

Influence of stolon tips position in the agronomic performance of strawberry plantlets

Abstract – The objective of this work was to evaluate whether the position of stolon tips influences the agronomic performance of strawberry plantlets. Two cultivars from Embrapa breeding program were evaluated: BRS DC22 and BRS DC25 (Fênix). The assessed parameters were crown diameter, root system length, root dry mass, yield, and agronomic characteristics. Cultivation in the municipality of Pelotas, Brazil, did not result in differences in mean fruit production, and yield. The BRS DC22 cultivar produced the highest number of fruits and crowns per plant while fruits from BRS DC25 (Fênix) cultivar had the highest mean fruit mass. The position of stolon tips directly influenced plantlets quality. First-order tips had larger crown diameters, while 4th order tips had greater root dry mass. The BRS DC25 (Fênix) cultivar tips had larger crown diameters and lower root dry mass compared with BRS DC22 cultivar plantlets. Propagule order did not affect mean fruit yield. The propagule position influences the survival rate of the BRS DC25 (Fênix) cultivar plantlets, with 1st order propagules showing the lowest survival rate for this genotype. The position of stolon tips may have a direct relationship with plantlet quality.

Index terms: *Fragaria x ananassa*, berry crops, breeding, cultivar selection.

Influência da posição da ponta dos estolões no desempenho agrônomo de mudas de morangueiro

Resumo – O objetivo deste trabalho foi avaliar se a posição das pontas dos estolões influencia o desempenho agrônomo de mudas de morangueiro. Foram avaliadas duas cultivares do programa de melhoramento da Embrapa: BRS DC22 e a BRS DC25 (Fênix). Os parâmetros analisados foram diâmetro da coroa, comprimento do sistema radicular, massa seca das raízes, rendimento e características agrônomicas. O cultivo no município de Pelotas não resultou em diferenças na produção média de frutas e produtividade. A cultivar BRS DC22 produziu um maior número de frutos e coroas por planta, enquanto as frutas da cultivar BRS DC25 (Fênix) apresentaram maior massa média. A posição das pontas dos estolões influenciou diretamente a qualidade das mudas. Pontas de estolões de primeira ordem apresentaram diâmetros de coroa maiores, enquanto as de quarta ordem apresentaram maior massa seca radicular. As pontas da cultivar BRS DC25 (Fênix) tinham maiores diâmetros de coroa e menor massa seca das raízes em comparação com as mudas da cultivar BRS DC22. A ordem das pontas não afetou a produção média de frutos. A posição das pontas influencia a taxa de sobrevivência das mudas da cultivar BRS DC25 (Fênix), com pontas de propágulos de primeira ordem mostrando a menor taxa de sobrevivência para esse genótipo. A posição das pontas dos estolões pode ter uma relação direta com a qualidade das mudas.

Termos para indexação: *Fragaria x ananassa*, culturas de bagas, melhoramento, seleção de cultivar.

Mateus Felipe Bernard^(✉) 
Universidade Federal de Pelotas, Pelotas, RS,
Brazil.
E-mail: mateusfelipebernard@hotmail.com

Andressa Vighi Schiavon 
Embrapa Clima Temperado, Pelotas, RS,
Brazil. E-mail: andressa.vighi@gmail.com

Adriel da Silva Alves 
Universidade Federal de Santa Catarina,
Florianópolis, SC, Brazil.
E-mail: adrieluffsc@gmail.com

Sandro Bonow 
Embrapa Clima Temperado, Pelotas, RS,
Brazil. E-mail: sandro.bonow@embrapa.br

Luís Eduardo Corrêa Antunes 
Embrapa Clima Temperado, Pelotas, RS,
Brazil. E-mail: luis.antunes@embrapa.br

✉ Corresponding author

Received
December 16, 2024

Accepted
January 6, 2026

How to cite
BERNARD, M.F.; SCHIAVON, A.V.; ALVES,
A. da S.; BONOW, S.; ANTUNES, L.E.C.
Influence of stolon tips position in the agronomic
performance of strawberry plantlets. **Pesquisa
Agropecuária Brasileira**, v.61, e03991, 2026.
DOI: <https://doi.org/10.1590/S1678-3921.pab2026.v61.03991>.

Introduction

The cultivation of strawberry (*Fragaria* × *ananassa* Duch.) is widely recognized for its socioeconomic relevance, as it represents a promising business opportunity and an important source of income for smallholder farmers (Madail, 2016; Hernández-Martínez et al., 2023). Brazil is the largest strawberry producer in South America and the seventh largest globally, with an estimated annual production of 165,000 tonnes across approximately 4,500 hectares (Antunes et al., 2021; Antunes & Bonow, 2023). Within Brazil, the state of Minas Gerais leads national production, accounting for roughly 55% of the total cultivated area. Significant production also occurs in the states of Paraná and Rio Grande do Sul, where strawberry cultivation is mainly managed by family farms (Antunes et al., 2021; Antunes & Bonow, 2023).

