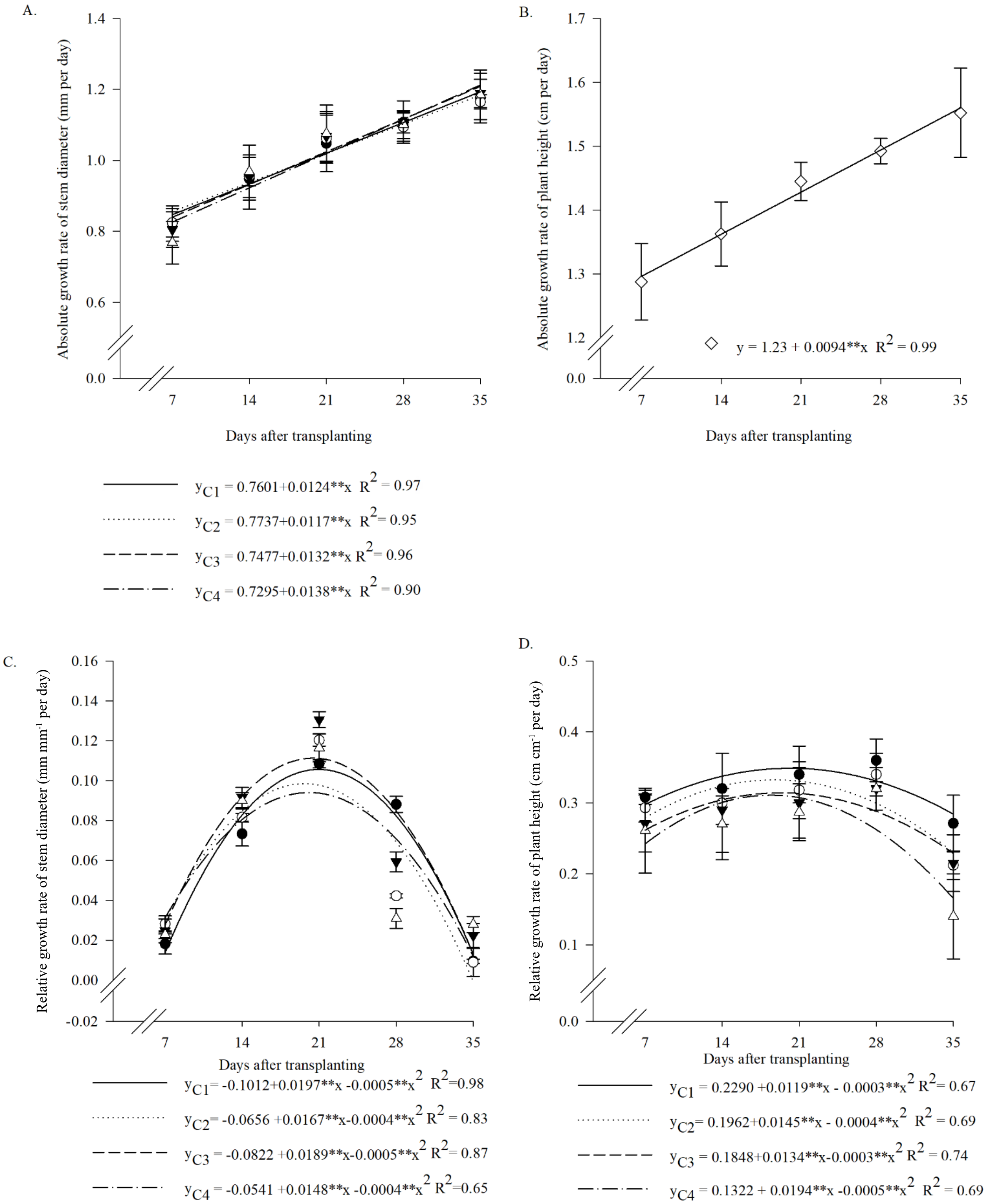
The relative growth rate in stem diameter of colored pepper plants increased from 0.035, 0.052, 0.047, 0.046 mm mm^{-1} per day to 0.092, 0.108, 0.096, and 0.08 mm mm^{-1} per day, at 20, 21, 19, and 19 DAT for the cultivars Spinel, Fulgor, Bachata, and Red Jet, respectively, with decreases from these evaluation days onward (Figure 2C). Similarly, the relative growth in height for Spinel, Fulgor, Bachata, and Red Jet increased up to 21, 21, 22, and 19 DAT, representing increases of 16.46, 16.61, 26.71, and 31.54% compared with the results found at 7 DAT (Figure 2D).

