Nativa, Sinop, v. 13, n. 3, p. 413-422, 2025.
Pesquisas Agrárias e Ambientais
DOI: https://doi.org/10.31413/nat.v13i3.19662
ISSN: 2318-7670

Evaluation of substrates enriched with wood ash for growing *Lycopersicum esculentum* var. Cerasiforme

Sérgio Plens ANDRADE [1], Tonny José Araújo da SILVA [1], Edna Maria BONFIM-SILVA [1], Luana Aparecida Menegaz MENEGHETTI [1], Ivis Andrei CAMPOS E SILVA [1], Niclene Ponce Rodrigues de OLIVEIRA [2], Alisson Silva Costa CUSTÓDIO [2], Rosana Andréia da Silva ROCHA [2], Letícia Melo Silva MARQUES [1], Patrícia Ferreira da SILVA *[3]

[1] Federal University of Rondonópolis, Rondonópolis, MT, Brazil.
[2] Federal University of Mato Grosso, Cuiabá, MT, Brazil.
[3] National Center for Monitoring and Alerting Natural Disasters - Cemaden/MCTI, SP, Brazil.
*E-mail: patrycyafs@yahoo.com.br

Submitted: 05/19/2025; Accepted: 07/27/2025; Published: 08/05/2025.

ABSTRACT: This study aimed to evaluate the performance of three cherry tomato cultivars enriched with wood ash in terms of vegetative development, productivity, and fruit quality in a protected environment. The study was conducted at Universidade Federal de Rondonópolis in a randomized block design in a 2x3 factorial scheme, with two types of substrates (substrate 1: mechanized Oxisol+wood ash; substrate 2: Oxisol from a preserved area + commercial compost + wood ash) and three cherry tomato cultivars (Carolina, Red Cherry, and Cherry), with eight replications. Substrate 2 contains approximately 54% more organic matter than substrate 1, which significantly contributes to greater fruit mass, leaf area, and water use efficiency in the cherry tomato cultivars. In substrate 2, fruit mass exceeded 600 g per plant, while leaf area surpassed 2000 cm² per plant. Additionally, for each liter of water supplied, fruit mass increased by 87 g. The titratable acidity of the fruit was higher in the fruit grown in substrate 1. The growing medium did not alter the total soluble solids content. The Carolina and Red Cherry cultivars had the highest average fruit mass, leaf area, and water use efficiency.
Keywords: cherry tomatoes; fruit quality; sustainable horticulture; alternative substrate; water use efficiency; agro-industrial residue.

Avaliação de substratos enriquecidos com cinzas de madeira para cultivo de *Lycopersicum esculentum* var. Cerasiforme

RESUMO: Objetivou-se com o estudo avaliar substratos enriquecidos com cinza de madeira no desempenho de três cultivares de tomate-cereja quanto ao desenvolvimento vegetativo, produtividade e qualidade de frutos em ambiente protegido. O experimento foi conduzido na Universidade Federal de Rondonópolis, em blocos casualizados em esquema fatorial 2x3, com dois tipos de substratos (substrato 1: Oxisol mecanizado+cinzas de madeira; substrato 2: Oxisol de área preservada + composto comercial+cinzas de madeira) e três cultivares de tomate cereja (Carolina, Red Cherry e Cherry), com oito repetições. O substrato 2 contém aproximadamente 54% mais matéria orgânica do que o substrato 1, o que contribui significativamente para uma maior massa de frutos, área foliar e eficiência do uso da água nas cultivares de tomate cereja. No substrato 2, a massa de frutos ultrapassou 600 g por planta, enquanto a área foliar ultrapassou 2000 cm² por planta. Para cada litro de água fornecido, a massa dos frutos aumentou em 87 g. A acidez titulável dos frutos foi maior nos frutos cultivados no substrato 1. O substrato não alterou o teor de sólidos solúveis totais. As cultivares Carolina e Red Cherry apresentaram as maiores médias de massa de fruto, área foliar e eficiência no uso da água.
Palavras-chave: tomate-cereja; qualidade do fruto; horticultura sustentável; substrato alternativo; eficiência do uso da água; resíduo agroindustrial.

1. INTRODUCTION

Cherry tomato cultivation has gained prominence due to its versatility in terms of nutritional value, resistance to pests and diseases, as well as high productivity and commercial value (AZEVEDO et al., 2024). To ensure high-quality production, it is essential to adopt alternative technologies, such as protected cultivation, alternative substrates, and the automation of temperature, light, and irrigation control systems, to maximize yield.

In horticulture, various substrate formulations are employed, including synthetic, organic, pure, or mixed substrates. The use of alternative materials or substrates enables sustainable and competitive production. These substrates must possess physical, biological, and chemical properties that support proper root system growth, provide adequate aeration, promote aggregation, and retain water effectively (SANTANA et al., 2024).

Commercial substrates are widely recommended for vegetable cultivation. However, the demand for new sustainable production alternatives that reduce reliance on non-renewable materials has been increasing. These solutions aim to meet the needs of plants and the environment while remaining economically viable for producers (SOUZA et al., 2024).

Thus, the use of organic substrates derived from plant and animal composts could emerge as an excellent option for enhancing both the production and quality of cherry tomato fruits (MENEZES JÚNIOR et al., 2023). This is because organic or alternative-based substrates are inherently rich in essential nutrients, which contribute to plant development.

The combination of agro-industrial residues, such as wood ash, with soil from cultivated or preserved areas creates an excellent organic input, resulting in a stable compost rich in high-quality organic matter. This reduces the need for synthetic substrates or the addition of chemical fertilizers to the growing substrates (BRITO et al., 2024).

Alternative substrates with high organic matter content, greater than 20%, contribute to an increase in the total mass of tomatoes during cultivation (SANTOS et al., 2024). When comparing organic and commercial substrates in cherry tomato production, Medeiros et al. (2013) observed that the addition of organic compounds, i.e., the organic substrate, resulted in greater leaf production and a higher quantity of tomato fruits (SOLDATELI et al., 2020) compared to the commercial substrate. Substrates with high organic matter content may gradually release nutrients to plants, which play a crucial role in the production of photoassimilates that ultimately contribute to fruit yield and quality.

In this context, substrates derived from agro-industrial residues, such as wood ash, combined with soils from areas near the cultivation region, can be a viable alternative to enrich the substrate used in vegetable production. The incorporation of these agro-industrial compounds not only increases organic matter content but also enhances ionic charge availability, improves porosity, optimizes moisture retention, and provides essential nutrients for healthy plant growth and development (WANG et al., 2017; CAMPOS et al., 2023).

The combination of organic compounds with soils that have either a long history of exploitation or minimal prior use is a widely discussed topic. However, the integration of agro-industrial residues, such as wood ash, with soils for vegetable cultivation substrates remains largely unexplored. Thus, the search for viable nutritional alternatives has been continuously increasing, particularly in controlled systems. Soils with a long history of cultivation are more susceptible to degradation, including acidification, fertility depletion, and reduced microbial diversity, compared to less-exploited soils (ZHANG et al., 2015; FU et al., 2017).

Thus, the hypothesis to be investigated is that using alternative substrates enriched with wood ash, combined with either cultivated or preserved-area soil, as a strategy for cherry tomato cultivation in a protected environment, can be a viable approach to enhancing both yield and fruit quality across different varieties.

