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Evaluation of biochar derived from açaí seed residues in the production of cherry tomato seedlings (*Solanum lycopersicum var. cerasiforme*)

Avaliação de biochar derivado de resíduos de sementes de açaí na produção de mudas de tomate-cereja (*Solanum lycopersicum var. Cerasiforme*)

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ABSTRACT

The use of biochar produced from açaí residues appears to be a promising alternative for sustainable agriculture, with the potential to improve substrate quality, increase productivity, and contribute to carbon sequestration. This study evaluated the effects of different proportions of activated biochar (AB) and commercial substrate (CS) on cherry tomato seedling production, maintaining the cell volume at 15 mL. Five combinations were tested: 0% AB + 100% CS, 12.5% AB + 87.5% CS, 25% AB + 75% CS, 50% AB + 50% CS, and 100% AB + 0% CS, with four replicates per treatment. In the immediate analysis, the moisture content of the composite substrate activated biochar + commercial substrate (ABCS) was 6.14%, indicating good water retention. The thermogravimetric (TG) analysis revealed that, from 550°C onward, there was a reduction in the thermal degradation rate, with 32.10% of material remaining, suggesting that biochar preserves fixed organic matter. Agronomically, the use of biochar activated positively influenced characteristics such as chlorophyll content (CC; 32SPAD), stem diameter (SD; 1.2 mm), plant height (PH; 7 cm), and number of leaves (NL; 5). Among the treatments, the combination of 12.5% AB and 87.5% SC obtained the best results, indicating an ideal balance between physical stability and plant growth promotion. The results suggest that açaí biochar activated, when used in appropriate proportions, can favor more efficient, economically viable, and environmentally responsible agricultural practices.

Keywords: bioeconomy; Amazon; agro-industrial waste; substrate amendment; carbon sequestration.

RESUMO

O uso de biocarvão produzido de resíduos de açaí mostra-se uma alternativa promissora para a agricultura sustentável, com potencial para melhorar a qualidade do substrato, aumentar a produtividade e contribuir para o sequestro de carbono. Neste estudo, avaliaram-se os efeitos de diferentes proporções de biocarvão ativado (BA) e substrato comercial (SC) na produção de mudas de tomate cereja, mantendo o volume por célula em 15 mL. Foram testadas cinco combinações: 0% BA + 100% SC, 12,5% BA + 87,5% SC, 25% BA + 75% SC, 50% BA + 50% SC e 100% BA + 0% SC, com quatro repetições por tratamento. Na análise imediata, o teor de umidade do substrato composto (BASC) foi de 6,14%, indicando boa retenção de água. A análise termogravimétrica revelou que, de 550°C em diante, há redução na taxa de degradação térmica, com 32,10% de material remanescente, sugerindo que o biocarvão preserva a matéria orgânica fixa. Agronomicamente, o uso do biocarvão influenciou positivamente características como teor de clorofila (32 SPAD), diâmetro do caule (1,2 mm), altura das plantas (7 cm) e número de folhas (5). Entre os tratamentos, a combinação com 12,5% de BN e 87,5% de SC obteve os melhores resultados, indicando equilíbrio ideal entre estabilidade física e promoção do crescimento vegetal. Os resultados sugerem que o biocarvão ativado de açaí, quando usado em proporções adequadas, possa favorecer práticas agrícolas mais eficientes, economicamente viáveis e ambientalmente responsáveis.

Palavras-chave: bioeconomia; Amazônia; resíduos agroindustriais; correção de substrato; sequestro de carbono.

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Introduction

Sustainable agriculture has become a global priority as the search for more environmentally friendly agricultural practices and efficient socioeconomic impact strategies gains prominence. While modern agriculture enhances food security through increased efficiency and technological advancements, it also faces significant environmental challenges. The heavy use of agrochemicals, particularly pesticides and fertilizers, not only increases crop yields but also raises concerns about environmental and health impacts (Alves et al., 2025).

At the same time, the livelihoods of many small- and medium-sized farmers in Brazil are vulnerable to changes in environmental and economic conditions, and many have limited capacity to adopt more sustainable agricultural practices that could help mitigate climate-related issues (Newton et al., 2016).

Ecosystem-based practices can be adopted where the use of biodiversity and ecosystem services is part of a comprehensive strategy to support the adaptation of populations to the adverse impacts of climate change (Convention on Biological Diversity, 2014). According to Silva and Dracha (2024), its objective is to help vulnerable communities adapt to climate change through effective ecosystem management practices.

In studies by Kullachonphuri et al. (2025), the application of biochar in coffee seedling and corncob production systems increased pH, cation exchange capacity, and organic matter and may help mitigate the adverse effects of water scarcity. The biochar is characterized as a solid product rich in carbon and can be used to improve soil productivity and reduce acidity (Zaparoli et al., 2023). Additionally, biochar can be activated to enhance its physical-chemical characteristics such as surface area, charge density, and adsorption capacity (Nguyen et al., 2022).

According to Chew et al. (2022), the biochar application increased the regulation of root nitrate transporters, promoted nitrogen uptake, and increased nutrient element uptake and growth in rice seedlings. Also, the biochar has considerable potential as a dual-purpose soil additive, providing disease suppression and microbial growth promotion in an integrated disease management strategy (Paveen et al., 2025).

The açaí palm (*Euterpe oleracea, Mart)*, native to the Amazon region, generates residues potentially suitable for biochar production. The açai generates approximately 1.3 million tons of waste during the harvesting and processing of its fruits, which has the potential to be converted into agricultural inputs through the production of high-quality biochar (Leal et al., 2025). The use of açaí biochar as a component of substrates for seedling growth can be an alternative in the pursuit of quality, increased resistance to environmental stress, and the promotion of sustainable agricultural practices in different crops.

Cherry tomatoes are among the most widely cultivated vegetables in the world, and their ability to adapt to Brazil's climate allows them to be grown in almost every state. For this reason, they were chosen as the model crop for this study. This fruit exhibits remarkable phytochemical properties, with antioxidant activity standing out among them (Guilherme et al., 2014), in addition to being rich in nutrients and soluble solids (Medeiros et al., 2011). Although there are commercially available substrates recommended for the cultivation of specific species, there is a search for introducing sustainable production technologies that are economically viable for producers, such as the use of substrates derived from waste (Zeist et al., 2019).

