Arboriculture & Urban Forestry 2024
https://doi.org/10.48044/jauf.2024.001

Silicon Mitigates the Attack of Pests and Diseases on Ipê-Roxo (*Handroanthus impetiginosus*) Seedlings

By Talita Cristina Campos Pereira da Silva, Gustavo Haralampidou da Costa Vieira, Gabriela Moura Serafim, Kelly Gabriela Pereira da Silva, Suleiman Leiser Araujo, Edilson Costa, Flávio Ferreira da Silva Binotti, Eduardo Pradi Vendruscolo, Murilo Battistuzzi Martins

Abstract. Background: Silicon in plants is a structuring element that promotes water and saline stress tolerance and decreases transpiration. The silica accumulated in the cuticle establishes a physical barrier and helps fight against pests and diseases. The present study aimed to evaluate the development of ipê-roxo (*Handroanthus impetiginosus*) seedlings in different environments, and the application of potassium silicate and its efficiency in mitigating the attack of pests and diseases. Methods: The experiment was carried out in an agricultural greenhouse and under full sun with silicic doses of 0 and 7.15 mg per plant in a completely randomized design arranged in a 2 × 2 factorial scheme, with 6 replications of 4 seedlings per plot. Plant height, chlorophyll, stem diameter, number of leaves, shoot dry matter, root dry matter, total dry matter, height-diameter ratio, root-shoot ratio, root-plant ratio, Dickson quality index, disease severity, and pest intensity were evaluated. Results: Silicon application did not confer biometric qualities to the seedlings. The application of silicon conferred 24.6% higher protection against disease severity at a 90% probability level. The protected environment promoted 48.8% more protection against the attack of pests on the seedlings. The silicon application decreases the intensity of pests in the protected environment by 36.3%. Seedlings in a protected environment increase the production of chlorophyll but are 29.6% more susceptible to the severity of diseases. The full sun promoted greater diameters, phytomass, and Dickson quality index by 18%, 73%, and 195%, respectively. Conclusions: The best *Handroanthus impetiginosus* seedlings were obtained under full sun. Silicon mitigated the attack of pests and diseases on *Handroanthus impetiginosus* seedlings.

Keywords. Bignoniaceae Family; Shading; Silicate.

INTRODUCTION

Handroanthus impetiginosus of the Bignoniaceae family, a tree species native to Brazil that can reach from 20 to 35 meters in height, is mainly known as ipê-roxo (Silva et al. 2015). Its wood is used in the furniture industry, and the bark has pharmacological properties (Ferreira et al. 2017), but visually, the appearance of the canopy confers a rare beauty that stands out in landscaping projects when in full bloom. It is one of the most produced native species in nurseries for landscaping in urban afforestation and recovery programs for degraded forest ecosystems.

Handroanthus impetiginosus quality seedling production is very important to establish commercial production, as pharmaceutical industries explore the species as an adult because it contains compounds in its bark that have anti-inflammatory activities (Koyama et al. 2000), antioxidant compounds (Park et al. 2003), antibacterial agents (Park et al. 2005; Park et al. 2006), and substances with acaricidal potential (Jeon and Lee 2011).

Obtaining quality seedlings requires, respectively, adequate phytotechnical and phytosanitary management. These aspects give robustness and sanity to the plants for their initial post transplantation growth since, from the seed collection to the final destination of the seedling, the phytosanitary quality must be prioritized, as a result, healthy seedlings. Silicon application in seedlings aims to promote rigidity to epidermal tissues and decrease pest attack and tolerance to certain diseases (Ma and Yamaji 2008; Guntzer et al. 2012; Islam et al. 2020; Kendra and Nayaka 2022).

According to Silveira and Higashi (2003), using phosphite and silicon may decrease the severity of bacteriosis and improve the quality of forest nurseries seedlings, maintaining uniformity.

Silicon is efficient in plant development, morphology, and structure during growth, mainly in plants that accumulate this element (Silva et al. 2019), as well as tolerance to water stress, saline stress, and decreased perspiration (Oliveira et al. 2019; Zhang et al. 2020; Zuffo and Aguilera 2020). Silicon is used as a biologically active and important element in agriculture due to leaf application in the form of potassium silicate (Coskun et al. 2019), as the benefits of K_2SiO_3 for plants are known (Debona et al. 2017). Silicon in foliar application promotes more resistant, erect leaves, better use of incident radiation (Mendonça et al. 2013), and prevents chlorophyll oxidation in high light conditions (Cavalcanti-Filho et al. 2018).

The exogenous application of silicon (Si) potentiates plants against biotic and abiotic stresses (Vulavala et al. 2016; Rastogi et al. 2021; Ahmed et al. 2023), regulates genes related to photosynthesis, protecting it, in addition to protecting chloroplasts (Rastogi et al. 2021), increases antioxidant defenses and decreases oxidative stress, limiting the production of reactive oxygen species (ROS)(Ahmed et al. 2023). The accumulation of Si in the aerial part of plants varies considerably between species and the transport, mediated by transporter or by passive diffusion, is radial (Mitani and Ma 2005). Si fertilization in potato cultivation under water stress conditions increased Si only in the tuber skin, suggesting greater lignification and suberization. However, the putative Si transporter (StLsi1) was detected twice as much in leaves and roots with fertilization and 5 times more in leaves under Si drought conditions (Vulavala et al. 2016). The higher density of a radial transporter associated with a xylem transporter is responsible for the high accumulation of Si in rice (Mitani and Ma 2005), and the combination of Si with bioagents improves the performance of plants under water stress (Costa et al. 2023).

In studies with different silicon concentrations, orchids showed greater growth at concentrations of 0.5 and 2.0 mg/L of calcium silicate in a culture medium, in a growth chamber (Soares et al. 2012). In Dorneles et al. (2018), potatoes cultivated in a nutrient solution with a concentration of 0.5 mm Si (NaSiO3) promoted the best growth parameters. Foliar application of Si at concentrations of 0.5 and 1.0 g/L of potassium silicate increased photosynthesis and productivity of soybean, corn, and cotton (Souza-Júnior et al. 2022). In sorghum cultivation, concentrations of 0.88 g/L of stabilized silicic acid and 0.84 g/L of potassium silicate, in foliar applications, increased plant growth, reduced water loss by transpiration, and had a positive impact on gas exchange at the phenological stages V4 and V8 (4 and 8 fully expanded leaves, respectively) and R1 (beginning of flowering) (Oliveira et al. 2019).