In this context, this study aimed to evaluate wood ash-enriched substrates in terms of their effect on the vegetative growth, productivity, and fruit quality of three cherry tomato cultivars grown in a protected environment.

2. MATERIALS AND METHODS

2.1. Location and experimental conditions

The experiment was conducted at the Universidade Federal de Rondonópolis (UFR), Mato Grosso, Brazil (15º 36' 41 "S and 56º 03' 53" W, altitude 165 m), The experiment was carried out in a controlled environment, which featured a Pad and Fan evaporative cooling system do tipo *Pad and Fan*, programmed to maintain the temperature at 26ºC ± 1ºC and the relative humidity at 65% throughout the experiment period, from May to September 2022.

According to the Köppen classification, the region's climate is Aw (tropical with a dry winter), characterized by a dry season from May to September and a rainy season from October to April.

2.2. Experimental design and treatments

The experimental design used was complete randomized blocks in a 2 x 3 factorial scheme, corresponding to two types of substrates (substrate 1: mechanized Oxisol + 3% wood ash; substrate 2: Oxisol from a preserved area + commercial compost + 3% wood ash) and three cherry tomato cultivars (Carolina, Red Cherry, and Cherry), with eight replications. Each block consisted of six experimental plots, each represented by a perforated plastic pot with a capacity of 16 dm³, filled with 10 dm³ of substrate for growing cherry tomatoes. The area occupied by the entire experiment was 28.8 m², with a spacing of 0.5 m between pots and 1 m between rows, using the same row spacing to separate the blocks.

Substrate 1 was prepared using Oxisol collected from a depth of 0-20 cm at the experimental field of the UFR university, classified as loam texture (380 g kg^{-1} clay, 125 g kg^{-1} silt, and 495 g kg^{-1} sand), but exhibiting a pH – 5.6 ($CaCl_2$), phosphorus - 8.5 mg dm^{-3}, potassium - 85 mg dm^{-3}, base saturation - 62%. For growing cherry tomatoes, 3% eucalyptus wood ash was added to the soil (BONFIM-SILVA et al., 2013).

Substrate 2 consisted of 40% Cerrado soil collected from a preserved area of UFR, with physical properties similar to those of the mechanized soil, but exhibiting a pH ($CaCl_2$) of 4.0, 0.0014 g dm^{-3} of phosphorus, 0.023 g dm^{-3} of potassium, and a base saturation of 9.7%. Additionally, the following components were added: 15% plant-based substrate (Vegetal HT, Vida Verde®, Mogi Mirim - SP, Brazil), adapted from Morais et al. (2019); 25% cured bovine manure (Mogifertil®, Mogi Mirim - SP, Brazil); 3% eucalyptus wood ash (BONFIM-SILVA et al., 2013); and 17% washed sand to complete the mixture. Table 1 presents the chemical properties of the substrates and the wood ash.

The cherry tomato cultivars used in this study were Carolina (Feltrin® Sementes, Farroupilha - RS, Brazil; Lot: 0069701930076010; germination rate: 96%; purity: 100%; expiration: November 2023), Red Cherry (Isla® Sementes, Porto Alegre - RS, Brazil; Lot: 150629-003 52; germination rate: 98%; purity: 99.8%; expiration: January 2024), and Cherry (Hortasul® Sementes, Prudentópolis - PR, Brazil; Lot: 47.1/02-21/1420094; germination rate: 92%; purity: 100%; expiration: February 2023).

2.3. Management and cultural practices

For sowing and seedling preparation, on May 28, 2022, a 128-cell expanded polystyrene tray was used. Three cherry tomato seeds were sown per cell in a vegetable substrate

(Vegetal HT, Vida Verde, Mogi Mirim, SP, Brazil), and the plants were grown in an agricultural greenhouse until transplanting. Seedlings emerged on June 2, and eight days after emergence (DAE), they were transplanted into pots containing the respective substrates within the greenhouse.

Table 1. Chemical properties of the mechanized soil, wood ash and alternative substrate used in the cultivation of tomato plants.
Tabela 1. Propriedades químicas do solo mecanizado, cinza de madeira e substrato alternativo utilizados no cultivo do tomateiro.

Substrate 1												
OM	pH	P	K	Ca	Mg	S	V	Mn	Cu	Fe	B	Zn
(g kg^{-1})	($CaCl_2$)	---------------------- (g dm^{-3}) ----------------------					(%)	---------------- (mg dm^{-3}) ----------------				
20.4	5.6	0.0085	0.085	0.044	0.18	0.003	62	69.2	0.5	38	0.14	2.6
Wood Ash												
P	K	Ca	S	Mn	B	Zn	Cu					
------------------- (g dm^{-3}) -------------------				--------------- (mg dm^{-3}) ------------								
9.5	15.4	15.3	8.45	0.0	110	60	60					
Substrate 2												
OM	pH	P	K	Ca	Mg	S	V	Mn	Cu	Fe	B	Zn
(g kg^{-1})	($CaCl_2$)	-------------------------- (g dm^{-3}) ------------------------					(%)	---------------- (mg dm^{-3}) -------------------				
44.4	6.0	0.57	0.90	0.10	0.37	0.027	87.7	64.6	0.7	92.0	0.87	10.2

OM – Organic matter; pH – hydrogen potential; P – Potassium; K – Phosphorus; Ca – Calcium; Mg – Magnesium; S – Sulphur; V – Base saturation; Mn – Manganese; Cu – Copper; Fe – Iron; B – Boron; Zn – Zinc.
OM – Matéria orgânica; pH – Potencial hidrogeniônico; P – Potássio; K – Fósforo; Ca – Cálcio; Mg – Magnésio; S – Enxofre; V – Saturação por bases; Mn – Manganês; Cu – Cobre; Fe – Ferro; B – Boro; Zn – Zinco.

All treatments received split nitrogen fertilization in four applications using urea (45% N) as the nitrogen source, applied at 14, 31, 46, and 67 days after transplanting (DAT). The nitrogen doses were 0.016 g dm^{-3} in the first application, 0.040 g dm^{-3} in the second, and 0.054 g dm^{-3} in the last two applications. In the first application, urea was dissolved in water and applied as a 50 mL dm^{-3} solution. In the subsequent applications, the granular fertilizer was applied directly to the pots, following the recommendations of Zambolim; Quezado-Duval (2022) for growing cherry tomatoes.

Three foliar fertilization applications were performed using a concentrated liquid fertilizer composed of calcium and boron (Base CaB2, Base Fertilizantes, Primavera do Leste, MT, Brazil). The first application was made at 32 DAT, the second at 45 DAT, and the last at 67 DAT for all treatments. In each application, the dose used was 1.5 mL L^{-1} of fertilizer and 35 mL of solution per plant, following the methodology proposed by Brandão Filho et al. (2018).

Irrigation was managed using evaporation data from a Class “A” pan installed inside the greenhouse, with a pan coefficient (Kp) of 0.85. The crop coefficient (Kc) values for the different development stages of tomato were adapted from Allen et al. (1998), with 0.60 for the initial stage, 0.85 for the vegetative stage, 1.15 for the reproductive stage, and 0.90 for the maturation stage. Based on this information, evaporation data and the crop coefficient were used to determine evapotranspiration, and irrigation management was based on daily consumption, with the volume of water applied during irrigation calculated according to the methodology proposed by Santos et al. (2018).

