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TOMATO YIELD AND SOIL-BORNE DISEASES IN A "BANDEIRANTE" GREENHOUSE USING GRAFTING AND SOILLESS CULTURE TECHNIQUES

PRODUÇÃO E DOENÇAS DE SOLO DO TOMATEIRO EM ESTUFA MODELO "BANDEIRANTE" USANDO TÉCNICAS DE ENXERTIA E CULTIVO SEM SOLO

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Abstract

.The objective of the study was to evaluate the effects of grafting with a disease-resistant rootstock and soilless cultivation on tomato yield and soil-borne diseases in a "Bandeirante"-type greenhouse. The experiment was conducted over three growing seasons (2019/20, 2020/21, and 2021/22) and compared three treatments: cultivation of the hybrid Coronel® tomato ungrafted and planted directly in the soil (control), cultivation of the hybrid Coronel® grafted onto the Shincheonggang® rootstock and planted directly in the soil, and cultivation of the hybrid Coronel® ungrafted and planted in pots filled with a mixed substrate. The variables evaluated included marketable and non-marketable fruit yield, incidence of bacterial wilt and darkening of the vascular system of the plants, and economic return of grafting and soilless cultivation techniques. The highest marketable yield (146.7 $t{\cdot}ha^{-1}$) was consistently obtained with ungrafted plants grown in pots and significantly exceeded by 63% (89.9 $t{\cdot}ha^{-1}$) and 48% (98.9 $t{\cdot}ha^{-1}$), respectively, the yield of ungrafted and grafted plants grown in soil. No incidence of bacterial wilt was observed, and darkening of the vascular system at the base of the stem was lower in ungrafted plants cultivated in pots. Only the soilless cultivation with mixed substrate provided a positive economic return (R$35,482.44) compared with the control. The results highlight the benefits of soilless cultivation with mixed substrate, including higher productivity and economic returns.
Keywords: *Solanum lycopersicum* L., protected cultivation, economic returns, rootstock.

Resumo

O objetivo do estudo foi avaliar os efeitos da enxertia com um porta-enxerto resistente a doenças e do cultivo sem solo sobre a produtividade do tomate e doenças de solo em uma estufa modelo "Bandeirante". O experimento foi repetido em três safras agrícolas (2019/20, 2020/21 e 2021/22) e compararam três tratamentos: (1) cultivo do híbrido de tomate Coronel® sem ser enxertado e plantado diretamente no solo (controle), (2) cultivo do híbrido Coronel® enxertado no porta-enxerto Shincheonggang® e plantado diretamente no solo e (3) cultivo do híbrido Coronel® sem ser enxertado e plantado em vasos com substrato misto. Foram avaliados a produção de frutos comercializáveis e não comercializáveis, a incidência de murcha bacteriana e escurecimento vascular das plantas, e o retorno econômico das técnicas de enxertia e cultivo sem solo. A maior produtividade comercial (146,7 $t{\cdot}ha^{-1}$) foi consistentemente obtida com o cultivo sem enxertia em vasos, superando significativamente em 63% a produtividades do cultivo sem enxertia no solo (89,9 $t{\cdot}ha^{-1}$) e em 48% a produtividade do cultivo enxertado no solo (98,9 $t{\cdot}ha^{-1}$). Não houve incidência de murcha bacteriana e as plantas sem enxertia cultivadas em vasos apresentaram menor escurecimento vascular na base do caule. Somente o cultivo sem solo com substrato misto proporcionou retorno econômico positivo (R$35.482,44) em relação ao controle. Os resultados destacam os benefícios do cultivo sem solo com substrato misto, incluindo maior produtividade e retorno econômico.
Palavras-Chaves: *Solanum lycopersicum* L., retorno econômico, cultivo protegido, porta-enxerto.

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Introduction

The tomato agribusiness in Santa Catarina holds a prominent position in the Brazilian context. According to data from Observatório Catarinense (2020), the state ranked as the ninth largest producer in Brazil in 2024, with a total output of 128 thousand tons. The Caçador region, located in Santa Catarina, is the fifth largest producer of tomatoes during summer, with 602 hectares of cultivated area in 2021 (CEPEA, 2022). All tomato production in this region occurs in open fields. The cost of tomato production in the Caçador region during the 2021/22 season ranged from R$145,000 to R$150,000 per hectare, with approximately 9.6% to 12.5% of this cost resulting from agricultural pesticides (DELEO; ASSIS, 2022). The high cost of pesticides can be attributed to favorable climatic conditions for major tomato diseases, such as mild temperatures, consistent rainfall (BECKER et al., 2016), and presence of insect pests (LINS JUNIOR et al., 2020).

