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Residue from the sugarcane agroindustry in the formulation of substrate for the production of *Physalis* seedlings

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ABSTRACT

Although recognized as an excellent alternative for sustainable agriculture, Brazilian farmers have yet to fully exploit the potential of *Physalis*. Thus, this study aimed to evaluate the performance of sugarcane bagasse, a byproduct of the sugarcane agro-industry, and its utility as a component in substrate formulations for producing *Physalis peruviana* seedlings at various concentrations. Five concentrations of sugarcane bagasse (0, 20, 40, 60, and 80%) were added to the substrate for growing *P. peruviana* seedlings in soil, along with an addition of 10% cured cattle manure. In the initial stage (from post-germination to pre-transplanting), the following traits were assessed: stem diameter (mm), number of leaves, percentage of emerged seedlings (%), and emergence speed index (ESI). In the second stage, following transplanting, measurements included height (cm), number of leaves, stem diameter (mm), substrate pH, root system length (cm), shoot fresh and dry weights (g), soil temperature (°C), and the Dickson quality index. The inclusion of sugarcane bagasse in the substrate was beneficial for germination and seedling emergence; however, it is not indicated for the development of *P. peruviana* seedlings. No significant differences were observed among the treatments concerning substrate temperature and the Dickson quality index.

Keywords: Waste utilization, Seedling production, Alternative substrates, Sustainable nursery, Sugarcane bagasse.

Resíduo da agroindústria canavieira na formulação de substrato para produção de mudas de *Physalis*

RESUMO

Mesmo sendo considerada uma excelente alternativa de agricultura sustentável, os agricultores brasileiros não exploram ainda todo o potencial contido no physalis. Assim, o objetivo deste trabalho foi avaliar o desempenho de bagaço de cana-de-açúcar, residual da agroindústria canavieira, e sua aplicação como componente na formulação de substrato para produção de mudas de *Physalis peruviana* sob diferentes dosagens. Foram avaliadas cinco concentrações de bagaço de cana-de-açúcar (0, 20, 40, 60 e 80%) adicionada ao substrato para produção de mudas *P. peruviana* junto ao solo, mais adição de 10% de esterco bovino curtido. Na primeira etapa (entre pós germinação e pré repicagem) foram avaliadas as características diâmetro do caule (mm), número de folhas, porcentagem de plântulas emergidas (%) e índice de velocidade de emergência (IVG) e na segunda etapa, após a repicagem, foram avaliadas a altura (cm), número de folhas, diâmetro do caule (mm), pH do substrato, comprimento do sistema radicular (cm), massa fresca e seca de parte aérea (g) e temperatura do solo (°C) e índice de qualidade de Dickson. A adição de bagaço de cana-de-açúcar ao substrato foi favorável a germinação e emergência de plântulas, contudo, não é indicada para o desenvolvimento das mudas de *P. peruviana*. Não houve diferença significativa entre os tratamentos em relação à temperatura do substrato e ao índice de qualidade de Dickson.

Palavras-chave: Aproveitamento de resíduos, Produção de mudas, Substratos alternativos, Viveiricultura sustentável, Bagaço de cana-de-açúcar.

1. Introduction

Substrate is defined as any material used to provide physical support and supply nutrients to plants until they are transferred to the nursery or production area (Hoffmann et al., 2005). It is one of the most important factors in the formation of fruit seedlings (Kuhn et al., 2012), and the use of an ideal substrate in the appropriate proportion allows for the production of healthier fruit seedlings (Matias et al., 2019). In this context, according to Spier et al. (2009), characterizing a material for use as a substrate in plant cultivation involves testing it in plant production scenarios.

A good substrate is characterized by its low cost and easy availability (Silva et al., 2006b). However, with the increasing scarcity of natural resources, there is a growing need to find alternative components for seedling production and plant cultivation (Klein, 2015). Recently, due to the depletion of certain substrates through uncontrolled extractivism, there has been a rising interest in alternative substrates that are economically viable and have minimal environmental impact (Meurer et al., 2008). These resources, often derived from waste reuse, contribute to environmental preservation and promote the generation of cleaner, renewable energy (Brito et al., 2024).

