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BIOLOGY

Organic compost in promoting growth and photosynthetic performance of *Pereskia aculeata* Mill. (Cactaceae) saplings

Nina Machado Suzigan[1] Gustavo dos Santos Cardoso[1] Nicole Almeida Barbosa[1] Giulianna Carolina Pincela da Costa[1] Geovana Gomes[1] Sara Dias Moura[1] Mônica Ellen Regis de Oliveira[1] Luiz Fernandes Cardoso Campos[2] Hyrandir Cabral de Melo[3] Letícia de Almeida Gonçalves[1,3*]

[1]Programa de Educação Tutorial Ciências Biológicas, Instituto de Ciências Biológicas, Universidade Federal de Goiás (UFG), 74690-900, Goiânia, GO, Brasil. E-mail: leticiaicbufg@ufg.br. *Corresponding author.
[2]Departamento Acadêmico de Agronomia, Universidade Federal de Rondônia (UNIR-Centro), Rolim de Moura, RO, Brasil.
[3]Departamento de Botânica, Instituto de Ciências Biológicas, Universidade Federal de Goiás (UFG), Goiânia, GO, Brasil.

ABSTRACT: *Pereskia aculeata*, commonly known as ora-pro-nóbis, is a Non-Conventional Food Plant (NCFP) native to Brazil. Considering the limited number of studies on species propagation and the importance of more sustainable practices for small-scale farmers, the objective was to evaluate the growth of *P. aculeata* saplings cultivated in substrates with different proportions of organic compost. The saplings were obtained by cuttings and cultivated in four distinct substrates, comprising three treatments and one control group. The substrates were prepared from a mixture of ant mound soil and commercial substrate, with the treatments determined by the amount of organic compost added. In the control group, no organic compost was incorporated, while in the other treatments, the compost represented 25, 50, and 75% of the total substrate mass. Mixed linear models were applied to morphological and physiological variables. It was possible to observe that, the higher the amount of organic compost in the substrate, the greater the growth of the shoots that developed from the cuttings, a result reflected primarily in the increased length and number of leaves on the largest branch, and the dry mass of the above-ground part. The rate of net photosynthesis and effective quantum efficiency of Photosystem II also significantly increased with the incorporation of organic compost into the substrate. It can be concluded that the addition of organic compost promoted the growth of *P. aculeata* cutting saplings, as well as their photosynthetic performance.
Key words: composting, unconventional food plants, ora-pro-nóbis, non-conventional food plant, sustainability.

Composto orgânico na promoção do crescimento e desempenho fotossintético de mudas de *Pereskia aculeata* Mill. (Cactaceae)

RESUMO: *Pereskia aculeata*, popularmente conhecida como ora-pro-nóbis, é uma Planta Alimentícia Não Convencional (PANC) nativa do Brasil. Considerando a baixa quantidade de trabalhos com a propagação da espécie e a importância de práticas mais sustentáveis voltadas para o pequeno agricultor, objetivou-se avaliar o crescimento de mudas de *P. aculeata* cultivadas em substratos com diferentes proporções de composto orgânico. As mudas foram obtidas por estaquia, e cultivadas em quatro substratos distintos, configurando três tratamentos e um tratamento controle. Os substratos foram preparados a partir da mistura de terra de formigueiro e substrato comercial, de forma que os tratamentos foram determinados pela quantidade de composto orgânico adicionado. No tratamento controle não foi incorporado composto orgânico, e nos demais tratamentos, o composto representava 25, 50 e 75% da massa total do substrato. Modelos lineares mistos foram aplicados a variáveis morfológicas e fisiológicas. Foi possível observar que, quanto maior a quantidade de composto orgânico no substrato, maior foi o crescimento das brotações que se desenvolveram nas estacas, efeito refletido, principalmente, pelo aumento do comprimento e do número de folhas do maior ramo, e da massa (fresca e seca) da parte aérea. A taxa de fotossíntese líquida e a eficiência quântica do fotossistema II também aumentaram significativamente com a incorporação de composto orgânico no substrato. É possível concluir que o incremento do composto orgânico promoveu o crescimento das mudas de *P. aculeata*, bem como seu desempenho fotossintético.
Palavras-chave: compostagem, desenvolvimento sustentável, ora-pro-nóbis, plantas alimentícias não convencionais, sustentabilidade.