The increasing consumer demand for fresh fruits and processed products has driven the expansion of strawberry cultivation in recent years, intensifying the need for high-quality plantlets (Madail, 2016; Hernández-Martínez et al., 2023). Currently, approximately 30% of the plantlets used in Brazil are imported from nurseries located in Patagonia. In the southern states this proportion exceeds 75% (Signorini et al., 2022; Palombini et al., 2023). Consequently, strawberry production in Brazil remains heavily dependent on these imports (Brandt et al., 2022). Moreover, the cost of establishing strawberry cultivation is relatively high, and it varies significantly according to the level of technology adopted in the crop (Souza et al., 2022). Additionally, these production costs have also experienced considerable fluctuations, largely influenced by exchange rate variations, which contribute to instability within the strawberry supply chain (Barth et al., 2020; Silva et al., 2023).

Strawberry production is influenced by several factors such as cultivar specific characteristics, temperature, photoperiod, and planting season (Sánchez Pineda & Ramirez Torres, 2017). Among these, plantlet vigor is critical. Consequently, plantlets with crowns smaller than 5 mm, advanced physiological age, and poorly developed root systems exhibit reduced establishment capacity. In contrast, larger and more vigorous crowns ensure better rooting, higher initial carbohydrate reserves, and more uniform stands (Bolda, 2023).

Crown diameter has been highlighted as an important parameter for estimating the vigor and productive potential of strawberry plantlets (Shi et al., 2021). Therefore, larger crowns are typically associated with enhanced root development and a greater number of floral primordia, both of which facilitate earlier bud initiation and contribute to more uniform, productive plant stands (Torres-Quezada et al., 2015; Cocco et al., 2016). Consequently, the quality and size of propagules play a decisive role in ensuring successful establishment and improved fruit yield.

Considering these aspects, it is essential to consolidate and optimize soilless plantlet production, as this system has been validated and proven highly viable (Schiavon et al., 2022; Signorini et al., 2022). In a closed soilless environment, mother plants are cultivated on elevated benches filled with carbonized rice husk. As temperature and photoperiod increase during late spring, the plants initiate stolon development. For potted plantlet production, all propagules are typically used, regardless of their position along the stolon.

The objective of this work was to evaluate whether the position of stolon tips influences the agronomic performance of strawberry plug plants.

Materials and Methods

The study was conducted in the municipality of Pelotas, in the state of Rio Grande do Sul, Brazil. The first phase was the plantlet production in greenhouses at Embrapa Clima Temperado, carried out from March to May 2022. The second phase focused on the field production, conducted from April to December 2022 at a producer's farm (31°39'40.4"S, 52°25'49.3"W; at 64 m above sea level). The soil at the site is classified as an Argissolo Vermelho-Amarelo, according to the Brazilian Soil Classification System (Santos et al., 2018), equivalent to a Red-Yellow Ultisol soil. According to the Köppen classification, the climate in the region is humid subtropical, characterized by hot summers, a mean annual temperature of 17.9°C, and total precipitation of 1,456.8 mm (Table 1).

A randomized complete block design was employed in a 2x4 factorial arrangement (genotypes × stolon tip position), with three replicates of six plants per experimental unit. The BRS DC25 (Fênix), and BRS DC22 cultivars, recently registered by Embrapa

Strawberry Breeding Program, were evaluated. This design allowed control of field variability and assessment of interactions between genotype and stolon tip position.

Mother plants derived from tissue culture were cultivated in a greenhouse on benches filled with carbonized rice husks. Irrigation was provided by two lines of self-compensating drip tape with emitters spaced 20 cm apart, connected to a 0.5 hp motor pump. The plants were fertigated using a nutrient solution based on the formulation proposed by Sonneveld & Straver (1994) and adapted by Peil et al. (2024). The macronutrient concentrations in mg L⁻¹ of solution were: 9.99 NO₃⁻; 1.28 H₂PO₄⁻; 2.48 SO₄²⁻; 0.75 NH₄⁺; 5.98 K⁺; 2.92 Ca²⁺; and 1.83 Mg²⁺. The micronutrient concentrations in mg L⁻¹ of solution were: 1.44 Fe; 0.5 Mn; 0.68 Zn; 0.42 B; 0.72 Cu; and 0.007 Mo. Stolon tips were classified in different orders according to their position relative to the mother plant: 1st order tips were the closest, 4th order tips were the farthest, while 2nd and 3rd order tips were intermediate. The propagules were collected and transferred to 72-cell polystyrene trays (124 mL per cell) containing Carolina Soil substrate (Carolina Soil, Santa Cruz do Sul, RS, Brazil) supplemented with 5 g L⁻¹ of Osmocote fertilizer (ICL, Tel-Aviv, Israel), following the instructions of Cocco et al. (2016).