Several studies have shown promising results using alternative substrates for seedling production. Matias et al. (2019) assessed the viability of decomposed buriti (*Mauritia flexuosa* L. f.) stems combined with soil in substrate formulations for producing ‘Hawaii’ papaya (*Carica papaya* L.) seedlings and observed positive outcomes. Biasi et al. (1995) discovered that a mixture of sugarcane bagasse and peat in equal volumetric proportions (1:1) serves as an effective substrate for tomato (*Lycopersicon esculentum* L.) and yellow passion fruit (*Passiflora edulis* f. flavicarpa) seedlings.

Massad et al. (2016) noted that sugarcane bagasse has significant potential in substrate compositions for producing red angico (*Anadenanthera peregrina* (L.) Speng) seedlings, reducing production costs and achieving environmental benefits through residue reuse. Chaves et al. (2020) reported that sugarcane bagasse is an appropriate substrate for producing hydroponic corn forage, as it minimizes moisture loss and nutrient solution drainage.

According to Vieira et al. (2019), sugarcane bagasse, produced from agro-industrial waste, is considered an alternative substrate. Serrano et al. (2006) confirmed its successful application in producing seedlings for various fruit and forest species, providing morphophysiological qualities comparable to or better than those achieved with commercial substrates. *Physalis* is a crop with considerable potential for expansion in Brazil, yet it remains undercultivated (Hoffmann and Rufato, 2012). Developing cultivation alternatives that benefit producers of all scales is therefore essential. Information on management and cultivation practices for *Physalis* is still limited (Santos et al., 2023). Kuhn et al. (2012) highlighted that the substrate recommended for the initial development of *Physalis* seedlings should possess physical and chemical properties conducive to water retention and sufficient porosity for gas exchange.

Given this backdrop, this study aimed to evaluate the performance of sugarcane bagasse, a byproduct of the sugarcane agroindustry, in various concentrations as a component in substrate formulations for the production of *Physalis peruviana* seedlings.

2. Material and Methods

The study was conducted in the experimental area of the Goiatuba University Center (UniCerrado), located in Goiatuba, Goiás, Brazil. The geographic coordinates for this location are 17°59’36” S and 49°21’53” W, at an altitude of approximately 722 m (Amaral et al., 2016). The prevailing atmospheric conditions in the region are tropical, characterized by higher rainfall during the summer than in winter. The climate is classified as Aw according to the Köppen-Geiger system. The average annual temperature in Goiatuba is 24.1 °C, and the average annual rainfall is 1498 mm (Climate Data, 2024).

The compost bin was assembled directly on the ground, measuring 1 m² with a depth of approximately 20 cm. Black plastic tarpaulin was used both to separate the ground sugarcane bagasse (SCB) from direct soil contact and to cover it, preventing direct exposure to the environment and facilitating composting actions. Daily watering was conducted to maintain moisture levels and promote the decomposition of the material. The SCB was turned weekly using a hoe to ensure uniform decomposition. Once the temperature inside the pile decreased (measured with a thermometer) and the material appeared homogeneous with particle characteristics similar to soil and a dark color, it was considered "mature" and ready for incorporation into the soil as part of the substrate composition. The SCB was purchased pre-ground from sugarcane agroindustries near the municipality of Goiatuba, Goiás.

The project was divided into two stages. In the first stage, which took place in May 2023, seeds were sown in 200-cell trays filled with varying proportions of substrate. Attributes related to germination were analyzed during this stage. Subsequently, in the second stage, some seedlings were transplanted once they developed a pair of fully expanded true leaves, approximately 28 days after germination. These seedlings were transferred to plastic bags measuring 20 x 10 cm (height and width) filled with the proposed substrate formulation. Attributes related to agronomic performance were then assessed. The treatments consisted of different concentrations of decomposed SCB mixed with soil and cattle manure, detailed in Table 1.

Table 1. Treatments evaluated and respective substrate compositions. Goiatuba, GO, Brazil, 2023.