INTRODUCTION

The world's population has been growing exponentially. According to the estimates of the United Nations, it is projected that the population may reach 10 billion people by 2050 (UN, 2019). To ensure food security for all without compromising natural resources, the adoption of more sustainable practices is necessary (WIJERATHNA-YAPA & PATHIRANA, 2022). Among the practices that can be adopted in agriculture, the use of organic composting and the introduction of Non-Conventional Food Plants (NCFP) in diets stand out.

The NCFP are edible plants with culinary uses, and their consumption, depending on their availability, can be limited to the population of a

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particular region or country, or even be used on the entire planet (KINUPP & LORENZI, 2021). The inclusion of these plants in the human diet can bring various benefits to health, to the environment, and society. This practice can certainly increase dietary diversity, promote sustainability, support the culture of local communities, and ensure food security and access to nutritious food, especially in regions facing food challenges (PADILHA et al., 2022).

Pereskia aculeata Mill. (Cactaceae), commonly known as ora-pro-nóbis, is a NCFP native to Brazil, with confirmed occurrences in the Northeast, Midwest, Southeast, and South regions of Brazil, primarily in the Caatinga, Cerrado, Atlantic Forest, and Pampa (ZAPPI & TAYLOR, 2020). Consuming *P. aculeata* is a viable alternative for those seeking a healthy diet. Its leaves are rich in bioactive compounds like proteins, phenolic compounds with antioxidant activity, vitamin C and vitamin A, folic acid, and high concentrations of Fe, K, Cu, Ca, Mg, Fe, Mn and Se (BARREIRA et al., 2021; MACIEL et al., 2021; SANTANA et al., 2018). As a result, it has been used, with good sensory acceptance, in recipes, such as in making bread (ALVES et al., 2021). Although, many studies explore the nutraceutical attributes of *P. aculeata*, few focus on its growing technology, and thus, specific properties inherent to the substrate that promote better plant development are not well-known.

Composting is used to transform various organic waste into fertilizer that, when added to the soil, improves its physical, chemical, and biological features, which can promote both an increase in nutraceutical properties and the plant growth itself (MIYAMOTO et al., 2023; ROUSSOS et al., 2022; VERRILLO et al., 2023). The use of compost is a relatively simple practice that, when compared to mineral fertilization, can significantly reduce production costs (FILHO et al., 2007). The use of composting products is an important strategy for promoting more sustainable agriculture, ensuring cost and waste reduction, nutrient recycling and biodiversity conservation. Moreover, the economic, environmental, and social benefits of the process contribute to sustainable development, a fundamental principle of current public policies aiming to provide well-being and quality of life to citizens (COSTA et al., 2015).

Considering the importance of *P. aculeata* for human nutrition and health, and the limited number of studies that contribute to guiding its technified growing, the objective of this study was to investigate the development and photosynthetic performance of cutting seedlings grown in substrates with different concentrations of organic compost.

MATERIALS AND METHODS

The experiment was conducted between the months of June and August 2022, in a greenhouse at Universidade Federal de Goiás, Instituto de Ciências Biológicas, Departamento de Botânica, in Goiânia-GO, Brazil (791 m, 16º36’11.9”S 49º15’35.2”W) (Google Earth; n.d.). The greenhouse was 12 meters in length, 5.3 meters in width, and 3.0 meters in height. The average temperature during the period was 22 ºC, with 50 mm of precipitation, and 55% relative humidity (CPTEC/INPE; 2019). The seedlings were irrigated by automatic sprinkler three times a day (8 AM, 12 PM, and 6 PM).

