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IRRIGAÇÃO DE PIMENTAS-DE-CHEIRO *Capsicum frutescens* L. E *Capsicum chinense* Jacq. EM AMBIENTE AMAZÔNICO

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1 RESUMO

A irrigação é essencial no cultivo de pimentas em ambiente protegido, garantindo água suficiente para o desenvolvimento das plantas e maior produtividade. O manejo adequado mantém a umidade ideal, influenciando o crescimento, a qualidade dos frutos e a eficiência do sistema de produção. Assim, definir o momento de irrigar e a quantidade de água é fundamental para bons resultados. O objetivo deste trabalho foi identificar a tensão de água no solo para o início da irrigação em *C. frutescens* (Acemira®) e *C. chinense* (Lupita®) na Amazônia sul-ocidental brasileira. Adotou-se o delineamento inteiramente casualizado com os tratamentos distribuídos em esquema fatorial duplo 2 x 5 (cultivares x tensão da água no solo), com 5 repetições. Os tratamentos adotados para o início da irrigação foram 15 kPa; 30 kPa; 45 kPa; 60 kPa e 75 kPa. Para ambas as variedades, a produtividade da pimenta-de-cheiro decresceu com o aumento da tensão da água no solo e aumentou quando as plantas foram cultivadas com umidade próxima à capacidade de campo. Para otimizar o desenvolvimento vegetativo e produtivo das pimenteiras Acemira e Lupita, a irrigação deve ser iniciada quando a tensão da água no solo alcançar 15 kPa.

Palavras-chave: Solanáceas, gotejamento, tensão da água no solo.

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2 ABSTRACT

Irrigation is essential for chili pepper cultivation in protected environments, ensuring sufficient water plant supply development and increased productivity. Proper management maintains optimal soil moisture, directly influencing plant growth, fruit quality, and production efficiency. Therefore, determining the timing and amount of water to be applied is fundamental for satisfying the results. This study aimed to identify the soil water tension threshold for initiating irrigation in *Capsicum frutescens* (Acemira®) and *Capsicum chinense* (Lupita®) under the climatic conditions of the Southwest Brazilian Amazon. A completely randomized design was adopted, with treatments arranged in a 2 × 5 factorial scheme (cultivars × soil water tension), with five replications. The soil water tension levels for initiating irrigation were set at 15, 30, 45, 60, and 75 kPa. For both cultivars, the pepper yield decreased with increasing soil water tension and increased when the plants were grown under moisture conditions close to field capacity. To optimize the vegetative and productive development of the Acemira and Lupita pepper plants, irrigation should begin when the soil water tension reaches 15 kPa.

Keywords: Solanaceae, dripping, soil water pressure head.

3 INTRODUCTION

Peppers (*Capsicum*) are vegetables widely cultivated in Brazil because of their distinct flavors and nutritional composition (Dutra *et al.*, 2010). The genus *Capsicum*, belonging to the family *Solanaceae*, includes the species *C. annuum, C. assamicum, C. baccatum, C. frutescens, C. chinense and C. pubescens*. (Ramchiary *et al.,* 2013). Acre is located in the humid tropics near the equator in the western Amazon and is characterized by a humid tropical climate with high temperatures and relative humidity throughout the year, as well as abundant rainfall. In this region, the species C. frutescens and C. chinense are widely cultivated.

In the Amazon, peppers are traditional vegetables in the local diet; they are cultivated and sold primarily as fresh fruits, which are usually harvested at a ripe stage. Furthermore, they are widely used in preserves and sauces, providing distinctive aromas and flavors to regional cuisine, with much of their consumption linked to these sensory properties (Reifschneider; Ribeiro, 2008). Furthermore, they have potential medicinal uses. The species C. frutescens has demonstrated antihyperglycemic, antihyperlipidemic, and protective properties (Maya *et al.,* 2021). The species C. chinense contains compounds with anti-inflammatory effects and antioxidant activity (Chel -Guerrero *et al.,* 2022), as well as antifungal and antiparasitic properties (Menezes *et al.,* 2022).