The irrigation system used was drip irrigation, and the water pump was controlled by a residential automation device (Sonoff TH16), which allowed defining the irrigation schedule and operation time. One emitter was installed per pot, with a flow rate of 5.66 L h^{-1}. A water meter was installed near the water pump to record the amount of water applied by the irrigation system throughout the entire crop cycle. Daily measurements of temperature and relative humidity (maximum, average, and minimum) were taken using a thermo-hygrometer (Termohigrômetro, Incoterm®, Porto Alegre – RS, Brazil) installed inside the greenhouse, with data collection throughout the entire crop cycle. During this period, the average temperature recorded was 27.73 °C, and the relative humidity was 52.07% (Figure 1). Considering a basal temperature of 10 °C for tomato plants, the accumulated thermal sum throughout the crop cycle was approximately 2196.71 degree days (°C day^{-1}).

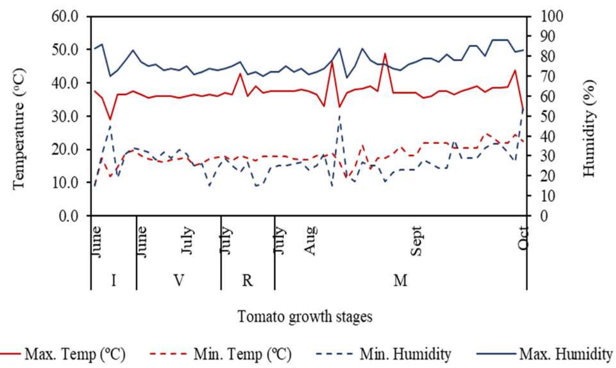

Figure 1. Maximum and minimum temperature and humidity inside the greenhouse during the experimental conduct of cherry tomatoes. I: initial; V: Vegetative; R: Reproductive; M: Maturation.
Figura 1. Temperatura máxima e mínima e humidade no interior da estufa durante a condução experimental do tomate-cereja. I: inicial; V: Vegetativo; R: Reprodutivo; M: Maturação.

The average crop cycle across the treatments lasted 100 days. The initial stage occurred from June 9 to 19, the vegetative stage from June 20 to July 11, the reproductive stage from July 12 to 24, and the maturation stage from July 25 to October 5, as illustrated in Figure 1.

Cultural practices, such as branch pruning, plant staking, pest and disease control, and fruit harvesting, were carried out following the methodology proposed by Brandão Filho et al. (2018). For pest and disease control, three applications of the insecticide (Epingle 100, Sumitomo Chemical do Brasil Representações LTDA, São Paulo - SP) were made at 10, 21, and 33 DAT to control the whitefly (*Bemisia tabaci*) at a dose of 1 mL L^{-1}.

2.4. Analyzed variables

The evaluated variables were: fruit mass (g $plant^{-1}$), leaf area (cm^2 $plant^{-1}$), soluble solids content (%), titratable acidity (g 100 mL^{-1}), and water use efficiency (kg L^{-1}).

For fruit mass, harvests were conducted every four days starting at 70 DAT, with fruits showing intense red coloration being weighed on a precision scale with an accuracy of 0.01 g. The leaf area was determined using a LICOR® leaf area integrator (model LI-3100), in which the leaves were collected, separated from the plant after fruit harvest, and passed through the leaf area meter. The soluble solids content was determined by reading the solution extracted from pressing the cherry tomato pulp using a refractometer (Biobrix, ATC-103, São Paulo, SP). Titratable acidity was determined following the methodology outlined by IAL, (2008) for citric acid analysis in fruits, with the results being transformed according to Tressler; Joslyn (1961) to express the outcome as grams of citric acid per 100 mL of solution. Water use efficiency was calculated as the ratio between fruit mass and the volume of water applied per plant throughout the crop cycle, following the methodology proposed by Zou et al. (2021).

2.5. Statistical analysis

The obtained results were subjected to homogeneity and normality tests, followed by analysis of variance (ANOVA) ($p \leq 0.001$, 0.01, and 0.05). Means were compared using Tukey's test at a 5% probability level. When the data did not follow a normal distribution, transformations were performed using the square root method. All statistical analyses were conducted using RStudio statistical software (version 4.2.1, R CORE TEAM, 2017), employing the Metan, Agricolae, Laercio, and Corrgram packages. Pearson's method was used to analyze the correlations between variables in the interpretation of the results.

3. RESULTS

3.1. Analysis of variance (ANOVA) for the studied factors

The different types of substrates significantly influenced fruit mass, leaf area, titratable acidity content, and water use efficiency in tomato plants (Table 2). Moreover, the tomato cultivars showed significant differences in all the variables studied (Table 2). There was no significant interaction between the type of substrate and the tomato cultivars for any of the variables evaluated (Table 2).

3.2 Fruit mass, leaf area, soluble solids, titratable acidity, and water use efficiency as a function of the cherry tomato cultivars studied

The fruit mass of the tomato cultivars Red (735.33 g $plant^{-1}$) and Carolina (631.85 g plant-1) was higher, significantly differing from the Cherry cultivar with 416.6 g $plant^{-1}$, representing a 43.3% reduction between Red and Cherry (Figure 2A). The largest leaf area (2518.59 cm^2 plant ^{1}) was observed for the Cherry cultivar, differing from the others, with a 23.64% and 24.49% reduction compared to the Carolina and Red cultivars, respectively (Figure 2B). Similar to the fruit mass, the Carolina (2.46%) and Red (2.39%) cultivars had the highest soluble solids content, differing from the Cherry cultivar (2.03%) (Figure 2C). The highest levels of titratable acidity were found in the Red (1.18 g/100 mL) and Cherry (1.10 g/100 mL) tomato cultivars, significantly differing from the Carolina cultivar (0.92 g/100 mL), with reductions of 22.03% and 16.36%, respectively (Figure 2D). The Red cultivar exhibited the highest water use efficiency, 0.0087 kg L^{-1}, while the Cherry cultivar had the lowest water use efficiency, 0.0066 kg L^{-1}, representing a 24.13% reduction between the two cultivars (Figure 2E).

3.3. Fruit mass, leaf area, soluble solids, titratable acidity, and water use efficiency of cherry tomato as a function of the substrates studied

The tomato plants grown in the substrate composed of Oxisol from a preserved area + commercial compost + 3% wood ash (substrate 2) exhibited higher fruit mass (650.25 g $plant^{-1}$), leaf area (2294.96 cm2 $plant^{-1}$), and water use efficiency (0.0087 kg L^{-1}) compared to the plants grown in the substrate composed of mechanized Oxisol + 3% wood ash (substrate 1), with 538.94 g plant-1, 1933.97 cm2 $plant^{-1}$, and 0.0069 kg L^{-1}, respectively, representing significant reductions of 17.11%, 15.73%, and 20.69% for each variable (Figure 3A, B, and E). The plants grown in substrate 1 (1.11 g 100 mL^{-1}) showed an 8.1% increase in titratable acidity compared to the tomato plants grown in substrate 2 (1.02 g 100 mL^{-1}) (Figure 3D). No significant differences were found in soluble solids content in plants grown in the different substrates.

Generally, the analyzed variables were positively correlated with one another (Figure 4). The strongest correlations were observed between fruit mass and soluble solids, as well as between fruit mass and water use efficiency.

Table 2. Summary of analysis of variance for the evaluated variables of cherry tomato (variety Carolina, Red cherry and Cherry) cultivated in two types of soil (Soil mechanized and alternative substrate).