The relative growth rate in height increased up to approximately 20 DAT, with significant decreases from this point onwards for most cultivars. This can be explained by decreases in net assimilation rate and leaf area due to the onset of flowering (Silva et al., 2010). Considering that the present study evaluated different cultivars of the same species, the variation in patterns can be attributed to the variability among these cultivars. Lang et al. (2020) also found differences

Table 1. Analysis of variance for absolute and relative growth rates in stem diameter and plant height of colored bell pepper cultivars as a function of evaluation times (days after transplanting)

Source of variation	DF	Mean squares			
		Absolute growth rate		Relative growth rate	
		Stem diameter	Plant height	Stem diameter	Plant height
Cultivars (C)	3	0.003^{ns}	0.58**	0.002*	0.11**
Residual 1	16	0.006	0.01	0.0006	0.04
Days (D)	4	6.11**	7.47**	0.08**	2.57**
C × D	12	0.01**	0.007^{ns}	0.002**	0.08**
Residual 2	64	0.001	0.002	0.001	0.28
CV 1 (%)		4.43	3.93	3.6	11.01
CV 2 (%)		2.42	1.61	5.1	13.39

DF - Degrees of freedom; CV (%) - Coefficient of variation; * and ** - significant at $p \leq 0.05$ and $p \leq 0.01$ by the F test, respectively; ns - not significant



** - Significant at $p \leq 0.01$ by the F test. C1 - Cultivar Spinel, C2 - Cultivar Fulgor, C3 - Cultivar Bachata, C4 - Cultivar Red Jet. Vertical bars represent the standard error of the mean (n = 5)

Figure 2. Absolute growth rate in stem diameter (A), plant height (B), relative growth rate in stem diameter (C) and plant height (D) of bell pepper cultivars as a function of evaluation times

in growth variables among colored bell pepper cultivars (Archimedes, Delirio, Flavorburst, Red Knight, Sirius, Summer Sweet, and Tequila).

According to the analysis of variance for the physiological variables of colored pepper plants (Tables 2 and 3), the effect of the interaction between factors (cultivar × evaluation stage) was significant for initial fluorescence, transpiration rate, intercellular CO_2 concentration, water use efficiency, intrinsic water use efficiency, electrolyte leakage, and relative water content.

The results found for initial, variable, and maximum fluorescence, net photosynthesis, stomatal conductance, water

Table 2. Analysis of variance for chlorophyll *a* (Chl a) and *b* (Chl b), total chlorophyll (Chl T), maximum fluorescence (F_m), initial fluorescence (F_0), variable fluorescence (F_v), quantum efficiency of photosystem II (F_v/F_m), and electrolyte leakage (EL) of plants of colored pepper cultivars as a function of evaluation stages (onset of flowering - 45 days after transplanting (DAT); onset of fruiting - 95 DAT)

Source of variation	DF	Mean squares							
		Clh a	Chl b	Chl T	F_m	F_0	F_v	F_v/F_m	EL
Cultivars (C)	3	57.50*	42.13*	195.71*	23,424.02*	2,131.82**	12,802.23^{ns}	0.001ns	39.48**
Residual 1	16	24.80	10.00	53.43	5,177.23	382.92	5,037.51	0.001	6.70
Days (D)	1	1,135.52**	1,115.27**	4,501.50**	661,261.22**	87,703.22**	267,322.50**	0.006*	10.33^{ns}
C × D	3	39.51^{ns}	7.73^{ns}	81.84^{ns}	1,092.62^{ns}	1,062.09**	2,676.63^{ns}	0.002^{ns}	48.71**
Residual 2	16	17.21	5.69	31.89	6,066.33	199.00	5,028.41	0.001	5.09
CV 1 (%)		9.72	19.63	10.85	10.43	9.47	14.68	5.76	11.35
CV 2 (%)		8.09	14.81	8.38	11.29	6.83	14.66	4.58	9.89
Mean (45 DAT)		47.49 b	12.38 b	59.88 b	818.55 a	253.40 a	565.30 a	0.68 b	22.30 a
Mean (95 DAT)		55.03 a	19.85 a	74.88 a	561.55 b	159.75 b	401.80 b	0.71 a	23.32 a