The seedlings were propagated by stem cuttings from parent plants cultivated at Universidade Federal de Goiás, Horta da Escola de Agronomia, Campus Samambaia, Goiânia-GO, Brazil. For standardization, only cuttings collected from the middle regions of the branches and containing four axillary buds were considered.

The growing substrates were prepared from mixtures, in different proportions, of the following materials: 1. Anthill soil, obtained from the flowerbed between Instituto de Ciências Biológicas I and Centro de Convivências, at Universidade Federal de Goiás, Campus Samambaia; 2. Commercial substrate “Biomix - Mudas e Plantio Orgânico”; 3. Organic compost, obtained through the windrow composting method (using dry leaves, grass, cattle manure, rice straw, and a pool of microorganisms cultivated from the fermentation of rice straw), and provided by Centro Primavesi de Agroecologia (Cepa), Escola de Agronomia, Universidade Federal de Goiás, Goiânia-GO, Brazil.

Four different substrates were tested: T_0 (control group), prepared with a mixture of anthill soil and Biomix substrate in a 1:1 ratio; T_1, T_2, and T_3 (treatments 1, 2, and 3), prepared with a mixture of anthill soil and Biomix substrate in a 1:1 ratio, and organic compost, with the latter representing, respectively, 25, 50, and 75% of the total mixture’s mass. Samples from each treatment were subjected to chemical analysis at Laboratório de Análise de Solo e Foliar, Escola de Agronomia, Universidade Federal de Goiás, Goiânia-GO, Brazil (Table 1).

Plastic bags measuring 15 cm in width, 21 cm in length, and with a thickness of 5 microns were used for cultivating the cuttings. Approximately one kilogram of substrate and one cutting were placed in each bag. Two axillary buds were buried, and two were kept above the substrate. For the experimental design, four blocks were set up, each consisting of

Table 1 - Chemical analysis of the substrates used for planting *P. aculeata* cuttings.

Substrate	O.M.	pH	P (Mehl)	K	Ca	Mg	H+Al	Al	CEC	M	V
	---%---	(CaCl2)	--------------mg/dm³	--------------		--------------------cmolc/dm³		------------------		----------%	-----------
T_0	4.0	6.5	86.6	380	3.0	1.1	1.1	0.0	6.2	0.0	82.2
T_1	9.6	6.8	866.0	445	4.7	4.3	1.0	0.0	11.1	0.0	91.0
T_2	9.9	6.8	1331.0	485	6.0	6.1	1.1	0.0	14.4	0.0	92.4
T_3	13.4	6.9	2032.5	610	6.7	8.0	1.0	0.0	17.3	0.0	94.2

T_0 (control group) = anthill soil + "Biomix Mudas e Plantio Orgânico" substrate (1:1); T_1, T_2 and T_3 = anthill soil + "Biomix Mudas e Plantio Orgânico" substrate + organic compost, with the latter representing, respectively, 25, 50, and 75% of the total mixture mass; Organic matter (O.M.); Soil acidity (pH); Cation exchange capacity (CEC); Aluminum saturation (M); Base saturation (V).

forty-four cuttings, with eleven cuttings from each treatment. In total, considering the four blocks, one hundred and seventy-six cuttings were planted. To reduce edge effects, the seedlings located on two edges of each block were excluded from the analysis, so only the twenty-four seedlings in the center of each block were considered, as outlined in figure 1. Thus, the sample size considered for morphometrical assessments and statistical analysis was twenty-four seedlings for each treatment.