Greenhouse cultivation offers an alternative for reducing pesticide costs (LINS JUNIOR et al., 2020), particularly for small-scale farmers who lack available areas for crop rotation. One prevalent greenhouse model for tomato cultivation in southern Brazil is the "Bandeirante". This model resembles the "Almeria" model widely used in the Almeria province (southern region of Spain) (MARTINÉZ et al., 2016). Both models feature wooden platforms supporting steel wire roofs covered in plastic film. However, unlike the "Almeria" model, the "Bandeirante" model lacks zenith ventilation and provides only lateral ventilation. One notable advantage of the "Bandeirante" model over metallic structures is its low installation and maintenance costs (RAMPAZZO, 2016), which can be managed by the farmers. Nevertheless, literature lacks studies evaluating tomato management within this greenhouse model.

Successive tomato cultivation in the same area, such as within a greenhouse, is not recommended because it may promote soil-borne diseases, including *Ralstonia solanacearum*, *Pectobacterium carotovorum* subsp. *carotovorum*, *Fusarium oxysporum* f. sp. *lycopersici*, and *Verticillium dahliae* (BECKER et al., 2016). Several techniques have been studied to enable successive tomato cultivation in the same area, such as grafting (ZEIST et al., 2019; MONTEIRO et al., 2020; RAHMAN et al., 2021) and soilless culture (SUBRAMANI et al., 2020).

Grafted tomatoes have proven to be the most effective method for preventing the soil-borne disease *V. dahliae* compared with biological control agents *Bacillus subtilis*, *Gliocladium catenulatum*, and biofumigation with mustard (RAHMAN et al., 2021). Similarly, grafted tomatoes have shown higher efficiency in controlling *R. solanacearum* race 1, biovar 1, and phylotype II than solarization and biofumigation with chicken manure (ZEIST et al., 2019). In a study conducted in an area of Caçador heavily infested with *R. solanacearum* race 3 and biovar 2, Monteiro et al. (2020) observed that planting tomatoes without grafting resulted in 100% plant mortality at the start of fruit harvesting. Even when using Green Power® and Shincheonggang® (i.e., resistant rootstocks), 54% and 36% of the plants, respectively, succumbed to *R. solanacearum* infection (MONTEIRO et al., 2020).

Substrate cultivation is another technique for successive tomato cultivation in greenhouses as it allows for the sanitation and replacement of the substrate, eliminating pathogens (VISCONTI et al., 2016). According to Subramani et al. (2020), tomatoes grown in substrates demonstrated higher productivity than those grown in soil. Additionally, the presence of potentially pathogenic fungi, such as *Fusarium* and *Verticillium*, was greater in the soil than in the substrate, although the community of biological control bacteria (e.g., *Pseudomonas* and *Bacillus*) was also more abundant in the soil (ANZALONE et al., 2022).

The objective of this study was to evaluate the effects of grafting with rootstocks resistant to soil-borne diseases and soilless culture using a mixed substrate on the yield and soil-borne diseases of tomato plants grown in a "Bandeirante" greenhouse model.

Material and Methods

The experiment was conducted in a "Bandeirante" greenhouse model over three seasons: 2019/2020, 2020/2021, and 2021/2022. The greenhouse was situated in Caçador, Santa Catarina, Brazil (geographic coordinates of 26º46'32" S; 51º00'50" W), which has an altitude of 960 meters. The greenhouse had 20-meter width, 45-meter length, 3-meter height, and was covered with 150-micron plastic without side curtains. In the 2018/2019 season before the experiment, tomatoes had been cultivated in the area. Between every tomato crop, a mixture of oats, rye, and radish was cultivated at a seed density of 80 kg·ha^{-1}.

The experiment comprised three planting methods based on grafting and substrate cultivation techniques: cultivation of the hybrid Coronel® tomato ungrafted and planted directly in the soil (control), cultivation of the hybrid Coronel® grafted onto the Shincheonggang® rootstock and planted directly in the soil, and cultivation of the hybrid Coronel® ungrafted and planted in pots filled with a mixed substrate. Each plot had a planting row measuring 3.2 meters in length, with eight plants spaced 0.40 meters apart within the row and 2.0 meters between rows, resulting in eight plants per plot and 12,500 plants per hectare. The experimental design employed randomized complete blocks, with five replications.