The cultivation of these species is based on the traditional knowledge of local farmers, who maintain them in small areas of the Amazon (Pereira *et al.,* 2017). Given the socioeconomic importance of this crop for the region, investigating cultivation practices and irrigation management is essential, especially during periods of drought or dry spells. For a plant to achieve satisfactory production, an adequate supply of water is necessary throughout the entire growing cycle to meet its average water demands (Pandey *et al*., 2013).

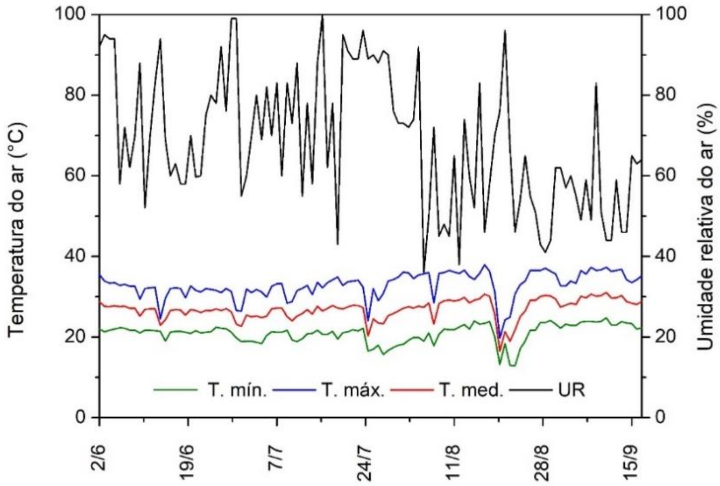
Agricultural producers face challenges at two distinct times of the year: during periods of high rainfall, excessive rainfall favors the emergence of pests and plant diseases; during dry periods, crop yields decline. In this context, protected cultivation has emerged as an effective alternative to increase and improve production, as it allows for the control of environmental conditions, enabling cultivation in adverse regions and climates (Nguyen; Lantzke, 2022). This system allows for production throughout the year, especially with the appropriate use of irrigation. This technique has been widely adopted by farmers in various regions of Brazil to cope with adverse weather conditions and achieve high-quality production.

Therefore, irrigation management is essential for meeting the water demands of plants, especially in protected systems. Understanding these interactions is essential to maximize growth and productivity, as well as to measure the effects of water stress. Research indicates that monitoring soil water tension favors the development and production of pepper plants by ensuring a balanced water supply and avoiding excess water. In this context, the objective of this study was to analyze the vegetative and productive performance of two varieties of sweet pepper—C. Frutescens (Acemira®) and C. chinense (Lupita®) were grown in a protected environment under different levels of soil water tension.

4 MATERIALS AND METHODS

The experiment was carried out in a greenhouse without environmental control in the municipality of Rio Branco, Acre, in the agricultural experimental area of the Federal University of Acre (UFAC), located on Highway BR-364, km 04 – Industrial District (9°57'35" S, 67°52'14" W; 163 m altitude). The local climate is hot and humid and is classified as Am according to Köppen (Alvares *et al.,* 2013). The region has an average annual temperature of 24.5 °C, relative humidity of approximately 84%, and annual precipitation of 1,700 to 2,400 mm, with a well-defined dry season. During the experiment, the minimum, average, and maximum air temperatures, as well as the relative humidity, were monitored by the Multi Sensor application (Android). The meteorological variables observed inside the greenhouse are presented in Figure 1.

Figure 1. Daily averages of air temperature and relative humidity during the period from 02/06/2020--15/09/2020 inside the greenhouse, UFAC, Rio Branco, Acre, 2020.



Source: Authors, 2019.