DF - Degrees of freedom; CV (%) - Coefficient of variation; *and ** - significant at $p \leq 0.05$ and $p \leq 0.01$ by the F test; ns - not significant

Table 3. Analysis of variance for CO_2 assimilation (A), stomatal conductance (gs), intercellular CO_2 concentration (Ci), transpiration rate (E), instantaneous carboxylation efficiency (iCE), water use efficiency (WUE), intrinsic water use efficiency (iWUE), and relative water content (RWC) of colored pepper cultivars as a function of evaluation of evaluation stages (onset of flowering - 45 days after transplanting (DAT); onset of fruiting - 95 DAT)

Source of variation	DF	Mean squares							
		A	gs	Ci	E	iCE	WUE	iWUE	RWC
Cultivars (C)	3	4.73^{ns}	0.002^{ns}	75.80^{ns}	1.64**	0.00009^{ns}	0.23^{ns}	34.03^{ns}	963.45**
Residual 1	16	8.50	0.002	216.01	0.28	0.0002	0.10	40.66	17.36
Days (D)	1	58.32**	0.01**	22.50^{ns}	1.48*	0.0009**	3.54**	0.68^{ns}	4598.73**
C × D	3	2.23^{ns}	0.001^{ns}	560.03**	2.59**	0.0001^{ns}	0.39**	110.25**	555.69**
Residual 2	16	3.57	0.001	63.33	0.22	0.00007	0.06	9.53	13.18
CV 1 (%)		18.78	18.35	5.86	8.79	22.76	12.80	10.89	9.54
CV 2 (%)		12.76	13.10	3.17	7.75	13.63	9.96	5.27	8.31
Mean (45 DAT)		16.74 a	0.28 a	250.15 a	5.90 b	0.06 a	2.86 a	58.43 a	32.96 b
Mean (95 DAT)		14.32 b	0.24 b	251.65 a	6.29 a	0.05 b	2.26 b	58.70 a	54.40 a

DF - Degrees of freedom; CV (%) - Coefficient of variation; *and ** - significant at $p \leq 0.05$ and $p \leq 0.01$ by the F test; ns - not significant

use efficiency, and instantaneous carboxylation at 45 DAT were higher by 58.62, 40.69, 45.76, 16.89, 16.67, 20.00, and 26.54%, respectively, compared to those found at 95 DAT (Tables 2 and 3). However, chlorophyll a, b, and total contents, transpiration rate, and relative water content were greater at 95 DAT. This occurred because the plants were at full flowering at 45 DAT and, therefore, had greater photosynthetic activity (Sousa et al., 2022), resulting in increased gas exchanges and chlorophyll fluorescence.

