

Do exogenous application of thiamine mitigates low soil base saturation effects on bell pepper plants?

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ABSTRACT

The intensive use of land to produce vegetables results in high soil degradation and cultivated area. The use of techniques and resources that make production possible under unfavorable conditions can be decisive for agriculture. Thus, this study aimed to evaluate the isolated and joint effects of liming and thiamine application on the development of bell pepper plants. The treatments consisted of three different soil base saturation (36, 60, and 80%), combined with foliar application of thiamine (with and without) at a concentration of 100 mg L⁻¹. It was found that thiamine mitigates the effects of low base saturation on the physiological traits of bell pepper plants. The increments related to the water use efficiency and instantaneous carboxylation efficiency allowed greater development of plants treated with thiamine. In addition, the application of thiamine is advantageous in cases where planting is carried out under conditions of low base saturation, followed by an adequate supply of nutrients or systems in which there is a partial or total correction of the soil chemical characteristics, promoting the development of plants and increased physiological activity.

Keywords: Carbon fixation, Biostimulants, Soil management, Plant protection.

Aplicação exógena de tiamina ameniza os efeitos da baixa saturação de bases do solo sobre plantas de pimentão?

RESUMO

O uso intensivo do solo para a produção de hortaliças resulta em elevada degradação do solo e da área de cultivo. A utilização de técnicas e recursos que viabilizem a produção sob condições desfavoráveis pode ser decisiva para agricultura. Desta maneira, o objetivo deste trabalho foi avaliar os efeitos isolados e conjuntos da correção do solo e da aplicação de tiamina sobre o desenvolvimento das plantas de pimentão. Os tratamentos foram compostos por três diferentes saturações de base do solo (36, 60 e 80%), combinadas à aplicação de tiamina via foliar (com e sem) na concentração de 100 mg L⁻¹. Verificou-se que a tiamina ameniza os efeitos da baixa saturação por base do solo sobre as características fisiológicas das plantas de pimentão. Os incrementos relativos à eficiência do uso da água e da eficiência instantânea de carboxilação, possibilitaram maior desenvolvimento das plantas tratadas com tiamina. Em complemento, a aplicação da tiamina é vantajosa para casos em que o plantio é realizado em condições de baixa saturação por bases, seguida da oferta adequada de nutrientes ou sistemas em que há parcial ou total correção das características químicas do solo, promovendo o desenvolvimento das plantas e aumento da atividade fisiológica.

Palavras-chave: Fixação de carbono, Bioestimulantes, Manejo do solo, Proteção vegetal.



1. Introduction

Intensive land use for agricultural production results in high degradation of soil and cultivation areas. According to a 2015 report by the United Nations Food and Agriculture Organization (FAO, 2015), soil degradation is a serious problem that affects 33% of land worldwide. Several factors lead to soil degradation, normally occurring in two phases, the first being agricultural degradation and the second biological degradation (Nogueira et al., 2012).

The first type of degradation consists of an initial process, where the production system presents a loss of economic production. In this situation, there will be losses due to the reduced production potential of cultivated plants. In addition, biological degradation is the final process in which there is a significant reduction in the capacity to produce plant biomass (Nogueira et al., 2012).

In the soil, after successive cultivations, there is a decrease in its capacity to supply nutrients and beneficial elements in an amount necessary to maintain crop yield levels. Thus, some measures must be adopted that are carried out by applying correctives that preserve the physical, chemical, and biological characteristics of the soil since only in this way can the soil fertility, in a broader sense, be maintained (Freire and Freire, 2013).

The soil acidity is corrected by liming, which is the most economical and efficient way to correct the soil pH and still provides adequate amounts of Ca and Mg for the plants. It is important to emphasize that the correction of soil fertility is a determining factor in ensuring the efficiency of applied nutrients through the use of mineral or organic fertilizers (Freire and Freire, 2013).

In addition to limestone, agricultural gypsum and calcium silicates are used as soil conditioners. Agricultural gypsum works by providing soluble sulfate to the soil, which is a source of sulfur and is also a chemical soil conditioner, which, among other benefits, improves nutrient distribution and neutralizes active acidity in-depth (Freire and Freire, 2013). Moreira et al. (2017) evaluated the physiological performance of soybean genotypes cultivated at two base saturation levels (40% and 70%). These authors found that net photosynthesis, stomatal conductance, and transpiration were higher in genotypes grown in high base saturation.