The soil of the experimental area is classified as Red–Yellow Argisol (Santos *et al.,* 2018). Two soil samples were collected at depths of 0--20 cm for chemical and physical analyses, with the following characteristics: pH (H_2O) = 4.6; K^+ = 62.6

mg dm^{-3}; Ca^{2+} = 1.6 cmolc dm^{-3}; Mg^{2+} = 0.8 cmolc dm^{-3}; B = 0.2 mg dm^{-3}; Cu = 0.3 mg dm^{-3}; Fe = 78 mg dm^{-3}; Mn = 2.1 mg dm^{-3}; Zn = 0.9 mg dm^{-3}; total sand = 420 g kg^{-1}; silt = 130 g kg^{-1}; and clay = 450 g kg^{-1}.

The pepper varieties used in this study were Acemira® (C. frutescens) and Lupita® (C. chinense), which were sown in 200 mL disposable plastic cups containing commercial organic substrate (Subras®). The seedlings were irrigated twice a day—early morning (7:00 am) and late afternoon (5:00 pm)—for 30 consecutive days. Transplantation into the soil was carried out after this period, when the seedlings were approximately 10 cm tall, vigorous, and healthy, according to Medeiros *et al*. (2010).

Forty days before transplanting, the soil was prepared through minimum tillage via a microtractor with a gross horsepower of 18 hp, coupled to a TA-49 rotary hoe with a working width of 750 mm, to disturb the soil and incorporate plant residues. Holes measuring 20 cm × 20 cm × 20 cm were subsequently dug manually. A dose of 10 t ha^{-1} of cured chicken litter was incorporated into the bottom of each well. A drip irrigation system was then installed, consisting of emitters with an average flow rate of 1.5 L h^{-1} spaced 20 cm apart in 16 mm diameter lateral lines connected to a 35 mm branch pipe. The system was pressurized via an Anauger® solar hydraulic pump powered by two 90 Wp photovoltaic panels with a manometric height of 40 mca and a flow capacity of up to 8,600 L d^{-1}.

Seedlings were transplanted on June 7, 2020 (dry season), with a spacing of 1.0 m × 0.75 m (equivalent to 13,333 plants ha^{-1}), totaling 25 plants per treatment. The dry plant residues from mowing the surrounding area were distributed on the soil surface along the planting rows as mulch.

The experiment followed a completely randomized design with a 2 × 5 factorial scheme (cultivars × soil water tensions), with five replicates. The treatments corresponded to the tensions adopted for the beginning of irrigation: 15 kPa (T1), 30 kPa (T2), 45 kPa (T3), 60 kPa (T4) and 75 kPa (T5).

For the first seven days, all the treatments received a 3.76 mm irrigation depth for 8 minutes to ensure seedling establishment. Starting on June 14, 2020, treatment differentiation began. For each treatment, irrigation was activated as soon as the soil water tension reached a preestablished value and was turned off when it returned to approximately 10 kPa.

The soil water tension for the 15 kPa treatment was monitored with Irrigás® sensors, whereas for the other treatments (30 to 75 kPa), puncture tensiometers with digital meters were used, all of which were installed at a depth of 20 cm.

The soil water retention curve was fitted from the sand and clay texture data according to Saxton *et al.* (1986). With the parameters obtained, Equation (1) was applied to estimate the current soil moisture, which was valid in the range of 0--100 kPa. The gross irrigation depth was determined via Equation 2, and the irrigation time was determined via Equation 3.

$$\Theta_a = 0{,}5483\ \mathrm{T}^{-0{,}211} \quad (\mathrm{R}^2) = 1 \qquad (1)$$

Θ_a: current soil moisture (cm^3 cm^{-3}), T: soil water tension (kPa).

$$\mathrm{L_b} = \left(\frac{\theta_{CC} - \theta_a * Z}{Ef}\right) \qquad (2)$$

L_b: gross depth (mm), Θ_{CC}: soil moisture at field capacity (cm^3 cm^{-3}), Θ_{actual}: soil moisture at the time of irrigation (cm^3 cm^{-3}), Z: irrigation depth of the root system (300 mm), Ef: water application efficiency (0.90).

$$\mathrm{T_i} = \left(\frac{60 * L_b * A}{e * qe}\right) \qquad (3)$$

Ti: irrigation time (min.), A: area occupied by the plant (m^2), E: emitters per plant (2), and qe: flow rate of each emitter (L h^{-1}).