Treatment	Substrate composition
1	90% soil + 10% cattle manure
2	70% soil + 10% cattle manure + 20% SCB
3	50% soil + 10% cattle manure + 40% SCB
4	30% soil + 10% cattle manure + 60% SCB
5	10% soil + 10% cattle manure + 80% SCB

The SCB, soil from deeper layers, and the manure underwent chemical analysis at regional laboratories to ascertain the chemical characteristics of each material (Tables 2, 3, and 4, respectively). Commercial cattle manure, Terral® brand, was used, and the seeds were sourced from production companies selling *P. peruviana* seeds under the HGP® brand. Throughout the experimental period, the seedlings were kept in a shaded environment with 50% light exposure until evaluations were conducted. Three applications of nitrogen fertilizer (urea) were administered at 75, 90, and 105 days after sowing, following the fertilization guidelines recommended by Silva et al. (2006a) for industrial tomato seedlings. A randomized block design was employed, comprising five treatments and five replicates, resulting in a total of 25 experimental plots with 15 plants per plot, summing up to 375 plants in the first stage. In the second stage, only five plants from each plot of the respective treatments were transplanted, totaling 125 plants.

The traits were analyzed in two stages. In the first stage were analyzed: Seedling height (cm); Number of leaves; Percentage of seedling emergence (%); Emergence speed index (ESI), as proposed by Maguire (1962), according to the formula:

$$ESI = \frac{S_1}{N_1} + \frac{S_2}{N_2} + \cdots + \frac{S_n}{N_n},$$

where S_1, S_2, S_n = number of seedlings emerged, recorded on the first, second, and last counting days, respectively; N_1, N_2, N_n = number of days from sowing to the first, second, and last counts, respectively.

Table 2. Physicochemical analysis of the soil. Goiatuba, GO, Brazil, 2023.

Soil	Sand	Silt	Clay	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	CEC	BS
Unit		%		-------------------------$cmol_c dm^{-3}$---------------------						%
	58	10	32	0.9	0.5	0.3	4.3	1.4	5.7	25.2
	pH		P		S		K		OM	
Unit	$CaCl_2$		-----------------------mg dc^{-3}--------------------------						g kg^{-1}	
	4.5		1.1		0.8		16.6		16.1	
Soil texture class = medium										

SB - sum of bases; CEC - cation-exchange capacity; BS - base saturation; OM - organic matter.

Table 3. Chemical analysis of sugarcane bagasse samples. Goiatuba, GO, 2023.

Bagasse	Moisture	OM	N	P_2O_5	K_2O	S	Ca	Mg
Unit			---------------------------------------%-------------------------------------					
	67.0	18.0	0.30	0.40	0.30	0.20	1.10	0.20
	B	Cu	Fe	Mn	Zn			
Unit	---------------------------------%-------------------------------							
	0.01	0.05	6.0	0.30	0.06			

OM - organic matter

Table 4. Chemical analysis of cattle manure samples. Goiatuba, GO, 2023.

Manure	Moisture	OM	N	P_2O_5	K_2O	S	Ca	Mg
Unit				-------------------------%-------------------------				
	8.0	53.0	1.40	1.50	1.30	0.60	1.60	0.30
	B	Cu	Fe	Mn	Zn			
Unit		-----------------------%-----------------------						
	0.01	0.04	8.0	0.70	0.50			

OM - organic matter

Measurements for seedling height and number of leaves were taken before transplanting using a tape measure and a digital caliper, respectively. A total count of seedlings was also performed to calculate the germination percentage. In the second stage were analyzed: Seedling height (cm); Stem diameter (cm); Root length (cm); Number of leaves; Dickson (1960) quality index; Shoot fresh weight (g); Substrate temperature (°C); Substrate pH; Shoot dry weight (g).

The Dickson (1960) quality index is utilized to assess the quality of the seedlings, providing a comprehensive measure of their development in terms of morphological quality. The index is calculated using the following formula:

$$DQI = \frac{TDW\ (g)}{\frac{H\ (cm)}{SD\ (mm)} + \frac{SDW\ (g)}{RDW\ (g)}},$$

where DQI = Dickson quality index; TDW (g) = total dry weight (g); H (cm) = height (cm); SDW (g) = shoot dry weight (g); SD (mm) = stem diameter (mm); RDW (g) = root system dry weight (g). For the measurements of shoot height and root length, which were cleansed of impurities under running water, precision was ensured using a tape measure marked in millimeters. Stem diameter was measured at the neck, using a digital caliper. Substrate pH levels were determined using a digital meter.