Brignoni et al. (2020) reported in their research with sorghum plants that the nitrogen (N) content was severely affected in the condition of low base saturation (V% 15), and in the base saturation of 35% the nitrogen contents did not differ between sorghum hybrids or according to different base saturation. Patinni et al. (2020) conducted a study with soybean crops, in which F3 populations were evaluated without correction of base saturation (V = 30%) and with correction, in which lime was applied three months before sowing to increase the base

saturation to 60%. These authors indicated that the water use efficiency and agronomic performance of F3 soybean populations depend on the soil base saturation condition.

The insertion of techniques to improve the use of soil nutrients must be prioritized, paying attention to the increase in yield and the reduction of financial losses. Thiamine, or vitamin B1, also has potential for application in the production systems of cultivated species since it plays a role in plant protection (Goyer, 2010) as a promoter of the production of secondary metabolites, which act on photosynthetic tissues to prevent oxidation of its components (Kaya et al., 2015). It regulates carbon metabolism in protein synthesis (Kaya et al., 2015) and induces the accumulation of reserves in plant tissues (Barakat, 2003) and cellular metabolic processes such as coenzyme (Goyer, 2010), which is a conditioning of the development of vegetables (Taiz et al., 2017).

Based on the hypothesis that liming and foliar application of thiamine can act together, improving plant development capacity, this study aimed to evaluate the isolated and combined effects of liming and thiamine application on the development of bell pepper plants.

2. Material and Methods

The experiment was conducted in an experimental area in Cassilândia, Brazil, from April 23 to June 18, 2021, in a protected environment (agricultural greenhouse), with a galvanized steel structure, 8.00 m wide by 18.00 m long and 4.00 m high, covered with a 150-micron low-density polyethylene film and a thermo-reflective screen with 42-50% shading under the film.

The completely randomized design with three replications was used. The treatments consisted of three soil conditioning managements to obtain different base saturations (36, 60, and 80%), combined with thiamine application via foliar (with and without). To obtain base saturations of 60 and 80%, the calcined limestone (ECCE 180%) was used 15 days before planting. Also, ten days after lime application, the pots received 50 mL of nutrient solution containing: N (10%), P (9%), K (28%), Ca (18%), Mg (3.3%), S (4.3%), Fe EDDHA (6%), B (0.06%), Cu (0.01%), Mo (0.0746%), Mn (0.05%), and Zn (0.02%). The 40-day-old bell pepper seedlings were obtained from a certified nursery and transplanted into pots with a capacity of 1 L after the period of soil correction.

Then, a solution containing thiamine at a concentration of 100 mg L⁻¹ (Vendruscolo and Seleguini, 2020) or water (in the case of treatments without the application of the vitamin) were applied. The soil used is classified as Neossolo Quartzarênico, composed of 12.5% clay, 7.5% silt, and 80% sand. The soil chemical characteristics after liming are shown in Table 1.

Table 1. Chemical characteristics of the soil after liming.

Characteristic	Unit	Base saturation estimated		
		36%	60%	80%
pH	CaCl ₂	4.2	5.6	5.5
OM	g/dm ³	8.0	7.0	7.0
P _{resin}	mg/dm ³	4.0	3.0	3.0
Al ³⁺		6.0	0.0	0.0
H+Al		25	13.0	13.0
K		3.3	4.0	2.3
Ca	mmol _c /dm ³	7.0	12.0	22.0
Mg		3.0	8.0	13.0
SB		14.0	24.0	37.0
CEC		39.0	37.0	50.0
BS	%	35.7	59.5	79.8

OM = organic matter; SB = sum of bases; CEC = cation exchange capacity.

The plants were cultivated for 40 days without new nutrient inputs, when photosynthesis (*A*), stomatal conductance (*gS*), intracellular CO₂ concentration (*Ci*), and transpiration (*E*) were evaluated using a photosynthesis meter (LCi, ADC Bioscientific, Hertfordshire, UK) were evaluated in the middle third leaf of the plants. Also, the instantaneous carboxylation efficiency (*EICI*) was calculated using the *A/Ci* ratio, the water use efficiency (*WUE*) was calculated using the *A/E* ratio, and the relative chlorophyll content was obtained using a digital chlorophyll meter.