The hybrid Coronel® tomato exhibits an indeterminate growth habit and produces globular and large fruits. The manufacturer states that the material has a high resistance to *Fusarium oxysporum* f. sp. *lycopersici* (races 1 and 2), *Stemphylium botryosum* f. sp. *lycopersici*, *Stemphylium lycopersici*, *Stemphylium solani*, *Tomato mosaic virus* (races 0, 1 and 2), tomato spotted wilt virus, *Verticillium albo-atrum*, and *Verticillium dahliae* (race 0); and an intermediate resistance to *Meloidogyne arenaria*, *M. incognita*, and *M. javanica*. For the Shincheonggang® rootstock, the manufacturer states that the material has a high resistance to *Fusarium oxysporum* f. sp. *lycopersici* (races 0 to 2), *Fusarium oxysporum* f. sp. *radicis-lycopersici*, *Ralstonia solanacearum*, *Tomato mosaic virus* (races 0, 1 and 2), *Verticillium albo-atrum*, and *Verticillium dahliae* (race 1); and a moderate resistance to *Meloidogyne arenaria*, *Meloidogyne incognita*, and *Meloidogyne javanica*. Tomato seedlings were planted on 12/04/2019, 11/27/2020, and 12/17/2021.

The soil at the experiment site was classified as dystrophic Oxisol. In the 0 to 20 cm layer, the soil exhibited the following chemical attributes for the respective 2019/2020, 2020/2021, and 2021/2022 seasons: pH (water) = 6.0, 6.0, and 6.0; P = 68.4, 31.1, and 21.5 mg· dm^{-3}; K = 260.0, 252.0, and 232.0 mg·dm^{-3}; organic matter = 3.0, 5.3, and 5.9 g·dm^{-3}; Al = 0.0, 0.0, and 0.0 cmol$_c$·dm^{-3}; Ca+Mg = 10.8, 13.8, and 15.1 cmol$_c$·dm^{-3}; and BS= 77.7%, 79.5%, and 81.3%. Fertilization during planting involved the incorporation of 8 t·ha^{-1}·year^{-1} of organic poultry fertilizer (2% N, 2.2% P_2O_5, 1.6% K_2O, and 80% dry mass) and 400 kg·ha^{-1} of P_2O_5 as triple superphosphate (44% P_2O_5) into the planting furrow. Side dressing fertilization consisted of 400 kg·ha^{-1} of N, 400 kg·ha^{-1} of K_2O, and 5 kg·ha^{-1} of B, using calcium nitrate (32% N), potassium nitrate (12% N, 45% K_2O), and boric acid (17% B). Weekly side dressing fertilization via fertigation followed the recommendations of Becker et al. (2016).

The mixed substrate used (Maxfértil®, Santa Catarina, Brazil) comprised pine bark, ash, expanded vermiculite, and the following physical-chemical attributes: electrical conductivity (EC) = 0.5 dS·m^{-1}, pH = 6.0, and water retention capacity = 58%. The mixed substrate was placed in 8 L pots, and the substrate was replaced with new substrate for the third season. Bricks were used to elevate the pots and prevent root contact with the ground. The irrigation water had an EC of 0.2 dS·m^{-1} and a pH of 6.9. The nutrient solution (FURLANI et al., 2004) contained calcium nitrate (15% N-NO_3, 19% Ca) at 885 mg·L^{-1}, potassium nitrate (13% N-NO_3, 36.5% K) at 760 mg·L^{-1}, monoammonium phosphate (11% N-NH_4, 26% P) at 140 mg·L^{-1}, magnesium sulfate (10% Mg, 13% S-SO_4) at 440 mg·L^{-1}, and micronutrient mix (0.85% B, 0.5% Cu, 3.4% Fe, 3.2% Mn, 0.06% Mo, and 4.2% Zn) at 50 mg·L^{-1}. The average electrical conductivity of the nutrient solution throughout the experiment was 2.0 ± 0.3 dS·m^{-1}.

For the treatment with tomato planting in the soil, a localized drip irrigation system with inline drippers was employed. The drippers had a flow rate of 1.6 L·h^{-1} and were spaced 30 cm apart along the planting line. Daily irrigation management followed the guidelines of Becker et al. (2016), who used tensiometers to monitor soil moisture. Irrigation was performed for 40 minutes whenever the tensiometer readings reached 400 mbar.

For the treatment with tomato planting in pots with substrate, a localized drip irrigation system with online drippers was used. The drippers had a flow rate of 4.0 L·h^{-1} and were placed individually beside each stem of the plants. Autonomous fertigation management was conducted according to Wamser et al. (2022) and used the gas tensiometry system, which consisted of Irrigás® sensors (CALBO, 2000) and an electronic irrigation controller model MRI-10/6 (Hidrosense, Jundiaí, São Paulo, Brazil). When the moisture tension of the substrate reached 5 kPa, the fertigation system was activated. The nutrient solution was applied until 15% of the daily volume was drained, following the recommendation of Miranda et al. (2011) for water irrigation with an EC less than 0.6 $dS \cdot m^{-1}$.