The objective of this study was to assess the chemical, eco-physiological, and morphometric responses of cherry tomato seedlings when biochar activated obtained from açaí waste (Euterpe oleracea, Mart) was applied, thereby promoting more sustainable agricultural practices, meeting the demands for quality food while reducing the environmental impact of agricultural production.

Materials and methods

Location of the experiment

The experiment was conducted in an agricultural greenhouse with plastic covering and black shade net on the sides, located in the experimental area of the Federal Institute of Education, Science, and Technology of Tocantins (IFTO), in the municipality of Palmas, in the state of Tocantins, Brazil (latitude: 10.1994; longitude: 48.3092; altitude: 277 m). According to the Köppen and Geiger classification, cited by Tamayo et al. (2024), the climate is characterized as Aw (hot and humid tropical). The annual averages for air temperature, precipitation, and relative humidity are 26.8°C, 1,977 mm, and 85%, respectively.

Characterization of the commercial substrate

The substrate used in the treatment compositions is commercially sourced from the Carolina SOIL brand, Class LXXXVI, which, according to the manufacturer's specifications, contains peat, vermiculite, charred rice husk, organic waste, nitrogen, phosphorus, and potassium (NPK), limestone, and other components. In terms of technical specifications, the Carolina SOIL substrate has a pH of 5.5±0.5, making it slightly acidic, which is an ideal condition for most horticultural crops (Bernardino, 2024). The electrical conductivity of 0.7±0.3 dS/m reflects the level of soluble salts present, indicating a substrate suitable for providing nutrients without causing osmotic stress to the plants (Ayres, 2024). The substrate density is 145 kg/m^3, providing a good weight-to-volume ratio that facilitates handling and transportation. The water retention capacity (WRC) is 55%, which is an adequate level of water availability for the plants, while the maximum moisture content is 50%, preventing saturation and consequent root asphyxiation (Basso et al., 2013).

2.3 Activated biochar production

The AB was produced by pyrolysis in a fixed bed reactor (FLYEVER, model FE50RPN and line 05/50, São Paulo, Brazil), heated by a reclining split furnace using heated water steam as a carrier gas. The pyrolysis was conducted at temperatures between 500 and 550°C, with a residence time of 20–30 min, and an activation temperature of 750°C. The mass of the açaí seed was measured before and after pyrolysis, and the yield of the obtained AB was calculated (Leal et al., 2025).

Immediate analysis

The immediate analysis was carried out in the physicochemical laboratory of the IFTO – Palmas Campus, to provide information on moisture, volatiles and ash content, and fixed carbon, which are fundamental data for evaluating the quality and composition of the substrate, according to ASTM D3173-87 (ASTM, 2003), ASTM D 3173-85 (ASTM, 1985), ASTM D2415-66 (ASTM, 1986), and ASTM D5373-16 (ASTM, 2016) standards, respectively.

Thermogravimetric/derivative thermogravimetric analysis

Thermogravimetric/derivative thermogravimetric analysis (TG/DTG) was conducted to provide details on the thermal stability and decomposition of the substrate components, helping to understand how it behaves under heating conditions. The TG analyses of the samples were performed using the DSCQ10-TA instruments. The temperature range extended from the starting point to 900°C, with a heating rate of 10°C/min, under a nitrogen atmosphere with a flow rate of 50 mL/min.

Fourier transform infrared spectroscopy

The substrate samples were analyzed using a Fourier transform infrared (FTIR) spectrometer (Agilent Cary630 FTIR spectrometer, Santa Clara, California, USA) with a range from 4.000 to 650 cm^{-1}, with a resolution of 4 cm^{-1}.

Experimental design

The completely randomized design was carried out in two planting cycles of 20 cherry tomato seedlings, with one treatment: AB and Commercial Substrate (CS), in four plots, divided into five repetitions, totaling 40 experimental units. The seedlings were cultivated in cells, with mixtures in the proportions as shown in Table 1.

In the experiment to produce cherry tomato seedlings using biochar, each cultivation cell was filled with a total volume of 15 mL of substrate. Two main raw materials were used to prepare the mixtures: AB, with a density of 0.47 g/mL, and CS, with a density of 0.1838 g/mL.

Based on these densities, the mass corresponding to a volume of 15 mL per cell was 7.05 g for AB and 2.76 g for CS, when used alone (100% of the volume). Based on these references, the proportions in grams for each experimental treatment were calculated, respecting the volumetric combinations between AB and CS, as detailed in the methodology.

This experimental structure was designed to allow for a precise analysis of the agronomic effects of the different combinations, with an emphasis on identifying the optimal proportion for the development of more vigorous and sustainable seedlings.

The treatments were organized to compare the effects of different concentrations of AB partially replacing the CS, keeping the total mass per cell constant. It is important to highlight that treatments T1 and T6 have identical composition, consisting of 0% AB and 100% CS, which corresponds to 2.76g of CS per cell and no biochar. Similarly, the pairs T2 and T7 (12.5% AB and 87.5% CS), T3 and T8 (25% AB and 75% CS), T4 and T9 (50% AB and 50% CS), and T5 and T10 (100% AB and 0% CS) also share the same proportions and amounts in grams of the compounds per cell. This duplication of treatments allows us to assess the consistency of results between blocks or experimental replicates.

Two seeds were sown in each cell of the tray in order to promote the homogeneous distribution of biochar in the substrate. The use of cells in the styrofoam tray provided control and facilitated the handling of the seedlings. This allowed for the precise application of biochar to the substrate, which is crucial to optimizing its properties as a soil amendment.

Planting was carried out in two cycles (Cycle 1 and Cycle 2), a practice that aims to ensure the validity, reliability, and applicability of the results in agronomy and other areas of scientific research. Cycle 1 of planting cherry tomato seedlings occurred on 08/30/2023, and the first data collection occurred on 09/15/2023, 15 days after planting. The second collection occurred on 09/30/2023, 30 days after planting.

Cherry tomato seedling planting cycle 2 took place on 10/17/2023, and the first data collection took place on 10/30/2023, 13 days after planting. The second collection took place on 11/15/2023, 28 days after planting. According to Sturião et al. (2020), the average development time of cherry tomato seedlings on a stem is 25 days with 2–4 definitive leaves.

Table 1 – Planting design of cherry tomato seedlings with the use of activated biochar.