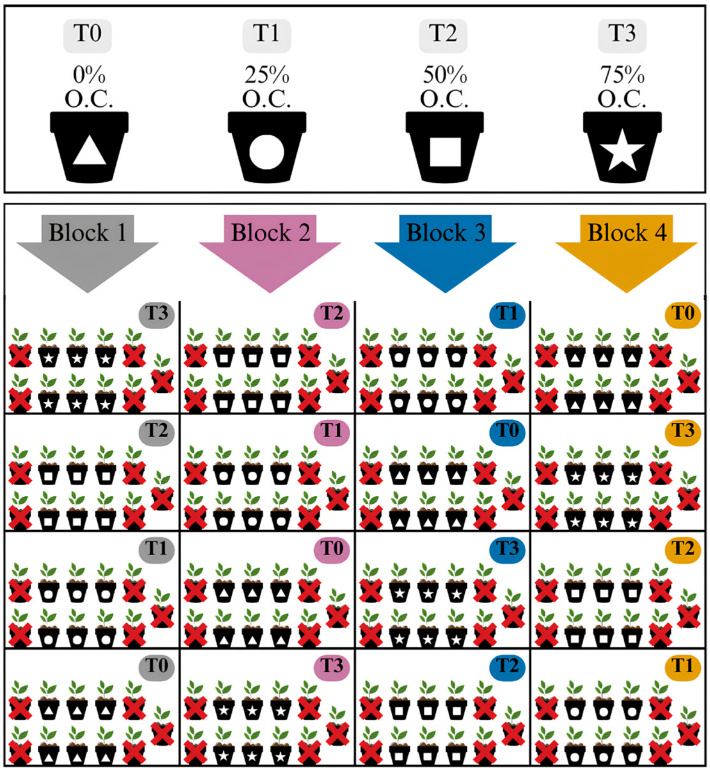

Figure 1 - Representation of the experimental design used to assess the development and photosynthetic performance of *P. aculeata* cutting seedlings grown in substrates with different concentrations of organic compost. T_0 (control group) = anthill soil + "Biomix Mudas e Plantio Orgânico" substrate (1:1); T_1, T_2 and T_3 = anthill soil + "Biomix Mudas e Plantio Orgânico" substrate + organic compost, with the latter representing, respectively, 25, 50, and 75% of the total mixture mass. Organic compost (O.C).

After 78 days from planting, the following morphometric variables were evaluated: total length (TL), internode length (IL) and diameter (D) of the longest branch; number of leaves on the longest branch (NL); dry mass of the above-ground part (DMAG) and roots (DMR). The number of leaves was determined considering both young and fully expanded leaves. The internode length was measured using a ruler. The diameter of the largest branch was determined using a caliper. For quantifying the dry masses, the seedlings were placed in a drying oven at temperatures between 30 and 40 °C inside paper bags. Once a constant weight was achieved, the final weights were measured using an analytical balance.

The effective quantum efficiency of Photosystem II (Fv'/Fm'), net photosynthesis rate (Pn), stomatal conductance (gs), and transpiration (E) were evaluated using the Infra Red Gas Analyzer (IRGA) LI-6400XTR (LI-COR Biosciences, Lincoln, NE, USA), with a chamber temperature of 24 ºC and LED light sources providing 1000 μmol photons m^{-2} s^{-1}. The assessments were conducted in the morning, between 8 a.m. and 11 a.m. Nine saplings from each treatment were analyzed for the gas exchange and fluorescence variables. The analysis was conducted on one fully expanded leaf from the central part of the seedlings.

The morphometric and physiological data were subjected to a mixed linear model using functions from the *lme4* (version 1.1-33) and *MuMIn* (version 1.47.5) packages, developed for the R programming language. All the analyses were conducted in the R software (version 4.3.1), within the RStudio development environment. The graphs were generated using functions from the *ggplot2* package (version 3.4.2). The script developed for the analysis and raw data are available on GitHub at the following address: <https://github.com/NinaMSuz/Supplementary_files_pereskia_aculeata_organic_compost_2024>.