The plants were trained with two main stems and supported with plastic threads. Periodic removal of lateral shoots was performed to maintain two main stems per plant. When the plants reached a height of 2.2 m, the tops of the main stems were pruned, leaving three leaves above the last cluster. Phytosanitary management adhered to the recommendations of Becker et al. (2016).

Fruit harvests started on 02/11/2020, 02/09/2021, and 02/22/2022. The number and production of marketable fruits in the extra AA and extra A classes, as well as unmarketable fruits, were evaluated over 107 days (14 harvests) in the 2019/20 season, 134 days (17 harvests) in the 2020/21 season, and 79 days (12 harvests) in the 2021/22 season. Extra AA fruits were defined as those weighing over 150 g, extra A fruits ranged between 100 and 150 g, and unmarketable fruits weighed less than 100 g (small fruit) or exhibited defects caused by physiological or phytopathological diseases and insect damage. Physiological diseases were categorized as blossom-end rot and catface, whereas damage caused by insects was divided into *Neoleucinodes elegantalis* and other insects. The frequency of plants exhibiting symptoms of bacterial wilt (*R. solanacearum*) and the number of plants showing darkening of the vascular system in the stem base region (i.e., indicative of the *F. oxysporum* + *V. dahliae* complex) were evaluated in the last two seasons.

Net income analysis considered the additional costs associated with grafting and substrate cultivation techniques. The prices of substrates and fertigation materials for tomato cultivation in soil and pots with mixed substrate were obtained from three regional stores, while the price of grafted and ungrafted tomato seedlings was obtained from the main nursery selling seedlings in the Caçador region. The cost of fertigation materials was divided over the three years of cultivation, as no replacement of materials occurred during this period. The substrate cost was divided over 1.5 years since it was changed once during the three-year study. The average tomato price paid to producers in the Caçador region during January, February, March, and April was obtained from the CEPEA/USP/ESALQ database for the 2019/2020, 2020/2021, and 2021/2022 seasons (CEPEA, 2023).

Data were analyzed using analysis of variance, and when statistical differences were found, means were compared using Tukey's test with a significance level of 5%.

Results and Discussion

Ungrafted tomato plants grown in pots with mixed substrate exhibited higher total, marketable, and unmarketable fruit yields than grafted and ungrafted tomatoes planted in the soil across all three growing seasons (Table 1 and Figure 1). Over the three seasons, ungrafted tomatoes grown in pots with mixed substrate showed an average yield increase of 67.3%, 63.2%, and 92.1% for total, marketable, and unmarketable fruit yields, respectively, compared with ungrafted tomatoes planted in the soil. Similarly, ungrafted tomato plants grown in mixed substrate pots outperformed other treatments in terms of producing extra A fruits, except for grafted tomatoes in the 2019/20 season. Moreover, they yielded higher quantities of extra AA fruits in the 2019/20, 2020/21, and 2021/22 seasons than the other treatments, except for the grafted tomatoes in the 2019/20 season (Figure 1). Overall, across the three seasons, ungrafted tomatoes planted in pots with mixed substrate exhibited an average yield increase of 78.0% for extra AA fruit yield compared with ungrafted tomatoes planted in the soil.

Significant differences in fruit yield and quality were found between the different treatments. Ungrafted tomato plants grown in pots with a mixed substrate consistently exhibited superior performance in terms of total, marketable, and unmarketable fruit yields compared with grafted and ungrafted tomatoes planted in the soil across all three growing seasons (Figure 1). These findings align with previous studies that reported enhanced tomato yields and quality in soilless cultivation systems (SUBRAMANI et al., 2020; VERDOLIVA et al., 2021).

Table 1. Mean square and F-test of the variables analyzed according to the sources of variation.

Variable	Sources of variation				Average	C.V. (%)
	Block	Harvest (H)	Treatment (T)	H x T		
Fruit yield						
Total	355.0^{ns}	12050.6**	22078.1**	1518.4**	129.7	9.0
Markatable	546.9*	10421.5**	14015.4**	1646.1**	111.8	10.6
Extra AA	360.8	5341.9	10281.7	2231.3	80.6	13.5
Extra A	112.2**	1100.9**	290.9**	222.7**	31.2	15.4
Unmarketable	44.3*	101.9**	955.8**	21.1^{ns}	17.8	22.7
Number of fruits/total number						
Small fruit	64.952**	170.069**	167.563**	54.767**	11.524	31.4
Other diseases	5.992^{ns}	11.024^{ns}	1.872^{ns}	9.945^{ns}	2.551	41.7
Blossom-end rot	0.354^{ns}	95.598**	156.855**	88.423**	1.989	32.1
Catface	0.671*	0.009^{ns}	2.185**	0.125^{ns}	0.696	68.8
N. elegantalis	0.369*	1.897**	0.048^{ns}	0.057^{ns}	0.250	66.2
Other insects	2.064	87.3541	0.362	5.068	3.258	45.9
Soil-borne disease						
Vascular darkening	318.7^{ns}	298.3^{ns}	23321.6**	793.6*	41.4	39.6

ns = not significant, * = significant at 5%, and * = significant at 1% according to the F-test.