Treatments:					
Activated Biochar (AB)	0%	12.5%	25%	50%	100%
Commercial Substrate (CS)	100%	87.5%	75%	50%	0%
Reps	**Treatments (g.cell^{-1})**				
	AB	**CS**		**AB**	**CS**
(T1)	**0%**	**100%**	(T6)	**0%**	**100%**
1 a 4	0	2.76	1 a 4	0	2.76
(T2)	**12.5%**	**87.5%**	(T7)	**12.5%**	**87.5%**
1 a 4	0.88	2.42	1 a 4	0.88	2.42
(T3)	**25%**	**75%**	(T8)	**25%**	**75%**
1 a 4	1.76	2.07	1 a 4	1.76	2.07
(T4)	**50%**	**50%**	(T9)	**50%**	**50%**
1 a 4	3.53	1.38	1 a 4	3.53	1.38
(T5)	**100%**	**0%**	(T10)	**100%**	**0%**
1 a 4	7.05	0	1 a 4	7.05	0
Subtotal	**52.88**	**34.52**		**52.88**	**34.52**
Total					
AB (g)	105.76				
CS (g)	69.04				

Experiment location

The trial was conducted in a greenhouse covered with shade netting that reduced 50% of the incident solar radiation on the plants. Irrigation was carried out once a day using a manual sprayer. At 15 and 30 days, the relative chlorophyll content (CC) was measured using a Konica Minolta SPAD-502 Plus Detection Meter (Tokyo, Japan). For measuring stem diameter (SD) and plant height (PH), a digital caliper from Worker brand, model: 111309 (Curitiba, Brazil), was used, along with visual counting of the number of leaves (NL).

Statistical analysis

Descriptive data analyses were performed using the Jamovi software (2022). This approach allowed the evaluation of the effects of these different compounds on the growth and development characteristics of the seedlings. Thus, the aim was not only to identify possible statistical differences between the analyzed groups but also to understand the impact of using biochar and the CS.

The data obtained, when normally distributed, were subjected to one-way analysis of variance (ANOVA), which allowed us to test if there was a significant difference between the treatments. For the others, non-parametric tests were performed:

Welch's ANOVA was used for CC in Cycle 1, for SDs in the different cycles, to analyze the values of F, df1, df2, and p, and provide information on whether there are significant differences between the group (treatment) means for PHs in the two periods analyzed.

The Kruskal–Wallis test ($p<0.05$) was used to check for significant statistical differences between the groups, especially when the assumptions of normality were not met, as applied in the CC test in Cycle 2.

Results and Discussion

Material characterization

The proportion of 12.5% AB and 87.5% CS, used in treatments T2 and T7, was selected because it presented the combination that promoted an ideal balance between the physical stability of the substrate and the physiological performance of the plants, with an emphasis on the increase in CC, larger SD, greater PH, and NL, indicating the potential of this formulation for the production of more vigorous and healthy seedlings. For the CS, the analyses focused on its general composition.

Immediate analysis

In the analysis of Table 2, the moisture content level indicates that the substrate retains a considerable amount of water, representing 6.14% of the content of activated biochar + commercial substrate (ABCS). According to Boyaci et al. (2024), for the cultivation of cherry tomatoes, good water retention is essential to keep the soil moist and prevent water stress in the plants, promoting healthy root growth and improving nutrient absorption. When comparing the immediate analysis of the CS with the ABCS, there was a decrease in moisture due to the addition of dry material to the CS, and a significant increase in fixed carbon, which are key characteristics of AB.

Volatile materials represent the organic matter present in the substrate that can be decomposed at high temperatures. In a study by Mafra et al. (2024), using seeds from Amazonian fruits of the Murumuru and Patauá palm trees, a high volatile material content (above 60%) was obtained, which was similar to that found in this study.

The amount of ash reflects the non-combustible minerals present in the substrate, associated with substances such as calcium, potassium, phosphorus, magnesium, iron, and sodium, which are primarily concentrated in the mesocarp of açaí, and are essential for plant development and disease resistance (De Oliveira et al., 2018). The ash value of 24.18% shows that the CS contains a considerable amount of minerals, compared to the observation of Vieira et al. (2024), where approximate amounts were found, with an average ash content of 3% for açaí granular charcoal. According to the above-mentioned study, ashes reduce the adsorptive capacity of activated charcoal due to their ability to block the porosity of the matrix and adsorb water because of their hydrophilic nature.

Fixed carbon is an indicator of substrate stability, helping to improve soil structure, increase water and nutrient retention, and promote a favorable environment for root growth (Leal et al., 2025). In this study, the biochar activated from açaí seed residues presented a relatively low residual carbon content (<24%), which can be attributed to the composition of the original biomass, characterized by the lignin content (40.3%) and a higher proportion of volatiles (73.8%), as well as the pyrolysis temperature used of 750°C (Leal et al., 2025).

This condition results in lower chemical stability and, consequently, lower potential for recalcitrance and long-term carbon sequestration when compared to biochars derived from woody materials. Despite this, this type of biochar can exhibit greater soil reactivity, favoring the gradual release of nutrients, and improved water availability for plants.

In the study by Upadhyay et al. (2024), the use of bamboo biochar with phosphate fertilizer was evaluated. The application of 12.5% biochar presented the best agronomic results; there was an improvement in soil structure and nutrient availability, the biochar showed high porosity, thermal stability, and functionalized surface, characteristics that indicate persistence in the soil and potential as a carbon sink.

Table 2 – Immediate analysis of commercial substrate (SC); mixture of activated biochar 12.5% + commercial substrate 87.5% (ABCS); and raw biochar.

Commercial Substrate (SC)		Activated Biochar + Commercial Substrate (ABCS)	Biochar Activated
Parameters	Average (%)		
Moisture	18.38±0.3	6.14±0.35	8.9±0.1
Volatiles	55.16±2	49.38±3.19	73.8±0.3
Ashes	24.18±1.37	20.36±1.10	2.2±1.9
Fixed carbon	2.31±0.5	24.12±.3.93	24.0±0.8

Thermogravimetric/derivative thermogravimetric analysis

The mass loss of ABCS (Figure 1a) at 50°C was 10%, while the mass loss of CS (Figure 1b) at 50°C was 25%, indicating that the presence of activated biochar increases water retention. It can be observed that there is an absence of the event related to the presence of moisture in the material studied here.

Through the analysis of the TG/DTG curves of the CS (Figure 1b), a decomposition event of organic matter was observed, with initial and final temperatures of 150 and 500°C, respectively. The mass loss during this event was 60.95%. From 550°C onward, a decrease in the thermal degradation of the sample is observed. The second mass loss event occurred between the temperatures of 600 and 900°C, with approximately 9.8%.