In addition to proper phytosanitary management in seedling production, another important aspect is the production environment. This environment can be protected or not with adequate micrometeorological conditions that aim to provide a favorable environment for the initial growth of the plants. No reports were found in the literature on the application of silicon in the formation of ipê seedlings. Given the above, the present study aimed to evaluate the development of ipê-roxo (*Handroanthus impetiginosus*) seedlings in different environments and the application of potassium silicate and its efficiency in mitigating the attack of pests and diseases.

MATERIALS AND METHODS

The experiment was conducted in an experimental area of the State University of Mato Grosso do Sul (UEMS) in Cassilândia from 2017 October 17 to 2018 March 1. The region is located at an altitude of 516 m, −51°44′03″W, and −19°06′48″S (CASSILANDIA-A742 automatic station). The climate in this region is tropical with a dry season.

Two environments were evaluated, one in full sun (A1), where the seedlings were placed on wooden pallets so as not to come into contact with the ground, at an approximate height of 40 cm; and in an agricultural greenhouse (A2), measuring 18 m × 8 m × 4 m (144 m^2), covered with a 150-micron, low-density polyethylene (LDPE) film and a LuxiNet 42/50 aluminized thermo-reflective screen, movable, under LDPE film.

The silicon source used was the Protect Silifol® product (Tatu Agronegócios, São José do Rio Preto, Brazil)(12% silicon and 12% potassium (K_2O), density of 1.43 g/mL) in doses of 0 and 2.0 mL diluted in 2.4 L of water and applied with the aid of a manual sprayer at 90 and 120 days after sowing (DAS). Approximately 50 mL of potassium silicate solution was applied to each seedling, corresponding to 7.15 mg of Si per plant.

For producing *Handroanthus impetiginosus* seedlings, polyethylene plastic bags (15 × 25 cm) were used, with a capacity of 1.8 L, containing a substrate composed of 50% soil, 30% cattle manure, and 20% super fine vermiculite. Substrate characteristics were: pH ($CaCl_2$) = 4.6; Ca = 2, Mg = 3.4, Al = 0.15, K = 0.36 (cmolc/dm^3); Cu = 0.5, Fe = 159, Zn = 47 (mg/dm^3); organic matter (OM) = 36.1 (g/dm^3); cation exchange capacity (CEC) = 9.3 (cmolc/dm^3); base saturation = 65.2%; base ratio: Ca/CEC = 21.6%, Mg/CEC = 36.7%, H + Al/CEC = 37.8%.

The plastic bags from the agricultural greenhouse were arranged on benches 1.4 m wide by 3.5 m long and 1 m high from the ground, in full sun on wooden pallets. Three seeds were sown per 1.8 L plastic bag on 2017 October 17. After forming 3 definitive leaves, thinning was performed (with scissors), always leaving the seedling more developed.

At 130 DAS, plant height (AP) in centimeters, chlorophyll by the SPAD index (CH)(or relative chlorophyll index), stem diameter (SD) in millimeters, and number of leaves (NL) were collected. Also, shoot dry matter (SDM), root dry matter (RDM), and total dry matter were evaluated; the values were given in g/plant. The height-diameter ratio (HDR), shoot-root ratio (SRR), root-total ratio (RTR), and the Dickson quality index (DQI) were determined, the latter being obtained through the DQI calculation: DQI = (MST/[PH/SD] + MSA/RDM).

The level of disease severity and pest attack was also evaluated. As there are no diagrammatic scales in the literature for determining these levels, a scale was proposed according to the different degrees of manifestation of diseases and pest attacks (Figure 1), based on the diagrammatic scales proposed by Belasque Júnior et al. (2005) and Cunha et al. (2001), for citrus and coffee, respectively. For this, percentage levels of pest attacks and incidence of diseases on leaves were determined, with levels 0%, 25%, 50%, 75%, and 100% of leaves showing symptoms of pest and disease attack. Grades were allocated according to percentages, corresponding to 1, 2, 3, 4, and 5, respectively. The evaluations of pests and diseases were carried out separately, that is, one for disease and another for pest attack, always consulting the literature for better identification (Auer 2001).

The pests found on the seedlings of ipê-roxo seedlings in the present study were cochineal (*Ceroplastes sinensis*), pasture leafhopper (*Mahanarva fimbriolata*), silverleaf whitefly (*Bemisia tabaci*), and chrysomelids (Coleoptera: Chrysomelidae). The diseases incident on the ipê-roxo seedlings in the present study

Figure 1. Proposed diagrammatic scale for assessing disease severity and pest attack on *Handroanthus impetiginosus* seedlings. Scale proposed by the authors. (Adapted from Cunha et al. [2001] and Belasque Júnior et al. [2005]).

were wire blight (*Ceratobasidium ochroleucum*) and brown scab (*Apiosphaeria guaranitica*).

The seedlings were irrigated twice daily, in the morning and afternoon, when necessary. Mineral fertilization was performed according to substrate analysis at 45, 90 and 135 DAS, using the NPK 05:20:20 formulation.

During the experiment, at 10:00 a.m., photosynthetically active radiation (μmol m^2/s) was measured in the cultivation environments (Model MP-200, Apogee Instruments, Inc., Logan, UT, USA)(Figure 2). The air temperature (°C), relative air humidity (%), and global radiation (W/m^2) were recorded in data logger MOD.CDR-550 (Instrutherm®, São Paulo, Brazil) every 10 minutes. Ambiance data were compared in a randomized block design with 5 repetitions (each repetition was a month of collection, from October to February). The precipitation was 95 mm (October), 365.80 mm (November), 308.20 mm (December), 259.00 mm (January), and 133.20 mm (February), with a total accumulated of 1161.20 mm (INMET Sonabra).

The experiment was carried out in a completely randomized design (CRD), in a 2 × 2 factorial scheme (2 environments × 2 silicon doses), with 6 replications of 4 seedlings each. Data were subjected to analysis of variance (*F*-test) and means compared by LSD test at 5% probability. Disease data were also subjected to the LSD test at 10% probability. Disease severity and pest intensity data were transformed into the square root of (x + 0.5).