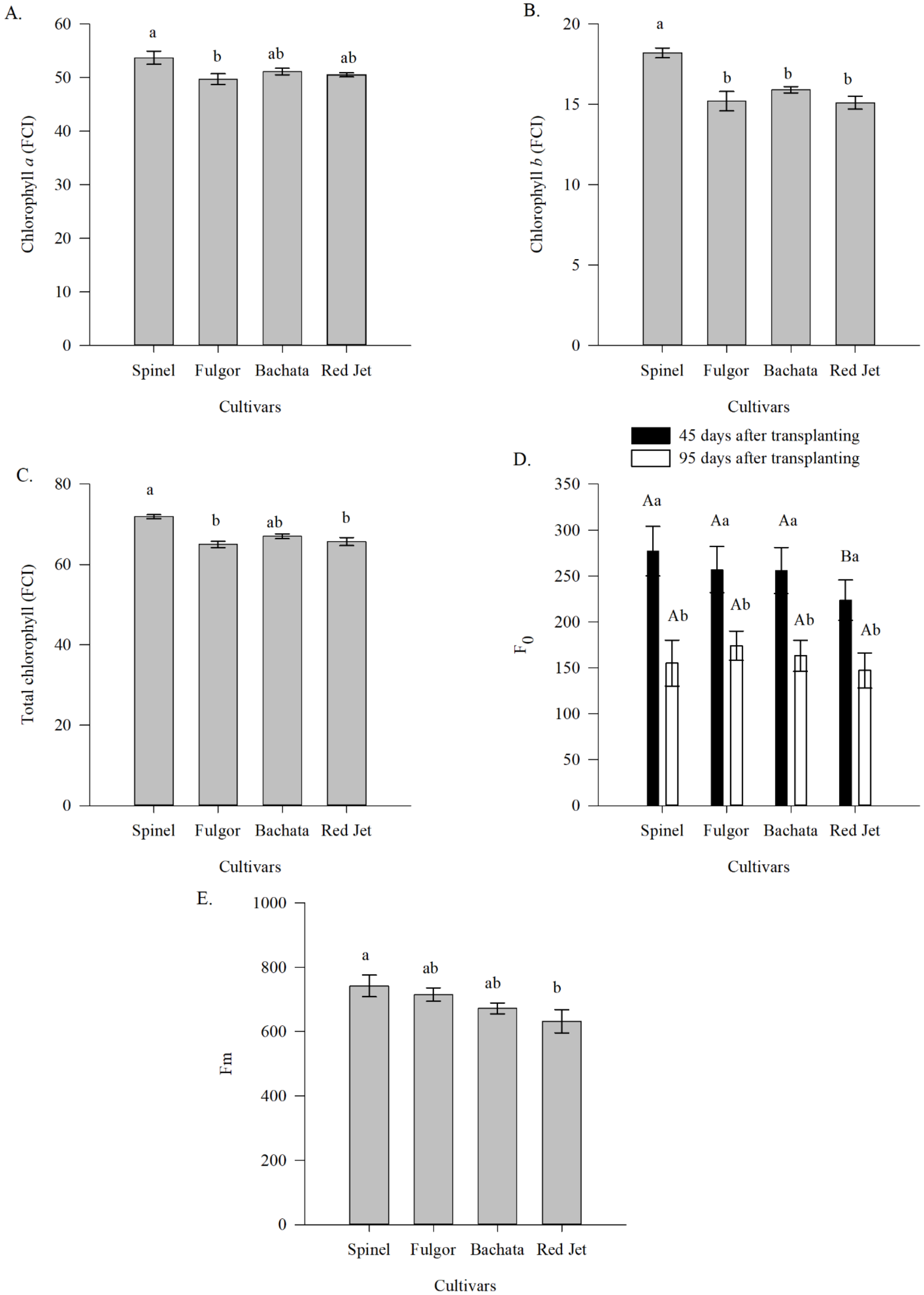
The chlorophyll a content in bell pepper plants was 7.45% higher for the cultivar Spinel compared to Fulgor (Figure 3A). Spinel presented significantly greater chlorophyll b content than the other cultivars (Figure 3B). The highest chlorophyll total was found for Spinel, differing significantly from Fulgor and Red Jet, which presented the lowest total chlorophyll contents (Figure 3C). Spinel bell pepper plants may have absorbed a greater amount of nitrogen than the others, as cultivars of the same species grown under the same nutritional conditions may differ in nitrogen use efficiency (Ibrahim et al., 2018), positively affecting chlorophyll contents. Moreover, chlorophyll index is used to indirectly estimate chlorophyll and N contents in leaves (Lang et al., 2020). Increases in chlorophyll contents in leaves triggers increases in photosynthetic activity, affecting plant growth and production (Ibrahim et al., 2018).

Bell pepper plants of the cultivars Spinel, Fulgor, and Bachata had higher initial fluorescence (F_0) at 45 DAT, significantly differing from Red Jet. However, no significant difference in F_0 was found among cultivars at 95 DAT (Figure 3D). Furthermore, all cultivars had higher F_0 at 45 DAT compared to 95 DAT. These greater F_0 values at 45 DAT indicate an increase in electron transport efficiency, which is usually associated with ideal conditions for photosynthesis (Ghassemi-Golezani et al., 2020).