To investigate the influence of propagule position along the stolon on plantlet growth, the initial diameter (ID) of the crowns was measured in millimeters using a digital caliper. After approximately 45 days, six plantlets per treatment were sampled to measure the final crown diameter (FD), diameter increment (DI), and root system length (RL) in millimeters. For the dry root system mass (DRSM) measurements in g per plant, roots were dried in a forced-air circulation oven at 65°C until constant mass was achieved. To ensure sufficient material for the assessments, double the required number of seedlings per treatment was produced.

On April 1st, 2022, plantlets from different stolon orders were transplanted into soil beds covered with 50 µm black polyethylene mulch, and protected with 100 µm transparent low-density polyethylene low tunnels. The plants were spaced 35 cm between rows and 40 cm within rows, with three rows per bed arranged in a staggered pattern. The beds were 1.10 m wide with 0.5 m spacing between them. The field drip irrigation system consisted of two lines of self-compensating drip tape with emitters spaced 20 cm apart, powered by a 3 hp motor pump. Fertilization was applied weekly through the irrigation system, while phytosanitary management and the application of agricultural defensives were conducted as needed

Table 1. Air temperature, precipitation, historical chilling hours, and chilling hours in the experiment site, recorded by Agrometeorology Laboratory (Agromet) of Embrapa Clima Temperado, from 1984 to 2017.

Month	Temperature °C)			Precipitation (mm)	Historical chilling hours ⁽¹⁾ (hour)	Chilling hours (hour)
	Mean	Minimum	Maximum			
January	24.9	20.6	30.4	130.8	-	-
February	23.4	18.8	29.5	70.4	-	-
March	21.2	16.8	26.9	135.8	-	-
April	18.4	14.2	24.0	190.0	-	-
May	14.5	10.7	19.1	76.2	28	26
June	11.5	7.5	16.0	163.6	80	99
July	14.2	10.4	18.9	246.2	119	42
August	13.2	8.7	18.4	151.0	64	48
September	14.4	10.0	19.5	66.6	31	11
October	17.3	13.0	22.4	150.0	-	-
November	20.3	15.3	25.9	51.0	-	-
December	22.6	17.7	28.6	25.2	-	-
Annual mean	17.9	13.6	23.3	-	-	-
SPCHA ⁽²⁾	-	-	-	1,456.8	322	226

⁽¹⁾Historical chilling hours from 1984 to 2017. ⁽²⁾SPCHA, Sum of accumulated precipitation and chilling hours.

by the producer following the recommendations for strawberry cultivation (Fialho et al., 2025).

Harvest started when the first fruit reached full maturity, and continued from June 2 to December 15, 2022. Only marketable fruits, defined as those with at least 75% red epidermis, and a minimum mass of 6 g, were considered. Fruits from individual plants were counted and weighed. Calculated variables included harvest initiation date, harvest duration in days, number of fruits per plant (NFP), fruit yield in g per plant, mean fruit mass in g per fruit, number of stolons per plant, and number of crowns per plant.

In order to evaluate the produced plantlets quality and the adaptability of each genotype to the experimental conditions, plant survival was assessed at the conclusion of the evaluation period by counting the number of living plants per experimental plot. The survival rate was recorded as a percentage relative to the initial number of plantlets per plot. This is particularly relevant in strawberry cultivation, since it directly influences crop establishment in the field.

Data were subjected to two-way analysis of variance (ANOVA). The experimental factors were genotype and stolon propagule order, following the model: $Y \sim \text{genotype} \times \text{order} + \text{block}$. The interaction between factors was tested using the F-test ($\alpha = 0.05$). Assumptions of normality, homogeneity of variances, and independence of errors were checked using Shapiro-Wilk's test ($\alpha = 0.05$), Levene's test ($\alpha = 0.05$), and Durbin-Watson's test ($\alpha = 0.05$), respectively. The assumptions were met, and no data transformation was required. Outliers and linearity were not formally verified, and a visual inspection was carried out in order to remove anomaly data. Durbin-Watson's test was evaluated through p-value associated to the d statistics. When significant differences were detected, means were compared using Tukey's test at 5% significance level. The statistical softwares used were Sisvar version 5.6 (Ferreira, 2014) for ANOVA, and R statistical language version 4.5.2 (R Core Team, 2025) for Durbin-Watson's test.

Results and Discussion

No significant interactions were observed between genotype and propagule order for any of the studied variables (Table 2). Regarding the main effects, ID of

the propagules and FD were larger in the BRS DC25 (Fênix) cultivar plantlets.