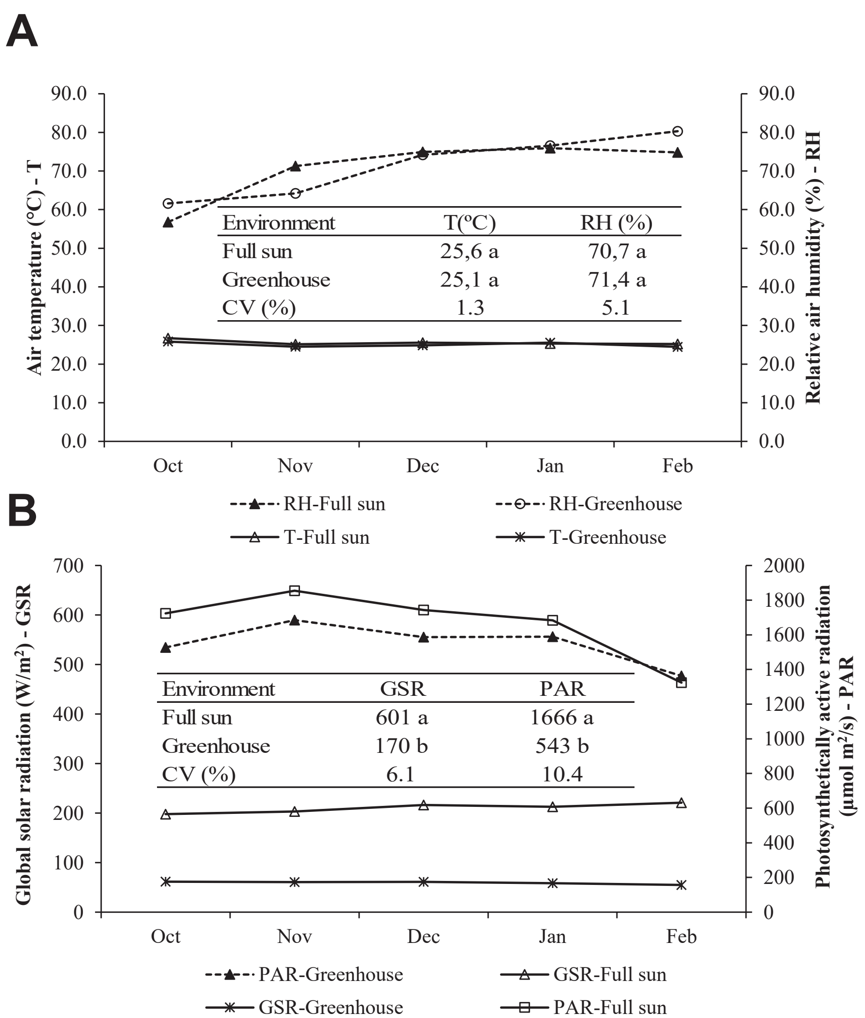

Figure 2. (A) Air temperature (T, °C) and relative humidity (RH, %); (B) Photosynthetically active radiation (PAR, μmol m^2/s) and global solar radiation (GSR, W/m^2) in production environments of *Handroanthus impetiginosus* seedling. CV = coefficient of variation.

RESULTS

The air temperature and relative humidity in the analyzed period were very similar in both environments, not differing significantly, even with great differences in radiation (Figure 2A).

Global solar radiation and photosynthetically active radiation in the full sun cultivation environment were 3.5 and 3.1 times higher than in the protected environment (Figure 2B).

Taller plants with smaller diameters and a greater relationship between these 2 variables (height-diameter ratio) were observed in the protected environment, and silicon did not influence these variables (Figure 3A).

The measured environmental conditions (Figures 2) associated with the rainfall in the period promoted *Handroanthus impetiginosus* plants with a higher number of leaves (Figure 3A), dry matter (Figures 3B and 4A), and Dickson quality index (Figure 4B) in the full sun environment. These variables were not influenced by silicon application, and it failed to influence the severity of diseases at a 5% level of significance and the biometric relationships of dry matter (Figure 3B).

Both the Dickson quality index (Figure 4B) and dry matter of the *Handroanthus impetiginosus* seedlings (Figures 3B and 4A) were not influenced by the application of silicon, and the best seedlings were formed in full sun. With a significance level of 10%—that is, with a 90% probability of occurrence—it was observed that silicon could minimize the severity of