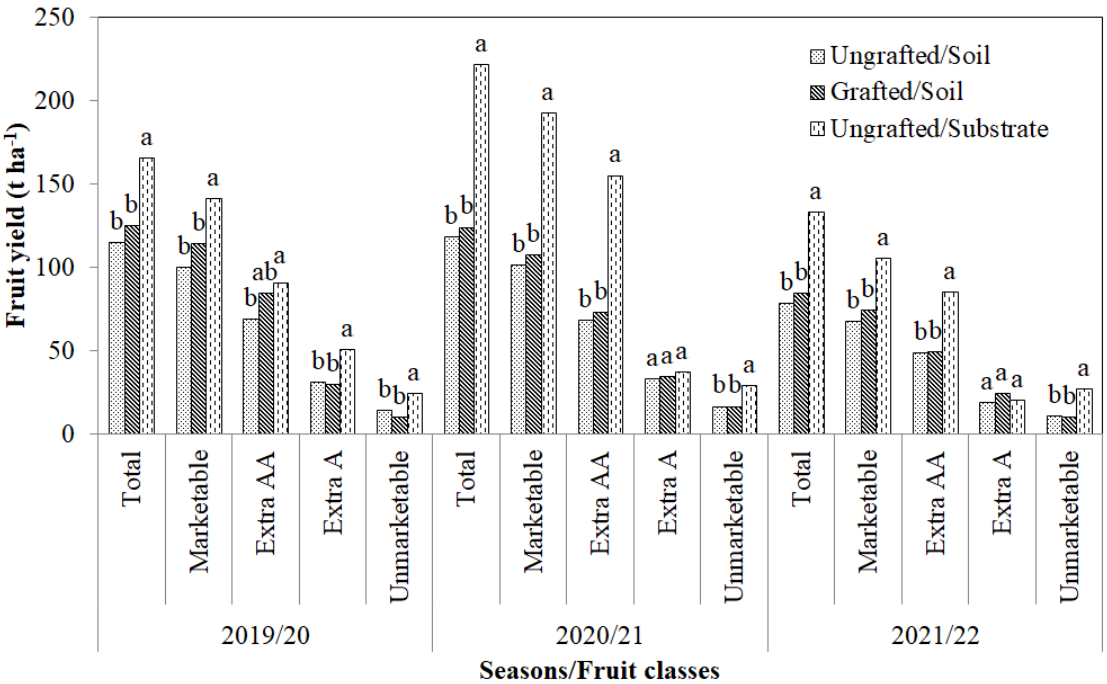

Figure 1. Total, marketable, and unmarketable fruit yield as a function of grafting and substrate cultivation techniques.
Note: Means followed by the same letter within each season and each fruit class were not significantly different according to Tukey's test at 5% probability of error.

The increased fruit yield observed in ungrafted tomatoes grown in pots with a mixed substrate can be attributed to several factors. Soilless cultivation systems, such as pot-based systems, offer enhanced control over nutrient availability and water management, leading to improved plant growth and productivity (VERDOLIVA et al., 2021). Consequently, the use of a mixed substrate in the pots, combined with precise fertirrigation management, may have created favorable conditions for root development and nutrient uptake, resulting in higher yields (WAMSER et al., 2022).

Furthermore, ungrafted tomato plants grown in mixed substrate pots outperformed other treatments in terms of producing extra A fruits, except for the grafted tomatoes in the 2019/20 season (Figure 1). The increased production of extra AA fruits was consistently observed in ungrafted tomatoes grown in mixed substrate pots across all three seasons. These findings indicate that the mixed substrate and soilless cultivation system positively influenced fruit quality, particularly the production of larger-sized fruits.

The results suggest that the use of a disease-resistant rootstock via grafting did not provide significant advantages in terms of fruit yield and quality compared with ungrafted plants grown in mixed substrate pots. Previous studies have reported mixed results regarding the benefits of grafting in disease management and yield improvement, with outcomes varying depending on the specific rootstock-scion combination, pathogen pressure, and environmental conditions (ZEIST et al., 2019; MONTEIRO et al., 2020; RAHMAN et al., 2021).