After the first evaluation, the application was repeated with 50 mL of the nutrient solution, followed by a new physiological evaluation 15 days after the application of nutrients (recovery period). After the physiological evaluation, the plants were partitioned and taken to the air-forced circulation oven at 65°C to obtain the dry mass of leaves, stem, shoot, root, and total. Data were submitted to preliminary normality and homoscedasticity tests. As the data all variables presented normal distribution and homogeneous variances, they were submitted to the analysis of variance. The significance of the mean squares obtained in the analysis of variance was tested by the F test at the level of 5% and 1% probability. The means of the treatments were submitted to the LSD test at a 5% probability level. Data analysis was performed using Sisvar software (Ferreira, 2014).

3. Results and Discussion

At 40 days after planting the seedlings, there was higher *Ci* for the treatment without liming and with the application of thiamine, both concerning the control treatment without application of the vitamin and the other treatments with foliar application and elevation of base saturation (BS) (Figure 1A). It was also observed that there was the superiority of *E* in the treatments in which thiamine was applied, as well as when there was an increase in BS (Figure 1B).

The influence of the interaction between the several factors was not observed on the *gS*; however, the elevation of BS level to 80% and the application of thiamine increased *gS* (Figure 1C). In addition, the characteristics of *A* and *EICI* were superior in treatments where the BS level was increased to 60% together with the application of the vitamin and in treatments in which liming was carried out to reach 80% of BS (Figure 1D, E). The soil correction to 80% of BS also raised the *RCI* concerning the other treatments (Figure 1F).

The increase in BS levels to 60% and 80% resulted in a reduction in the *WUE* by about 23.5% and 36.5%, respectively, concerning treatment without the use of limestone when there was no application of the thiamine. In addition, thiamine spray provided an average reduction of 43% in *WUE* compared to untreated plants (Figure 2). At 15 days after plant recovery with fertilization, it was found that the highest values of *Ci* continued to be observed for the combined treatment between the application of thiamine and the non-amendment of the soil on the other treatments with an application of vitamin and the control treatment without vitamin application. It was also found that when the BS was raised to 80%, the treatment without the application of vitamin was superior, both concerning the treatment with the application of thiamine and treatments with lower BS (Figure 3A).

The application of thiamine increased the *E*, *gS*, and *A*, when the soil was not corrected or when the BS was raised to 60% (Figure 3B, C, D). The increase in BS levels increased the characteristics of *E* and *gS* when thiamine was not applied. At the same time, for treatments with the application of the vitamin, there was a decreasing effect as the BS level was increased. In addition, it was found that *A* was higher when the vitamin was applied to plants grown without liming and when BS was increased to 60%, both concerning plants grown in 80% BS treated with thiamine and when compared to untreated plants.