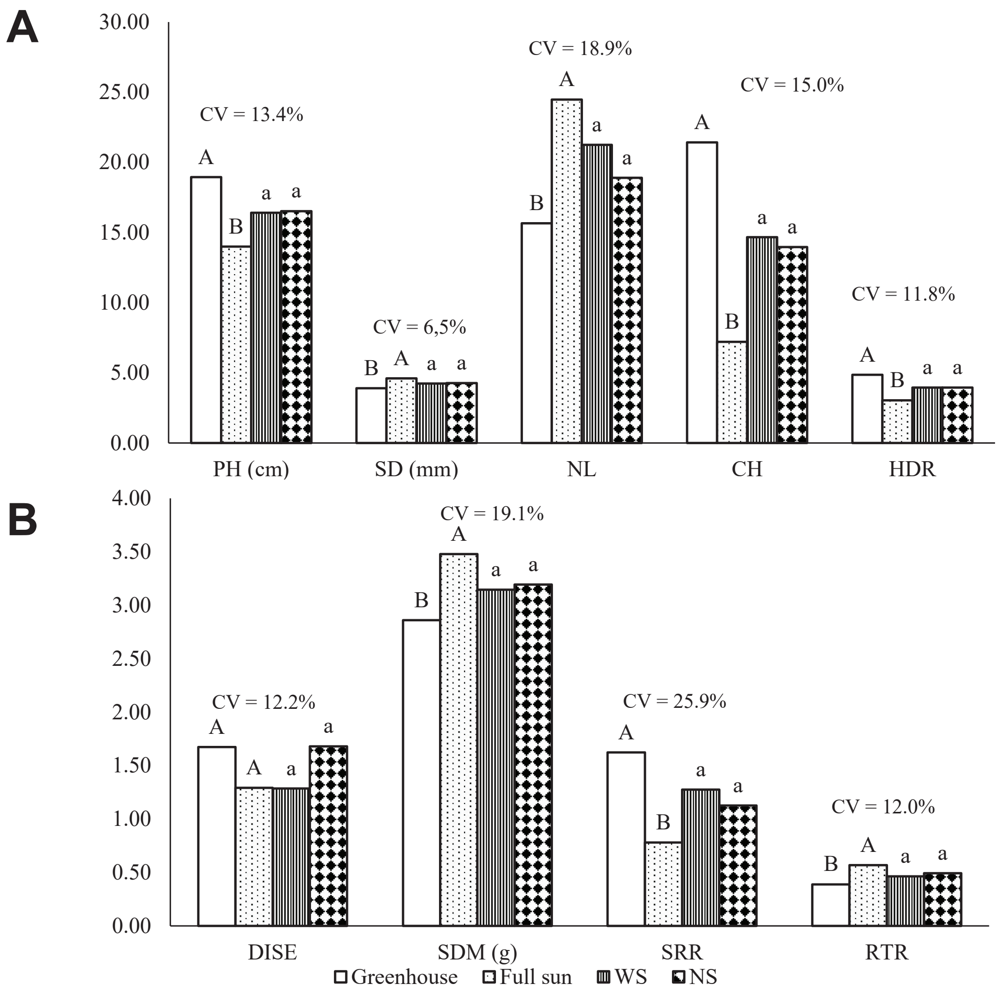

Figure 3. (A) Plant height (PH, cm), stem diameter (SD, mm), number of leaves (NL), relative chlorophyll index (CH), and height-diameter ratio (HDR); (B) The severity of disease (DISE), shoot dry matter (SDM, g), shoot-root ratio (SRR), and root-total ratio (RTR) of *Handroanthus impetiginosus* seedlings in production environments. Uppercase letters compare the environments for each variable. Lowercase letters compare the silicon doses for each variable. LSD test at 5% significance. WS = with silicon; NS = no silicon; CV = coefficient of variation.

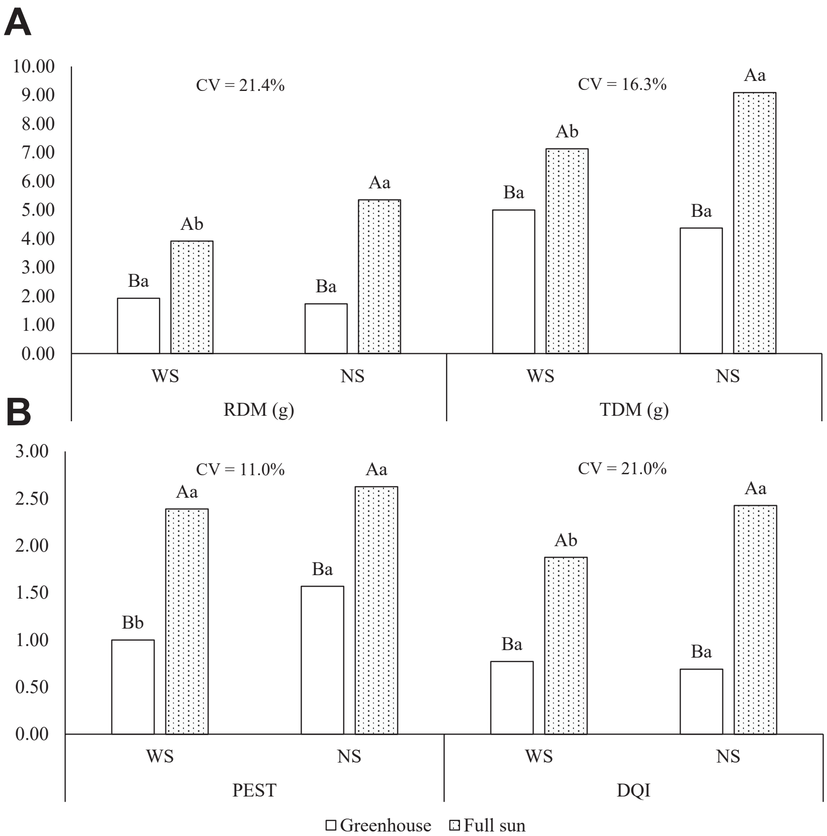

Figure 4. (A) Root dry matter (RDM) and total dry matter (TDM); (B) Intensity of pest attacks (PEST) and Dickson quality index (DQI) of *Handroanthus impetiginosus* seedlings in environments of cultivation and application of silicon. LSD test at 5% significance. Uppercase letters compare the environments inside the silicon for each variable. Lowercase letters compare the silicons within the environments for each variable. WS = with silicon; NS = no silicon; CV = coefficient of variation.

diseases in *Handroanthus impetiginosus* seedlings and that greenhouse seedlings were more susceptible (Figure 5).

DISCUSSION

In hot climate regions, such as the one in the present study, the temperature inside the protected environment is strongly related to the precipitation of the period, and the greater and better distributed over time, the more similar the monthly averages of internal and external temperatures (Silva et al. 2021b) as verified in the present study. In winter, the average monthly temperatures also tend to balance the internal and external environments (Paula et al. 2017). The more the irrigation system is used inside the environment covered with low-density polyethylene film, the more the thermal amplitude between it and the outside decreases.

The variation and reduction of global solar radiation and photosynthetically active radiation inside production environments, with significant differences, are related to the type of plastic covering film associated or not with the shading screen, as well as the individual use of the shading screen in coverage (Paula et al. 2017; Silva et al. 2021a; Silva et al. 2021b).

Solar radiation, air temperature, and relative humidity are the main environmental factors that influence plant physiology (Lambers and Oliveira 2019). The average temperatures of both environments (25 ºC) were within the appropriate conditions for the production of *Handroanthus impetiginosus* seedlings, which allowed the proper functioning of the stomata, carbon dioxide (CO_2) assimilation, and the catalytic activity of Rubisco (Bhatla and Lal 2018), thus, radiation conditions, as well as precipitation, were the ones that most influenced the formation of *Handroanthus impetiginosus* seedlings, altering their photosynthetic activities. Direct effects of solar radiation on plant photosynthesis affect energy absorption and transfer and cause changes in CO_2 assimilation, stomatal

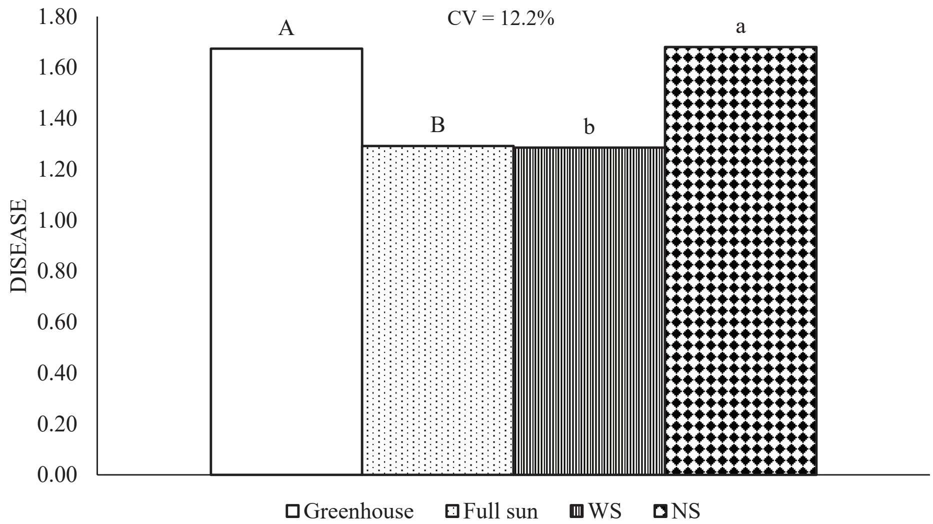

Figure 5. Severity of disease (DISEASE) in *Handroanthus impetiginosus* seedlings in production environments and application of silicon. Uppercase letters compare the environments for each variable. Lowercase letters compare silicons for each variable. LSD test at 10% significance. WS = with silicon; NS = no silicon; CV = coefficient of variation.