Tabela 2. Resumo da análise de variância para as variáveis avaliadas do tomate cereja (variedade Carolina, Red cherry e Cherry) cultivado em dois tipos de solo (Solo mecanizado e substrato alternativo)

Source of variation	Mean squares					
	DF	Fruit mass (g $plant^{-1}$)	Leaf area (cm^2 $plant^{-1}$)	[1]Soluble solids (%)	[1]Titratable acidity (g 100 mL^{-1})	Water use efficiency (Kg L^{-1})
Soil	1	148675*	1563801**	0.0176ns	0.08841*	0.0000418**
Variety	2	422997***	1961669***	0.8471***	0.26376***	0.0000198**
Block	7	41975ns	230858ns	0.0425ns	0.04149ns	0.0000079ns
S x V	2	7317ns	49212ns	0.0368ns	0.02001ns	0.0000003ns
Residual	35	25218	160235	0.0343	0.01929	0.0000036
CV (%)	-	26.70	18.93	8.05	12.97	24.49

***, **, *, ns - Significant at $p \leq 0.001$, 0.01, 0.05 and not significant, respectively, by F test; [1]Square root transformed data; DF – Degrees of freedom; CV – Coefficient of variation.

***, **, *, ns - Significativo em $p \leq 0,001$, 0,01, 0,05 e não significativo, respectivamente, pelo teste F; 1Dados transformados em raiz quadrada; DF – Graus de liberdade; CV – Coeficiente de variação.

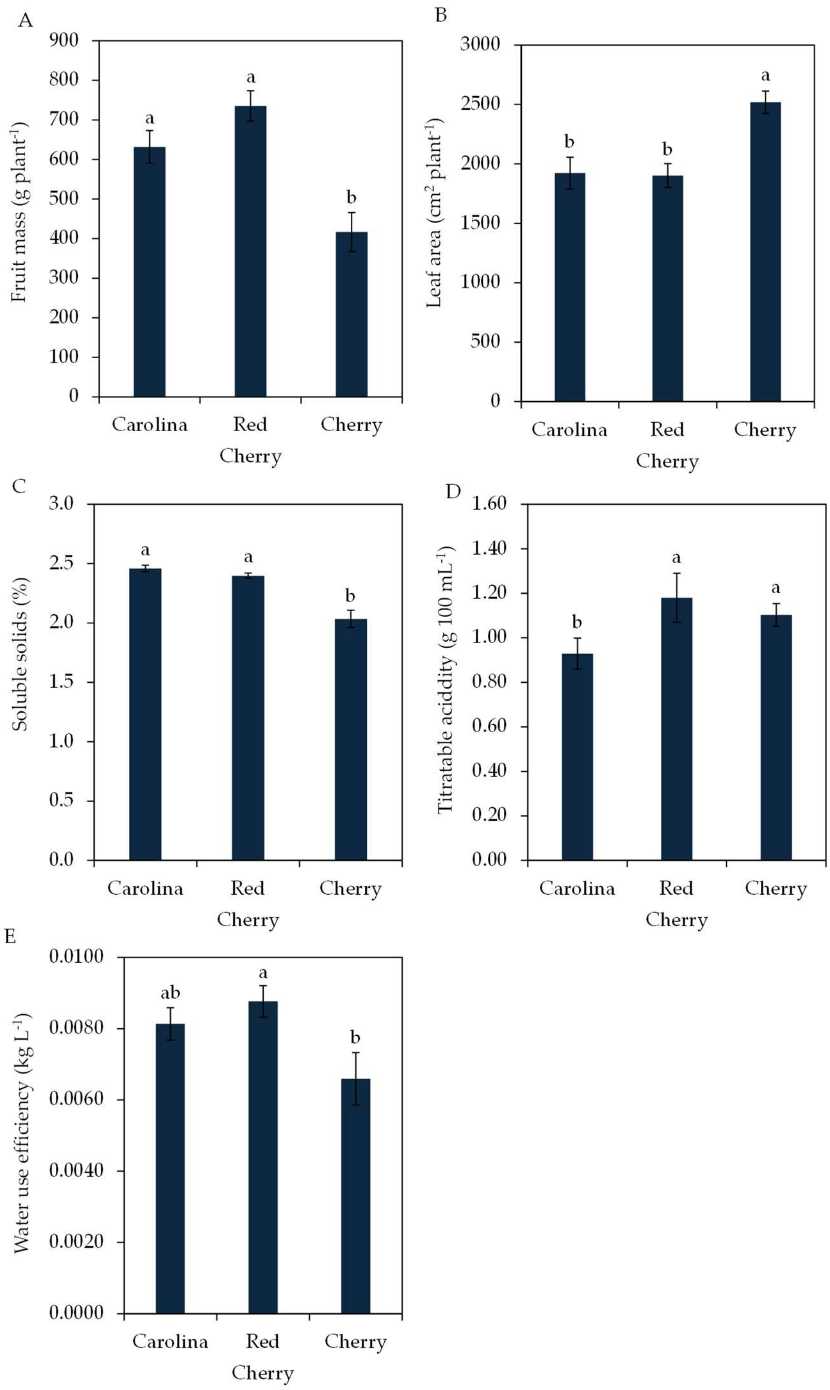

Figure 2. Fruit mass (A); Leaf area (B); soluble solids (C); Titratable acidity (D); and water use efficiency (E) as a function of tomato varieties (Carolina, Red cherry and Cherry). The vertical bars represent the standard error. Means followed by the same letters are not statistically different according to Tukey's test ($p \leq 0.05$).
Figura 2. Massa do fruto (A); Área foliar (B); Sólidos solúveis (C); Acidez titulável (D); e eficiência no uso da água (E) em função das variedades de tomate (Carolina, Red cherry e Cherry). As barras verticais representam o erro padrão. Médias seguidas pelas mesmas letras não são estatisticamente diferentes de acordo com o teste de Tukey ($p \leq 0,05$).

4. DISCUSSION

The use of alternative substrates enriched with wood ash as a substrate enhancer, combined with different cherry tomato cultivars, demonstrated that substrates with higher organic matter content, specifically those incorporating wood ash and soil from preserved areas, contribute to increased productivity and fruit quality. These substrates stand out as a promising growing medium and a sustainable alternative for growing vegetables of significant social and economic importance.

When evaluating different substrate types for cherry tomato cultivation, Soldateli et al. (2020) observed lower fruit mass performance in plants grown solely in soil. This could be attributed to the soil's low organic matter content, which necessitates enrichment with either organic or synthetic fertilizers. In contrast, substrates with higher organic matter content, due to their composition, provide a gradual supply of nutrients to the tomato plants, resulting in positive increases in both productivity and fruit quality (MATOS et al., 2021).

It is noteworthy that the higher fruit mass of cherry tomatoes observed in substrate two may be attributed to its higher organic matter content, approximately 44%, and the base saturation present in this substrate, in comparison to the mechanized soil substrate, which contains only 20% organic matter.

Substrates based on organic compounds are rich in humic acid (HA), considered a component of humus, which, when present in cultivation substrates, helps to reduce the incidence of biotic and abiotic stresses and enhances vegetable productivity (FOROTAGHE et al., 2022). The application of humic acid (HA) in vegetable production, particularly in tomato cultivation, can improve both primary and secondary metabolic processes in plants, increase productivity and crop quality, and reduce the incidence of pests and diseases (EBRAHIMI et al., 2021; NAJARIAN et al., 2022). These findings are consistent with the results of this study, as the organic matter content in substrate 1 was 20.04%, while in substrate 2 it was 40.44%. Thus, the higher organic matter content in substrate two allowed for the adsorption of a greater quantity of mineralized chemical elements by the solid particles that composed the substrate, providing the plants with a more significant nutritional supply compared to those grown in substrate 1.