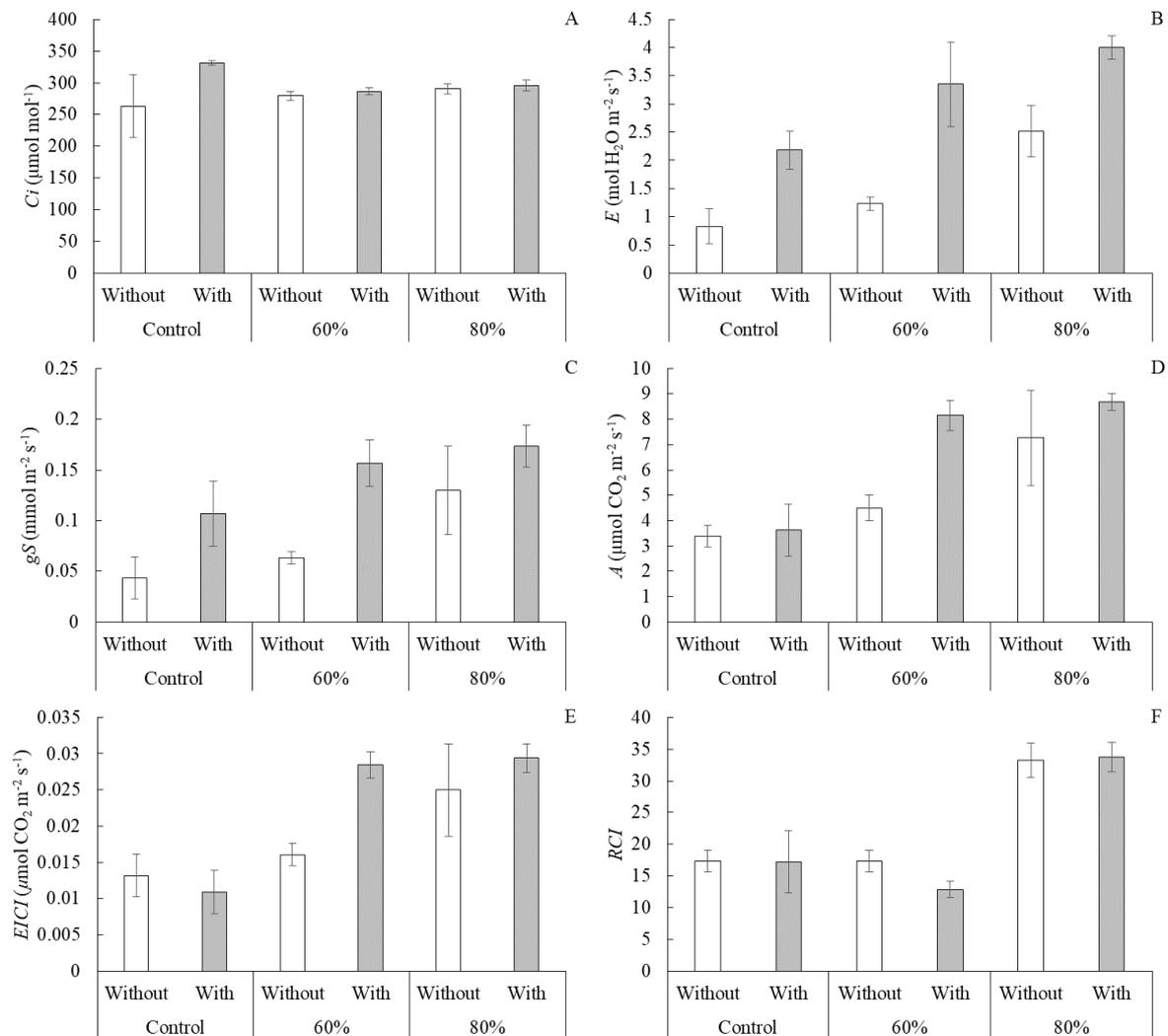


Figure 1. (A) Internal CO₂ concentration, (B) transpiration, (C) gas exchange, (D) net photosynthesis, (E) instantaneous carboxylation efficiency, and (F) relative chlorophyll index of bell pepper plants grown in different soil base saturation and thiamine application, 40 days after planting. Bars represent standard deviation (n = 3).

For EICI, the interaction between the factors was not observed; however, there was the superiority of the characteristic when the plants were grown in soil with BS of 60%, with no difference for the soil without liming, and when the plants were treated with thiamine. On the other hand, the RCI was favored by the increase in BS, regardless of the treatment with thiamine. Its application promoted higher RCI values in plants grown in soil without limestone or when there was an increase in BS to 60% (Figure 3F).

After fertilization recovery, a similar effect of BS increase and thiamine application was found compared to the first evaluation. In this sense, the increase in BS to 60% and 80% resulted in a reduction in the *WUE* by about 35.6% and 40.2%, respectively, concerning treatment without the use of liming when there was no application of the thiamine. In addition, thiamine spray provided an average reduction of 20.3% in *WUE* compared to untreated plants (Figure 4). The accumulation of dry mass of leaves, stems, and shoots

was favored by the increase in BS and the application of the vitamin when the plants were grown under conditions of BS of 80%. However, for the accumulation of dry mass in the roots, it was found that there was just a difference between the BS conditions, in which superior values were found when the liming was performed.