Mean crown diameter of strawberry plantlets varied significantly across different stolon orders for both ID and FD. The 1st order exhibited the largest ID, while 2nd and 3rd order propagules did not differ significantly from each other, they were smaller than the 1st order, and larger than 4th order. A similar trend was observed regarding FD, where plantlets originating from 1st order propagules exhibited the largest crown diameters. Plantlets from the 3rd order showed intermediate FD, with no significant differences compared with the 1st and 2nd orders, while those originating from 4th order had the smallest diameters.

These differences in ID and FD across stolon orders suggest that the stolon tip position can influence the development and growth of strawberry plantlets. The crown diameter is an important parameter that provides valuable information about plant quality and vigor. Plantlets with larger crown diameters tend to establish more rapidly after transplantation, as a more robust root system enhances their capacity to absorb water and nutrients, thereby promoting faster growth and initial development (Cocco et al., 2016; Fagherazzi et al., 2021).

Crown diameter is closely associated with plantlet resistance to environmental stress. Generally, plantlets with larger crowns exhibit superior survival and recovery capacities under adverse conditions due to higher reserves of nutrients and energy stored as starch. Furthermore, a greater number of buds capable of differentiation in these larger crowns suggest they may also achieve higher productive potential (Torres-Quezada et al., 2015).

According to Fagherazzi et al. (2021), the strawberry plantlet crown diameter has been associated with better productive performance and improved fruit quality. The authors also observed that plantlets of the Pircinque cultivar, with larger crown diameters, exhibited greater vigor, resulting in an earlier harvest.

The increase in diameter demonstrates the growth of the plantlets during the period they remained in the tray. Results showed that while stolon propagule order was related to plantlet diameter, it did not influence the productive parameters of the evaluated genotypes. An isolated effect was observed for the genotype factor, where the BRS DC25 (Fênix) cultivar showed a greater increase in crown diameter compared with the BRS DC22 cultivar (Table 2).

DRSM was influenced by the isolated effects of both genotype and stolon order, with no interaction observed between them. BRS DC22 cultivar showed the highest mean for this variable. Regarding the stolon propagule order, the highest DRSM was recorded in 4th order plantlets. This result can be attributed to the younger physiological age of these propagules, which had younger root primordia and greater rooting potential.

In a study investigating growth, development, and production of strawberries from plantlets with different plug volumes, Cocco et al. (2015) observed that strawberry plantlets with a larger crown diameter and higher DRSM exhibited earlier fruit production.

The mean values of root length were not statistically significant, which could be explained by the limitation of available space for root growth due to the limited tray dimensions, which had a volume of 124 mL.

For ID, FD, DI, DRSM, and root length in the BRS DC25 (Fênix) and BRS DC22 cultivars, no interaction was detected between the studied factors (Table 2). Regarding fruit yield per plant, no statistical differences were observed for either genotypes or stolon order. Both cultivars yielded more than 1,200 g per plant.

Regarding the NFP, a significant difference was found for the genotype factor, with 'BRS DC22' producing considerably more fruits than 'BRS DC25' (Fênix) (Table 3). Physiologically, this higher NFP may have reduced individual fruit mass, which may explain the higher mean fruit mass of 'BRS DC25' (Fênix). In a study of the same cultivars during the 2022 crop season, Alves (2023) reported average fruit mass values similar to those observed in the present study.

Concerning the harvest initiation, 'BRS DC25' (Fênix) reached its first harvest at an average of

Table 2. Means of initial (ID) and final diameter (FD) of propagules, diameter increment (DI), dry root system mass (DRSM), and root length of strawberry (*Fragaria × ananassa*) plantlets from propagules of different orders and the BRS DC25 (Fênix) and BRS DC22 genotypes⁽¹⁾.

Order	ID (mm)	FD (mm)	DI (mm)	DRSM (g)	Root length (mm)
1 st	6.26a	7.89a	1.64 ^{ns}	0.18b	11.43 ^{ns}
2 nd	5.67b	7.13bc	1.47 ^{ns}	0.20b	11.46 ^{ns}
3 rd	5.43b	7.29ab	1.85 ^{ns}	0.22b	11.31 ^{ns}
4 th	4.97c	6.46c	1.49 ^{ns}	0.28a	11.50 ^{ns}
Genotypes					
'BRS DC25' (Fênix)	5.78a	7.71a	1.93a	0.20b	11.42 ^{ns}
'BRS DC22'	5.38b	6.67b	1.29b	0.24a	11.43 ^{ns}

⁽¹⁾Means followed by the same letters in the column do not differ among themselves by Tukey's test, at 5% probability level. ^{ns}Nonsignificant.

Table 3. Means of fruit yield, number of fruits per plant, mean fruit mass, and start of the harvest of strawberry (*Fragaria × ananassa*) plantlets from propagules of different stolon orders and the 'BRS DC25' (Fênix) and 'BRS DC22' genotypes⁽¹⁾.