conductance, transpiration, carboxylation, stomatal conduction, and the difference between external and internal temperatures of environments (Cruces et al. 2017; Ribeiro and Coêlho 2021).

Larger plants, with smaller diameters and a greater relationship between these two variables, show that the protected environment had excessive shading and impaired seedling growth, as this excess promotes disorganized plant growth in search of light (Taiz et al. 2017), tending to etiolation and the plants show an inadequate coefficient of robustness.

Silicon did not influence the growth and development of *Handroanthus impetiginosus* seedlings, as verified in *Eucalyptus benthamii* seedlings (Schultz et al. 2012) and corn cultivation (Freitas et al. 2011). Silicon (Si) has been widely reported to increase the growth and yield of many important plant species (Guntzer et al. 2012), however, it did not influence the growth of *Handroanthus impetiginosus* seedlings. Silicon did not improve the quality of *Handroanthus impetiginosus* seedlings, unlike what was seen in tomato (Cao et al. 2015; Shi et al. 2016; Nunes et al. 2019) and sorghum (Ahmed et al. 2014) cultivation and in the mitigation of stress in corn (Freitas et al. 2011; Munaro and Simonetti 2016; Miranda et al. 2018).

As for pest attacks, both with and without silicon application, the protected environment mitigated the incidence of pests compared to the full sun environment due to the barriers imposed by the side screens. The application of silicon had a positive effect on the intensity of pest attack only in the protected environment, having no effect in the environment in full sun, and due to the physical mechanism, the plant incorporates the deposition of Si below the cuticle, which prevents the entry of pathogens and the activity food of insect pests (Islam et al. 2020). As with *Handroanthus impetiginosus* seedlings in the protected environment, the supply of Si in rice plants reduced the damage caused by the yellow stem borer, as it increased the Si content and caused the insect to have less preference for the plant (Ranganathan et al. 2006). Similar results occurred in sugarcane, where calcium silicate was beneficial for the plant, being resistant to *Diatraea saccharalis* (Anderson and Sosa 2001).

With a significance level of 10%—that is, with a 90% probability of occurrence—it was observed that silicon was able to minimize the severity of diseases in *Handroanthus impetiginosus* seedlings, as it influences the increase in physical blockages due to the deposition of Si in the cuticles and biochemical blocks by increasing enzymatic activities (Islam et al. 2020), in addition, it improves structural integrity and increases tolerance to disease, drought, and mineral toxicity (Kendra and Nayaka 2022).

The seedlings in the greenhouse were more susceptible, as in protected environments, diseases proliferate more quickly and can become more destructive (Vida et al. 2004). The diseases incident on the *Handroanthus impetiginosus* seedlings in the present study were white-thread blight (*Ceratobasidium ochroleucum*) and brown crust (*Apiosphaeria guaranitica*). However, a disease considered to be very important and severe that occurs in ipês, called rust, caused by fungi of the genus *Prospodium* (Figueiredo and Passador 2008), was not detected.

Seedlings in full sun were less susceptible to disease severity, as there is a greater exchange rate of air in an open environment, greater control by natural enemies, and, in the present study, the contribution given by silicon, which together mitigated the severity of diseases in this environment. In a protected environment, there is greater disease dissemination due to shading and local humidity, conditions more favorable to pathogens, especially brown crust, powdery mildew, and sooty mold (Wielewski et al. 2002).

The severity of the diseases is more aggressive in cultures of *Handroanthus impetiginosus* seedlings without silicon application, as the application brought positive and beneficial results for the species, as Si has the potential to form a double layer of cuticle, resulting in barrier protection against disease-causing pathogens (Ma and Yamaji 2008), as already observed in the induction of resistance of *Eucalyptus benthamii* to the incidence of powdery mildew (Schultz et al. 2012) and reduction of anthracnose in common bean with an application of calcium silicate (Moraes et al. 2006). Applications of liquid potassium silicate resulted in reduced powdery mildew severities in strawberries (Kanto et al. 2006) and grapes (Yildirim et al. 2002). Leaf and root applications of Si reduced powdery mildew severity on cucumber leaves (Lee et al. 2000). Liang et al. (2005) observed that silicon contributes to rice resistance to pests and diseases.

In addition to the activities previously described the participation of silicon, encompassing the direct action on the increase in resistance caused by the disposition of this element in plant tissues, is also observed in the action regarding the activation of specific genes, also related to the increase of resistance of plants to different environmental factors. In this sense, the presence of silicon modulates or increases the expression of genes related to plant defense against stresses caused by salinity, the presence of heavy metals, water deficit, diseases, and pests (Zhu et al. 2019; Souri et al. 2021), acting in a complex way in the plant defense of practically all forms of stress that can affect plants in the different growing conditions.

Knowledge about the genes that comprise the absorption and translocation of silicon in different plant species is also an important tool for plant genetic improvement since the increased expression of these genes will result in the entire range of responses mentioned above, improving the conditions for the development of species of agricultural interest, cultivated under different environments (Zargar et al. 2019).

CONCLUSION

The best *Handroanthus impetiginosus* seedlings were formed in full sun, with greater diameters, phytomass, and Dickson quality index, and the application of silicon did not influence the biometric variables. The protected environment promoted greater protection against pest attacks and increased the production of chlorophylls but allowed greater susceptibility to the severity of diseases in the *Handroanthus impetiginosus* seedlings. The silicon application decreases the intensity of pests in the protected environment and confers protection against disease severity at a 90% probability level. Silicon mitigated the attack of pests and diseases on *Handroanthus impetiginosus* seedlings.