RESULTS AND DISCUSSION

The proportion of the organic compound in the substrate had a positive influence on the development of *P. aculeata* cutting seedlings, as shown in figure 2C. The mixed linear models applied to the experiment are summarized in table 2. Assuming

Figure 2 - Development of *P. aculeata* cutting seedlings grown in substrates with different proportions of organic compost. Recording of cuttings on the day of planting (A) and 78 days after (B). Seedlings grown in the four different substrates, with a progressive increase in the proportion of organic compost from left to right (C).

Table 2 - Summary of the mixed linear models applied to the morphometric and physiological variables of *P. aculeata* cutting seedlings cultivated in substrates with different proportions of organic compost (0, 25, 50, and 75%).

Nº	Abbreviation	--------α-------	------SEα-----	--------β-------	------SEβ-----	-------R^2------	----P-value----
1	TL	0.021	2.899	0.501	0.029	0.785	< 0.001
2	IL	0.422	0.105	0.025	0.001	0.753	< 0.001
3	D	2.779	0.150	0.032	0.003	0.534	< 0.001
4	NL	5.904	1.036	0.151	0.010	0.728	< 0.001
5	DMAG	1.083	0.303	0.051	0.003	0.704	< 0.001
6	DMR	6.352e - 02	4.101e - 02	3.944e - 03	4.385e - 04	0.546	< 0.001
7	Pn	2.905	0.837	0.108	0.014	0.649	< 0.001
8	Fv'/Fm'	2.428e - 01	1.566e - 02	2.907e - 03	3.347e - 04	0.683	< 0.001
9	gs	6.842e - 02	4.405e - 02	2.311e - 03	9.419e - 04	0.147	0.019
10	E	1.936	0.538	0.048	0.011	0.333	< 0.001

Intercept (α); Standard error of the intercept (SEα); Linear coefficient (β); Standard error of the linear coefficient (SEβ); Conditional R-squared (R^2); Total length (TL), internode length (IL) and diameter (D) of the longest branch; Number of leaves (NL) on the longest branch; Dry mass of the above-ground part (DMAG); Dry mass of the roots (DMR); Net photosynthesis rate (Pn); Effective quantum efficiency of Photosystem II (Fv'/Fm'); Stomatal conductance (gs); and Transpiration (E).

a significance level of 95% (P-value < 0.05), the results were significant for all variables analyzed.

According to the soil analyses (Table 1), an increase in the proportion of compound in the substrate was accompanied by an increase in organic matter content, as well as the minerals P, K, Ca, and Mg. Additionally, it contributed to enhancing the substrate's ability to carry out cation exchange. Organic matter, besides being a source of nutrients, including N (OLDFIELD et al., 2019), also improves the physical quality of the substrate (LAL, 2020). In addition, the increase in mineral content favored the increase in morphometric and physiological variables such as total length, internode length and diameter of the longest branch (Figure 3); number of leaves on the longest branch (Figure 3); dry mass of the above-ground part and roots (Figure 4); net photosynthesis rate and effective quantum efficiency of Photosystem II (Figure 5), which showed a linear trend as higher proportions of organic compounds were incorporated into the substrate. Considering that plant growth depends directly on the production of organic carbon through photosynthesis (ANLI et al., 2020; MODARELLI et al., 2022; GARCIA et al., 2022), and that the increase in nutrients can support the photosynthetic process in different ways, we can infer that the greater development of plants occurred due to the increased availability of nutrients resulting from the use of composted material.

