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PLANTING DATES FOR GREENHOUSE TOMATO CULTIVATION USING THE 'BANDEIRANTE' MODEL IN SOUTHERN BRAZIL

DATAS DE PLANTIO PARA O CULTIVO DO TOMATEIRO EM ESTUFA MODELO "BANDEIRANTE" NO SUL DO BRAZIL

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Abstract

This study aimed to assess the profitability and fruit yield associated with tomato planting dates in a "Bandeirante" model greenhouse. The treatments were four planting dates: September 15, 2020, October 21, 2020, November 27, 2020, and January 4, 2021. The experimental design was completely randomized, with six replicates. The Coronel® hybrid tomato was chosen for this experiment. The number and yield of marketable fruits in the extra AA and extra A classes, as well as the proportion of unmarketable fruits and the gross income were measured. The data analysis utilized analysis of variance, and when statistical differences were identified, means comparisons were made using Tukey's test at a 5% significance level. The highest marketable yield was recorded for the second planting date (163.6 t ha^{-1}), which did not significantly differ from the first planting date (143.4 t ha^{-1}). In contrast, the lowest marketable yield was observed for the fourth planting date (53.0 t ha^{-1}), significantly differing from the third planting date (105.9 t ha^{-1}). These results indicate that early planting times, specifically in September and October, yielded the highest productivity and fruit quality, which correlated with increased gross income, partially due to higher average market prices during these periods.

Keywords: *Solanum lycopersicum*, protected cultivation, economic return, microclimate.

Resumo

Este estudo teve como objetivo avaliar a rentabilidade e a produtividade de frutos associadas às datas de plantio de tomate em uma estufa modelo "Bandeirante". Os tratamentos foram quatro datas de plantio: 15 de setembro de 2020, 21 de outubro de 2020, 27 de novembro de 2020 e 4 de janeiro de 2021. O delineamento experimental utilizado foi inteiramente casualizado, com seis repetições. O tomate híbrido Coronel® foi escolhido para este experimento. O número e a produtividade de frutos comercializáveis nas classes extra AA e extra A, assim como a proporção de frutos não comercializáveis e a renda bruta, foram medidos. A análise dos dados utilizou a análise de variância, e quando diferenças estatísticas foram identificadas, as comparações de médias foram realizadas utilizando o teste de Tukey ao nível de 5% de significância. A maior produtividade de frutos comercializáveis foi registrada para a segunda data de plantio (163,6 t ha^{-1}), que não diferiu significativamente da primeira data de plantio (143,4 t ha^{-1}). Em contraste, a menor produtividade de frutos comercializáveis foi observada para a quarta data de plantio (53,0 t ha^{-1}), diferindo significativamente da terceira data de plantio (105,9 t ha^{-1}). Esses resultados indicam que as datas de plantio mais precoces, especificamente em setembro e outubro, apresentaram a maior produtividade e qualidade de frutos, o que se correlacionou com um aumento da renda bruta, parcialmente devido aos maiores preços médios de mercado durante esses períodos.

Palavras chave: *Solanum lycopersicum*, cultivo protegido, retorno econômico, microclima.

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Introduction

The region of Caçador, SC, Brazil, has earned national recognition for its high-quality open-field tomato production (VIEIRA NETO; HAHN, 2022). However, the climatic conditions in this region pose considerable challenges to farmers, necessitating robust phytosanitary management strategies to maintain and enhance productivity, as well as profitability (MONTEIRO et al., 2021; MONTEIRO et al., 2023). To overcome these challenges, growers are increasingly turning to greenhouse cultivation, which offers a controlled environment that can help mitigate the impact of seasonal climate fluctuations, such as low temperatures and heavy rainfall (LINS JUNIOR et al., 2020; WAMSER, 2021).

One prevalent greenhouse model for tomato cultivation in southern Brazil is the "Bandeirante." This model bears resemblance to the widely used "Almeria" model in the southern region of Spain's Almeria province (PENÃ et al., 2020). 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 only provides lateral ventilation. One notable advantage of the "Bandeirante" model over metallic structures is its low installation and maintenance costs (RAMPAZZO et al., 2016), which can be managed by the farmers themselves.