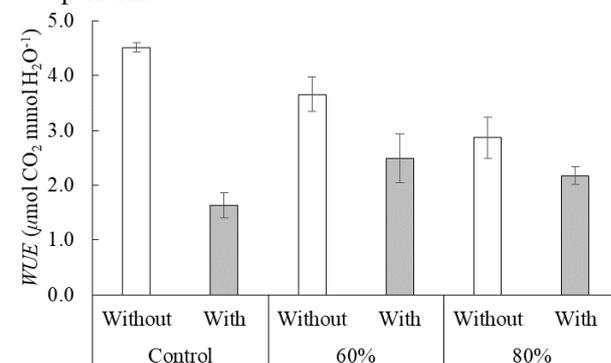


Figure 2. Water use efficiency of bell pepper plants grown in different soil base saturation and thiamine application, 40 days after planting. Bars represent standard deviation (n = 3).

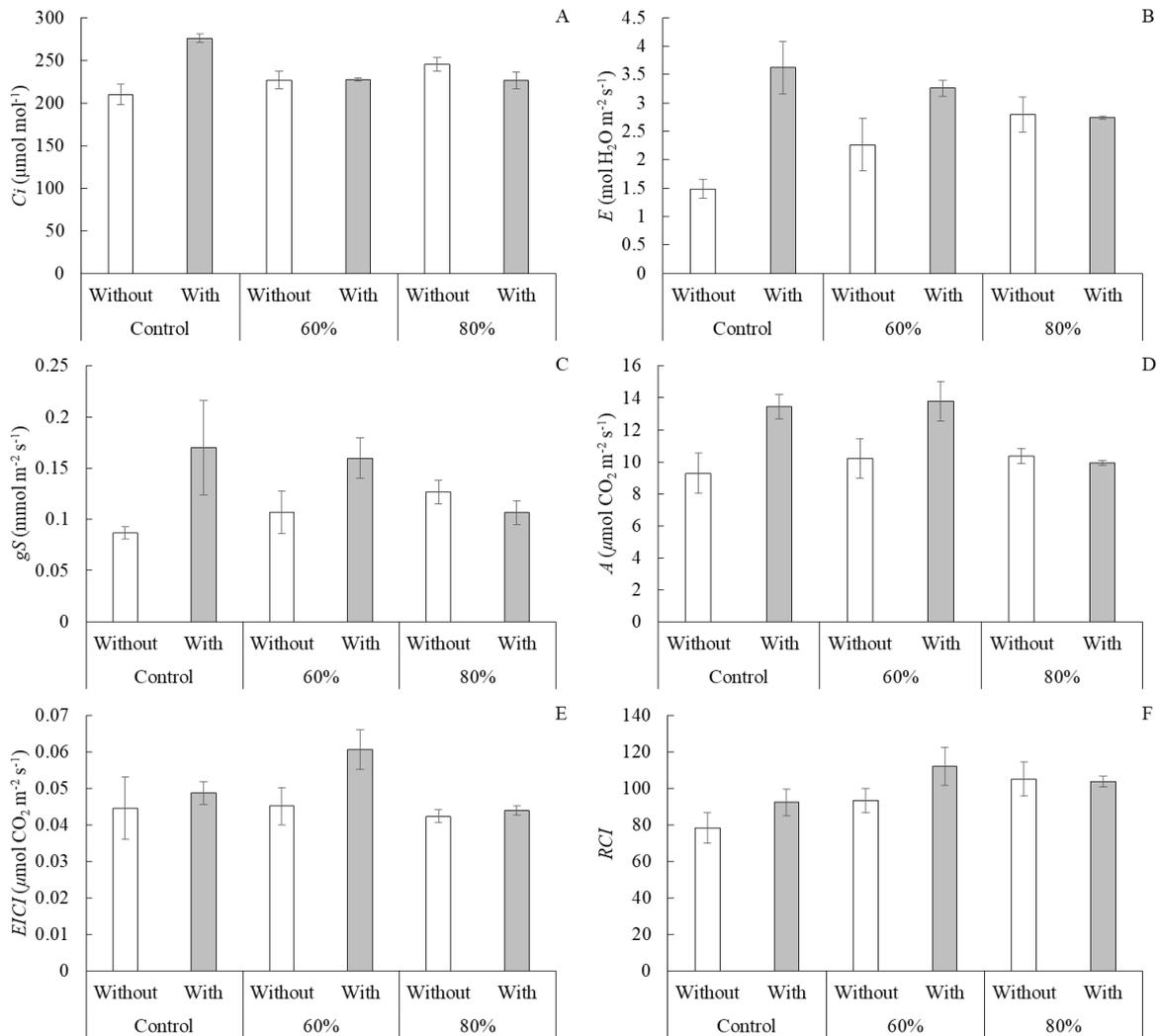


Figure 3. (A) Internal CO₂ concentration, (B) transpiration, (C) gas exchange, (D) net photosynthesis, (E) instantaneous carboxylation efficiency, and (F) relative chlorophyll index of bell pepper plants grown in different soil base saturation and thiamine application, 15 days after nutritional recovery. Bars represent standard deviation (n = 3).

In addition, for the total dry mass of the plants, it was found that both soil correction and the application of thiamine resulted in increases in this characteristic, and, as the BS was high, there was an increase in the total dry mass, as well as for the application of thiamine in all BS conditions (Figure 5). BS is a strong indicator of soil fertility; only a high value obtained in this parameter can indicate good nutrient availability (Ronquim, 2010).