The organic compost had a positive effect on both the net rate of photosynthesis (Figure 5A) and the ability of the cuttings to convert light energy into chemical energy during photosynthesis (Figures 5B). Directly, we can mention the role of nitrogen contained in organic matter, well known in contributing to the formation of proteins, including those that integrate the apparatus required for the photochemical and biochemical phases of photosynthesis (KHAN et al., 2020). Nitrogen is also necessary for the formation of important and abundant pigments required for light absorption, the chlorophylls (PERALTA-SÁNCHEZ et al., 2023). Nitrogen and phosphorus are essential for the formation of energy molecules like ATP, and also for the formation of nucleic acids. Energetic molecules like ATP are necessary for the reactions in photosynthesis itself or for different metabolic processes crucial for plant growth (POIRIER et al., 2022). An increase in magnesium can also favor chlorophyll production (HAUER-JÁKLI & TRÄNKNER, 2019). Magnesium and calcium are fundamental in the formation of cell wall structures (LIU et al., 2019). Although, potassium is not involved in the structure of any biomolecule, it plays a crucial role in osmoregulation leading to stomatal opening (AHAMMED et al., 2022).

Stomatal conductance and the effective quantum efficiency of Photosystem II are the two most limiting factors for photosynthesis (YU et al., 2009; SINGH & RAJA REDDY, 2011). The former represents a limitation due to the entry of CO_2 into the system, while the latter is related to the structural capacity to propel the light-induced event (LI et al., 2021; WANG et al., 2022). In the current study, we observed a moderate linear trend of increased effective quantum efficiency of Photosystem II (Figure 5B), likely due to the increased availability of essential

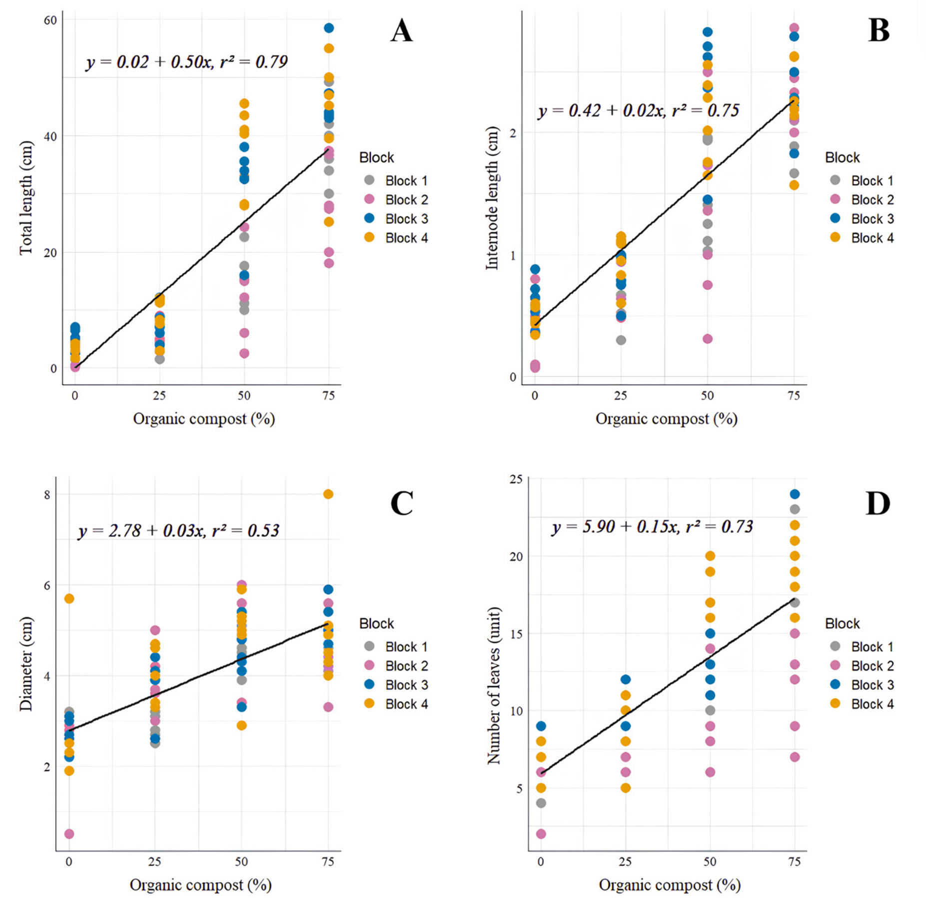

Figure 3 - Development of *P. aculeata* seedlings grown in substrates with different proportions of organic compost (0, 25, 50, and 75%). Total length (A), internode length (B), and diameter (C) of the longest branch, in centimeters. Number of leaves on the longest branch (D).