Fresh weight assessments were conducted using a precision scale. These measurements took place in the multidisciplinary laboratory of the Agronomy course at the Goiatuba University Center and were recorded in grams. To determine dry weight, different plant parts (root system and shoots) and oven-dried at a constant temperature of 65 °C until weight stabilization, after which they were weighed on a precision scale. The results were analyzed using the F-test. In cases of significant differences between treatments, regression analysis was conducted using Sisvar software (Ferreira, 2011) to determine the most appropriate model for the data's behavior. Graphs were generated using Excel software (Microsoft®, 2010).

3. Results and Discussion

The data was collected over a 112-day seedling production cycle, from sowing to laboratory analysis. The analysis revealed that linear models best explained the behavior of seedlings in relation to sugarcane bagasse concentrations for pre-transplanting height, number of leaves before transplanting, post-transplanting height, stem diameter, and root system length. Quadratic models were more suitable for the number of leaves, substrate pH, and shoot fresh and dry weight, as detailed in Table 5. As illustrated in Figure 1, notable differences were observed in the seedlings subjected to substrates composed of varying rates of sugarcane bagasse, soil, and cattle manure. In the first stage (pre-transplanting stage), significant differences were noted among the treatments for both height and number of leaves, as detailed in Table 6.

Table 5. Regression equations for growth traits of *P. peruviana* seedlings cultivated in substrate with different concentrations of sugarcane bagasse.

Variable	Equation	R^2
	Pre-transplanting	
Pre-transplanting height (cm)	$\hat{Y}$ = - 0.0182x + 2.1788*	0.7288
Number of leaves pre-transplanting	$\hat{Y}$ = - 0.0457x + 3.96*	0.9109
Percentage of seedling emergence	$\hat{Y}$ = 0.5133x + 10.4	0.9369
Emergence speed index	$\hat{Y}$ = 0.0107x + 0.1728	0.9267
	Post-transplanting	
Height (cm)	$\hat{Y}$ =-0.0877x + 8.3748*	0.7893
Number of leaves	$\hat{Y}$ =0.0014x^2 - 0.1652x + 7.4053*	0.8885
Stem diameter (mm)	$\hat{Y}$ = -0.0471x + 4.7832*	0.803
Substrate pH	$\hat{Y}$ = 0.0003x^2 - 0.0246x + 4.6794*	0.8224
Root system length (cm)	$\hat{Y}$ = -0.1847x + 22.104*	0.5273
Shoot fresh weight (g)	$\hat{Y}$ = 0.0025x^2 - 0.2967x + 8.9451*	0.8106
Shoot dry weight (g)	$\hat{Y}$ = 0.0003x^2 - 0.0316x + 0.8711*	0.9044

* - Significant at 0.05 probability; R^2 - Coefficient of determination.

Figure 1. P. *peruviana* seedlings across different substrate mixtures at 112 days after sowing in Goiatuba, GO, 2023.

Table 6. Analysis of variance for height and number of leaves in the pre-transplanting stage in *Physalis seedlings* produced with substrate containing different concentrations of sugarcane bagasse. Goiatuba, GO, 2023.

		Mean square			
SV	DF	Height (cm)	N of leaves	Percentage of emergence	ESI
Bagasse concentration	4	2.274914*	11.453686*	1406.237116*	0.618866*
Block	4	0.163144	0.442596	57.336006	0.048116
Error	16	0.133416	0.252611	40.394616	0.017084
Total	24	-	-	-	-
CV (%)	-	25.18	23.57	20.55	21.74

SV - source of variation; DF - degrees of freedom; ESI - emergence speed index; CV - coefficient of variation. * Significant at the 0.05 probability level by the F test.