Neither grafting with a disease-resistant rootstock nor soilless cultivation in a mixed substrate had a significant impact on the incidence of fruit damage caused by *N. elegantalis* and other insect pests across all three seasons (Table 1 and Figure 2). However, the responses concerning other categories of unmarketable fruit varied depending on the season. In the 2020/21 and 2021/22 harvests, grafted tomatoes grown in the soil exhibited the highest percentage of fruits with catface, although not significantly different from ungrafted tomatoes grown in the soil (Figure 2). Catface is a cosmetic disorder characterized by scarring and deformities on the tomato fruit surface, often caused by environmental factors or irregular fruit set (MASARIRAMBI et al., 2009). The occurrence of catface in grafted tomatoes may be attributed to variations in fruit development and physiological responses influenced by the grafting process and rootstock-scion interactions. Further research is needed to establish a more conclusive relationship between grafting and the occurrence of catface.

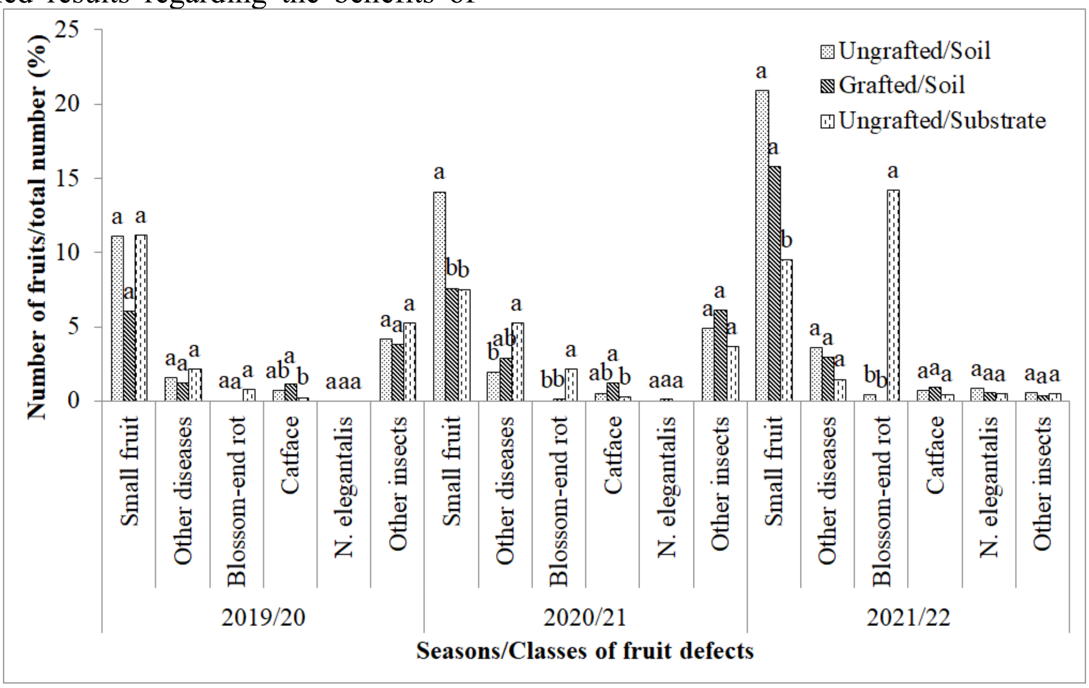

Figure 2. Percentage of unmarketable fruits in different classes of defects, in relation to the total number of fruits, as a function of grafting and substrate cultivation techniques.

Note: Means followed by the same letter within each season and each fruit class were not significantly different according to the Tukey's test at 5% probability of error.

Ungrafted tomatoes grown in the mixed substrate exhibited a higher incidence of blossom-end rot during the 2020/21 and 2021/22 harvests, except for the 2019/20 harvest, in which no difference was observed compared with grafted tomatoes grown in soil (Figure 2). About other diseases, the tomatoes grown in mixed substrate demonstrated a higher percentage of unmarketable fruits in the 2020/21 season, with no difference compared with grafted tomatoes grown in the soil (Figure 2). Blossom-end rot is a physiological condition caused by calcium deficiency or imbalances in fruit tissues, resulting in necrotic lesions at the blossom end of the fruit (HO; WHITE, 2005). The increased occurrence of apical rot in ungrafted tomatoes cultivated in a mixed substrate can be attributed to water stress. This stress was observed once during the crop cycle of the 2020/21 season and three times in the 2021/22 season due to temporary power outages in the fertigation automation system. The water deficit manifested as withered leaves located at the apex of the plants. During these situations, the irrigation system was manually activated to ensure the viability of the plants. This highlights the need for improved control of the irrigation system when cultivating vegetables in pots with substrate. Compared with soil, the limited volume of water available for plants in pots is quickly exhausted.