Weed management was carried out manually, while preventive phytosanitary control consisted of the application of Indian neem oil (*Azadirachta indica* A. Juss.).

Two harvests were carried out: the first on September 1, 2020 (85 days after transplanting), when the fruits were ready for harvest, and the second on September 19, 2020 (104 days after transplanting), when the fruits were already ripe. The following variables were evaluated: average stem diameter (MSD, in mm), plant height (HP, in cm), number of stems per plant (SHP, unit), number of leaves per plant (SHP, unit), number of fruits per plant (SHP, unit), average fruit length (SHP, in cm), average fruit diameter (SHP, in mm), and fresh fruit weight (FHP, in g).

The data were subjected to the outlier verification test (Grubbs, 1969), analysis of the normality of the residuals via the Shapiro–Wilk test (1965), and evaluation of the homogeneity of the population variances via the Bartlett test (1937). The analysis of variance was subsequently performed via Fisher's test. The effects of soil water tension on the evaluated variables were represented by regression equations (Ferreira, 2019).

5 RESULTS AND DISCUSSION

The irrigation management of pepper plants according to the start of irrigation for different soil water tensions is presented in Table 1.

Table 1. Irrigation management parameters for the sweet pepper varieties Acemira® (*C. frutescens*) and Lupita® (*C. chinense*), which were irrigated by drip irrigation and grown in a greenhouse, UFAC/Rio Branco, Acre 2020.

Soil water tension (kPa)	Total irrigation (un.)	Irrigation time (min.)	Average interval between irrigations (days)
15	35	8	2
30	17	20	5
45	9	26	10
60	7	31	12
75	5	34	17

Source: Authors, 2019.

The treatment with the highest irrigation frequency was initiated at 15 kPa, with an 85.7% increase compared with the lowest frequency observed, which occurred at 75 kPa. With respect to the intervals between irrigations, the longest interval was recorded in the 75 kPa treatment, with irrigations performed, on average, every 17 days—a difference of 15 and 12 days, respectively, compared with the 15 kPa and 30 kPa treatments.

The Acemira® (*Capsicum frutescens*) and Lupita® (*Capsicum chinense*) pepper plants presented distinct vegetative and productive development patterns (Table 2). Irrigation initiated with a soil tension of 15 kPa provided better growth and production, surpassing other irrigation levels. Water deficiency compromises cell growth and essential physiological processes, resulting in water stress and a consequent reduction in development (Tognon, 2010). Ramos *et al.* (2021) corroborated this relationship by reporting that a tension of 20 kPa increased the average number of fruits.

Table 2. Average fruit length (cm), average fruit diameter (mm), average stem diameter (mm), number of leaves per plant (unit), plant height (cm) and number of stems (unit) per plant of sweet pepper Acemira ® (*C. frutescens*) and Lupita ® (*C. chinense*) as a function of different soil water tensions at the start of irrigation.

Varieties	CMF (cm)	DMF (mm)	DMC (mm)	NFP (un.)	AP (cm)	NHP (un.)
Acemira	5.9 a	19.5 to	9.6 a	113.2 a	74.1 a	4.4 a
Lupita	5.7 b	20.8 b	9.2 b	103.1 b	64.1 b	4.2 a
CV (%)	3.80	6.41	4.46	4.65	4.9	4.65

CMF: mean fruit length; DMF: mean fruit diameter; DMC: mean stem diameter; NFP: number of leaves per plant; AP: plant height; and NHP: number of stems per plant. Means followed by the same letter in the columns do not differ from each other, according to the F test at the 5% significance level.
Source: Authors, 2019.