Choosing the correct planting time for tomatoes grown in a greenhouse is a pivotal factor that can significantly influence the success of a harvest. This decision is not merely about agronomic conditions but also has far-reaching implications for the economics of tomato production, given the seasonality of prices and market demand (BOTEON, 2023). Planting at the optimal time allows growers to maximize their yield during periods when prices are at their peak, leading to greater revenue. In addition to market trends, climatic conditions play a crucial role in determining the best time for planting. Tomatoes require a certain range of temperatures to thrive (PANDOLFO et al., 2005). In regions with extreme temperature variations, like Caçador, planting too early could expose plants to late frosts, which can severely damage or kill young plants. Similarly, planting too late may lead to a shorter growing season, reducing overall yield. The agroclimatic zoning for tomato cultivation in Caçador extends from October 11 to December 10 (PANDOLFO et al., 2005). Thus, a thorough understanding of the local climate, including frost dates, is essential for successful tomato cultivation in greenhouses. Moreover, certain planting times might align with higher humidity levels and lower temperatures, promoting fungal infections such as powdery mildew (JACOB et al. 2008). Similarly, planting during peak seasons for specific pests can lead to increased pressure from insects, requiring additional pest management measures (MICHEREFF FILHO et al., 2022).

The objective of the present study was to evaluate the profitability and fruit yield depending on the tomato planting dates in a "Bandeirante" model greenhouse.

Material and Methods

Planting material

The experiment was conducted in a "Bandeirante" model greenhouse during the 2020/2021 season. The greenhouse was located in Caçador, SC, Brazil, at geographic coordinates 26°49'05.2" S, 50°59'43.3" W, with an altitude of 940 meters. It measured 20 meters in width, 45 meters in length, and had a height of three meters. The structure was covered with 150-micron plastic and did not have side curtains. Before the experiment, the area had been cultivated with a mixture of oats, rye, and forage turnip.

The treatments consisted of four planting dates: September 15, 2020, October 21, 2020, November 27, 2020, and January 4, 2021 (Figure 1). Each plot consisted of a planting row 3.2 meters in length, with eight plants spaced 0.40 meters apart within the row and 2.0 meters between rows, for a total of eight plants per plot and 12,500 plants per hectare. The experimental design was completely randomized, with six replications. The tomato hybrid used was Coronel®, which has an indeterminate growth habit and produces large, globular fruits.

The soil at the experiment site was classified as a typical dystrophic Oxisol. In the 0-20 cm layer, the soil had the following chemical characteristics: pH (water)=6.0; P = 31.1 mg dm^{-3}; K = 252.0 mg dm^{-3}; organic matter = 53.0 g dm^{-3}; Al = 0.0 $cmol_c$ dm^{-3}; Ca+Mg = 13.8 $cmol_c$ dm^{-3}; and Ca-Mg-K saturation = 79.5%. At planting, fertilization involved incorporating 8 t ha^{-1} of organic poultry manure (2% N, 2.2% P_2O_5, 1.6% K_2O, 80% dry matter) and 400 kg ha^{-1} of P_2O_5 as triple superphosphate (44% P_2O_5) into the planting furrows. Sidedressing fertilization consisted of 400 kg ha^{-1} of N, 400 kg ha^{-1} of K_2O, and 5 kg ha^{-1} of B, applied as urea (45% N), potassium nitrate (12% N, 45% K_2O), and boric acid (17% B). Weekly sidedressing via fertigation followed the recommendations of Hahn and Suzuki (2016).