No instances of plants exhibited symptoms of bacterial wilt (*R. solanacearum*) throughout the three tomato seasons. However, in the last two harvests, a higher number of plants displaying darkening of the vascular tissue in the stem was observed in ungrafted tomatoes cultivated in the soil compared with other treatments (Table 1 and Figure 3). Moreover, tomato plants grown in a mixed substrate showed the lowest incidence of plants with symptoms of vascular tissue darkening, with no difference from the grafted tomato plants grown in the soil, except in the 2020/21 season (Figure 3). Despite the occurrence of vascular tissue darkening on plants with rootstock, visually, the symptom appeared to be less intense than that observed in ungrafted plants.

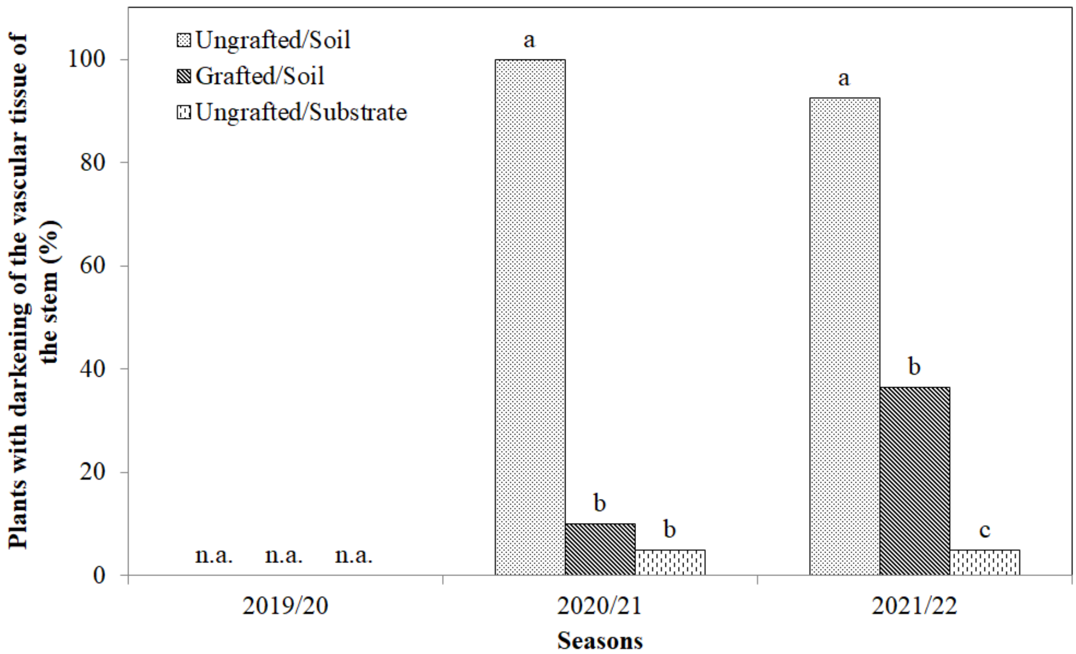

Figure 3. Percentage of plants with darkening of the vascular tissue at the stem base region as a function of grafting and substrate cultivation techniques.

Note: Means within each season followed by the same letter were not significantly different according to Tukey's test at 5% probability of error. n.a. = Data not assessed.

The following precautionary measures (BECKER et al., 2016) were diligently implemented to prevent the introduction of the disease into the tomato growing area: thorough cleaning of tools and equipment, sourcing seedlings from specialized nurseries, and preventing the transportation of soil or surface runoff of rainwater into the greenhouse. The successful implementation of these preventive measures ensured the absence of the disease not only throughout the three-year experiment but also in the year preceding the experiment (i.e., during the 2018/19 harvest). Consequently, in the absence of bacterial wilt in the area, the use of rootstocks resistant to soil diseases may have yielded limited benefits to the producer. On the other hand, the use of rootstocks becomes crucial in areas previously infested by *R. solanacearum* (MONTEIRO et al., 2020). In fact, after detecting tomato wilt (*R. solanacearum*) in the cultivation area, disease-resistant rootstock (e.g., Shinchonggang®) is recommended in the following year to avoid aggravating the problem.