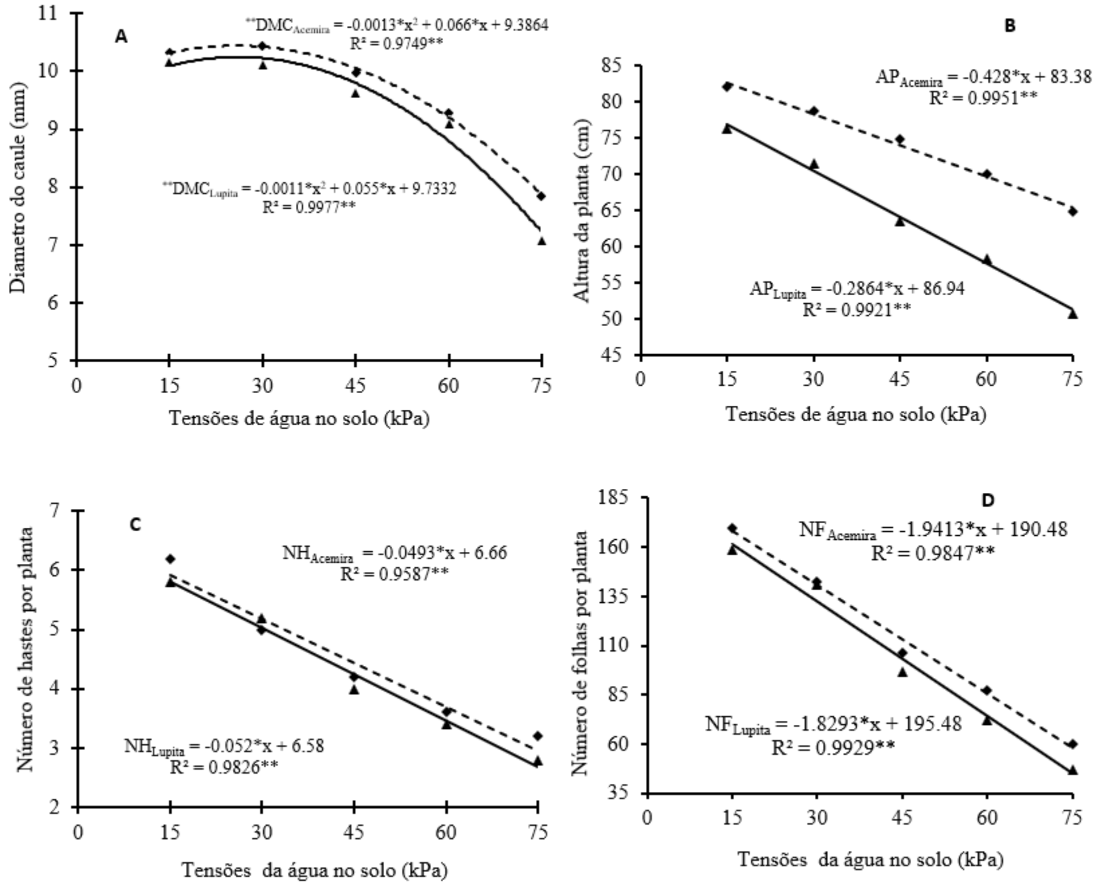
The results presented in Table 2 demonstrate significant differences in the growth and development of the Acemira® (*Capsicum frutescens*) and Lupita® (*Capsicum chinense*) varieties compared with each other. The Acemira® variety presented superior vegetative performance, with relatively high values for the mean fruit length (CMF), mean stem diameter (MSD), number of leaves per plant (NFP), plant height (AP), and number of stems per plant (NHP). These results indicate that Acemira® has more vigorous development than Lupita®, which may be a determining factor in the choice of cultivar for production systems that prioritize greater biomass and productivity.

The Lupita® cultivar presented a larger mean fruit diameter (MFD), suggesting an advantageous characteristic for markets that value larger fruits. Statistical analysis confirmed that all evaluated variables differed significantly between cultivars, according to the F test at the 5% significance level ($p < 0.05$).

These results reinforce the importance of varietal choice, since Acemira® stands out for its superior vegetative and productive development, whereas Lupita® has an advantage in terms of fruit size.