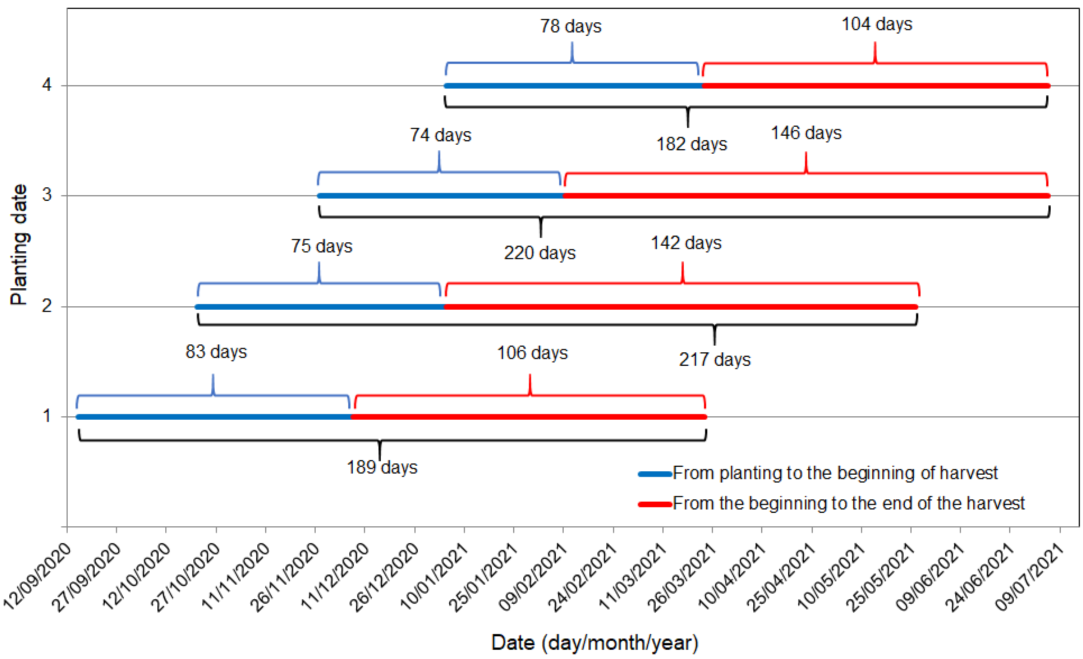

Figure 1. Number of days to harvest initiation and harvest days as a function of tomato planting date in a "Bandeirante" greenhouse model, in Caçador, SC.
Note: Planting date "1" on 09/15/2020; Planting date "2" on 10/21/2020; Planting date "3" on 11/27/2020; Planting date "4" on 01/04/2021.

A localized drip irrigation system with inline drippers was used for each treatment. The drippers had a flow rate of 1.6 L h^{-1} and were spaced 30 cm apart along the planting row. Irrigation was managed with conventional tensiometers to monitor soil moisture daily. When the tensiometer reading reached 400 mbar, irrigation was applied for 40 minutes.

The plants were trained with two main stems and supported by plastic twine. Lateral shoots were pruned periodically to maintain two main stems per plant. When the plants reached a height of 2.6 meters, the main stems were pruned, leaving three leaves above the last cluster.

Greenhouse Conditions

Air temperature, relative humidity (RH%), and photosynthetically active radiation (PAR) inside the greenhouse were recorded using a microstation data logger, model H21-002 (Onset, Bourne, MA, USA) (Figure 2).

Harvesting

Fruit harvesting began on December 7, 2020, January 4, 2021, February 9, 2021, and May 7, 2021 (Figure 1). The number and yield of marketable fruits in the extra AA and extra A grades, as well as unmarketable fruits, were evaluated over 104 days in the first planting date, 146 days in the second planting date, 142 days in the third planting date, and 106 days in the fourth planting date (Figure 1). Extra AA fruits weighed over 150 g, extra A fruits weighed between 100 and 150 g, and unmarketable fruits weighed less than 100 g or exhibited defects due to physiological or phytopathological disorders and insect damage. Physiological disorders included blossom-end rot and catfacing. The average fruit mass in the extra AA and extra A grades was calculated by dividing total production by the number of fruits harvested.

Data Analysis

Data were subjected to analysis of variance, and when significant differences were found, means were compared using Tukey's test at a 5% significance level. Gross income analysis considered the average price paid to tomato producers in the Caçador region during the months of December 2020, and January through July 2021, as reported by the CEPEA/USP/ESALQ database for the 2020/2021 season (CEPEA, 2021).