In an experiment whose objective was to evaluate the influence of zinc doses and increasing soil base saturation on zinc availability for corn plants, it was found that base saturation influences the shoot dry mass of corn. The stem diameter did not show a statistical difference between treatments, but it can be noted that those with a greater amount of lime on the plants have higher results, in which the 80% treatment stood out among the others.

Brasil and Nascimento (2010) obtained similar results in terms of stem diameter with their base saturation treatments in passion fruit, in which treatments with higher amounts of lime had a greater

influence on the increase in diameter. The treatments did not show statistical variation in plant height, but the base saturation of 60% was the most suitable. The adequate growth performance related to phosphorus absorption is due to the action of limiting, which is essential during the development and maturation of plant organisms (Martins and Pitelli, 2000).

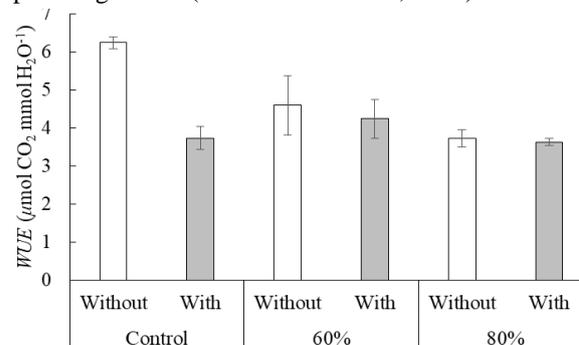


Figure 4. Water use efficiency of bell pepper plants grown in different soil base saturation and thiamine application, 15 days after nutritional recovery. Bars represent standard deviation (n=3).