The variables DMC, AP, NHP, and NFP are also presented in Figure 2, allowing a clear visualization of the differences between varieties. Therefore, the choice of cultivar to be used should consider the cultivation objectives: whether to maximize vegetative growth and total fruit production (Acemira®) or to serve markets that value larger diameter fruits (Lupita®).

Figure 2. (A) Stem diameter, (B) plant height, (C) number of stems per plant, and (D) number of leaves per plant of Acemira® (*C. frutescens*) and Lupita® (*C. chinense*) pepper plants when irrigation was initiated at different soil water tensions, Rio Branco, Acre, 2020.



Source: Authors, 2019.

The R^2 values were significant at $p \leq 0.01$(**), indicating a strong fit of the regression models to the data. The DMC variable presented a quadratic trend line (Figure 2), with the maximum technical efficiency obtained when irrigation started at 30 kPa for the Acemira® (*Capsicum frutescens*) variety and at 15 kPa for the Lupita® (*C. chinense*) variety, resulting in average diameters of 10.4 mm and 10.2 mm, respectively.

Okunlola's findings *et al.* (2017) demonstrated a reduction in the development of species of the genus Capsicum at all stages of growth under water deficit, since water is essential for adequate physiological functioning. According to Paongpetch *et al.* (2012), the leaf area can be reduced by more than 50% under water stress, which is a good indicator of pepper plant productivity. These results reinforce the idea that water is a limiting factor for plant growth.

For the species *C. frutescens*, a reduction in water availability significantly decreased both the dry weights of the shoots and roots and the relative water content. On the other hand, there was an increase in water use efficiency (Siaga, 2020). Additionally, for this species, Zamlien *et al.* (2020) reported that water stress (50% of field capacity) reduces productivity and causes floral abscission, making a third harvest unfeasible.

With respect to the species *C. chinense*, Goto *et al.* (2021) reported that leaf water potential and stomatal conductance decreased with increasing water stress.

This reduction in stomatal conductance directly affects the rate of photosynthesis, negatively impacting productivity. Lathifah and Siswanti (2021) also reported that the interval between irrigations significantly influenced the productivity of this species.

With respect to NHP and DMC, they presented linear behavior, with the best responses obtained when irrigations were initiated at the lowest soil water tension, 15 kPa (Figure 2).

The number of leaves per plant (NFP) and plant height (AP) of *Capsicum chinense cultivars* were evaluated 138 days after sowing, and a decreasing linear response was observed with increasing soil water tension, with maximum values obtained when irrigation started at 15 kPa (Figure 2).

The minimum heights observed for the cultivars were 65 cm and 51 cm, respectively, under irrigation initiated at 75 kPa, representing percentage reductions of 21% and 32% in relation to the maximum values. This highlights the decrease in vegetative growth with increasing water stress (Figure 2). Similar results were reported by Lima *et al.* (2013), who reported an increase in the height of bell pepper plants with increasing irrigation depth.

The NFP behavior followed the same trend as that of AP, showing decreases with increasing soil water tension. Water stress directly interferes with cell expansion and elongation, and physiological processes are dependent on water availability, whose restriction paralyzes growth and reduces leaf area (Tognon, 2010).

Increased soil water tension reduces water availability, hindering plant absorption and leading to a decrease in vegetative size. Taiz and Zeiger (2013) emphasized that limited available water causes a decrease in leaf turgor, resulting in slower growth and, consequently, a decrease in leaf area.