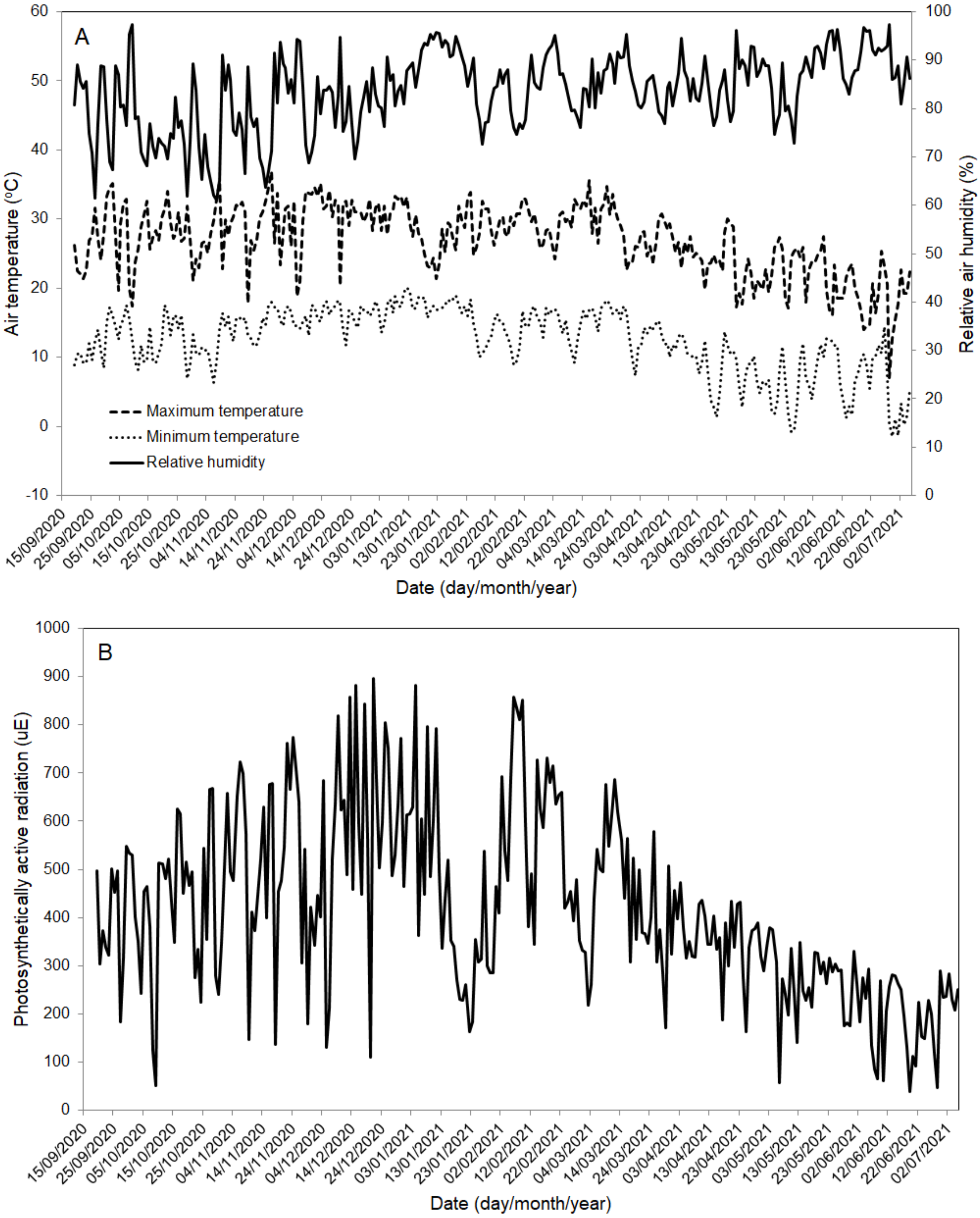

Figure 2. Daily maximum and minimum temperatures and daily average relative air humidity (A), and daily average photosynthetically active radiation (B) inside the 'Bandeirante' model greenhouse during the experiment period, in Caçador, SC, Brazil.

Results and Discussion

Significant differences in tomato planting dates were observed across all fruit yield categories (Figure 3). The highest marketable yield was recorded on the second planting date (163.6 t ha^{-1}), with no significant difference compared to the first planting date (143.4 t ha^{-1}). However, the lowest marketable yield was noted on the fourth planting date (53.0 t ha^{-1}), showing a stark contrast with the third planting date (105.9 t ha^{-1}). The highest yield from the second planting date exceeded the lowest yield from the fourth by 208.7%. These results highlight the critical importance of selecting the right planting date to ensure a successful harvest, as crops respond more favorably to optimal environmental conditions during their growth stages. The impact of planting dates on tomato productivity was also noted by Singh et al. (2015) and Dhaliwal et al. (2017). These findings align with fluctuations in photosynthetically active radiation (PAR) throughout the cultivation cycle (Figure 2), which increased from the start of the experiment, peaking on December 20, 2020, before declining toward the end of the harvesting period. The well-established relationship between solar radiation and tomato growth underscores the crucial role light plays in both vegetative development (SILVA et al., 2013) and fruit yield (HOLCMAN et al., 2015; HOLCMAN et al., 2017; MARQUES et al., 2020).