The Spinel cultivar showed higher maximum fluorescence (F_m) than Red Jet (Figure 3E). Considering that Spinel plants presented the highest chlorophyll contents, they consequently had higher F_m. Maximum fluorescence is an indicator that represents the maximum intensity of fluorescence when practically all quinones and reaction centers are reduced, reaching their maximum capacity for photochemical reactions (Ghassemi-Golezani et al., 2020); therefore, plants of cultivar Spinel utilized available energy more effectively.

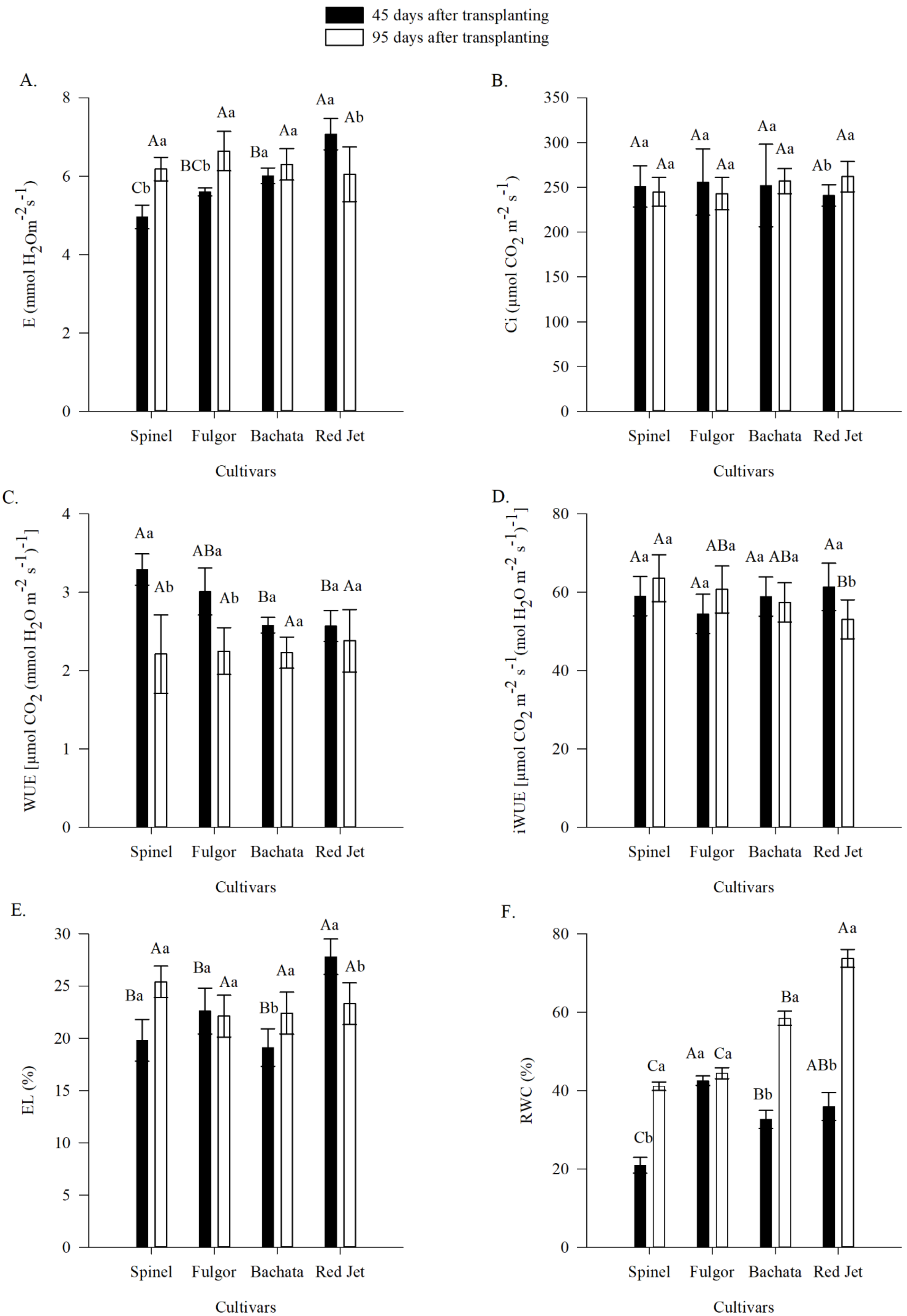
Bell pepper plants of the cultivar Red Jet showed higher transpiration rate compared to the other cultivars at 45 DAT. However, the evaluation at 95 DAT showed no significant difference among cultivars for this variable (Figure 4A). A higher transpiration rate causes stomata to open, consequently allowing greater water output, whereas stomata closure promotes water savings (Wagas et al., 2021), which is consistent with the results of water use efficiency, which was low in Red Jet plants.