For ABCS (Figure 1a), decomposition at 500°C was reduced, reaching 32.10%, which may indicate that the biochar preserves fixed organic matter (cellulose and lignin). The breakdown of lignin in Figure 1b occurs between 500 and 900°C, while in Figure 1a, it occurs between 500 and 950°C.

The ash content and fixed carbon were 29%. The ash contents detected at temperatures of 600, 800, and 900°C were 36, 32, and 29%, respectively (Figure 1b). This decrease in the ash content may be due to the breaking of bonds of inorganic carbon present in carbonate compounds (CO_3^{2-}, HCO_3^-), decomposition of inorganic oxides, as well as the decomposition of lignin.

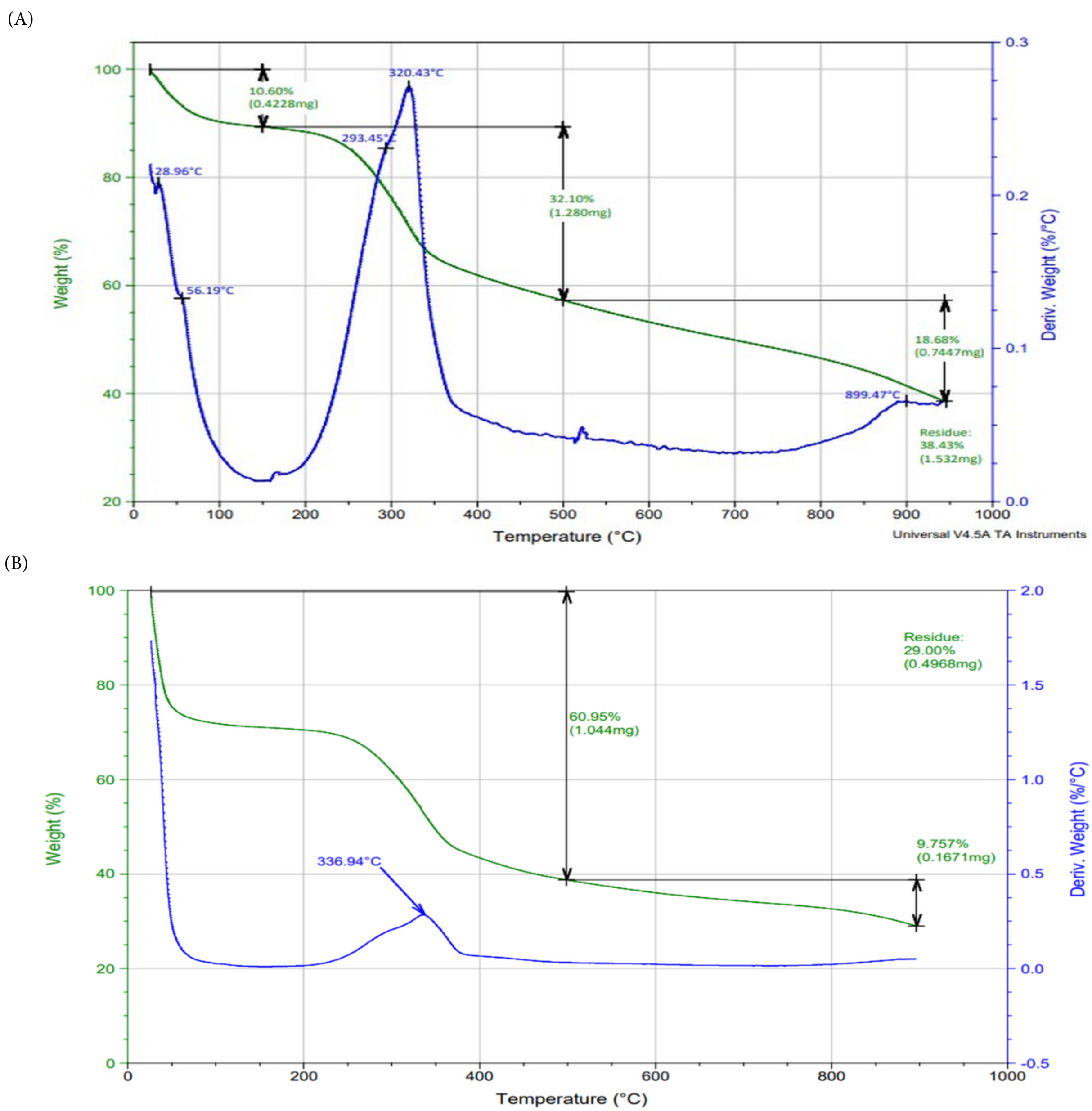

Figure 1 – TG/DTG Curves of (a) ABCS and (b) CS.

According to Pedroza et al. (2023), the decomposition of the remaining lignin begins at low temperatures; however, it continues up to around 900°C. It is important to highlight that the substrate studied in this investigation consists of some inorganic materials, namely: vermiculite, rice husk ash, potassium, phosphorus, and limestone.

The practical implication of these differences is that, in the ABCS mixture, there is an interaction between the thermal stability of the biochar and the thermal inertia of mineral components, resulting in a material with mixed physicochemical characteristics. This may favor its agricultural application, as the presence of biochar activated may ensure persistence and adsorption capacity, while substrate minerals contribute nutrients and physical structure. In addition, slow lignin decomposition up to 900°C suggests that biochar carbon remains kidnapped for long periods, increasing the potential for use as a soil conditioner and carbon sink.

Fourier transform infrared spectroscopy

Two samples were analyzed using the FTIR technique: a mixture of ABCS and AB. Both materials exhibit the presence of functional groups, such as hydroxyl (–OH), carbonyl (C=O), aromatic bonds (C=C), carboxyl (–COOH), ether (C–O–C), phenolic (C–O–H), amine (–NH_2 or –NH), and carbonate (CO_3^{2-}), which may be associated with the components of the CS (peat, vermiculite, charred rice husk, organic waste, NPK, and limestone, among others) (Yang et al., 2024), as well as the thermally resistant organic compounds present in the biochar sample.

The characteristic band identified at 3,300 cm^{-1}, with the presence of broad bands in the substrate line, indicated the occurrence of hydroxyl groups (OH^-), common in peat and organic waste compounds, similar to the findings of Yang et al. (2024), who identified this at 3,200 cm^{-1}. A band at 2,900 cm^{-1} was also observed in the CS line, corresponding to C-H stretching vibrations, typically associated with organic compounds, including aliphatic materials. It was also observed for the CS in the band between 1,700 and 1,600 cm^{-1}, associated with carbonyl groups (C=O), suggesting the presence of carboxylic compounds, esters, or lignin. According to Ribeiro et al. (2024), the 1,700 cm^{-1} band can also indicate the presence of aldehydes or ketones.