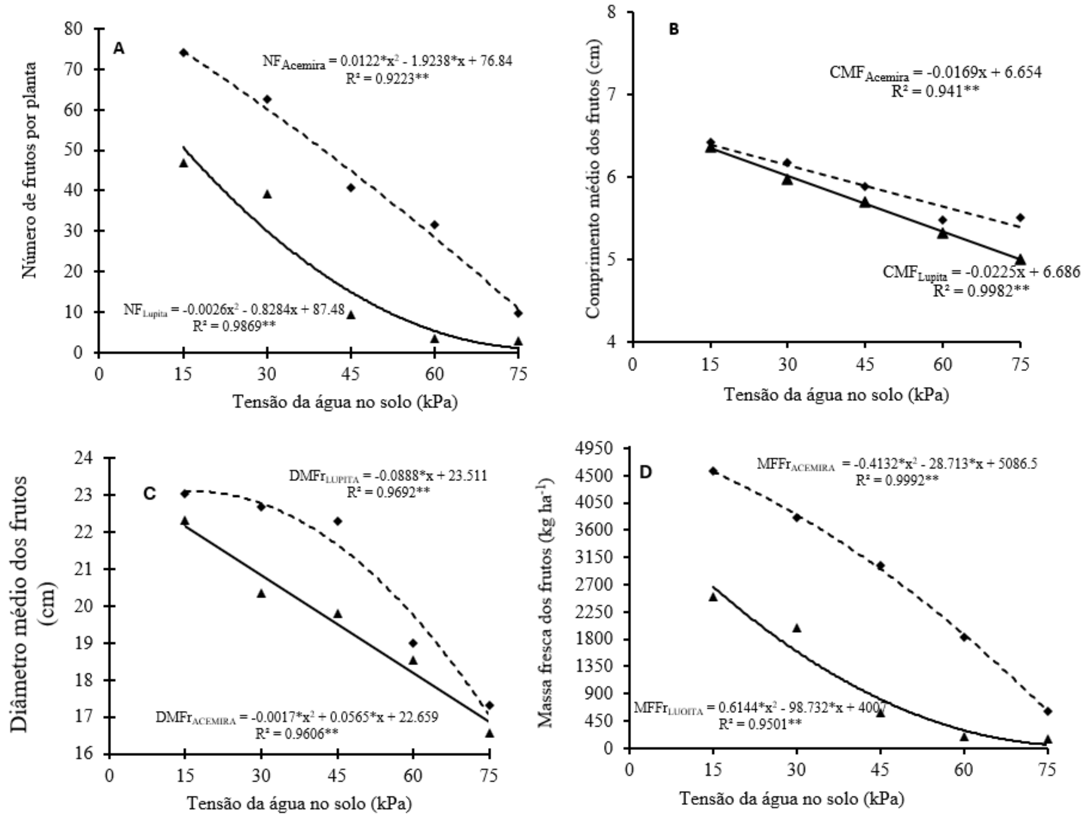
Lees *et al.* (2021) investigated the effects of acute water stress on the biochemical composition of bell pepper fruits and reported that stress at different stages of development delays fruit ripening and modulates the accumulation of bioactive compounds, which play a fundamental role in the redox status and osmotic adjustment of plants.

Okunlola *et al.* (2017) reported that, under water deficit, the development of plants of the genus *Capsicum* is compromised at all stages. According to Paongpetch *et al.* (2012), a reduction in leaf area of more than 50% under water stress is a good indicator of the physiological responses of pepper plants, with the leaf/stem and stem/root ratios also being useful as evaluation criteria under such conditions.

Most adaptive responses to drought allow plants to operate under conditions of limited resources, such as water and minerals (Poorter; Nagel, 2000). Furthermore, water scarcity compromises nutrient uptake—especially nitrogen and calcium—with significant negative effects on plant growth (Mcdonald; Davies, 1996).

The reduction in the number of fruits (NF) was an important factor that contributed to the decrease in productivity with increasing soil water tension (Figure 3). The cultivars Acemira ® (*C. frutescens*) and Lupita ® (*C. chinense*) presented relatively high productivity under irrigation initiated at 15 kPa and 30 kPa. Owing to these tensions, production was reduced by more than 30 percentage points in the other treatments.

Figure 3. (A) Number of fruits per plant, (B) average fruit length, (C) average fruit diameter, and (D) fresh fruit weight of Acemira® (*C. frutescens*) and Lupita® (*C. chinense*) pepper plants when irrigation was initiated at different soil water tensions, Rio Branco, Acre, 2020.



Source: Authors, 2019.