nutrients for the formation of photosynthetic pigments or other structural components, as mentioned in the previous paragraph. This trend was reflected in net photosynthesis (Figure 5A). Conversely, there was no observed influence of stomatal conductance on the increase in net photosynthesis rates, reaffirming that, in this study, the most limiting factor for photosynthesis was the structural capacity related to the effective quantum efficiency of Photosystem II.

The fact that stomatal conductance was not a limiting factor was expected, as its limitation is more influenced by environmental conditions that impose the need for stomatal closure to conserve water (CHEN et al., 2022; FLEXAS et al., 2002), which was not the case in the experiment at hand. Over the 78 days of growth, the plants were not subjected to stress conditions that would justify the need for more frequent stomatal closure, such as water deficiency stress. This fact, in turn, justifies the absence of a growth trend in the values of this variable in response to the increase in organic compost in the substrate (Figure 5C). It is also inferred that the potassium content, which is necessary for stomatal opening (SARDANS & PEÑUELAS, 2021), was already sufficient for stomatal opening in the control treatment (Table 1); and therefore, it was not a limiting factor for stomatal conductance. Transpiration rate is closely related to stomatal conductance and vapor pressure (ZHANG et al., 2022), with the latter being reduced by the three times a day sprinkler irrigation throughout the experiment. Therefore, it was already expected that plant transpiration would not be influenced by the increased use of composted products in the substrate, as can be seen in figure 5D.

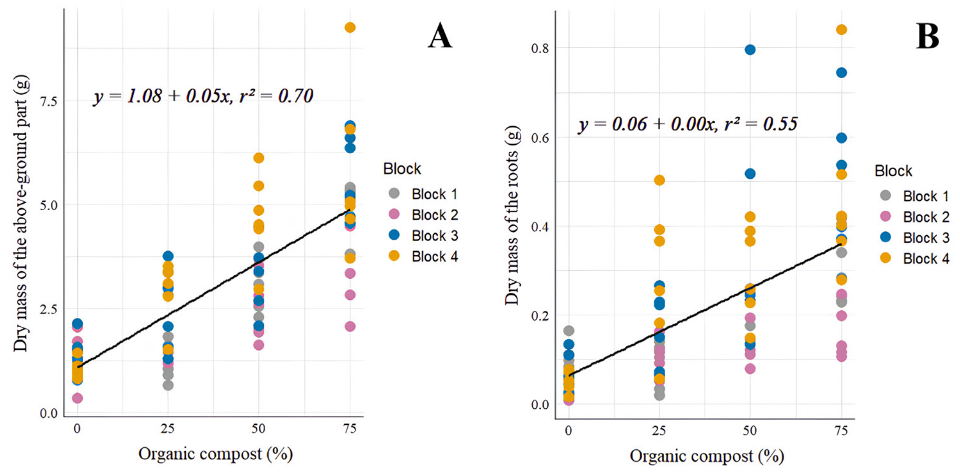

Figure 4 - Development of *P. aculeata* seedlings grown in substrates with different proportions of organic compost (0, 25, 50, and 75%). Dry mass of the above-ground part (A) and roots (B), in grams.