The band around 1,634 cm^{-1}, evident in the ABCS, indicates the presence of lignin, which may also be associated with the aromatic C=C structure formed during the mineralization of proteins, cellulose, and hemicelluloses. This increase in aromatic carbon is considered an indicator of an increasing degree of humification of the organic matter, associated with the maturity and stability of the compost and its transformation into a highly humified substrate.

This same behavior was observed in both materials analyzed here CS and ABCS. For CS, band values were obtained between 1,400 and 1,000 cm^{-1}, a clear indication of C-O bonding, and consequently the presence of ethers or alcohols, common in the structure of cellulose and hemicellulose, according to Evaristo et al. (2023).

Thus, the analysis of the FTIR spectrum responses clearly confirmed the trend of chemical and organic complexity of the potential substrate. Above all, it highlighted the presence of lignin, cellulose, and inorganic compounds, which contribute to its thermal and chemical characteristics. Understanding the presence and proportion of these components is essential to define the possible applications and benefits of the substrate and biochar, whether in terms of agricultural use, soil property improvement, or other applications.

The Fourier transform infrared (FTIR) spectra revealed the main functional groups present in both the activated biochar and the composite substrate (ABCS), including hydroxyl (–OH), carbonyl (C=O), and aromatic (C=C) bonds, confirming the chemical interactions between organic and inorganic components (Figure 2).

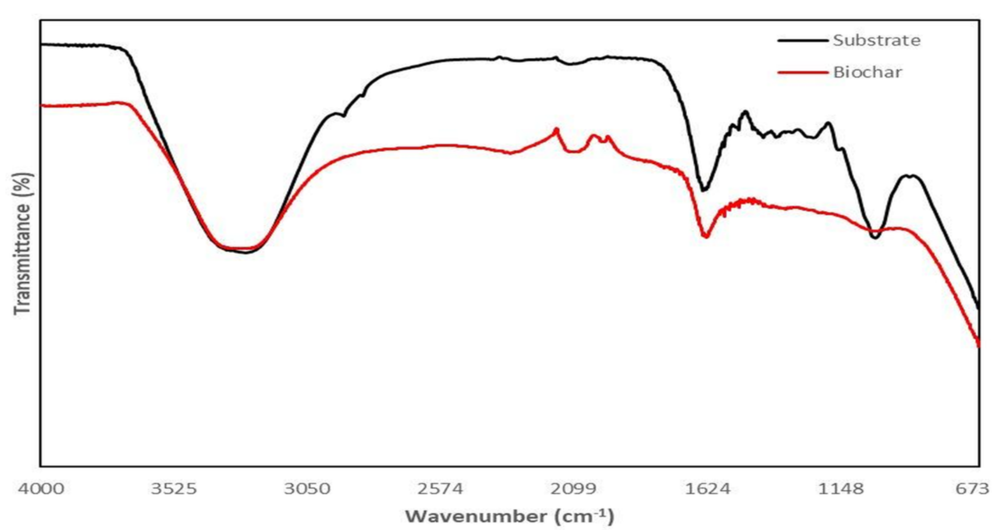

Figure 2 – FTIR of ABCS (87.5% CS/12.5% AB) and raw biochar.

Experimental results

Chlorophyll content

The seeds took an average of 14 days to germinate, which is slightly longer than observed by Ferreira et al. (2013), who found that hybrid tomato "Mariana" seeds took an average of 10 days to germinate. The CC results suggest that there is a statistically significant difference between treatments, but only in Cycle 1. The responses for CC in Cycle 2 show no statistically significant differences between treatments (gl=4; p=0.430, and p=0.502) for 15 and 30 days after transplanting, respectively.

In Cycle 1 (Figures 3a and 3b), during the first collection, treatment T1 showed the highest CC with 30 SPAD, followed by T7 (28 SPAD), T2, and T6 (23-24 SPAD), while T8 showed the lowest value with 20 SPAD. In the second collection, T1's CC dropped to 23 SPAD (a 23.33% decrease), T6 significantly increased to 32 SPAD (a 39.13% increase), while T2, T7, and T8 remained stable or with small variations.

In Cycle 2 (Figures 3c and 3d), for CC, T1 showed an increase of 28%, while T5 and T7 also showed smaller increases. On the other hand, T6, T8, T9, and T10 recorded decreases ranging from 7% to 18.75% in SPAD values.

The results indicate a significant effect of the treatments only in Cycle 1, with marked variations between the groups such as the 39.13% increase in T6 and the 23.33% reduction in T1, showing that some substrates can positively influence photosynthetic activity in the initial stages. In Cycle 2, the lack of statistical difference between the treatments and the reductions observed in some groups suggests a loss of effect over time, possibly due to nutrient depletion.

Since chlorophyll is directly related to energy efficiency and plant growth, these data reinforce the importance of selecting substrates that ensure a consistent physiological response throughout the production cycle (Huang et al., 2024). The same authors, using another method, extreme learning machine (ELM), obtained 0.86, 0.83, and 0.83 for chlorophyll a, chlorophyll b, and carotenoids in cherry tomato seedlings.

Soares et al. (2022) obtained results similar to this study for cherry tomato crops, without the addition of biochar, with averages between 27.66 and 27.89 SPAD.

According to Wiszniewska et al. (2022), non-activated biochars did not influence CC but reduced the carotenoid content, while all activated carbon products promoted an increase in chlorophyll levels.

Other studies showed that high chlorophyll concentrations are associated with better growth performance, influenced by the photosynthetic activity and nutritional status (Shadchina and Dmitrieva, 1995; Luo et al., 2019), in addition to indicating greater stress tolerance (Koÿmiÿska et al., 2019). Increases in CC were also observed in mung bean and sweet basil treated with biochar (Torabian et al., 2018; Ding et al., 2020).

Stem diameter

The SD is a higher survival capacity of the seedling in the field, as it will have a larger aerial part and better root development (Dos Santos et al., 2016).