The intercellular CO_2 concentration (*Ci*) of all cultivars did not differ significantly at 45 and 95 DAT; however, within



Bars with the same lowercase letters comparing evaluation stages within each cultivar, and uppercase letters comparing cultivars within each evaluation stages, are not significantly different from each other by the Tukey's test ($p \leq 0.05$). Vertical bars represent the standard error of the mean ($n = 5$)

Figure 3. Mean chlorophyll *a* (A), chlorophyll *b* (B), chlorophyll total (C), and maximum fluorescence - F_m (E) of colored bell pepper cultivars; and initial fluorescence - F_0 (D) as a function of evaluation stages (flowering, 45 days after transplanting - DAT; and fruiting, at 95 DAT)



Bars with the same lowercase letters comparing evaluation stages within each cultivar, and uppercase letters comparing cultivars within each evaluation stages, are not significantly different from each other by the Tukey's test ($p \leq 0.05$). Vertical bars represent the standard error of the mean (n = 5)

Figure 4. Transpiration rate - E (A), intercellular CO_2 concentration - Ci (B), water use efficiency - WUE (C), intrinsic water use efficiency -iWUE (D), electrolyte leakage - EL (E), and relative water content - RWC (F) of bell pepper cultivars as a function of evaluation stages (flowering, 45 days after transplanting - DAT; and fruiting, at 95 DAT)

evaluation stages, the cultivar Red Jet presented difference, with the highest *Ci* at 95 DAT (Figure 4B). Variations in physiological patterns among cultivars may be attributed to genotype variation in response to the environment, enabling the selection of superior cultivars (Sousa et al., 2019). This difference in *Ci* in plants of the cultivar Red Jet is due to increases in transpiration rate caused by a greater stomatal opening, resulting in a lower photosynthetic efficiency under semiarid conditions.

The cultivar Spinel showed higher water use efficiency (WUE) at 45 DAT compared to the other cultivars, whereas no significant difference was found among cultivars at 95 DAT. However, within evaluation stages, WUE was higher at 45 DAT (Figure 4C). High WUE indicates high net CO_2 assimilation and lower transpiration rate; this is interesting because pepper plants are sensitive to water stress (Kabir et al., 2021), thus, selecting cultivars with greater WUE promotes plant's adaptation to water stress conditions; therefore, the cultivar Spinel is an interesting alternative for growing bell peppers in semiarid regions.

The bell pepper cultivars did not significantly differ in intrinsic water use efficiency (iWUE) at 45 DAT (Figure 4D). However, Red Jet presented lower iWUE [53.10 μmol CO_2 m^{-2} s^{-1} (mol H_2O m^{-2} $s^{-1})^{-1}$] compared to Spinel [63.60 μmol CO_2 m^{-2} s^{-1} (mol H_2O m^{-2} $s^{-1})^{-1}$] at 95 DAT. This lower iWUE for Red Jet may be attributed to a greater stomatal opening compared to the other evaluated cultivars. Wen et al. (2023) reported that pepper cultivars differ in stomatal opening under the same environmental conditions, causing variation in photosynthesis patterns, consequently differing in iWUE, as it is based on CO_2 assimilation rate (*A*) and stomatal conductance (*gs*). Therefore, low *A* and high *gs* result in reduced iWUE.