It is also evident that the use of a commercial substrate for vegetables combined with aged cattle manure and 3% wood ash in substrate preparation may have led to an increase in the nitrogen content of substrate 2, as well as an increase in microbial biomass volume due to the addition of ash (OLIVEIRA et al., 2024), resulting in higher mineralization and, consequently, greater nutrient availability. This, in turn, contributes to increased photoassimilate production, favoring fruit mass production per plant.

This result may also be related to the fact that substrate 2 contains organomineral sources in its composition, which contribute to increasing the organic matter content of the substrate. This, in turn, influences the quantity of ionic charges, the substrate's porosity, moisture retention, and the availability of nutrients that are easily accessible for root absorption (MATOS et al., 2021; PEDÓ et al., 2022).

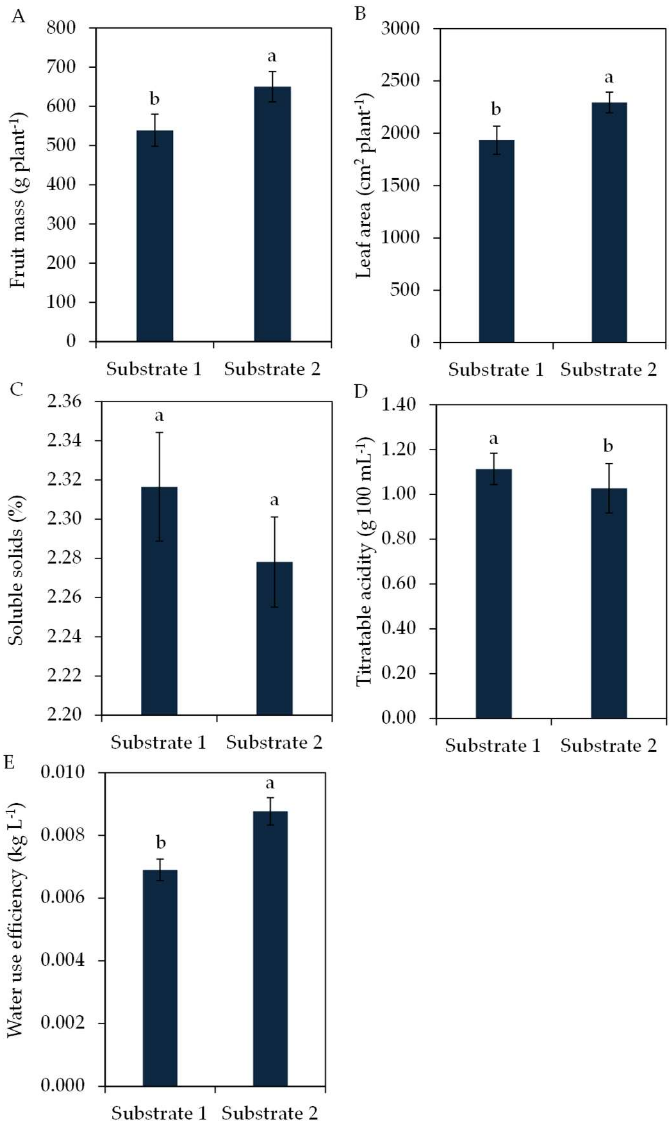

Figure 3. Fruit mass (A); Leaf area (B); Soluble solids (C); Titratable acidity (D); and Water use efficiency (E) as a function of soil type (Soil mechanized and alternative substrate). The vertical bars represent the standard error. Means followed by the same letters are not statistically different according to Tukey's test ($p \leq 0.05$).

Figura 3. Massa do fruto (A); Área foliar (B); sólidos solúveis (C); Acidez titulável (D); e Eficiência no uso da água (E) em função do tipo de solo (Solo mecanizado e substrato alternativo). As barras verticais representam o erro padrão. Médias seguidas pelas mesmas letras não são estatisticamente diferentes de acordo com o teste de Tukey ($p \leq 0,05$).

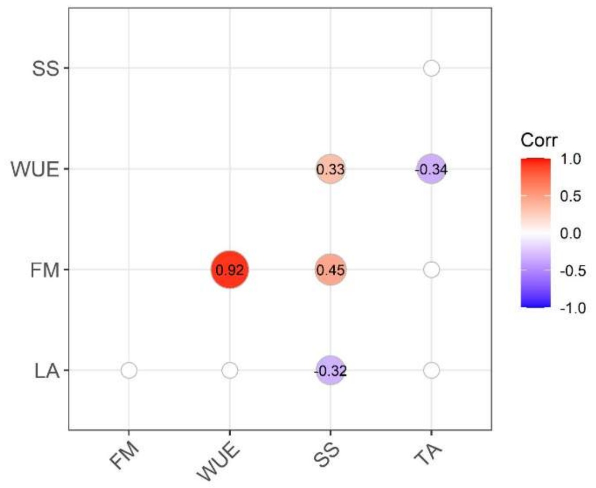

Figure 4. Pearson's correlation coefficients (r) of cherry tomato, (variety Carolina, Red cherry and Cherry) cultivate in two types of soil (Soil mechanized and alternative substrate) for the variables soluble solids (SS), water use efficiency (WUE), fruit mass (FM), leaf area (LA), and titratable acidity (TA). Red colors represent positive correlation, and blue colors represent negative correlation. White circles represent insignificant correlations ($p < 0.05$).
Figura 4. Coeficientes de correlação de Pearson (r) do tomate cereja, (variedade Carolina, Red cherry e Cherry) cultivado em dois tipos de solo (Solo mecanizado e substrato alternativo) para as variáveis sólidos solúveis (SS), eficiência do uso da água (WUE), massa do fruto (FM), área foliar (LA), e acidez titulável (TA). As cores vermelhas representam correlação positiva, e azul, a correlação negativa. Círculos em branco representam correlações não significativas ($p<0.05$).

Among the cherry tomato cultivars, Carolina and Red Cherry showed the best performance in terms of fruit mass, while the Cherry cultivar had the lowest fruit mass per plant. These results suggest that the productivity of cherry tomato fruits among these cultivars may be related to the genetic characteristics of each cultivar and their ability to absorb and convert mineral nutrients into photoassimilates.

The leaf area of tomato plants grown in substrate 2 was greater than that of those grown in substrate 1. This variable serves as an indicator of plant growth and vegetative development, as well as a precursor to estimate photoassimilate production. Based on these results, it can be inferred that substrate 2 provided a higher nutritional input to the cherry tomato plants, resulting in greater nutrient absorption compared to substrate 1. This finding is further supported by Matos et al. (2021); Soldateli et al. (2020), who reported improved vegetative development of tomato plants in various substrates compared to cultivation in soil.

In addition to the organic matter content of Substrate 2 being 54.05% higher than that of Substrate 1, its base saturation was 29.30% higher than that of Substrate 1. This likely contributed to Substrate 2 providing a more significant nutrient supply to the plants, which, in turn, promoted greater vegetative development of the cherry tomato plants. This resulted in a larger leaf area per plant, leading to a higher rate of photoassimilates and consequently, better productive performance of the cherry tomato plants cultivated in Substrate 2 compared to those grown in Substrate 1, as shown in Figure 5.