Order ⁽²⁾	FYP (g per plant)	NFP	MFM (g per fruit)	SH (DAP)
1 st	1,235.05 ^{ns}	80.52 ^{ns}	17.37 ^{ns}	75.17 ^{ns}
2 nd	1,513.83 ^{ns}	96.28 ^{ns}	16.63 ^{ns}	79.83 ^{ns}
3 rd	1,455.74 ^{ns}	95.58 ^{ns}	16.11 ^{ns}	76.33 ^{ns}
4 th	1,336.90 ^{ns}	80.61 ^{ns}	17.40 ^{ns}	80.00 ^{ns}
Genotype				
'BRS DC25' (Fênix)	1,289.34 ^{ns}	61.51b	20.73a	72.67b
'BRS DC22'	1,481.42 ^{ns}	113.98a	13.02b	83.00a

⁽¹⁾Means followed by the same letters in the column do not differ among themselves by Tukey's test, at 5% probability level. ^{ns}Nonsignificant. ⁽²⁾FYP, mean fruit yield; NFP, number of fruits per plant; MFM, mean fruit mass; SH, start of harvest; and DAP, days after planting.

72.67 days after planting, while 'BRS DC22' required 83.00 days (Table 3). The earlier harvest of 'BRS DC25' (Fênix) is attributed to its genetic traits. While 'BRS DC22' exhibits typical behavior of short-day genotypes, 'BRS DC25' (Fênix) shows reduced sensitivity to photoperiod. This distinction is relevant given day length and higher temperatures during the planting period (Table 1).

Harvesting for both 'BRS DC25' (Fênix) and 'BRS DC22' began in June and continued until the conclusion of the experiment, in December. The BRS DC25 (Fênix) cultivar reached its production peak in September and October. However, during September, 'BRS DC25' (Fênix) fruit yield was lower for plants originated from 1st order propagules (Table 4). This reduction in yield can be attributed to the smaller root system and lower vigor compared with 'BRS DC22', which affected the productive performance.

During the months of June, July, and August, the BRS DC25 (Fênix) cultivar demonstrated considerable fruit yield, indicating an early production in the study area. This offers an advantage over imported plantlets, typically sourced from Argentina and Chile, which are delivered to producers in the second half of May (Cocco, 2014; Cocco et al., 2015). Consequently, early yield of 'BRS DC25' (Fênix) allow producers to offer fruits to the market at a time when prices are higher, since producers relying on imported plantlets have not yet initiated harvesting.

Similarly, 'BRS DC22' exhibited a production peak during the months of September and October, with high yields extending into November. The reduction in yield observed in December is attributed to the high

temperatures recorded coupled with the conclusion of the experimental period on December 15.

The highest fruit mass mean was recorded at the beginning of the harvest season and gradually declined as it progressed. Periods of reduced fruit size coincided with a higher NFP, likely driven by intensified competition for water and assimilates along with nutrient reduction. In addition, the progressive increase in temperatures throughout the season may have intensified this reduction in fruit size by accelerating plant metabolism and altering assimilate partitioning, thus limiting fruit growth and development (Menzel, 2021).

There was no interaction between factors regarding the number of crowns per plant (Table 5). However, 'BRS DC22' produced a significant higher total number of crowns compared with 'BRS DC25' (Fênix). Regarding the total production of stolons during the experimental period, no significant effect was found for either the interaction or the isolated factors. Furthermore, at the end of the experiment, the BRS DC22 cultivar showed a higher survival rate compared with 'BRS DC25' (Fênix). Specifically, plant survival of 'BRS DC25' (Fênix) plantlets of 3rd order propagules was not significantly lower than 'BRS DC22'. When comparing the other propagule orders within each genotype, no significant differences were observed in 'BRS DC22' survival rate.

Given the low survival rate of 'BRS DC25' (Fênix) 1st order plantlets at the end of the experiment, the final plant stand would be reduced to 8,990 plants per hectare, resulting in an estimated yield of 11 Mg ha⁻¹, based on the 'BRS DC25' (Fênix) mean yield (Table 3). A similar trend of lower survival in plantlets produced

Table 4. Monthly yield distribution of strawberry (*Fragaria × ananassa*) plantlets derived from the BRS DC25 (Fênix) and BRS DC22 cultivars propagules of different stolon orders.

Genotype	Order	Strawberry yield (%)						
		Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
BRS DC25	1 st	4.51	13.23	7.26	16.78	24.93	21.52	12.21
	2 nd	3.45	9.05	6.12	29.57	20.76	20.30	10.74
	3 rd	3.37	14.52	5.61	30.11	23.57	14.39	8.44
	4 th	4.98	12.78	7.92	16.78	24.34	20.31	12.90
BRS DC22	1 st	0.51	6.85	4.80	27.63	32.29	16.73	11.18
	2 nd	1.37	5.90	2.89	24.54	30.90	20.64	13.76
	3 rd	1.41	4.46	3.69	26.54	28.52	22.31	13.07
	4 th	0.95	7.18	6.01	26.06	27.99	19.32	12.48

Table 5. Means of plant survival, number of crowns per plant, and total number of stolons produced by plants of strawberry (*Fragaria × ananassa*) derived from propagules of different orders and the BRS DC25 (Fênix) and BRS DC22 cultivars⁽¹⁾.