LITERATURE CITED

Ahmed M, Asif M, Hassan F. 2014. Augmenting drought tolerance in sorghum by silicon nutrition. *Acta Physiologiae Plantarum*. 36(2):473-483. https://doi.org/10.1007/s11738-013-1427-2

Ahmed SR, Anwar Z, Shahbaz U, Skalicky M, Ijaz A, Tariq MS, Zulfiqar U, Brestic M, Alabdallah NM, Alsubeie MS, Mujtaba H, Saeed AM, Zahra T, Hasan MdM, Firdous H, Razzaq A, Zafar MM. 2023. Potential role of silicon in plants against biotic and abiotic stresses. *Silicon*. 15(7):3283-3303. https://doi.org/10.1007/s12633-022-02254-w

Anderson DL, Sosa O Jr. 2001. Effect of silicon on expression of resistance to sugarcane borer (*Diatraea saccharalis*). *Journal of the American Society of Sugar Cane Technologists*. 21:43-50. http://www.nutricaodeplantas.agr.br/site/downloads/unesp_jaboticabal/si_praga11.pdf#page=53

Auer CG. 2001. *Doenças em ipê*: Identificação e controle. Colombo-PR (Brazil): Embrapa Florestas. Documentos 67. 18 p. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/17077/1/doc67.pdf

Belasque Júnior J, Bassanezi RB, Spósito MB, Ribeiro LM, de Jesus Junior WC, Amorim L. 2005. Escalas diagramáticas para avaliação da severidade do cancro cítrico. *Fitopatologia Brasileira*. 30(4):387-393. https://doi.org/10.1590/S0100-41582005000400008

Bhatla SC, Lal MA. 2018. *Plant physiology, development and metabolism*. Singapore: Springer. 1237 p. https://doi.org/10.1007/978-981-13-2023-1

Cao BL, Ma Q, Zhao Q, Wang L, Xu K. 2015. Effects of silicon on absorbed light allocation, antioxidant enzymes and ultrastructure of chloroplasts in tomato leaves under simulated drought stress. *Scientia Horticulturae*. 194:53-62. https://doi.org/10.1016/j.scienta.2015.07.037

Cavalcanti-Filho PFM, Baitelle DC, Freitas SJ, Silva WS, Santos PC, Berilli SS, Freitas SP. 2018. Potassium silicate in the acclimatization of arabica coffee seedlings under shaded and full sun conditions. *Journal of Experimental Agriculture International*. 25(4):1-7. https://doi.org/10.9734/JEAI/2018/43307

Coskun D, Deshmukh R, Sonah H, Menzies JG, Reynolds O, Ma JF, Kronzucker HJ, Belanger RR. 2019. The controversies of silicon's role in plant biology. *New Phytoligist*. 221:67-85. https://doi.org/10.1111/nph.15343

Costa NB, Faria DR, Mendonça SM, de Moraes MG, Coelho GRC, de Filippi MCC, Bhosale R, de Castro AP, Lanna AC. 2023. Silicon and bioagents pretreatments synergistically improve upland rice performance during water stress. *Plant Stress*. 7:100142. https://doi.org/10.1016/j.stress.2023.100142

Cruces E, Rautenberger R, Rojas-Lillo Y, Cubillos VM, Arancibia-Miranda N, Ramirez-Kushel E, Gomez I. 2017. Physiological acclimation of *Lessonia spicat*a to diurnal changing PAR and UV radiation: Differential regulation among down-regulation of photochemistry, ROS scavenging activity and phlorotannins as major photoprotective mechanisms. *Photosynthesis Research*. 131:145-157. https://doi.org/10.1007/s11120-016-0304-4

Cunha RL, Pozza EA, Dias WP, Barretti PB. 2001. Desenvolvimento e validação de uma escala diagramática para avaliar a severidade da ferrugem *(Hemileia vastratix*) do cafeeiro. In: *Proceedings of the II research symposium on coffees in brazil*. 2nd Brazilian Coffee Research Symposium. Brasília-DF (Brasil): Embrapa/CNP&D-Café. p. 1101-1108. http://www.sapc.embrapa.br/arquivos/consorcio/spcb_anais/simposio2/doenca09.pdf

Debona D, Rodrigues FA, Datnoff LE. 2017. Silicon's role in abiotic and biotic plants tresses. *Annual Review of Phytopathology*. 55:85-107. https://doi.org/10.1146/annurev-phyto-080516-035312

Dorneles AOS, Pereira AS, Possebom G, Sasso VM, Rossato LV, Tabaldi LA. 2018. Growth of potato genotypes under different silicon concentrations. *Advances in Horticultural Science*. 32(2):289-295. https://www.jstor.org/stable/26525447

Ferreira FCS, Castro CEC, Barbosa CHG, Freitas CR, Dayrell DM, Castro DP. 2017. As plantas medicinais no bioma cerrado. *Revista Agroveterinária, Negócios e Tecnologia*. 2(1):52-69.

Figueiredo MB, Passador MM. 2008. Morfologia, funções dos soros e variações dos ciclos vitais das ferrugens. *Arquivos do Instituto Biológico*. 75(1):117-134. https://doi.org/10.1590/1808-1657v75p1172008

Freitas LB, Coelho EM, Maia SCM, Silva ERB. 2011. Adubação foliar com silício na cultura do milho. *Revista Ceres*. 58(2):262-267. https://doi.org/10.1590/S0034-737X2011000200020

Guntzer F, Keller C, Meunier JD. 2012. Benefits of plant silicon for crops: A review. *Agronomy for Sustainable Development*. 32(1):201-213. https://doi.org/10.1007/s13593-011-0039-8

Islam W, Tayyab M, Khalil F, Hua Z, Huang Z, Chen HYH. 2020. Silicon-mediated plant defense against pathogens and insect pests. *Pesticide Biochemistry and Physiology*. 168:104641. https://doi.org/10.1016/j.pestbp.2020.104641

Jeon JH, Lee HS. 2011. Acaricidal activity of *Tabebuia impetiginosa* bark-derived constituent against domestic and spider mites (Arachnida: Acari). *Journal of the Korean Society for Applied Biological Chemistry*. 54(4):551-557. https://doi.org/10.3839/jksabc.2011.084

Kanto T, Miyoshi A, Ogawa T, Maekawa K, Aino M. 2006. Suppressor effect of liquid potassium silicate on strawberry powdery mildew in the soil. *Journal of General Plant Pathology*. 72(3):137-142. https://doi.org/10.1007/s10327-005-0270-8