When comparing the cultivars, 'Cherry' exhibited the largest average leaf area per plant compared to the other cultivars, as shown in Figure 6. The differences in leaf area growth, productivity, and fruit quality among cherry tomato cultivars may have been influenced by factors such as the cultivars' adaptability to the experimental conditions and their genetic development characteristics.

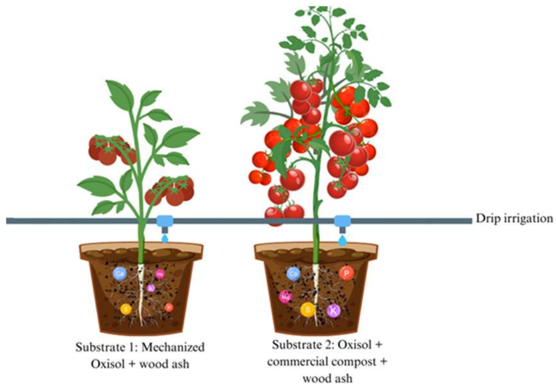

Figure 5. Representation of the vegetative development of cherry tomato regardless of cultivar, based on the different substrates used in the experiment.
Figura 5. Representação do desenvolvimento vegetativo do tomate cereja, independentemente da cultivar, com base nos diferentes substratos utilizados na experiência.

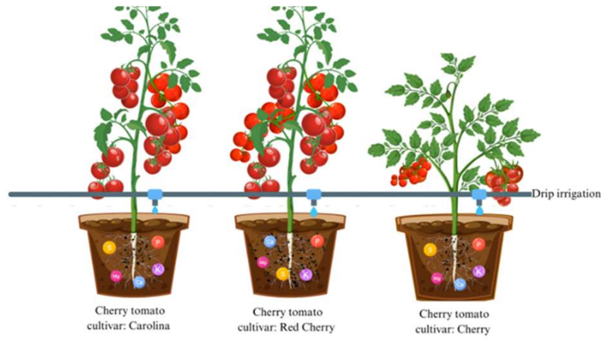

Figure 6. Representation of the vegetative development of cherry tomato cultivars regardless of the substrates used in the experiment.
Figura 6. Representação do desenvolvimento vegetativo das cultivares de tomate cereja independentemente dos substratos utilizados no experimento.

There are many cherry tomato cultivars available for cultivation in the country, each with its unique characteristics. Some cultivars are better suited to specific climates or soil types, which can significantly impact their growth and development. In contrast, others are more resistant or tolerant to heat or better adapted to cold climates.

Tomato plants require suitable conditions to grow healthily and produce fruit. The adaptability of the Carolina and Red Cherry cultivars to various factors, including sunlight, ambient temperature, soil or substrate humidity, soil or substrate quality, drainage, and nutrient availability, may have negatively impacted their growth in terms of leaf area, resulting in a reduced level of development compared to the Cherry cultivar.

No significant differences were found when evaluating the effect of substrates with different strategies for using wood ash on the variable soluble solids content in cherry tomato fruit. The results observed for the total soluble solids content in this experiment are corroborated by those obtained by Fontes et al. (2004), who also observed no difference in the soluble solids content of tomato fruit grown in different substrates.

The average soluble solids content of cherry tomato fruit observed in this research was 5.34%, which is lower than that observed by Dantas et al. (2021), who, when assessing the quality of cherry tomatoes, observed a soluble solids content of 7.60%. The soluble solids content is of great importance in the food sector, as it assesses the quality of plant products. These evaluations provide information on the level of ripeness of the fruit and the amount of substances present, mainly sugars (GUEDES et al., 2020).

The soluble solids content can vary depending on the crop's growth stage, the fruit's ripeness, weather conditions, and the cherry tomato cultivar. In general, cherry tomatoes tend to have a sweeter flavor than other types due to their smaller size and higher sugar concentration (CHANG et al., 2024). However, in this research, although substrate 2 had higher nutrient availability and base saturation, this was still insufficient to promote a difference in the soluble solids content of the cherry tomato fruit.

The highest levels of soluble solids observed in the cultivars Carolina and Red Cherry may be directly related to the genetic characteristics of these cultivars. As for the soluble solids content of the fruit, the analysis of this quality indicator is important in the area of food, especially in assessing the quality parameters of products of plant origin, as it indicates the degree of ripeness of fruit and the quantity of substances, mainly sugars, present in these foods (MATOS et al., 2021).

Using wood ash in the different substrates used to grow cherry tomatoes also affected the fruit's acidity. The fruit grown in substrate 1 had the highest acidity, compared to that observed in fruit grown in substrate 2. The values of the average acidity obtained in this study are considerably higher than those observed by Casals et al. (2019), who recorded an average acidity content in cherry tomatoes of 0.39%, or 0.39 g 100 mL^{-1}. However, the average acidity observed in this study for fruit grown in different substrates with wood ash as a strategic complement is close to that obtained by Santiago et al. (2018), who found an acidity content of 1.03% in cherry tomato fruit.

The intensity with which each nutrient was made available to the tomato plants varied depending on the environment in which they were grown, so the right balance of nutrients may have influenced the metabolism of the plants, the acidity of the fruit, and, consequently, the taste of the cherry tomatoes.

The different pH levels in the substrates formulated for growing tomatoes may also have affected the availability of nutrients for the plants. Soils and/or substrates with an acidic pH tend to reduce the availability of nutrients and have high levels of elements such as aluminum (HUE; LICUDINE, 1999). For this reason, using wood ash as a strategic component in the substrates helped mitigate the effect of soil acidity, as reported by Meneghetti et al., (2023); Oliveira et al., (2023).

Titratable acidity was also higher in the fruits of the Red Cherry and Cherry cultivars. In tomatoes, total acidity indicates the amount of organic acids present and the fruit's astringency. It is one of the most influential factors in determining the taste of the fruit, especially cherry tomatoes (SAMPAIO; FONTES, 1998).

Although fertilization levels and the pH of growing substrates can influence the titratable acidity level of tomato fruit, it is essential to note that genetic and environmental factors also play a role in determining the acidity of tomatoes. Specifically, each cherry tomato cultivar has its unique genetic characteristics, including its natural level of acidity.

Some cherry tomato cultivars may naturally have more acidic fruit than others (BERTIN; GÉNARD, 2018). It is essential to note that the taste of cherry tomatoes is a complex result of several factors, and the cultivar is just one of them. In addition, climatic conditions, irrigation management, harvest time, ripeness, and storage can also significantly impact the final taste of cherry tomatoes (BERTIN; GÉNARD, 2018; CHANG et al., 2024).

The greater efficiency of water use observed in cherry tomato plants grown in substrate two may be related to the fact that it was composed of specific mixtures of other materials such as commercial substrate and cattle manure + 3% wood ash, which in turn may have optimized water retention, drainage and the supply of nutrients to the plants, promoting better conditions for the development of the crop, resulting in greater efficiency of water use. Due to their capacity for retention and controlled drainage, substrate cultivation can result in lower water consumption compared to traditional cultivation, thereby facilitating more effective irrigation management.

5. CONCLUSIONS

The use of substrate 2 in growing cherry tomatoes promotes greater leaf area per plant, higher fruit mass production per plant, better water use efficiency, and lower fruit acidity, regardless of the variable used. Additionally, growing cherry tomatoes in both substrates does not result in differences in the total soluble solids content of the fruits.