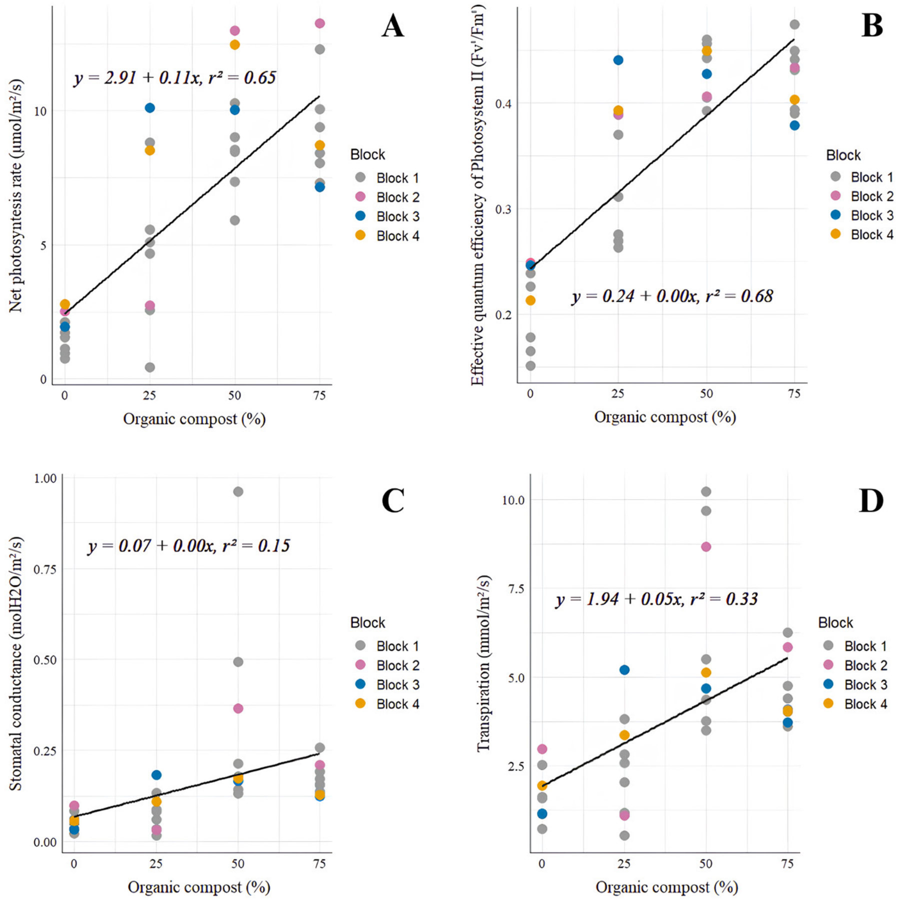

Figure 5 - Development of *P. aculeata* seedlings grown in substrates with different proportions of organic compost (0, 25, 50, and 75%). Net photosynthesis rate (A), in µmol·m^{-2}·s^{-1}. Effective quantum efficiency of Photosystem II (B). Stomatal conductance (C), in molH2O·m^{-2}·s^{-1}. Transpiration (D), in mmol·m^{-2}·s^{-1},

As rates of net photosynthesis are favored by the increase of composted products in the substrate, we can presume a greater availability of the organic compounds necessary for plant growth. This enables the development of new plant organs, such as leaves, and an increase in stem length and diameter, as evidenced by branch and internode length measurements (Figure 3). These effects are also reflected in the increased dry mass of the aboveground and roots, as observed in figure 4. These observations align with what happens in other plant species, as reported in the studies of BARAI et al. (2022), HONG et al. (2022), and TOYAMA et al. (2021).

CONCLUSION

The addition of organic compost to the cultivation substrate promoted the growth and increased the photosynthetic performance of *P. aculeata* cutting seedlings. All morphometric variables increased linearly, and the photosynthetic performance was significantly higher with the increase in organic compost. Cultivating *P. aculeata* in substrates with organic compost proved to be effective in enhancing the physiological and growth performance of the plants.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

The authors NMS, GSC, NAB, GCPC, GG, SDM, MERO, LFCC contributed equally for the conception and writing of the manuscript. HCM helped analyze the results and manipulate the IRGA apparatus; and LAG was the group's advisor. All authors critically revised the manuscript and approved of the final version.

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