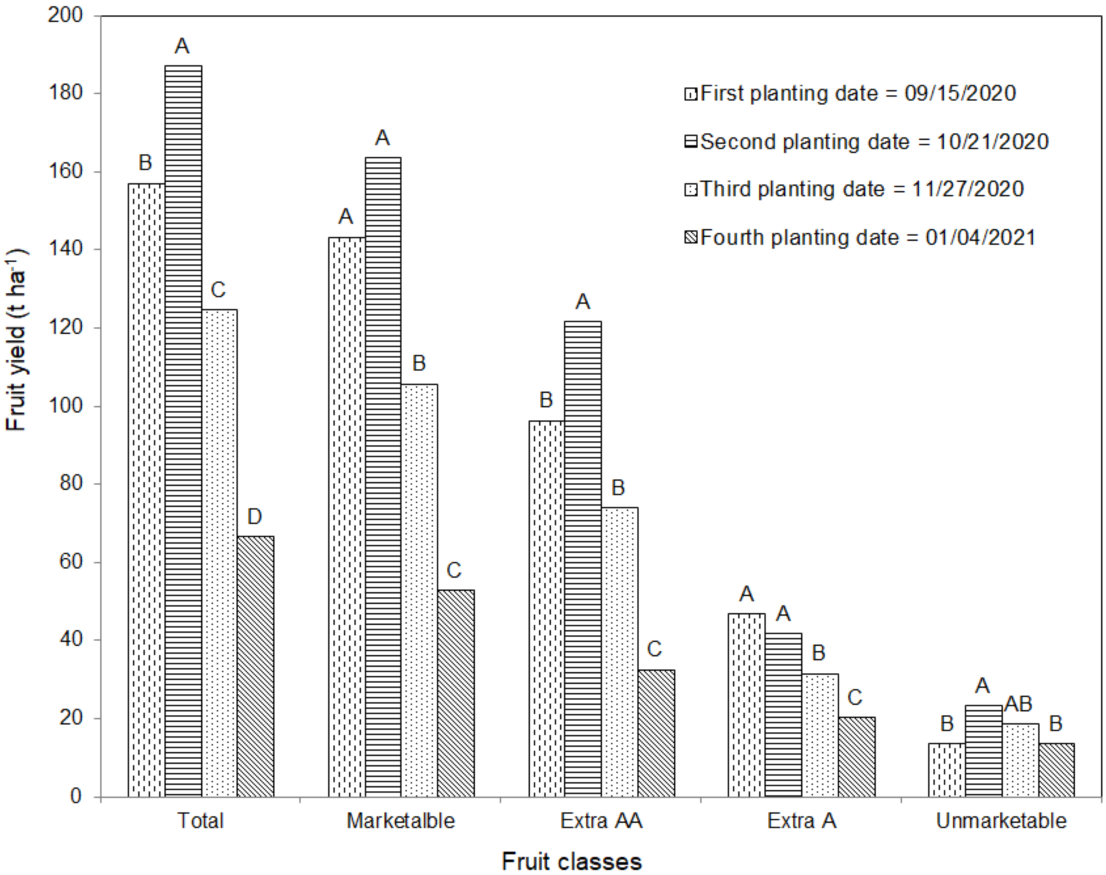

Figure 3. Fruit yield as a function of tomato planting date in a "Bandeirante" greenhouse model in Caçador, SC. Means followed by the same letter within each fruit classes do not differ by Tukey's test at a 5% probability of error.

Moreover, the duration of the tomato cultivation cycle varied based on the planting date (Figure 1), with longer cycles observed in the second and third planting dates, and a shorter cycle during the fourth due to frost, which hindered plant development. These results emphasize the need to select the optimal planting date for maximizing tomato yield in greenhouses, factoring in both solar radiation availability and the risk of adverse weather events. Agroclimatic zoning for field-grown tomatoes in the Caçador region, SC, spans from October 11 to December 10 (PANDOLFO et al., 2005), based on the absence of frost and average temperatures ranging from 17.5ºC to 25.5ºC during a 100-day cycle. Establishing current agroclimatic zoning for tomatoes cultivated in "Bandeirante" greenhouses is crucial, given the greenhouse's partial frost protection and the longer cultivation cycle (182 to 220 days – Figure 1).

Notably, the highest marketable fruit yields from the first (143.4 t/ha) and second (163.6 t/ha) planting dates in the "Bandeirante" greenhouse were more than double the average yield of 70.0 t/ha achieved in the same 2020/21 harvest season under open-field cultivation in Caçador (VIEIRA NETO; HAHN, 2022). These findings suggest that selecting the right planting date is key to making greenhouse investments viable and encouraging farmers in the Caçador region to adopt this protected cultivation system.

The planting date also influenced the proportion of discarded fruits in various unmarketable categories (Figure 4). The fourth planting date, on January 4, 2021, had the highest incidence of small, insect-damaged, and physiologically or phytopathologically affected fruits, similar to the third planting date (November 27, 2020). In contrast, the first planting date (September 15, 2020) showed the lowest percentage of such fruits. A strong effect was observed between the occurrence of blossom-end rot and the planting date, with the disorder being more prevalent in the first planting period and less so in subsequent periods. These results reflect the complex interaction between planting dates, environmental conditions, and the incidence of physiological disorders and pests throughout the growth cycle. For example, the reduction in PAR after the peak on December 20, 2020, may have contributed to a decrease in fruit mass during later plantings, as solar radiation is essential for assimilate production, which supports fruit growth (KLÄRING; KRUMBEIN, 2013). Similarly, higher solar radiation and air temperatures, combined with lower relative humidity during early planting periods, likely intensified the vapor pressure deficit, contributing to the higher incidence of blossom-end rot in earlier plantings (MAX et al., 2009).