The Carolina and Red Cherry cherry tomato cultivars produce the highest fruit mass per plant, the highest total soluble solids content, and the greatest water use efficiency. Furthermore, the use of substrates enriched with wood ash and fallow soil or forest soil is an alternative to increase both the productivity and quality of cherry tomato fruits.

5. REFERENCES

ALLEN, R. G.; PEREIRA, L. S.; RAES, D.; SMITH, M. **Crop evapotranspiration: guidelines for computing crop water requirements**. Rome, Italy: Food and Agriculture Organization of the United Nations, 1998. 333p. (FAO Irrigation and Drainage Paper, 56)

AZEVEDO, G. A.; AZEVEDO, J. R. de; SANTOS, C. A. F. dos; RODRIGUES, E. B. dos S. Use of alternative substrates for biometric evaluation of cherry tomato seedlings (*Solanum lycopersicum* L.). **Revista Multidisciplinar do Nordeste Mineiro**, v. 7, n. 1, p. 1-8, 2024. https://10.61164/rmnm.v7i1.2537

BERTIN, N.; GÉNARD, M. Tomato quality as influenced by preharvest factors. **Scientia Horticulturae**, v. 233, p. 264-276, 2018. https://doi.org/10.1016/j.scienta.2018.01.056

BONFIM-SILVA, E. M.; CABRAL, C. E. A.; SILVA, T. J. A. da; MOREIRA, J. C. F.; CARVALHO, J. C. S. de. Vegetable ash: productive characteristics and chlorophyll in palisadegrass. **Bioscience Journal**, v. 29, n. 5, p. 1215-1225, 2013.

BRANDÃO FILHO, J. U. T.; FREITAS, P. S. L. de; BERIAN, L. O. S.; GOTO, R. **Hortaliças-fruto**. Maringá: Eduem, 2018. 536p.

BRITO, W. R. O.; OLIVEIRA, C. N. M.; MORAES, R. P. Use of compost-prepared substrate for seedling production: a systematic literature review. **Revista JRG de Estudos Acadêmicos**, v. 7, n. 14, e141009, 2024. https://doi.org/10.55892/jrg.v7i14.1009

CAMPOS, R. S.; COSTA, E.; CAVALCANTE, D. F.; FREITAS, R. A.; BINOTTI, F. F. da S. Ornamental cherry tomatoes in different protected environments and reflector materials in cultivation Bench. **Revista Caatinga**, v. 36, n. 1, p. 9-20, 2023. https://doi.org/10.1590/1983-21252023v36n102rc

CASALS, J.; RIVERA, A.; SABATÉ, J.; DEL CASTILLO, R. R.; SIMÓ, J. Cherry and fresh market tomatoes: Differences in chemical, morphological, and sensory traits and their implications for consumer acceptance. **Agronomy**, v. 9, n. 1, e09, 2019. https://doi.org/10.3390/agronomy9010009

CHANG, Y.; ZHANG, X.; WANG, C.; MA, N.; XIE, J.; ZHANG, J. Fruit quality analysis and flavor comprehensive evaluation of cherry tomatoes of different colors. **Foods**, v. 13, n. 12, e1898, 2024. https://doi.org/10.3390/foods13121898

DANTAS, L. O.; MAIA, A. G.; MORENO, M. N.; MELO, N. G. M.; SOUZA, R. P.; SOUZA, R. Á. T.; MARTIM, S. R. Análise físico-química e microbiológica de tomates cereja (*Solanum lycopersicum* var. cesariforme) comercializados em empórios de Manaus-AM. **Research, Society and Development**, v. 10, n. 15, p. e527101523276, 2021. https://doi.org/10.33448/rsd-v10i15.23276

EBRAHIMI, M.; MOUSAVI, A.; SOURI, M. K.; SAHEBANI, N. Can vermicompost and biochar control *Meloidogyne javanica* on eggplant? **Nematology**, v. 23, n. 9, p. 1053-1064, 2021. https://doi.org/10.1163/15685411-bja10094

FONTES, P. C. R.; LOURES, J. L.; GALVÃO, J. C. C.; CARDOSO, A. A.; MANTOVANI, E. C. Produção e qualidade do tomate produzido em substrato, no campo e em ambiente protegido. **Horticultura Brasileira**, v. 22, n. 3, p. 614-619, 2004. https://doi.org/10.1590/S0102-05362004000300023

FOROTAGHE, Z. A.; SOURI, M. K.; JAHROMI, M. G.; TORKASHVAND, A. M. Influence of humic acid application on onion growth characteristics under water deficit conditions. **Journal of Plant Nutrition**, v. 45, n. 7, p. 1030-1040, 2022. https://doi.org/10.1080/01904167.2021.1994604

FU, H.; ZHANG, G.; ZHANG, F.; SUN, Z.; GENG, G.; LI, T. Effects of continuous tomato monoculture on soil microbial properties and enzyme activities in a solar greenhouse. **Sustainability**, v. 9, n. 2, e317, 2017. https://doi.org/10.3390/su9020317

GUEDES, M. A. A.; PAULA, N. C. C.; JARDIM, V. H. P.; COSTA, N. V.; SILVA, F. C. Qualidade físico-química e microbiológica de derivados de tomate comercializados em Ituiutaba-MG. **Revista Inova Ciência & Tecnologia**, v. 6, n. 2, p. 22-30, 2020.

HUE, N. V.; LICUDINE, D. L. Amelioration of subsoil acidity through surface application of organic manures. **Journal of Environmental Quality**, v. 28, n. 2, p. 623-632, 1999. https://doi.org/10.2134/jeq1999.00472425002800020028x

IAL_Instituto Adolfo Lutz. **Métodos físico-químicos para análise de alimentos**. 4 ed. São Paulo: IAL, 2008. 1000p.

MATOS, R. M.; SILVA, P. F.; NETO, J. D.; LIMA, A. S.; LIMA, V. L. A.; SABOYA, L. M. F. Organic fertilization as an alternative to the chemical in cherry tomato growing under irrigation depths. **Bioscience Journal**, v. 37, p. e37006, 2021. https://doi.org/10.14393/BJ-v37n0a2021-48270

MEDEIROS, D. C.; AZEVEDO, C. M. S. B.; MARQUES, L. F.; SOUSA, R. A.; OLIVEIRA, C. J. Qualidade de mudas de tomate em função do substrato e irrigação com efluente de piscicultura. **Revista Brasileira de Agroecologia**, v. 8, n. 2, p. 170-175, 2013.