Order	Plant survival (%)		Number of crowns per plant	Number of stolons
	BRS DC25	BRS DC22		
1 st	22.22bB	94.44aA	5.64 ^{ns}	2.27 ^{ns}
2 nd	72.22aB	100.00aA	7.7 ^{ns}	2.28 ^{ns}
3 rd	83.33aA	94.44aA	7.28 ^{ns}	1.62 ^{ns}
4 th	77.78aB	100.00aA	5.92 ^{ns}	2.39 ^{ns}
Genotype				
BRS DC25	-	-	4.29b	2.77 ^{ns}
BRS DC22	-	-	8.97a	1.51 ^{ns}

⁽¹⁾Means followed by the same letters, lowercases in the columns and uppercases in the rows, do not differ by Tukey's test, at the 5% probability level.

^{ns}Nonsignificant.

from 1st order propagules was documented by Höhn et al. (2013), which used the Camarosa cultivar to produce seedlings in trays.

The lower survival percentage observed in seedlings from 1st order propagules of 'BRS DC25' (Fênix) is likely attributed to aging, suberization, and necrosis of the root primordia, which typically occurs in older propagules (Giménez et al., 2009; Höhn et al., 2013; Cocco et al., 2016). Lower root development in plantlets was expected, evidenced by the reduced DRSM in plantlets originating from 1st order propagules. Another determining factor may have been the impaired development and renewal of primary and secondary roots; this limitation likely reduced the capacity for water and nutrient absorption and, consequently, compromised the establishment of plantlets.

Therefore, it is recommended that the plug plant strawberry production system consider, among other factors, the timing of stolon collection, giving preference to the use of propagules that are not in advanced physiological age.

Conclusions

1. Younger stolon tips of strawberry (*Fragaria × ananassa*) plantlets favor root system growth, likely enhancing water and nutrient uptake efficiency.

2. Strawberry genotype determines harvest earliness and number of fruit per plant, suggesting differences in developmental timing and resource allocation.

3. Strategic timing of stolon collection optimizes plug plant establishment and production efficiency of strawberry.

References

- ANTUNES, L.E.C.; BONOW, S. Produção brasileira de mudas de morangueiro: oportunidade de mercado. **Jornal da Fruta**, 6 mar. 2023. Available at: <<https://www.revistadafruta.com.br/noticias-do-pomar/producao-brasileira-de-mudas-de-morangueiro-oportunidade-de-mercado-luis-eduardo-correa-antunes-e-sandro-bonow,425998.jhtml>>. Accessed on: June 23 2023.
- ANTUNES, L.E.C.; REISSER JUNIOR, C.; BONOW, S. Morango: produção aumenta ano a ano. **Campo & Negócios: Anuário HF 2021**, p.87-90, 2021.
- BARTH, E.; RESENDE, J.T.V. de; MOREIRA, A.F.P.; MARIGUELE, K.H.; ZEIST, A.R.; SILVA, M.B.; STULZER, G.C.G.; MAFRA, J.G.M.; GONÇALVES, L.S.A.; ROBERTO, S.R.; YOUSSEF, K. Selection of experimental hybrids of strawberry using multivariate analysis. **Agronomy**, v.10, art.598, 2020. DOI: <https://doi.org/10.3390/agronomy10040598>.
- BOLDA, M.P. Initial bare-root crown size and early-season flower cluster removal has little effect on subsequent plant performance in day-neutral strawberry. **HortTechnology**, v.33, p.342-348, 2023. DOI: <https://doi.org/10.21273/HORTTECH05161-22>.
- BRANDT, G.Q.; SILVA, L.F.L. e; SOUZA, D.C. de; RESENDE, L.V.; NUNES, N.S. Productivity and analysis of morphological characters of experimental strawberry genotypes. **Horticultura Brasileira**, v.40, p.426-431, 2022. DOI: <https://doi.org/10.1590/s0102-0536-20220411>.
- COCCO, C. **Produção e qualidade de mudas e frutas de morangueiro no Brasil e na Itália**. 2014. 124p. Tese (Doutorado) - Universidade Federal de Pelotas, Pelotas.
- COCCO, C.; GONÇALVES, M.A.; PICCOLOTTO, L.; FERREIRA, L.V.; ANTUNES, L.E.C. Crescimento, desenvolvimento e produção de morangueiro a partir de mudas com diferentes