Red Jet showed greater electrolyte leakage at 45 DAT, representing 40.40, 23, and 45.54% of those found for Spinel, Fulgor, and Bachata, respectively. However, the cultivars did not significantly differ at 95 DAT (Figure 4E). Regarding relative water content (RWC) in bell pepper plants (Figure 4F), Fulgor presented the highest RWC (42.50%) at 45 DAT, significantly differing from the others cultivars, whereas Spinel and Bachata showed the lowest RWC. However, Red Jet showed 79.31, 66, and 26.19% greater RWC at 95 DAT than Spinel, Fulgor, and Bachata, respectively. Additionally, plants of cultivars Spinel, Bachata, and Red Jet presented a significant increase in RWC from 45 to 95 DAT.

The increase in electrolyte leakage found for the cultivar Red Jet denotes stress conditions, possibly salt stress, as this cultivar may have absorbed more toxic ions, such as Na^+ and Cl^-, from salts applied by fertigation; a greater accumulation of macro and micronutrients may occur in closed hydroponic systems, and the absorption efficiency varies among cultivars of the same species (Singh et al., 2019). The excess of toxic ions in leaf tissues leads to increased electrolyte leakage due to cell membrane damage, and these responses differ among cultivars of the same species (Sousa et al., 2019). Consequently, RWC decreases, negatively affecting water use efficiency for the same cultivar (Red Jet).

Diameter, length, weight, pH, and soluble solids content of bell pepper fruits were significantly affected by the cultivar (Table 4), denoting variability in these parameters among bell pepper cultivars.

The largest mean fruit diameter (55.20 mm) was found for the cultivar Fulgor, while the smallest (52.60 mm) was found for Spinel (Figure 5A). Spinel and Fulgor had greater fruit lengths (13.08 and 12.70 cm, respectively) than the other cultivars Figure 5B). The highest total fruit weight per plant (1.55 kg per plant) was found for Fulgor, whereas the lowest (0.85 kg per plant) was found for Spinel (Figure 5C).

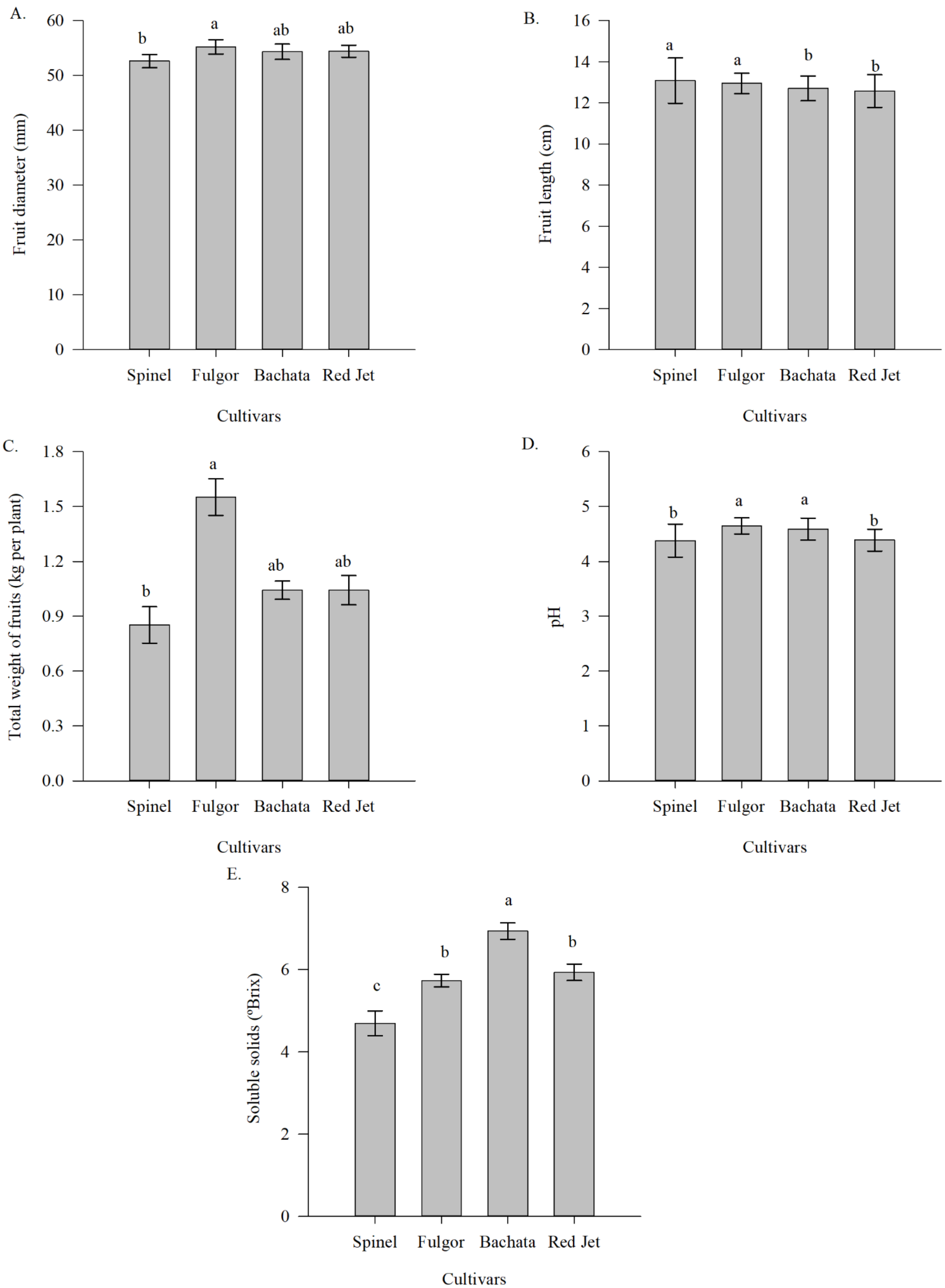
The cultivars exhibited different patterns regarding production variables. Fulgor showed longer fruits and greater total fruit weight and fruit pH. Fruit length and diameter are the main important characteristics in the commercialization of bell peppers (Souza et al., 2022). These attributes have a significant economic importance as they are essential for consumer evaluation, affecting the fruit attractiveness, choice, and consequently the purchase of the product (Leal et al., 2020).