MENEGHETTI, L. A. M.; BONFIM-SILVA, E. M.; DA SILVA, T. J. A.; DUARTE, T. F.; PINHEIRO, E. A. R.; OLIVEIRA, J. R. Biomass and water use efficiency of chrysanthemum under organic, mineral, and organomineral fertilization. **Revista Brasileira de Engenharia Agrícola Ambiental**, v. 27, n. 7, p. 505-511, 2023. https://doi.org/10.1590/1807-1929/agriambi.v27n7p505-511

MENEZES JÚNIOR, F. O. G.; SOUZA, A. G.; SARAIVA, F. R. S. Qualidade dos frutos de cultivares de morangueiro submetidos a pulverização com nutrientes em sistema semi-hidropônico. **Revista Vértices**, v. 25, n. 1, e25116681, 2023. https://doi.org/10.19180/1809-2667.v25n12023.16681

MORAIS, A. A.; MELO, R. A. de C.; SILVA, J.; BRANDÃO, M.; PEREIRA, R. B.; OLIVEIRA, V. R. **Cultivo de melão nobre tipo cantaloupe em substrato sob ambiente protegido**. Brasília: Embrapa, 2019. 42p. (Circular Técnica, 166)

NAJARIAN, A.; SOURI, M. K.; NABIGOL, A. Influence of humic substance on vegetative growth, flowering and leaf mineral elements of *Pelargonium* x *hortorum*. **Journal of Plant Nutrition**, v. 45, n. 1, p. 107-112, 2022. https://doi.org/10.1080/01904167.2021.1943432

OLIVEIRA, N. P. R.; BONFIM-SILVA, E. M.; SILVA, T. J. A.; SILVA, P. F.; SILVA ROCHA, R. A.; MENEGHETTI, L. A. M.; CUSTÓDIO, A. S. C.; GUIMARÃES, S. L.; DUARTE, T. F.; KOETZ, M. Effects of fertilization types and base saturation on the growth and water productivity in *Panicum maximum* cv. BRS Zuri. **Agriculture**, v. 13, n. 10, e1872, 2023. https://doi.org/10.3390/agriculture13101872

OLIVEIRA, W. C. M. de; BONFIM-SILVA, E. M.; SILVA, T. J. A. da; FERRAZ, A. P. F.; GUIMARÃES, S. L.; MENEGHETTI, L. A. M. Soil organic matter and microbial biomass under cultivation of *Urochloa brizantha* fertilized with wood ash in the Cerrado of Mato Grosso. **Communications in Soil Science and Plant Analysis**, v. 55, n. 14, p. 2090-2102, 2024. https://doi.org/10.1080/00103624.2024.2343351

PEDÓ, T.; ROLIM, J. M.; MEDEIROS, L. B.; PETER, M.; PEREIRA, L. H. dos S.; MARTINAZZO, E. G.; AUMONDE, T. Z.; MAUCH, C. R. Production of grafted tomato seedlings in the south of Rio Grande do Sul. **Pesquisa Agropecuária Pernambucana**, v. 27, n. 1, p. e2331272022, 2022. https://doi.org/10.12661/pap.2022.002

R CORE TEAM. *R:* **A language and environment for statistical computing**. Vienna: R Foundation for Statistical Computing, 2017. Disponível em: http://www.r-project.org/. Acesso em: nov. 2023.

SAMPAIO, R. A.; FONTES, P. C. R. Qualidade de frutos de tomateiro fertirrigado com potássio em solo coberto com polietileno preto. **Horticultura Brasileira**, v. 16, n. 2, p. 136-139, 1998. https://doi.org/10.1590/S0102-05361998160000200009

SANTANA, M. P. de; JESUS, M. S. de; BARRETTO, M. C. de V.; VIÉGAS, P. R. A.; HOLANDA, F. S. R.; BARBOSA, A. V. G.; MARINO, R. H. Growth of cherry tomato seedlings in substrate colonized by edible fungi. **Ensaios & Ciência: Ciências Biológicas, Agrárias e da Saúde**, v. 28, n. 3, p. 311-318, 2024. https://doi.org/10.17921/1415-6938.2024v28n3p311-318

SANTIAGO, E. J. P.; OLIVEIRA, G. M.; LEITÃO, M. M. V. B. R.; ROCHA, R. C.; PEREIRA, A. V. A. Qualidade do tomate cereja cultivado sob lâminas de irrigação em ambiente protegido e campo aberto. **Agrometeoros**, v. 26, n. 1, p. 213-221, 2018.

SANTOS, D. P.; SANTOS, C. S.; SILVA, L. M.; SANTOS, M. A. L.; SANTOS, C. G. Performance of methods for estimation of table beet water requirement in Alagoas. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 22, n. 3, p. 189-193, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n3p189-193

SANTOS, M. A.; SILVA, A. J. P.; SANTOS, D. B.; ALVES, M. S.; FREITAS, F. T. O. Water use efficiency of grape tomatoes subjected to different types of substrates, methods of conduction and irrigation management strategies. **Horticultura Brasileira**, v. 42, e279426, 2024. https://doi.org/10.1590/s0102-0536-2024-e279426

SOLDATELI, F. J.; BATISTA, C. B.; GODOY, F.; MELLO, A. C.; SOARES, F. dos S.; BERGMANN, M. D.; ETHUR, L. Z. Crescimento e produtividade de cultivares de tomate cereja utilizando substratos de base ecológica. **Colloquium Agrariae**, v. 16, n. 1, p. 1-10, 2020. https://doi.org/10.5747/ca.2020.v16.n1.a342

SOUZA, M. M. J.; SILVA, E. D.; PASSOS, N. R. F.; SANTANA JÚNIOR, J. P. F.; OLIVEIRA, F. J. V. Use of different organic substrates in the growth and initial development of land cress (*Barbarea verna*). **Scientific Electronic Archives**, v. 17, n. 1, p. 28-31, 2024. https://doi.org/10.36560/17120241835

TRESSLER, D. K.; JOSLYN, M. A. **Fruit and vegetable juice: Processing technology**. Westport: AVI, 1961. 1028p.

WANG, X.-X.; ZHAO, F.; ZHANG, G.; ZHANG, Y.; YANG, L. Vermicompost improves tomato yield and quality and the biochemical properties of soils with different tomato planting history in a greenhouse study. **Frontiers in Plant Science**, v. 8, e1978, 2017. https://doi.org/10.3389/fpls.2017.01978

ZAMBOLIM, L.; QUEZADO-DUVAL, A. M. **Produção integrada do tomateiro tutorado**. Viçosa: UFV, 2022. 315p.

ZHANG, X.; TIAN, L.; WU, P.; GAO, Y.; LI, J. Changes of soil nutrients and microbal community diversity in responses to different growth environments and cultivation practices in 30 years. **Journal of Plant Nutrition and Fertilizer**, v. 21, n. 6, p. 1581-589, 2015. https://doi.org/10.11674/zwyf.2015.0625

ZOU, Y.; SADDIQUE, Q.; ALI, A.; XU, J.; KHAN, M. I.; QING, M.; AZMAT, M.; CAI, H.; SIDDIQUE, K. H. M. Deficit irrigation improves maize yield and water use efficiency in a semi-arid environment. **Agricultural Water Management**, v. 243, e106483, 2021. https://doi.org/10.1016/j.agwat.2020.106483

Acknowledgements: The authors would like to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the Fundação de Amparo à Pesquisa do Estado de Mato Grosso (FAPEMAT).

Authors' contributions: S.P.A. – methodology, research or data collection, writing (original), writing (revision and editing), statistical analysis; T.J.A.S. – conceptualization, methodology, supervision; E.M.B.-S. – writing (revision and editing), validation; L.A. M. M. – research, writing (revision and editing); I.A.C.S. – research, statistical analysis, writing (revision and editing); N.P.R.O. – research, writing (revision and editing); A.S.C.C. – research, writing (review and editing); R.A.S.R. – research, writing (review and editing); L.M.S.M. – writing (review and editing); P.F.S – statistical analysis, writing (review and editing), validation. All authors read and agreed to the published version of the manuscript.

Data availability: Study data can be obtained by email from the corresponding author or first author upon request.

Conflict of interest: The authors declare that they have no conflict of interest.