Increased soil water tension hinders plant water and nutrient uptake. This limitation contributed to a reduction in fruit set (FN) of approximately 86% for the Acemira® (*C. frutescens*) cultivar and 94% for the Lupita® (*C. chinense*) cultivar when the 15 kPa treatment was compared with the 75 kPa treatment. Low soil water availability is one of the main factors affecting plant growth and development, resulting in production losses of more than 60%, which significantly compromises crop yield (Rabara *et al.,* 2015).

Although the means were significantly different, the mean fruit length (MFL) was lower in both cultivars under irrigation initiated at 75 kPa, with a reduction of 0.90 cm (14%) for Acemira ® and 1.4 cm (22%) for Lupita ®, compared with irrigation initiated at 15 kPa.

The average fruit diameter (DMFr) did not significantly differ among the tested factors. Regardless of the cultivar, a positive response (greater fruit length and diameter) was observed for the reduction in soil water tension (Figure 3).

With respect to fresh fruit mass (MFFr), 139 days after planting (with harvests carried out on September 1st and 16th), the productivity results were influenced by the interaction between cultivar and soil water tension. Maximum productivity was obtained with irrigation initiated at 15 kPa: 4,576 kg ha $^{-1}$ for Acemira ® and 2,507 kg ha $^{-1}$ for Lupita ®. According to Fisher's mean comparison test ($p < 0.05$), Acemira® presented an increase of 2,069 kg ha $^{-1}$ (45%) in relation to Lupita ® under the same irrigation conditions.

Compared with irrigation started at 15 kPa, the production of the Acemira® cultivar was reduced by 87% (3,960 kg ha^{-1}). In relation to the 30 kPa treatment, the reduction was 16% (770 kg ha^{-1}).

For the Lupita® cultivar, the increase in irrigation frequency (35 irrigations in the 15 kPa treatment, compared with only 5 in the 75 kPa treatment) resulted in a 94% increase in production, representing an increase of 2,362 kg ha^{-1} (Table 1). These data show that the presence of water in the soil was a limiting factor for full productive development, reflected in the MFFr indices (Figure 3D).

The results obtained corroborate those of Caldas *et al*. (2016), who, when studying Cayenne pepper plants, reported that water deficit reduces vegetative growth and productivity, with the best responses obtained when the soil is maintained close to field capacity. The same authors reported that the difference between treatments with tensions of 120 kPa and 20 kPa resulted in a reduction of up to 479.39 g in the average mass of fruits per plant.

When the average production of the two cultivars was compared (Figure 3D), a significant difference was detected ($p < 0.05$). The Acemira® cultivar achieved a fresh fruit mass of 4,576 kg ha^{-1} under irrigation initiated at 15 kPa, whereas Lupita® obtained 2,507 kg ha^{-1}, indicating a greater than 40% reduction in productivity. At pressures of 45 kPa and 60 kPa, the Lupita® cultivar presented productivities that were 80% and 77% lower, respectively, than those of the Acemira® cultivar (Figure 3A). Therefore, under the conditions evaluated in this study, the Acemira® cultivar was the most productive.

6 CONCLUSION

Soil water tension significantly impacts the growth, development, and productivity of the sweet pepper cultivars Acemira® (*Capsicum frutescens)* and Lupita® *(Capsicum chinense*). To ensure the optimal vegetative and productive performance of these varieties, irrigation should begin when tension reaches 15 kPa. The Acemira® cultivar was the most productive and presented the greatest average fruit length, stem diameter, number of leaves per plant, plant height, and number of stems. On the other hand, the Lupita® cultivar presented fruits with a relatively large average diameter, a desirable characteristic for certain market niches.

Producers are recommended to adopt efficient irrigation systems, such as drip irrigation, along with soil water tension monitoring, with irrigation starting at 15 kPa. This approach favors increased productivity and improved fruit quality, in addition to minimizing losses related to water stress.

Furthermore, management practices such as mulching are recommended because they help conserve soil moisture and reduce irrigation frequency. Future studies should investigate different irrigation depths and the interactions between water regimes and fertilization strategies, with the aim of optimizing the productivity of sweet pepper cultivars under various growing conditions.

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