Kendra VK, Nayaka P. 2022. Effect of foliar spray of potassium silicate on growth and yield of paddy (*Oryza sativa* L.). *Annals of Plant and Soil Research*. 24(3):476-480. https://doi.org/10.47815/apsr.2022.10195

Koyama J, Morita I, Tagahara K, Hirai KI. 2000. Cyclopentene dialdehydes from *Tabebuia impetiginosa*. *Phytochemistry*. 53(8):869-872. https://doi.org/10.1016/S0031-9422(00)00028-5

Lambers H, Oliveira RS. 2019. Plant water relations. In: Lambers H, RS Oliveira, editors. *Plant physiological ecology*. 3rd Ed. New York (NY, USA): Springer. p. 28-48. https://doi.org/10.1007/978-3-030-29639-1_5

Lee JS, Park JH, Kim SK. 2000. Effect of soluble silicon on the severity of powdery mildew (*Sphaerotheca fuliginea*) in cucumber leaves. *Journal of the Korean Society for Horticultural Science*. 41:356-360.

Liang YC, Sun WC, Si J, Römheld V. 2005. Effects of foliar- and root-applied silicon on increasing powdery mildew-induced resistance in Cucumis sativus. *Plant Pathology*. 54:678-685. https://doi.org/10.1111/j.1365-3059.2005.01246.x

Ma JF, Yamaji N. 2008. Functions and transport of silicon in plants. *Cellular and Molecular Life Sciences*. 65(19):3049-3057. https://doi.org/10.1007/s00018-008-7580-x

Mendonça AO, Tavares LC, Brunes AP, Monzón DLR, Villela FA. 2013. Acúmulo de silício e compostos fenólicos na parte aérea de plantas de trigo após a adubação silicatada. *Bioscience Journal*. 29(3):1154-1162. https://seer.ufu.br/index.php/biosciencejournal/article/view/22432

Miranda OS, Moraes TR, Santos JRE, Carvalho FD, Viana JP, Pérez-Maluf R. 2018. Aplicação de silício na cultura do milho. *Revista de Ciências Agroambientais*. 16(1):1-6. https://doi.org/10.5327/rcaa.v16i1.1853

Mitani N, Ma JF. 2005. Uptake system of silicon in different plant species. *Journal of Experimental Botany*. 56(414):1255-1261. https://doi.org/10.1093/jxb/eri121

Moraes SRG, Pozza EA, Alves E, Pozza AAA, Carvalho JG, Lima PH, Botelho AO. 2006. Efeitos de fontes de silício na incidência e severidade da antracnose do feijoeiro. *Fitopatologia Brasileira*. 31(1):69-75. https://doi.org/10.1590/S0100-41582006000100012

Munaro MF, Simonetti APMM. 2016. Aplicação foliar de silício no milho 2 a safra: Influência na produtividade. *Revista Cultivando o Saber*. 9(4):145-154. https://www.fag.edu.br/upload/revista/cultivando_o_saber/58543456d5fad.pdf

Nunes AMC, Nunes LRL, Rodrigues AJO, Uchôa KSA. 2019. Silício na tolerância ao estresse hídrico em tomateiro. *Revista Cientifica Rural*. 21(2):239-258. https://doi.org/10.30945/rcr-v21i2.2658

Oliveira RLL, Prado RM, Felisberto G, Cruz FJR. 2019. Different sources of silicon by foliar spraying on the growth and gas exchange in sorghum. *Journal of Soil Science and Plant Nutrition*. 19(4):948-953. https://doi.org/10.1007/s42729-019-00092-1

Park BS, Kim JH, Lee SE, Kim KS, Takeoka GR, Ahn YJ, Kim JH. 2005. Selective growth-inhibiting effects of compounds identified in *Tabebuia impetiginosa* inner bark on human intestinal bacteria**.** *Journal of Agricultural and Food Chemistry*. 53(4):1152-1157. https://doi.org/10.1021/jf0486038

Park BS, Lee HK, Lee SE, Piao XL, Takeoka GR, Wong RY, Ahn YJ, Kim JH. 2006. Antibacterial activity of *Tabebuia impetiginosa* Martius ex DC (Taheebo) against *Helicobacter pylori*. *Journal of Ethnopharmacology*. 105(1-2):255-262. https://doi.org/10.1016/j.jep.2005.11.005

Park BS, Lee KG, Shibamoto T, Lee SE, Takeoka GR. 2003. Antioxidant activity and characterization of volatile constituents of taheebo (*Tabebuia impetiginosa* Martius ex DC). *Journal of Agricultural and Food Chemistry*. 51(1):295-300. https://doi.org/10.1021/jf020811h

Paula RCM, Silva AG, Costa E, Binotti FFS. 2017. Monitoramento de variáveis micrometeorológicas em diferentes ambientes protegidos no período de inverno. *Revista de Agricultura Neotropical*. 4(5):38-44. https://doi.org/10.32404/rean.v4i5.2210

Ranganathan S, Suvarchala V, Rajesh YBRD, Prasad MS, Padmakumari AP, Voleti SR. 2006. Effects of silicon sources on its deposition, chlorophyll content, and disease and pest resistance in rice. *Biologia Plantarum*. 50:713-716. https://doi.org/10.1007/s10535-006-0113-2

Rastogi A, Yadav S, Hussain S, Kataria S, Hajihashemi S, Kumari P, Yang X, Brestic M. 2021. Does silicon really matter for the photosynthetic machinery in plants…? *Plant Physiology and Biochemistry*. 169:40-48. https://doi.org/10.1016/j.plaphy.2021.11.004

Ribeiro JES, Coelho ES. 2021. Factores abióticos sobre aspectos ecofisiológicos de *Handroanthus impetiginosus* y *Handroanthus serratifolius*. *Valdivia*. 42(1):121-129. https://doi.org/10.4067/S0717-92002021000100121

Schultz B, Bora KC, Nogueira AC, Auer CG. 2012. Uso do silicato de potássio no controle de oídio em mudas de *Eucalyptus benthamii*. *Pesquisa Florestal Brasileira*. 32(69):93-99. https://pfb.cnpf.embrapa.br/pfb/index.php/pfb/article/view/286

Shi Y, Zhang Y, Han W, Feng R, Hu Y, Guo J, Gong H. 2016. Silicon enhances water stress tolerance by improving root hydraulic conductance in *Solanum lycopersicum* L. *Frontiers in Plant Science* 7(1):1-15. https://doi.org/10.3389/fpls.2016.00196