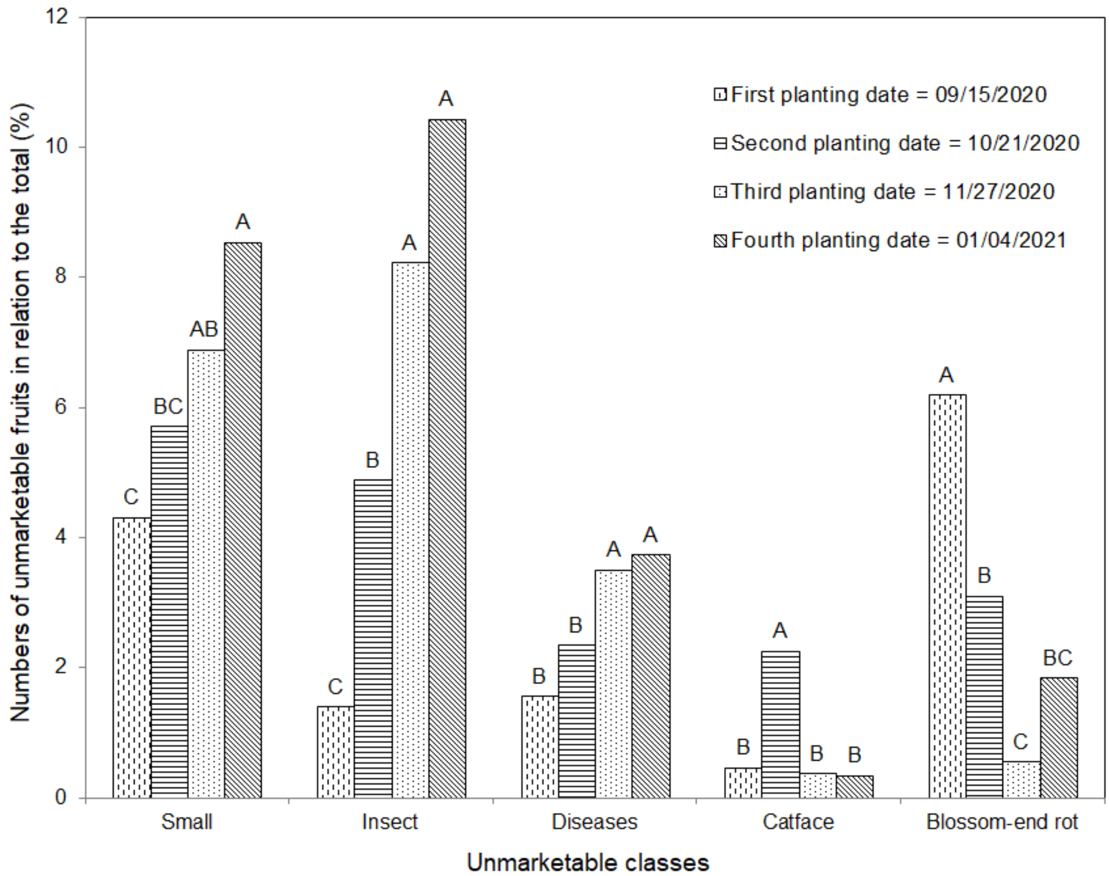

Figure 4. Percentage of unmarketable fruits relative to the total, as a function of the tomato planting date in the "Bandeirante" model greenhouse, in Caçador, SC. Means followed by the same letter within each fruit class do not differ by Tukey's test at 5% probability of error.

Under the cultivation conditions in the "Bandeirante" greenhouse, few diseases were observed in this present study, mainly related to milder environmental conditions toward the end of the growth cycle. Diseases such as powdery mildew, Alternaria leaf blight, gray mold, and other fungal leaf spots, along with late blight, were noted, typically associated with cooler temperatures or the approach of autumn. The primary insect pests damaging tomato fruits in the Caçador region are the tomato leafminer (*Tuta absoluta*) and borers (*Neoleucinodes elegantalis*, *Spodoptera* spp., and *Helicoverpa armigera*). Infestations typically begin between November and December, coinciding with the first harvests. However, pest intensity tends to increase during the summer months, as observed in the second, third, and fourth planting dates (Figure 4). Consequently, tomato yields and production costs for later plantings may be adversely affected by insect damage and the increased need for insecticide applications during periods of higher pest pressure (LINS JUNIOR et al., 2020). These findings underscore the importance of not only selecting the appropriate planting date but also considering environmental conditions and pest dynamics when planning tomato cultivation in greenhouses, with the goal of mitigating negative impacts on yield and fruit quality.