As the concentration of sugarcane bagasse in the substrate increased, a corresponding decrease was observed in both the height and number of leaves of *Physalis* (*P. peruviana*) seedlings. This relationship demonstrates an inverse proportionality to the increase in bagasse content (Figures 2 and 3). While the addition of sugarcane bagasse to the substrate proved unsuitable for the seedlings of this species, it has yielded satisfactory results in other species, such as orchids from the genera Cattleya and Vanda, as observed by Meurer et al. (2008).

Conversely, increases in the percentage of emergence and ESI were noted alongside rising concentrations of SCB in the substrate (Figures 4 and 5). The germination rate peaked at 62.67%, with 235 of the 375 sown seeds germinating over a 64-day period until pre-transplanting. The use of SCB in the pre-transplanting stage is advocated for producing healthy seedlings swiftly and cost-effectively. Massad et al. (2015) recommend employing alternative substrates that incorporate organic waste readily available in the region and accessible to producers. Furthermore, SCB, a byproduct of the sugarcane agroindustry, is abundantly available across most Brazilian regions, as noted by Uliana et al. (2014).

In the second stage of the experiment, significant differences were observed among the treatments for various traits, including height, number of leaves, stem diameter, substrate pH, root system length, and both fresh and dry weight of shoots. These differences in the post-transplanting stage are detailed in Table 7. Figures 6 through 10 illustrate the effect of SCB on the height, number of leaves, stem diameter, substrate pH, and root system length. The addition of SCB to the substrate was found not to enhance the development of the seedlings; therefore, its use for this purpose is not recommended.

As depicted in Figures 6, 7, and 8, there was a decreasing trend in height, number of leaves, and stem diameter as the concentration of bagasse in the substrate increased. This trend suggests an inverse relationship between the development of seedlings and the use of bagasse as a substrate component. Figure 9 shows a tendency for substrate pH to become more acidic with increasing concentrations of bagasse, with the highest acidity recorded at 40% bagasse concentration. Beyond this point, the pH began to rise, eventually stabilizing at similar levels found in the substrates with 0% and 80% bagasse concentrations (Figures 2, 3, 4, 5, 6, 7 e 8).

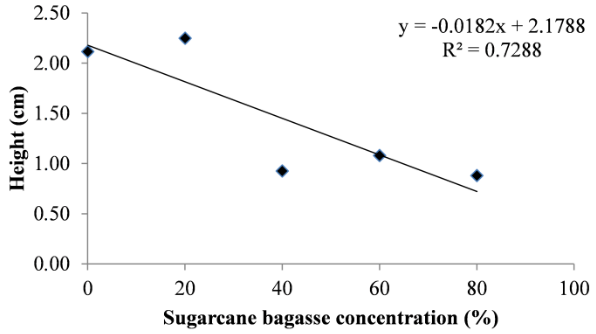

Figure 2. Pre-transplanting height of *P. peruviana* seedlings as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023**.**

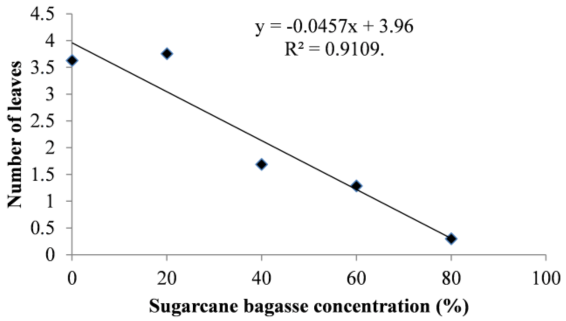

Figure 3. Number of leaves in the pre-transplanting stage of *P. peruviana* as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023.

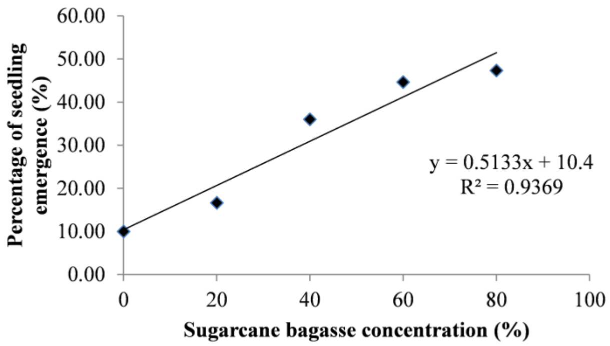

Figure 4. Percentage of seedling emergence (%) in the pre-transplanting stage of *P. peruviana* as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023.