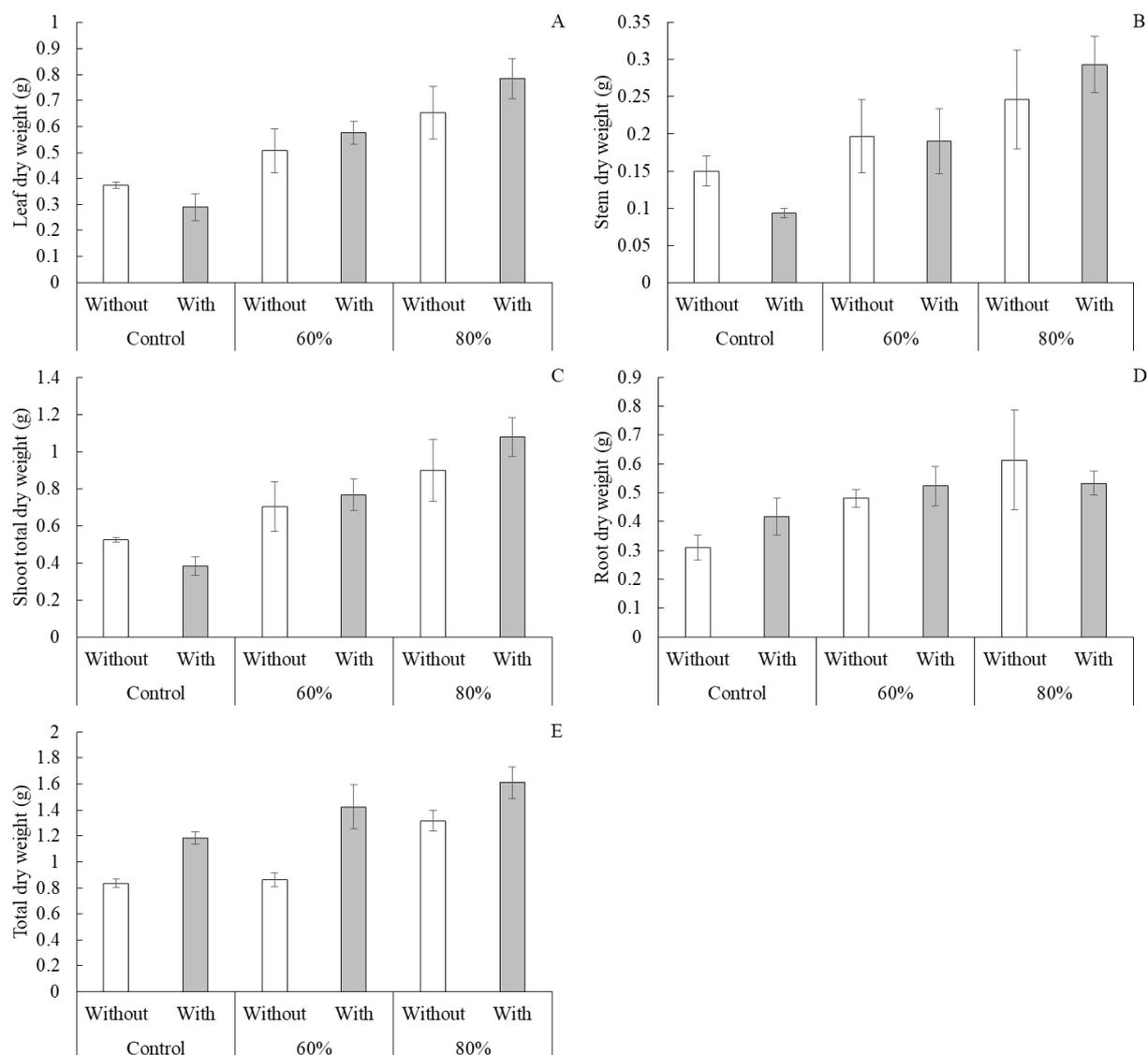


Figure 5. (A) Leaf dry mass, (B) stem dry mass, (C) shoot dry mass, and (D) root dry mass of bell pepper plants grown in different soil base saturation and thiamine application, 15 days after nutritional recovery. Bars represent standard deviation (n = 3).

Similarly, in another study, the biometry and dry mass production of bell pepper plants were evaluated according to the liming based on the base saturation method. Concerning the length and width of the leaves, there was no significant statistical variation; however, the treatment of 20% of BS limited the growth in length and 80% for the width. Therefore, the *Capsicum* genus was considered demanding concerning chemical characteristics of the soil (Ribeiro et al., 2020), which attributes such results to the improvement of soil characteristics caused by the application of limestone (Cardoso et al., 2014).

For the genus *Capsicum*, the gains in development when BS is increased is due to the occurrence of greater absorption of nutrients and thus having greater accumulation in the shoot, which is a result of a more favorable pH for the plant, influencing root development, also responsible for greater fruit production. For the number of fruits and the accumulation of phytomass in the roots and shoot, BS close to 60% significantly

increases (Cardoso et al., 2014). In addition to the negative interactions of nutrient absorption and low soil pH, the presence of higher levels of Al when soil pH is not corrected can also be highlighted.