The planting date significantly affected both the average weight of marketable fruits, especially in the Extra AA grade, and their proportion of the total production (Table 1). The second planting date (October 21, 2020) resulted in the highest average fruit weight, followed by the third (November 27, 2020), suggesting that intermediate planting periods favor fruit development, likely due to optimal levels of PAR (Figure 2). In contrast, the fourth planting date (January 4, 2021) produced the lowest average fruit weight, indicating that later planting dates may expose crops to less favorable conditions for fruit growth. Although the second planting period had a higher proportion of Extra AA fruits, the differences with the first and third periods were not statistically significant. The early planting date produced a higher percentage of marketable fruits, despite having a lower average fruit weight, while the fourth planting date had the lowest proportion of marketable fruits, emphasizing the importance of selecting the optimal planting date to enhance both quality and yield in greenhouse tomato production.

Table 1. Average fruit mass and percentage of marketable fruits, as a function of the tomato planting date in the "Bandeirante" model greenhouse, in Caçador, SC.

Planting date	Average fruit mass			Fruit yield	
	Marketable	Extra AA	Extra A	Extra AA/ Marketable	Marketable/ Total
	---------------- g fruto^{-1} ----------------			-------------- % --------------	
09/15/2020	166.1 b	187.9 b	134.4ns	67.1 ab	91.2 a
10/21/2020	177.0 a	197.2 a	136.6	74.1 a	87.4 ab
11/27/2020	171.6 ab	193.2 ab	135.8	69.5 ab	86.4 b
01/04/2021	162.9 b	187.7 b	134.6	61.2 b	78.7 c

Means followed by the same letter within each fruit class do not differ by Tukey's test at 5% probability of error.

The planting date of tomatoes in a "Bandeirante" greenhouse significantly influenced the production pattern of marketable fruits throughout the cultivation cycle (Figure 5). The first planting date (September 15, 2020) showed faster initial growth with a slowdown during the 104-day harvest period, while later planting dates, particularly the third (November 27, 2020) and fourth (January 4, 2021), exhibited slower growth, influenced by less favorable environmental conditions, such as lower light intensity and temperature (Figure 2). This information is crucial for adjusting management practices, such as irrigation and fertilization, to optimize the production of marketable fruits for each planting date in greenhouse cultivation.

Gross income from marketable tomatoes was closely related to planting date and profitability (Figure 6). The first planting date (September 15, 2020) yielded the highest gross income (R$ 238,400.00), reflecting both higher marketable fruit yields (Figure 3) and higher average market prices (CEPEA, 2021). The second planting date (October 21, 2020) generated a slightly lower gross income (R$ 199,640.00), despite similar yields, due to reduced tomato prices during that period. The third (November 27, 2020) and fourth (January 4, 2021) planting dates resulted in even lower gross incomes (R$ 116,000.00 and R$ 63,120.00, respectively), corresponding to decreases in both yield and fruit quality. Gross income from the first planting was 377.65% higher than that from the fourth. Therefore, this experiment highlights the critical role of planting date selection in maximizing profitability in greenhouse tomato production, considering not only yield but also fruit quality and market demand. Effective management strategies that address climate variability and market fluctuations are essential for the economic success of tomato production in greenhouses in the Caçador, SC, region.