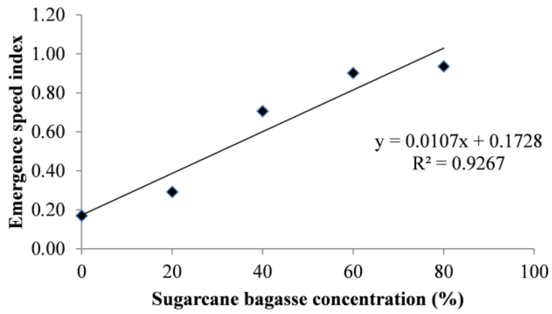

Figure 5. Emergence speed index in the pre-transplanting stage of *P. peruviana* as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023.

Table 7. Analysis of variance for the variables analyzed in the post-transplanting stage in *Physalis* seedlings produced in substrate containing different concentrations of sugarcane bagasse. Goiatuba, GO, Brazil 2023.

		Mean square					
SV	DF	Height (cm)	N of leaves	Stem diam. (mm)	Substrate temp. (°C)	Substrate pH	Root sys. length
Concentration	4	48.730504*	24.082636*	13.830560*	0.189004^{ns}	0.298600*	323.490150*
Block	4	2.557214	1.624516	2.568980	2.700734	0.080480	11.917650
Error	16	3.402044	2.440966	0.985465	0.207984	0.065355	23.061713
Total	24	-	-	-	-	-	-
CV (%)	-	37.90	38.66	34.25	1.52	5.83	32.63

		Mean square		
SV	DF	SFW (g)	SDW (g)	Dickson index
Concentration	4	76.885844*	0.631846*	0.965686^{ns}
Block	4	3.242044	0.035006	4.025646
Error	16	4.983737	0.022304	3.780536
Total	24	-	-	-
CV (%)	-	70.83	47.99	72.36

SV - source of variation; DF - degrees of freedom; SFW - seed fresh weight; SDW - seed dry weight. * Significant at the 0.05 probability level by the F test. ns Not significant at the 0.05 probability level by the F test.

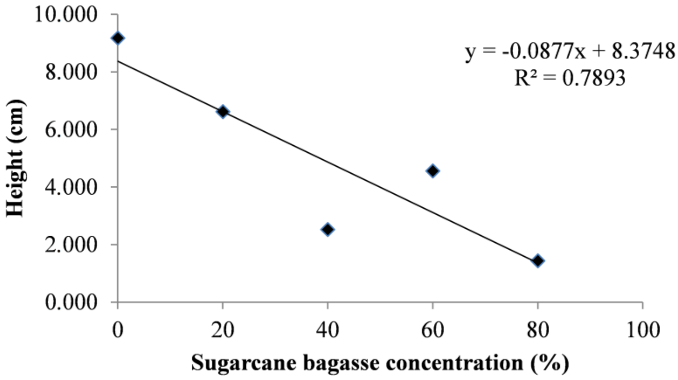

Figure 6. Height of *P. peruviana* seedlings (cm) as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023.

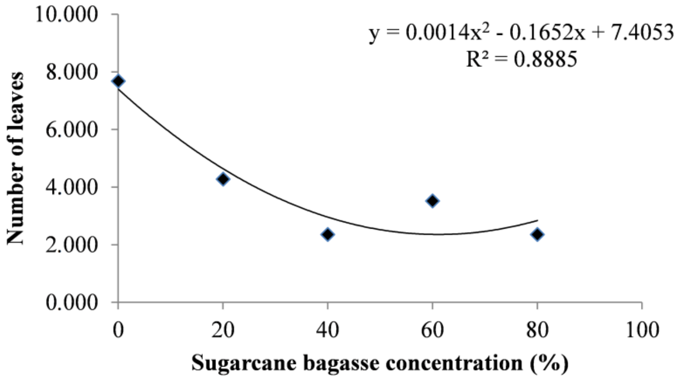

Figure 7. Number of leaves in *P. peruviana* seedlings as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023.