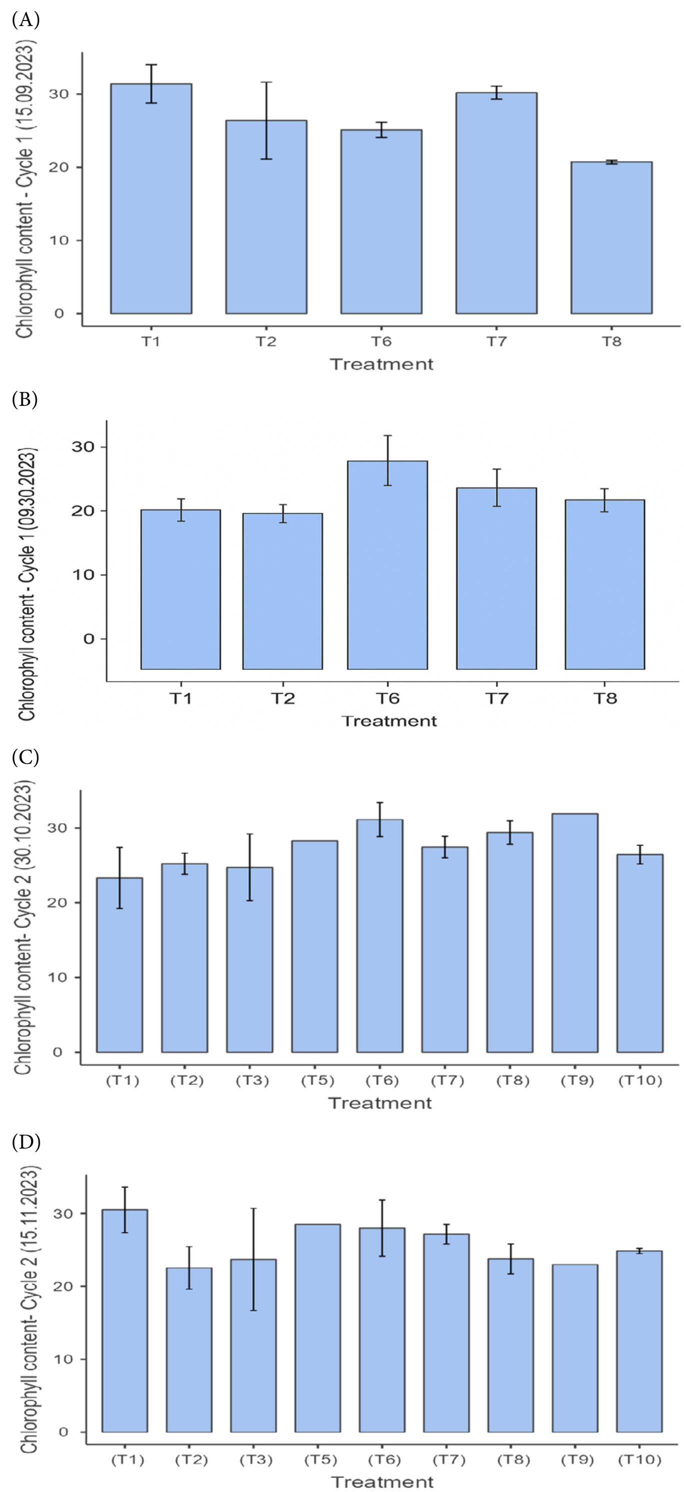

Figure 3 – Chlorophyll Content results from different treatments.

The results for SD parameters in Cycle 1 suggest that there is a statistically significant difference between treatments, but only in the first collection. The results for SD in Cycle 2 suggest that there is a statistically significant difference between treatments, but only in the second collection.

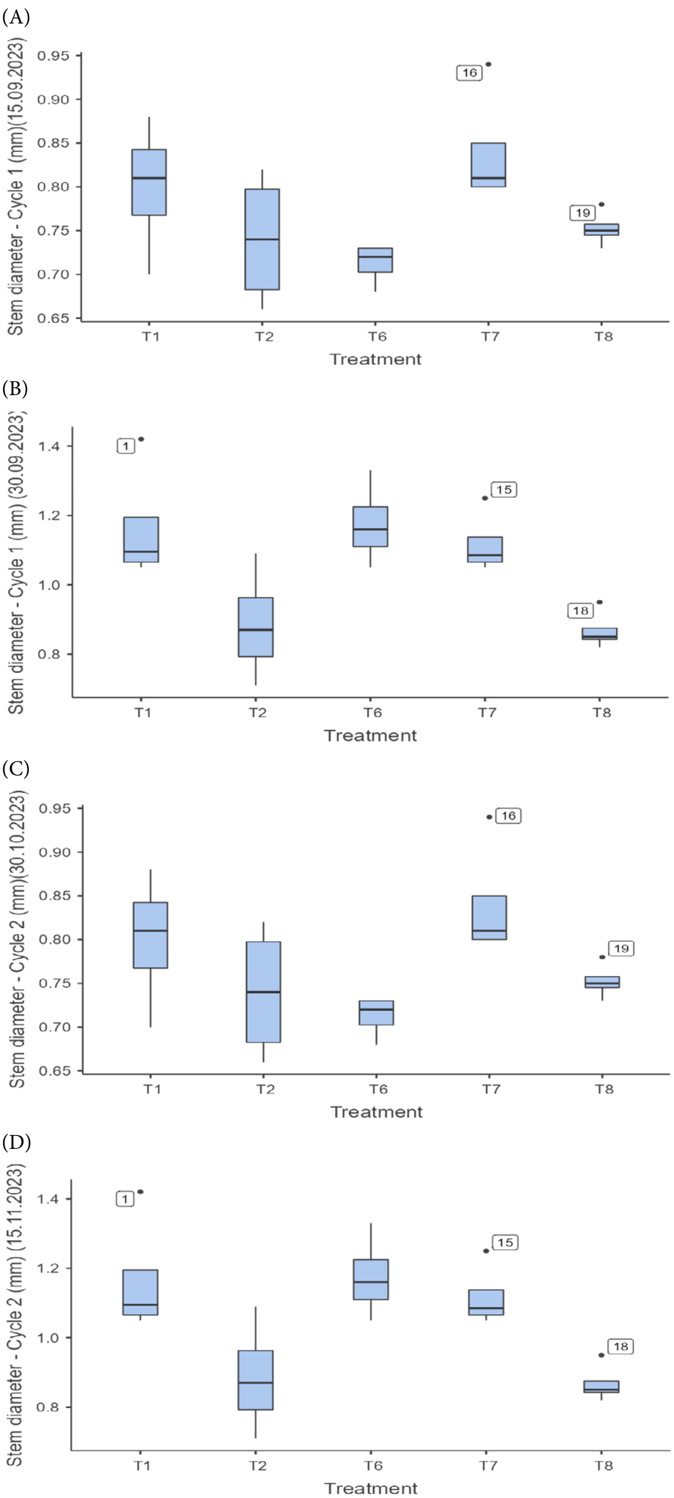

Figure 4 – Stem diameter results (Cycle 1 and Cycle 2) from different treatments.