- volumes de torção. **Revista Brasileira de Fruticultura**, v.37, p.961-969, 2015. DOI: <https://doi.org/10.1590/0100-2945-250/14>.
- COCCO, C.; GONÇALVES, M.A.; VIGNOLO, G.K.; PICOLOTTO, L.; ANTUNES, L.E.C.; ALMEIDA, I.R. de. Produção de mudas. In: ANTUNES, L.E.C.; REISSER JÚNIOR, C.; SCHWENGBER, J.E. (Ed.). **Morangueiro**. Brasília: Embrapa, 2016. p.79-109.
- FAGHERAZZI, A.F.; SUEK ZANIN, D.; SANTOS, M.F.S. dos; LIMA, J.M. de; WELTER, P.D.; RICHTER, A.F.; NERBASS, F.R.; KRETZSCHMAR, A.A.; RUFATO, L.; BARUZZI, G. Initial crown diameter influences on the fruit yield and quality of strawberry pircinque. **Agronomy**, v.11, art.184, 2021. DOI: <https://doi.org/10.3390/agronomy11010184>.
- FERREIRA, D.F. Sisvar: a guide for its bootstrap procedures in multiple comparisons. **Ciência e Agrotecnologia**, v.38, p.109-112, 2014. DOI: <https://doi.org/10.1590/S1413-70542014000200001>.
- FIALHO, F.B.; ANTUNES, L.E.C.; UENO, B.; NAVA, G.; SANTOS, R.S.S. dos; GOMES, C.B.; NICKEL, O.; CANTILLANO, R.F.F.; NAVROSKI, R.; BENATI, J.A.; BARRETO, C.F. **UZUM morango**: sistema especialista para diagnóstico de doenças, pragas e distúrbios fisiológicos em morangueiros. Available at: <https://www.cnpv.embrapa.br/uzum/morango/>. Accessed on: Sept. 10 2025.
- GIMÉNEZ, G.; ANDRIOLO, J.L.; JANISCH, D.; COCCO, C.; DAL PICIO, M. Cell size in trays for the production of strawberry plug transplants. **Pesquisa Agropecuária Brasileira**, v.44, p.726-729, 2009. DOI: <https://doi.org/10.1590/S0100-204X2009000700012>.
- HERNÁNDEZ-MARTÍNEZ, N.R.; BLANCHARD, C.; WELLS, D.; SALAZAR-GUTIÉRREZ, M.R. Current state and future perspectives of commercial strawberry production: a review. **Scientia Horticulturae**, v.312, art.1118893, 2023. DOI: <https://doi.org/10.1016/j.scienta.2023.111893>.
- HÖHN, D.; GONÇALVES, M.A.; NARDELLO, I.C.; MARCHI, P.M.; COCCO, C.; ANTUNES, L.E.C. Posição do propágulo na produção de mudas de morangueiro. In: CONGRESSO DE INICIAÇÃO CIENTÍFICA DA UNIVERSIDADE FEDERAL DE PELOTAS, 22.; ENCONTRO DE PÓS-GRADUAÇÃO, 15., 2013, Pelotas. **Anais**. Pelotas: UFPel, 2013. Available at: https://anais-siiepe.ufpel.edu.br/2013/CA_01405.pdf. Accessed on: Sept. 10 2025.
- MADAIL, J.C.M. Panorama econômico. In: ANTUNES, L.E.C.; REISSER JÚNIOR, C.; SCHWENGBER, J.E. (Ed.). **Morangueiro**. Brasília: Embrapa, 2016. p.15-33.
- MENZEL, C. Higher temperatures decrease fruit size in strawberry growing in the subtropics. **Horticulturae**, v.7, art.34, 2021. DOI: <https://doi.org/10.3390/horticulturae7020034>.
- PALOMBINI, M.C.; PALENCIA, P.; PAVÃO, J.M.S.J.; CHIOMENTO, J.L.T. Efficiency of strawberry cultivation under the effect of different types of plants in a soilless system in the high-altitude regions of Southern Brazil. **Agronomy**, v.13, art.2179, 2023. DOI: <https://doi.org/10.3390/agronomy13082179>.
- PEIL, R.M.N.; DUTRA, J.G.; SILVEIRA, C.A.P.; ANTUNES, L.E.C. **Cultivo do morangueiro em substrato com recirculação da solução drenada**. Pelotas: Embrapa Clima Temperado, 2024. 19p. (Embrapa Clima Temperado. Circular técnica, 253).
- R CORE TEAM. **R: a language and environment for statistical computing**. version 4.5.2. Vienna: R Foundation for Statistical Computing, 2025. Available at: <https://www.R-project.org/>. Accessed on: Dec. 23 2025.
- SÁNCHEZ PINEDA, D.E.; RAMÍREZ TORRES, N.L. Diseño de un modelo de programación lineal para la planeación de producción en un cultivo de fresa, según factores costo/beneficio y capacidades productivas en un periodo temporal definido. **Ingenierías USBMed**, v.8, p.7-11, 2017. DOI: <https://doi.org/10.21500/20275846.2564>.
- SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.A. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; ARAUJO FILHO, J.C. de; OLIVEIRA, J.B. de; CUNHA, T.J.F. **Brazilian soil classification system**. 5th ed. rev. and exp. Brasília: Embrapa, 2018. E-book.
- SCHIAVON, A.V.; BECKER, T.B.; DELAZERI, E.E.; VIGNOLO, G.K.; MELLO-FARIAS, P.; ANTUNES, L.E.C. Production and quality of strawberry plants produced from different nutrient solutions in soilless cultivation. **Revista Ceres**, v.69, p.348-357, 2022. DOI: <https://doi.org/10.1590/0034-737X202269030013>.
- SHI, X.; HERNÁNDEZ, R.; HOFFMANN, M. Timing of stolon removal alters daughter plant production and quality in the ever-bearing strawberry 'albion'. **HortScience**, v.56, p.650-656, 2021. DOI: <https://doi.org/10.21273/HORTSCI115624-20>.
- SIGNORINI, C.B.; PEIL, R.M.N.; NEUTZLING, C.; LUZ, T.F. da; GROLLI, P.R. Conditioners for raw rice husk substrate to produce strawberry transplants. **Revista de Ciencias Agrícolas**, v.39, p.35-49, 2022. DOI: <https://doi.org/10.22267/rcia.202239E.194>.
- SILVA, I.F.L. da; SHIMIZU, G.D.; SANTOS, E.L. dos; ERPEN-DALLA CORTE, L.; ZEIST, A.R.; ROBERTO, S.R.; RESENDE, J.T.V. de. Breeding short-day strawberry genotypes for cultivation in tropical and subtropical regions. **Horticulturae**, v.9, art.614, 2023. DOI: <https://doi.org/10.3390/horticulturae9060614>.
- SONNEVELD, C.; STRAVER, N. **Nutrient solutions for vegetables and flowers grown in water or substrates**. Naaldwijk: Proefstation voor Tuinbouw onder Glas, 1994. 45p.
- SOUZA, M.A. de; BATISTA, E.J.; MENEZES, A.F.T. Panorama nacional da produção de morangos. **Campo & Negócios**, 21 abr. 2022. Available at: <https://revistacampoenegocios.com.br/panorama-nacional-da-producao-de-morangos/>. Accessed on: July 8 2023.
- TORRES-QUEZADA, E.A.; ZOTARELLI, L.; WHITAKER, V.M.; SANTOS, B.M.; HERNANDEZ-OCCHOA, I. Initial crown diameter of strawberry bare-root transplants affects early and total fruit yield. **HortTechnology**, v.25, p.203-208, 2015. DOI: <https://doi.org/10.21273/HORTTECH.25.2.203>.