Silva AG, Costa E, Zoz T, Binotti FFS. 2021a. Micrometeorological characterization of protected environments for plant production. *Revista de Agricultura Neotropical*. 8(4):e6177. https://doi.org/10.32404/rean.v8i4.6177

Silva GH, Santos RV, Lucena RJ. 2015. Seedlings production of *Handroanthus impetiginosu*s (Mart. ex DC.) Mattos in substrate containing vermiculite co-product. *Scientific Electronic Archives*. 8(2):22-28. https://doi.org/10.36560/822015167

Silva LA, Salles JS, Cambui Neto LM, Costa E, Silva AG, Cavalcante DF, Binotti FFS, Zoz T. 2021b. Production of ornamental pyramid pepper with reflective material on benches in different environments. *Revista de Agricultura Neotropical*. 8(1):e4842. https://doi.org/10.32404/rean.v8i1.5698

Silva TTS, Spada G, Faria MF, Goulart LML, Furtado EL, Passos JRS, Guerrini IA. 2019. Fitossanidade e qualidade de mudas de *Eucalyptus urophylla* × *Eucalyptus grandis* em função da aplicação de fosfito e silício**.** *Summa Phytopathologica*. 45(3):332-336. https://doi.org/10.1590/0100-5405/184112

Silveira RLVA, Higashi EN. 2003. *Aspectos nutricionais envolvidos na ocorrência de doenças com* ênfase *para o eucalipto*. *Circular Técnica* IPEF. 200:1-13. https://www.ipef.br/publicacoes/ctecnica/nr200.pdf

Soares JDR, Pasqual M, Araujo AG, Castro EM, Pereira FJ, Braga FT. 2012. Leaf anatomy of orchids micropropagated with different silicon concentrations. *Acta Scientiarum Agronomy*. 34(4):413-421. https://doi.org/10.4025/actasciagron.v34i4.15062

Souri Z, Khanna K, Karimi N, Ahmad, P. 2021. Silicon and plants: Current knowledge and future prospects. *Journal of Plant Growth Regulation*. 40(3):906-925. https://doi.org/10.1007/s00344-020-10172-7

Souza-Júnior JP, Prado RM, Diniz JF, Guedes VHF, Silva JLF, Roque CG, Alvarez RCF. 2022. Foliar application of innovative sources of silicon in soybean, cotton, and maize. *Journal of Soil Science and Plant Nutrition*. 22:3200-3211. https://doi.org/10.1007/s42729-022-00878-w

Taiz L, Zeiger E, Moller I, Murphy A. 2017. *Fisiologia e desenvolvimento vegetal***.** 6th Ed. Porto Alegre (Brazil): Artmed. 888 p.

Vida JB, Zambolim L, Tessmann DJ, Brandão Filho JUT, Verzignassi JR, Caixeta MP. 2004. Manejo de doenças de plantas em cultivo protegido. *Fitopatologia Brasileira*. 29(4):355-372. https://doi.org/10.1590/S0100-41582004000400001

Vulavala VK, Elbaum R, Yermiyahu U, Fogelman E, Kumar A, Ginzberg I. 2016. Silicon fertilization of potato: Expression of putative transporters and tuber skin quality. *Planta*. 243(1):217-229. https://doi.org/10.1007/s00425-015-2401-6

Wielewski P, Auer CG, Grigoletti A. 2002. Levantamento de doenças em ipê-amarelo (*Tabebuia chrysotricha*) em Curitiba, PR. *Revista Floresta*. 32(2):277-281. https://doi.org/10.5380/rf.v32i2.2292

Yildirim A, Onogur E, Irshad M. 2002. Investigations into the efficacy of some natural chemicals against powdery mildew (*Uncinula necator* [Schw.] Burr.) of grape. *Journal of Phytopatholy*. 150(11-12):697-702. https://doi.org/10.1046/j.1439-0434.2002.00827.x

Zargar SM, Mahajan R, Bhat JA, Nazir M, Deshmukh R. 2019. Role of silicon in plant stress tolerance: Opportunities to achieve a sustainable cropping system. *3 Biotech*. 9(3):1-16. https://doi.org/10.1007/s13205-019-1613-z

Zhang Z, Fan J, Wu J, Zhang L, Wang J, Zhang B, Wang-Pruski G. 2020. Alleviating effect of silicon on melon seed germination under autotoxicity stress. *Ecotoxicology and Environmental Safety*. 188:109901. https://doi.org/10.1016/j.ecoenv.2019.109901

Zhu YX, Gong HJ, Yin JL. 2019. Role of silicon in mediating salt tolerance in plants: A review. *Plants*. 8(6):147. https://doi.org/10.3390/plants8060147

Zuffo AM, Aguilera JG. 2020. *Agronomia*: Avanços e Perspectivas. Nova Xavantina (Brazil): Pantanal Editora. 137 p. https://doi.org/10.46420/9786599120862

ACKNOWLEDGEMENTS

To the Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado do Mato Grosso do Sul—FUNDECT (FUNDECT/CNPq/PRONEM—MS, Process n. 59/300.116/2015—Nº FUNDECT 080/2015)—and to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

Talita Cristina Campos Pereira da Silva
Agronomy
University of State of Mato Grosso do Sul (UEMS)
Cassilândia-MS, Brazil

Gustavo Haralampidou da Costa Vieira
Agronomy
University of State of Mato Grosso do Sul (UEMS)
Cassilândia-MS, Brazil

Gabriela Moura Serafim
Agronomy
University of State of Mato Grosso do Sul (UEMS)
Cassilândia-MS, Brazil

Kelly Gabriela Pereira da Silva
Agronomy
University of State of Mato Grosso do Sul (UEMS)
Cassilândia-MS, Brazil

Suleiman Leiser Araujo
Agronomy
University of State of Mato Grosso do Sul (UEMS)
Cassilândia-MS, Brazil

Edilson Costa (corresponding author)
Agronomy
University of State of Mato Grosso do Sul (UEMS)
Cassilândia-MS, Brazil
edilson.costa@uems.br

Flávio Ferreira da Silva Binotti
Agronomy
University of State of Mato Grosso do Sul (UEMS)
Cassilândia-MS, Brazil

Eduardo Pradi Vendruscolo
Agronomy
University of State of Mato Grosso do Sul (UEMS)
Cassilândia-MS, Brazil

Murilo Battistuzzi Martins
Agronomy
University of State of Mato Grosso do Sul (UEMS)
Cassilândia-MS, Brazil

Conflicts of Interest:
The authors reported no conflicts of interest