In the first collection (Figure 4a), treatments T1 (CS 100%) and T7 ABCS (CS 12.5%/AB 87.5%) showed the largest SD, with 0.75 mm, indicating a positive response to the substrate used. In the second collection (Figure 4b), a general increase in SD was observed, with T1 and T6 reaching 1.2 mm, representing a 60% increase. In contrast, treatment T2 showed a more modest increase, from 0.75 to 0.8 mm (6.67%). T6 exhibited the greatest growth among the treatments, also with a 60% increase.

In Cycle 2 (Figures 4c and 4d), the largest increases were recorded in T1 and T6, with variations of 60 and 100%, respectively. These results indicate that T1 and T6 promoted more robust stem development, enhancing nutrient and water absorption, which can increase plant productivity and resilience to stress.

The study by Santana et al. (2023) revealed that, at 28 days, the cherry tomato seedlings had an average SD of 1.35 mm, highlighting good structural development of the plants during this period.

Plant height

The results for PH in Cycle 1 suggest that there is a statistically significant difference between treatments. The average PH remained stable throughout the investigated period (Figures 5a and 5b), with no significant changes in the effects of the treatments. Treatment T8 was the most effective, with the highest average height of 7.0 cm in both periods, followed by T7 with 6.5 cm. T1 recorded an average height of 6.0 cm, while T2 and T6 recorded the lowest heights, both at 5 cm. In Cycle 2 (Figures 5c and 5d), we observed that T1 grew by 16.4%, followed by T2 with 13.3%. T3 remained stable, while T5 showed a sharp decline, possibly indicating issues with the treatment. T6 had the highest increase, at 47.1%, while T7, T8, and T9 showed a growth of around 4%, and T10 remained stable.

In the study by Costa et al. (2015), maximum heights of cherry tomato seedlings were found to be 4.2 cm at 15 days and 5.3 cm at 30 days after transplanting. The work by Santana et al. (2023), using only CS, demonstrated significant growth over 28 days. In the first 14 days, the seedlings reached an average height of 5.25 cm, and between the 14th and 21st day, a growth of 33.33% was observed, resulting in a height of 7.00 cm. In the following interval, from the 21st to the 28th day, the growth was even more pronounced, with a 45.71% increase, bringing the seedlings to 10.2 cm. The research conducted in this study achieved better results than Costa et al. (2015) and similar results to Santana et al. (2023).

In the study by Kubo et al. (2024), poultry litter biochar, pyrolyzed at 350°C, presented high levels of N, P, and K, which explains its positive impact on SD and PH, presenting results in more advanced projects (up to 120 days) with field applications. Açaí biochar, pyrolyzed at 500°C, has a high pH, good water retention, and low density, favoring germination and initial seedling growth, and is more efficient in the early stages (up to 30 days).

Number of leaves

The results suggest that there is a statistically significant difference in the NL between treatments in the first collection, and for the second collection, there are no statistically significant differences in the NL between treatments.

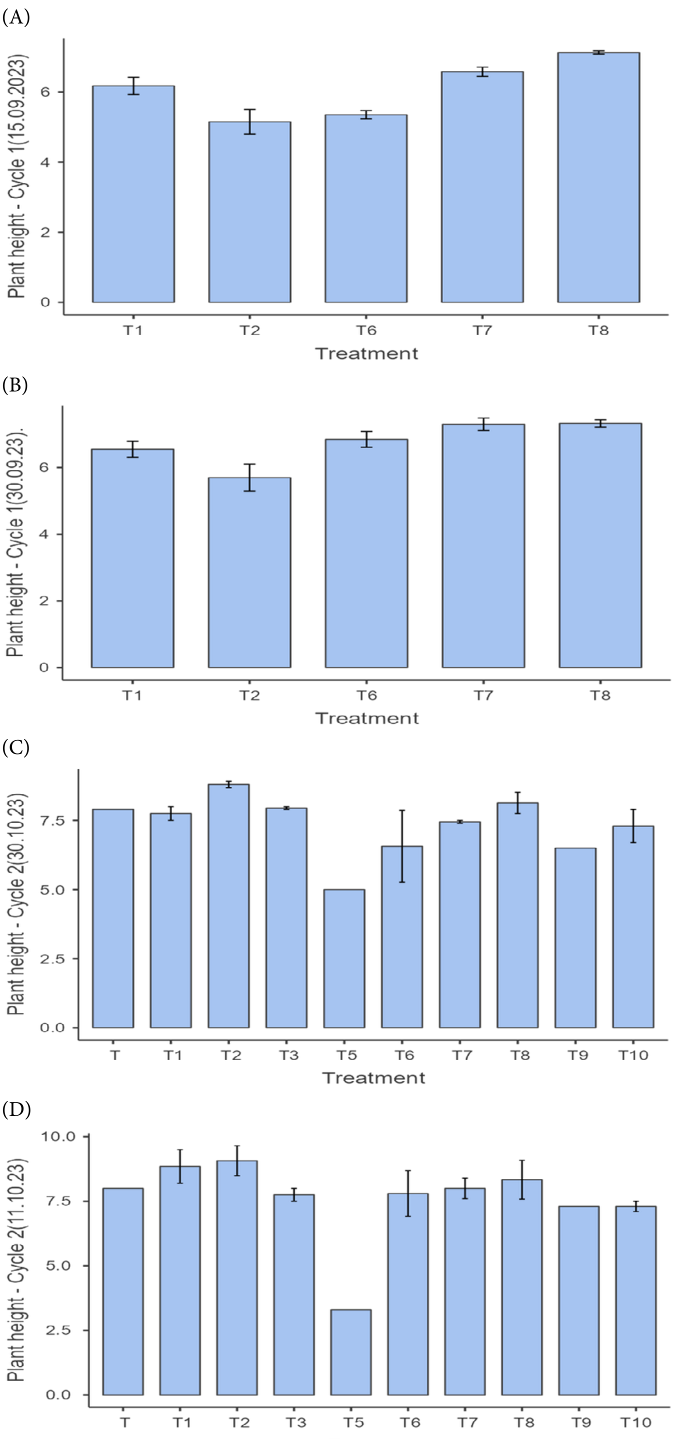

Figure 5 – Plant Height results from different treatments.