Author contributions

Mateus Felipe Bernard: conceptualization (equal), data curation (lead), formal analysis (lead), Investigation (lead), methodology (lead), project administration (lead), software (lead), validation (lead), visualization (lead), writing - original draft (lead), writing - review & editing (lead). **Andressa Vighi Schiavon:** data curation (supporting), investigation (supporting), writing - review & editing (supporting). **Adriel da Silva Alves:** data curation (supporting), investigation (supporting), writing - review & editing (supporting). **Sandro Bonow:** funding acquisition (supporting), methodology (supporting), resources (supporting), supervision (supporting), writing - review & editing (supporting). **Luís Eduardo Corrêa Antunes:** conceptualization (equal), funding acquisition (lead), methodology (supporting), project administration (lead), resources (lead), validation (supporting), writing - review & editing (supporting).

Chief editor: Edemar Corazza

Edited by: Daniel Kinpara

Data availability statement

Data available upon request: research data are only available upon reasonable request to the corresponding author.

Declaration of use of AI technologies

During the preparation of this work, the author(s) used ChatGPT and Perplexity for text revision, translation correction, and grammatical correction. After this use, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the final version.

Conflict of interest statement

The authors declare no conflicts of interest.

Acknowledgements

To Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), for financing, in part, this study (Finance Code 001), and to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and to Empresa Brasileira de Pesquisa Agropecuária (Embrapa), for their financial support.

Disclaimer/Publisher's note

The statements, opinions, and data contained in all texts published in Pesquisa Agropecuária Brasileira (PAB) are solely those of the individual author(s) and not of the journal's publisher, editor, and editorial team, who disclaim responsibility for any injury to people or property resulting from any referred ideas, methods, instructions, or products.

The mention of specific chemical products, machines, and commercial equipment in the texts published in this journal does not imply their recommendation by the publisher.