As indicated in Figure 10, the root system length exhibited a growth rate that was inversely proportional to the increase in bagasse concentration. Shoot fresh weight decreased at higher concentrations of bagasse, showing a slight increase from the 60% concentration until reaching the lowest value at 80% (Figure 11). A similar pattern was observed for the dry weight of shoots (Figure 12), where higher bagasse concentrations initially led to decreased dry weight accumulation, followed by a slight recovery and an upward trend from the 60% concentration. The lowest value for this trait also occurred near this concentration.

It is evident that the addition of sugarcane bagasse to the substrate did not favor the development of *P. peruviana* seedlings, as those grown in substrates with added bagasse demonstrated inferior development compared to those where bagasse was absent. In *Physalis* sp. species, seedling characteristics are known to determine its vigor and the timing of transplantation, which affects field performance and crop yield (Machado et al., 2024).

This highlights the importance of careful substrate formulation and selection in this stage. The growth curves for seedling development indicated impairment with the addition of sugarcane bagasse. However, in other species, the effect of bagasse was positive; for instance, Serrano et al. (2006) reported that substrates composed of sugarcane agroindustry waste, when combined with slow-release fertilizers, are suitable for producing yellow passion fruit seedlings. No significant differences were found in substrate temperature across treatments, suggesting that temperature remained consistent regardless of bagasse concentration.

Literature on substrate composition for seedling cultivation of species of the genus *Physalis* sp. shows mixed results. Cecco et al. (2018) found that different substrate mixtures benefitted two species differently: *P. ixocarpa* and *P. minima*. They recommended a mixture of Húmus Fértil® and medium-textured expanded vermiculite or Latosol with added vermiculite for *P. ixocarpa*, and a combination of Húmus Fértil® with vermiculite for *P. minima*.

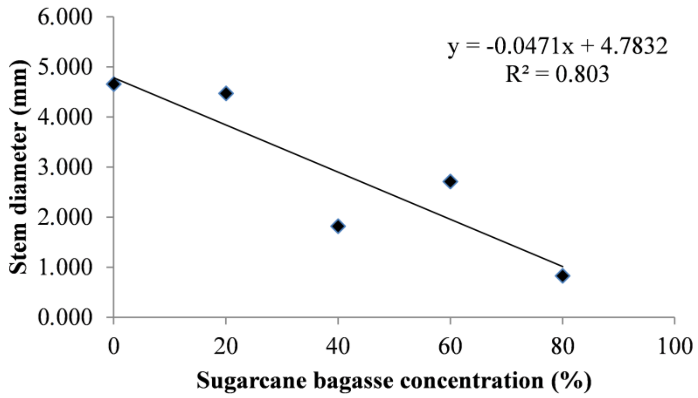

Figure 8. Stem diameter in *P. peruviana* seedlings as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023.

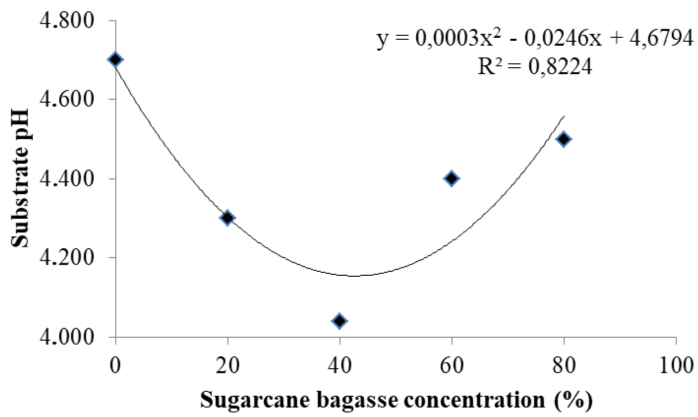

Figure 9. Substrate pH of *P. peruviana* seedlings as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023.