This element has a deleterious effect on the development of pepper plants, resulting in lower development and morphological alteration of the leaf blade and stomata (Konarska, 2010). These results for pepper plants and other species of the Solanaceae family are related to the suppression of cell division, reduction of root development and nutrient absorption, destruction of cellular structures, and production of oxidative elements in plant organs (He et al., 2019). It was also found that the increase in soil pH enables greater resistance of plants to Al, minimizing such effects (He et al., 2019).

Along with the positive effects of increasing BS, the foliar application of thiamine represents a technology to be explored to improve the condition of developing bell pepper plants, regardless of the edaphic condition. In the

present study, the combination of an increase in the characteristics of gS , E , and A , caused by the application of thiamine, resulted in higher values of $EICI$ and a reduction of WUE , indicating that plants treated with the vitamin suffered less from the stress caused by the low BS. This was confirmed by the increased biometric characteristics, mainly due to the greater dry mass accumulation.

It is observed that plants subjected to stressful conditions of cultivation tend to have a lower gS , resulting in a decrease in gas exchange and, consequently, loss of photosynthetic capacity. Due to stomata closure, lower values of gS also limit water loss by plants, which increases WUE and decreases the plant development rate (Buesa et al., 2021; Hatfield and Dold, 2018). This makes it possible to refer to thiamine as a compound with a protective character, which allows the maintenance of the physiological activities of pepper plants even under stressful conditions.

According to Goyer (2010) and Martinis et al. (2016), the increase in the development and yield of plants treated by thiamine is mainly related to the proper regulation of photosynthesis and energy supply reactions. Kaya et al. (2015) observed that improved growth in thiamine-treated plants is associated with reduced membrane permeability, malondialdehyde and H_2O_2 levels, and altered activities of antioxidant enzymes such as catalase, superoxide dismutase, peroxidase, as well as increased concentration of photosynthetic pigment and PSII activity.

In a study with the corn crop, it was found that the foliar application of thiamine (100 ppm) increased the leaf area index, the number of green leaves, and delayed leaf senescence. Furthermore, biological traits and grain yield have been increased by thiamine, which has increased photosynthetic efficiency and canopy photosynthesis (Sahu et al., 1993). In a similar study, the application of thiamine significantly reduced the concentration of Na^+ but increased N, P, Ca^{2+} , and K^+ in corn (Kaya et al., 2015), while the application of thiamine in *Thuja orientalis* increased the percentage of N, P, and K (Abd El-Aziz et al., 2007).

Furthermore, thiamine can protect cell membranes and their binding transporter, leading to greater mineral absorption and translocation (Sayed and Gadallah, 2002; Mady, 2009). Its application also increases the solubility of nutrients in the rhizosphere of plants treated with vitamins through the secretion of organic acids in the soil, which is another reason for greater plant absorption (Abd El-Aziz et al., 2007). Results of the positive effect of thiamine application were also obtained for *Vicia faba* (Hamada and Khulaef, 2000), *Oryza sativa* (Bahuguna et al., 2012), and *Lupinus termis* (El-Awadi et al., 2016). In addition to the highlighted effects, the increases related to the application of the vitamin are directly related to the

increase in the profitability indexes of treated crops (Vendruscolo et al., 2018a and Vendruscolo et al., 2018b), making thiamine a potential technology to be explored by the agricultural sector as a plant growth-promoting vitamin.

4. Conclusions

Thiamine mitigates the effects of low soil base saturation on the physiological characteristics of bell pepper plants. However, the increase in physiological activity increases the nutritional requirement of plants, which results in less efficient assimilation of atmospheric carbon and, therefore, less plant development. In addition, the application of the vitamin is advantageous in cases where planting is carried out in conditions of low base saturation, followed by the adequate supply of nutrients or systems in which there is a partial or total correction of the soil chemical characteristics, promoting the development of plants and increased physiological activity.

Authors' Contribution

Eduardo Pradi Vendruscolo, Vitória Dantas Alves, Gabriela Rodrigues Sant'Ana, Fernanda Pacheco de Almeida Prado Bortolheiro, Murilo Battistuzzi Martins, contributed to the execution of the experiment, data collection, writing, interpretation and review of the manuscript. Cássio de Castro Seron, Maria Ingrid de Souza and Thaise Dantas contributed to the writing, interpretation and revision of the manuscript.

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