Regarding the quality of bell pepper fruits, the highest pH levels (4.65 and 4.59) were found for the cultivars Fulgor and Bachata, respectively (Figure 5D). Bachata bell pepper fruits had greater soluble solids content (SSC): 6.93 °Brix (Figure 5E). SSC is an indicator of sugar contents in fruits (sucrose, fructose, and glucose), indicating that colored bell pepper fruits with greater SSC are sweeter (Bomfim et al., 2020). Therefore, the cultivar Bachata (yellow bell peppers) stood out in the present study regarding SSC, presenting similar results to those found by Bernado et al. (2018), who evaluated colored bell pepper cultivars and reported greater SSC for yellow bell peppers (8.2 °Brix). Lang et al. (2020) conducted a study for selecting colored pepper cultivars grown in a protected environment and found significant differences in pH and °Brix among cultivars: the highest and lowest pH (5.8 and 4.9) were found for Tequila and Archimedes, respectively, while the highest °Brix (8.4) was found for Summer Sweet and the lowest for Sirius.

Table 4. Analysis of variance for fruit diameter (FD), fruit length (FL), total fruit weight (TFW), pH, and soluble solids content (SSC) of bell pepper cultivars

Source of variation	DF	Mean squares				
		FD	FL	TFW	pH	SSC
Cultivars (C)	3	1,760.34**	124.64**	52.452*	0.03**	0.02**
Residual	16	359.84	13.11	16.99	0.001	0.001
CV (%)		13.7	20.3	17.2	0.7	20.3

DF - degrees of freedom; CV (%) - coefficient of variation; * and ** - significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, by the F test



Bars with the same letters are not significantly different from each other by the Tukey's test ($p \leq 0.05$). Vertical bars represent the standard error of the mean ($n = 5$)

Figure 5. Fruit diameter (A), fruit length (B), total fruit weight (C), pH (D), and soluble solids content (E) of bell pepper cultivars

Conclusions

1. Chlorophyll *a* and *b*, maximum fluorescence, and water use efficiency were higher in bell pepper plants of the cultivar Spinel.

2. The cultivar Bachata produced the sweetest fruits.

3. The cultivar Fulgor was the most suitable for growing under the studied conditions due to its greater fruit length and diameter and total fruit weight.

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