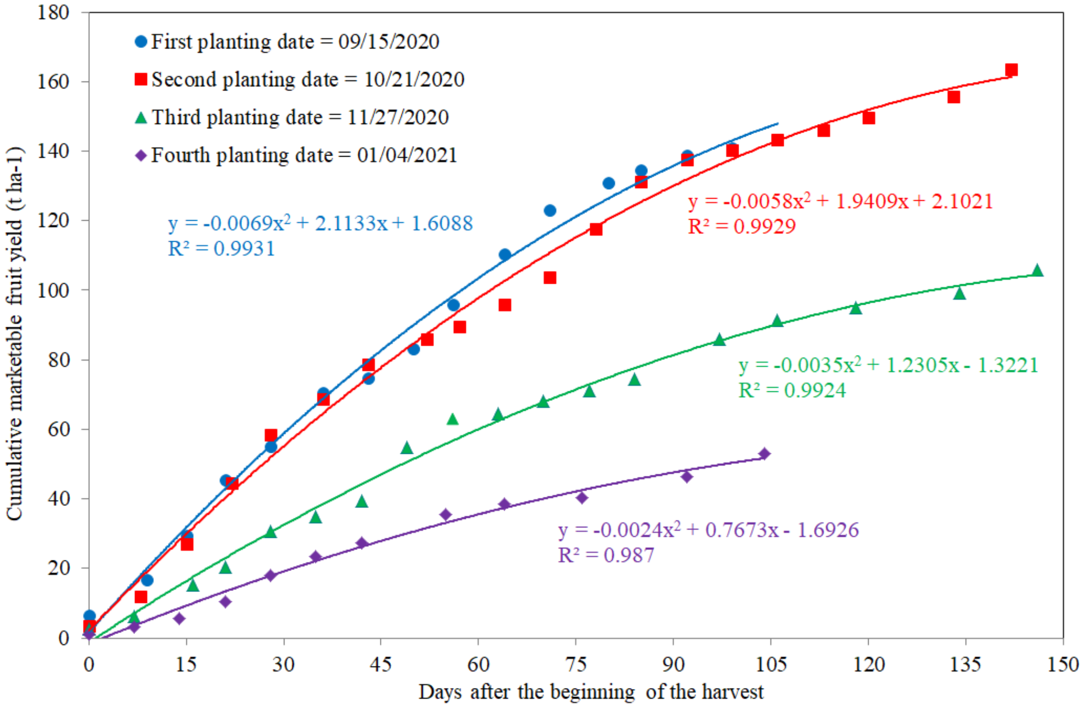

Figure 5. Cumulative marketable fruit yield throughout the harvest period, as a function of the tomato planting date in the "Bandeirante" model greenhouse, in Caçador, SC.

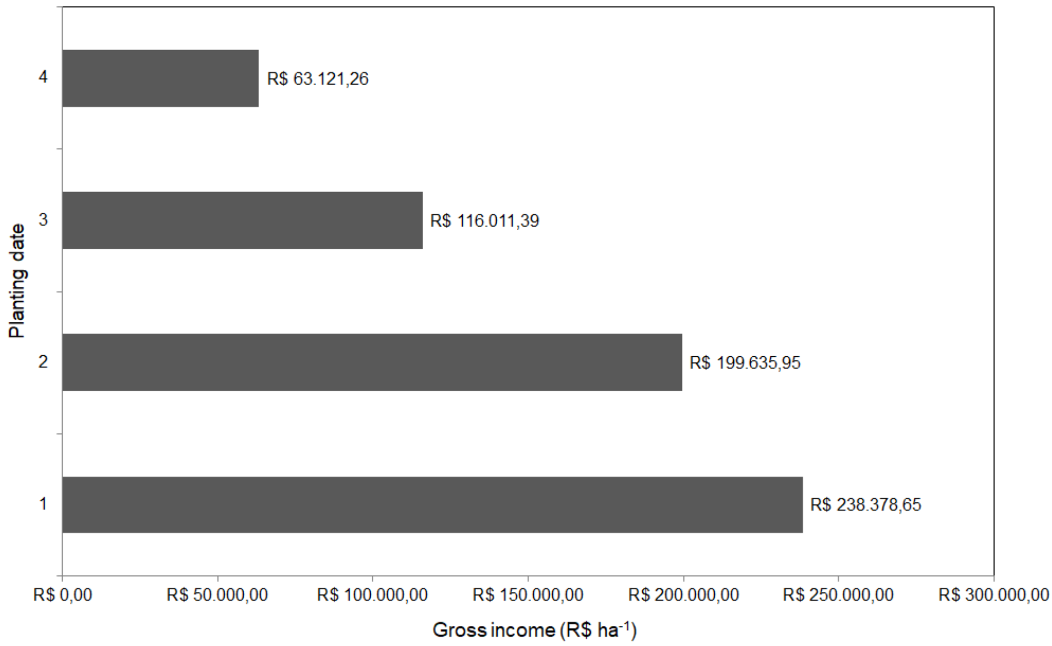

Figure 6. Gross income from the sale of marketable tomatoes, as a function of the planting date in "Bandeirante" model greenhouse, in Caçador, SC.
Note: Planting date "1" on 09/15/2020; Planting date "2" on 10/21/2020; Planting date "3" on 11/27/2020; Planting date "4" on 01/04/2021.

Conclusion

The choice of planting date for tomatoes in "Bandeirante" model greenhouses in the Caçador region, SC, has a significant impact on fruit yield and the profitability.

Early planting date, conducted in September and October, resulted in higher yield, leading to higher gross income, partly due to higher average market prices.

In contrast, later planting seasons, in November and January, experienced a reduction in fruit yield, resulting in lower gross income.

Farmers in Caçador, SC, must carefully consider the planting season for tomatoes in greenhouses, taking into account not only yield but also market price variations and the climatic risks associated with each season.

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