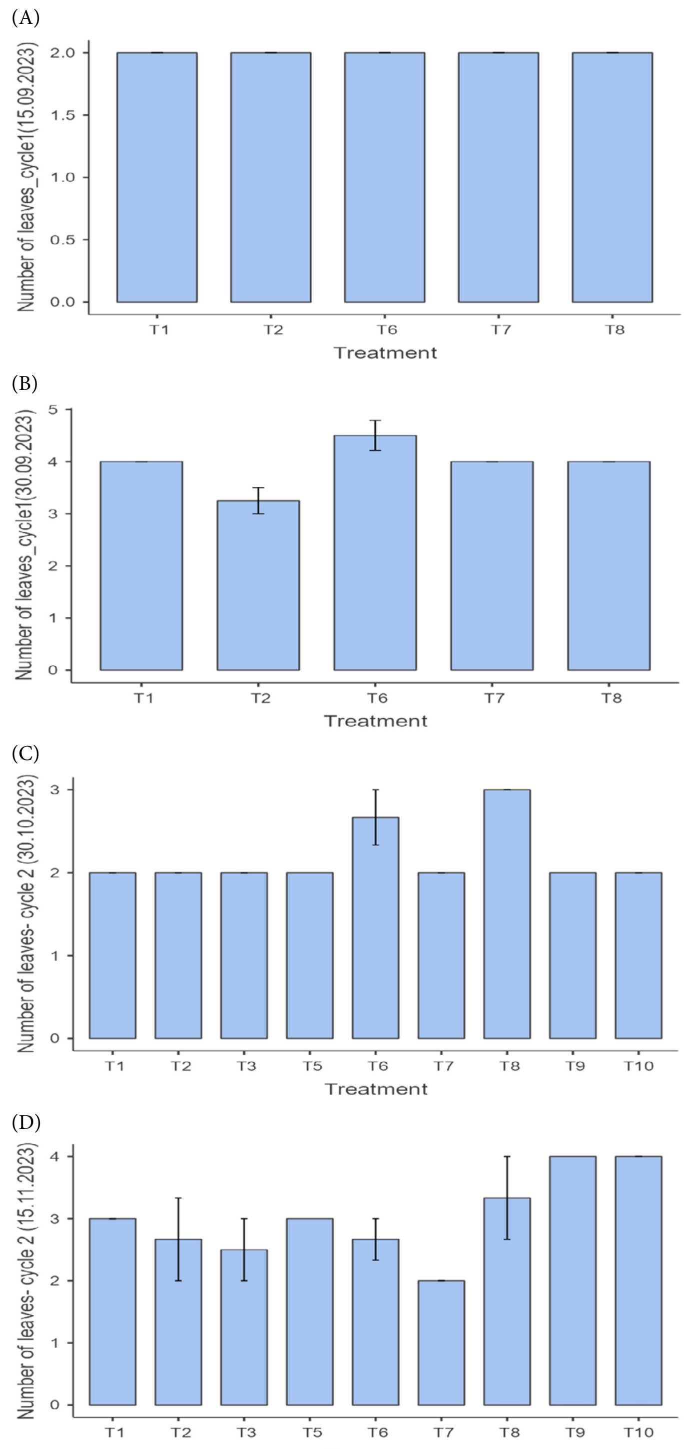

Figure 6 – Number of leaves (Cycle 1 and Cycle 2) from different treatments.

In Cycle 1 (Figures 6a and 6b), all treatments (T1, T2, T6, T7, and T8) had two leaves in the first collection, with no variation. In the second collection, T6 stood out with the highest NL (5), followed by T1, T7, and T8 with four leaves. T2 showed the lowest performance, with three leaves. T6 remained the most effective treatment, while T2 continued to be the least efficient. In the first collection of Cycle 2 (Figure 6c), most treatments had two leaves, except for T6 and T8, which had three leaves, standing out positively. In the second collection (Figure 6d), all treatments showed an increase in the NL, with T9 and T10 reaching the highest NL (4).

In the research by Coelho et al. (2018) with cherry tomatoes in different organic compounds, four to six leaves were found in the 35 (DAS) collection. Similar results were found in the study by Dos Santos et al. (2016), where the changes were collected at 30 days after sowing (DAS), with values between two and five leaves, under different doses of hydroponic fertigation, the study highlights that leaf development in seedlings is beneficial, since the leaves are the organs of the plant responsible for the processes of converting light energy into chemical energy.

Conclusion

The use of AB derived from açaí seed residues showed promising agronomic responses in the production of cherry tomato seedlings, especially at low proportions (12.5% biochar and 87.5% CS). This formulation favored a physical-chemical balance in the substrate, resulting in occasional improvements in characteristics such as SD, NL, and CC, although these differences were not always statistically significant throughout the growth cycles.

However, the results also indicate that the effect of biochar may be limited or variable depending on the parameter evaluated and the cultivation period. In some cases, seedling responses were similar to or lower than those observed with CS alone. Additionally, the açaí-derived biochar exhibited a relatively low proportion of fixed carbon compared to other biomass sources, which may limit its effectiveness as a carbon sink and its long-term stability in the soil.

Therefore, although açaí AB shows potential as a substrate conditioner during early development stages, caution is advised when generalizing its effects. Further studies are needed to optimize pyrolysis conditions, explore different application rates, and assess performance in later growth stages and open-field conditions. However, the valorization of local waste such as açaí reinforces alignment with the principles of bioeconomy and regional sustainability.

Authors' Contributions

Leal, J. E. C: Conceptualization, Methodology, Formal Analysis, Investigation, Visualization, Writing – original draft, Project administration, Supervision; **Fagnani**, H. M. C.: Methodology, Validation, Writing – review & editing; **Monteiro**, L. A: Data curation, Formal Analysis, Writing – review & editing; **Jaconi**, A.: Resources, Software, Validation, Writing – review & editing; **Pedroza**, M. M.: Investigation, Resources, Writing – review & editing; **Rambo**, M. C. D.: Supervision, Validation, Writing – review & editing; **Rambo**, M. K. D.: Funding acquisition, Project administration, Supervision, Writing – review & editing.

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