In the last two harvests, the occurrence of plants displaying darkening of the vascular tissue in the stem was higher in ungrafted tomatoes cultivated in the soil than in other treatments (Figure 3). Darkening of the vascular tissue is often associated with infection by soil-borne pathogens, including *Fusarium* spp. and *Verticillium* spp. (INOUE-NAGATA et al., 2016). The susceptibility of ungrafted tomatoes to these pathogens may be attributed to the lack of resistance mechanisms provided by the rootstock (YANG et al. 2014; RONCERO et al. 2003).

Importantly, tomato plants grown in a mixed substrate exhibited the lowest incidence of symptoms of vascular tissue darkening, with no difference from grafted tomato plants grown in the soil, except in the 2020/21 season (Figure 3). The use of a mixed substrate in soilless cultivation systems has been reported to reduce the incidence and severity of soil-borne diseases due to its improved physical and chemical properties, such as better drainage and reduced pathogen populations (VÁZQUEZ, 2004). The observed decrease in darkening of the vascular tissue in the mixed substrate treatment supports the potential of this cultivation technique in mitigating soil-borne diseases.

The darkening of the vascular tissue in grafted tomato plants grown in the soil, although lower than observed in the ungrafted tomatoes, indicates that the rootstock alone may not provide complete protection against soil-borne pathogens. Additional factors, such as distance from the grafting point and the soil, environmental conditions, and specific pathogen populations present in the soil, may contribute to disease development and should be considered in future studies.

The *Fusarium* and *Verticillium* complex that cause disease in the tomato crop in Brazil comprises the following species: *F. oxysporum* f. sp. *radicis-lycopersici*, *F. oxysporum*. f.sp. *lycopersici* (races 1, 2, and 3), *Verticillium dahliae* (races 1 and 2), and *Verticillium albo-atrum* (REIS; LOURENÇO JÚNIOR; LOPES, 2021). *Fusarium striatus* has also been reported as an etiologic agent of tomato disease (MOINE et al. 2014). This variability in the etiologic agent of tomato wilt is crucial in determining the effectiveness of rootstock resistance, as it may work for one group but fail when another is present.

The economic analysis revealed that cultivating ungrafted tomatoes in pots with a mixed substrate resulted in a substantial incremental revenue of approximately R$100,000.00 per hectare compared with growing in the soil (Table 2). This increase in revenue may be attributed to the higher total, marketable, and unmarketable fruit yields observed in the mixed substrate treatment compared with grafted and ungrafted tomatoes in the soil (Figure 1).

In contrast, the additional revenue obtained from growing grafted tomatoes in the soil was substantially lower: 84.4% less than the additional revenue achieved by cultivating ungrafted tomatoes in a mixed substrate. This result suggests that grafting alone may not be sufficient to offset the benefits of soilless cultivation in terms of fruit yield and economic returns. While grafting provides disease resistance and other advantages, the combination of grafting with soilless cultivation techniques could offer even greater benefits in terms of yield and profitability.

Furthermore, the analysis revealed that the extra costs associated with growing ungrafted tomatoes in pots with a mixed substrate were 186.3% higher than cultivating grafted tomatoes in the soil. However, despite the higher costs, the net income derived from the cultivation of ungrafted tomatoes in pots with a mixed substrate remained positive, indicating its economic viability. In contrast, cultivating grafted tomatoes in the soil resulted in a negative net income, suggesting potential economic challenges associated with this approach.

Table 2. Net income of Coronel® tomatoes grown in a greenhouse model "Bandeirante" as a function of grafting and substrate cultivation techniques.

Treatment	Average yield	Yield gain over control	Additional income over control	Additional cost over control	Net income (loss) over control
	------- t ha^{-1} year^{-1} -------		------------ R$ ha^{-1} year^{-1} ------------		
Ungrafted/Soil[1]	89.9	-	-	-	-
Grafted/Soil[2]	98.9	9.0	15,560.28	22,500.00	(6,939.72)
Ungrafted/Substrate[3]	146.7	56.8	99,898.77	64,416.33	35,482.44

[1]Control treatment; [2]The additional cost of substrate cultivation refers to the values of R$4.10/pot, R$1.50/brick, R$20.51/50L of substrate, R$2.40/m ¾ plastic tube, and R$2.63/online dripper minus the value of R$975.00/meter of inline drippers; [3]The additional cost refers to the value of R$2.50/grafted seedlings minus the value of R$0.70/ungrafted seedlings.

Conclusion

The experiment demonstrated the advantages of planting ungrafted tomatoes in pots with mixed substrate, including higher yields, improved fruit quality, and positive economic returns. This approach provides an alternative and promising cultivation method for tomato growers, offering potential benefits in terms of productivity and profitability.

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