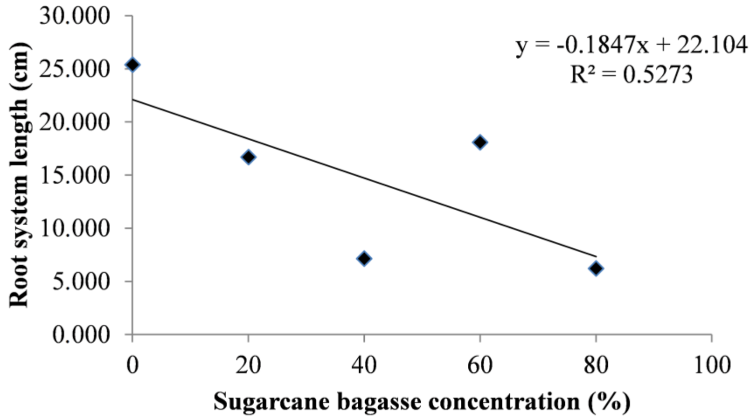

Figure 10. Root system length in *P. peruviana* seedlings as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023.

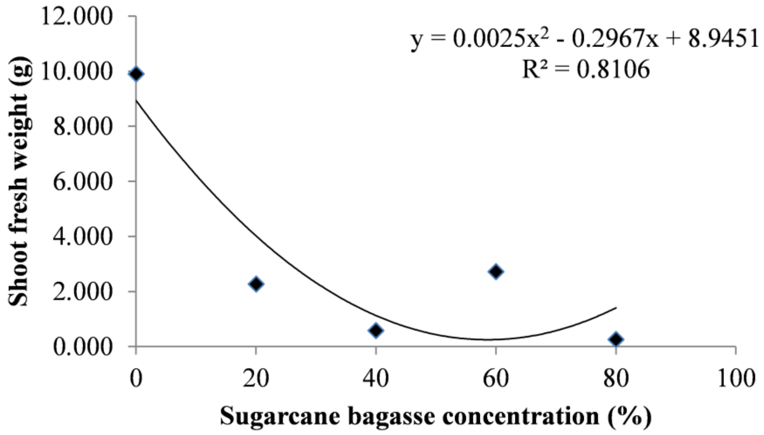

Figure 11. Shoot fresh weight in *P. peruviana* seedlings as a function of sugarcane bagasse concentrations added to the substrate. Goiatuba, GO, 2023.

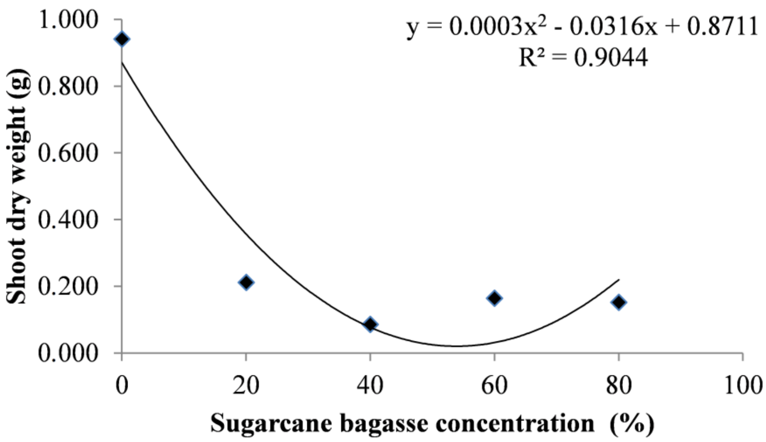

Figure 12. Shoot dry weight in *P. peruviana* seedlings as a function of concentrations of sugarcane bagasse added to the substrate. Goiatuba, GO, 2023.

4. Conclusions

The use of sugarcane bagasse in substrate formulations for *P. peruviana* seedlings throughout their development is not advisable due to its detrimental effects on growth. However, seedling emergence was positively affected by increasing concentrations of sugarcane bagasse in the substrate for *P. peruviana*. No significant differences has been observed between treatments in terms of substrate temperature or the Dickson quality index.

Authors' Contribution

The authors, Matheus Rocha Oliveira and Givago Coutinho, were responsible for creating all figures and tables and for writing the main texts in the manuscript. Matheus Rocha Oliveira conducted all field evaluations during the experiment. Professor Givago Coutinho handled the data analysis. Both authors reviewed the final manuscript.

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