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Effect of planting date on the yield and quality of Brazilian strawberry cultivars

Efeito da data de plantio na produção e qualidade de cultivares brasileiras de morangos

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Highlights

Early production coincided with a window of low market supply.
Cultivar choice defines strategy for earliness and fruit quality.
Planting date effect varies with annual climatic conditions.

Abstract

Climate change has increasingly affected Brazilian agriculture, with higher temperatures during the strawberry planting period altering crop performance. This study aimed to evaluate the agronomic performance of strawberry cultivars under different planting times, from late summer to early autumn, in Pelotas, RS, during the 2022 and 2023 seasons. The cultivars BRS DC22, BRS Fênix, and BRS DC09, developed by the Embrapa strawberry breeding program, were evaluated for yield per plant, harvest onset, number and average fruit weight, number of crowns, and physicochemical attributes. A significant genotype × planting date interaction was observed only for harvest onset in 2022. 'BRS Fênix' showed earlier harvest and higher average fruit weight, while 'BRS DC22' produced more fruits and crowns per plant. In 2023, higher temperatures during early planting reduced the influence of planting time on most variables. Fruit production was concentrated between September and November, with an early onset in July and August. 'BRS Fênix' exhibited greater brightness and a higher soluble solids/acidity ratio, whereas 'BRS DC22' produced fruits with higher acidity. The results highlight that cultivar selection and planting time definition should be adjusted according to climatic conditions to optimize earliness, yield, and fruit quality.
Key words: *Fragaria × ananassa* Duch. Breeding. Climate change. Earliness. Fruit quality.

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Resumo

As mudanças climáticas têm afetado a agricultura brasileira, com o aumento das temperaturas durante o período de plantio do morangueiro, alterando o desempenho das plantas. O objetivo deste estudo foi avaliar o desempenho agronômico de cultivares de morangueiro sob diferentes épocas de plantio, do final do verão ao início do outono, em Pelotas (RS), durante as safras de 2022 e 2023. As cultivares BRS DC22, BRS Fênix e BRS DC09, desenvolvidas pelo programa de melhoramento genético da Embrapa, foram avaliadas quanto à produtividade por planta, início da colheita, número e peso médio de frutos, número de coroas e atributos físico-químicos dos frutos. Observou-se interação significativa entre genótipos e épocas de plantio apenas para o início da colheita em 2022. A cultivar BRS Fênix apresentou colheita mais precoce e frutos de maior massa média, enquanto 'BRS DC22' produziu maior número de frutos e coroas por planta. Em 2023, as temperaturas mais elevadas nas épocas de plantio iniciais reduziram a influência dessa variável sobre os demais parâmetros. A produção concentrou-se entre setembro e novembro, com início antecipado em julho e agosto. 'BRS Fênix' apresentou maior brilho e maior relação sólidos solúveis/acidez, enquanto 'BRS DC22' produziu frutos com maior acidez. Os resultados indicam que a escolha da cultivar e a definição da época de plantio devem ser ajustadas conforme as condições climáticas, visando maximizar a precocidade, a produtividade e a qualidade dos frutos.
Palavras-chave: Fragaria x ananassa Duch. Melhoramento genético. Mudança climática. Precocidade. Qualidade de frutas.

Introduction

The cultivation of strawberry (Fragaria × ananassa Duch.) stands out for its socioeconomic relevance, representing a promising business opportunity and source of income for growers. Its production may be directed toward both the fresh fruit market and industrial processing (Madail, 2016; Hernández-Martínez et al., 2023). Brazil is the largest strawberry producer in South America and ranks 7th globally. Minas Gerais, accounting for approximately 55% of the cultivated area in the country, is the leading producing state, followed by Paraná and Rio Grande do Sul, where strawberry cultivation is primarily carried out by small family farms (Antunes et al., 2021; Bonow & Antunes, 2023).

Strawberry cultivation in Rio Grande do Sul is a well-established tradition, with three specific regions standing out: Vale do Caí, Serra Gaúcha, and the Pelotas region (Cocco et al., 2020). Despite the adoption of new technologies, such as soilless cultivation, and the introduction of new day-neutral cultivars, the conventional soil-based system still predominates. This system involves planting short-day cultivars using plastic mulching and low tunnels (Reisser & Vignolo, 2016).

Climatic and genetic factors, the cultivation system, planting date, and the origin of transplants are all key determinants of strawberry yield (Pineda & Torres, 2017). Successful strawberry production relies on the interaction between the physiological and phytosanitary quality of the transplants and the production system and its characteristics, such as substrate or soil type, and climatic and nutritional conditions (Wei et al., 2020; Wurz et al., 2021; Palombini et al., 2023).

In Brazil, the production chain faces several challenges, such as the limited availability of locally adapted cultivars and dependency on imported transplants from Chile, Spain, and Argentina, since domestic production is insufficient to meet the demand. This scenario increases production costs and hinders agricultural planning, compromising planting at the optimal time and the supply of strawberries during the off-season, when fruit prices are more favorable (Antunes et al., 2015; Becker et al., 2016; Oliveira & Antunes, 2016; Diel et al., 2017; Zeist & Resende, 2019).

Menzel (2025) demonstrated that small variations in planting date (approximately three weeks) significantly affected yield and fruit weight due to interactions with climatic factors, such as rainfall and high temperatures. These findings have direct implications for Brazil, where planting calendars and the effects of global warming also influence cultivar performance in states like Minas Gerais, Paraná, Rio Grande do Sul, and São Paulo, among others.

Several studies have examined the effects of planting date on strawberry yield and fruit quality in different regions (Rahman, 2014; Paul et al., 2017; Naidk et al., 2022), but most were conducted under environmental conditions different from those in southern Brazil and using foreign cultivars. These studies consistently show that planting time influences vegetative growth, flowering, fruit weight, and productivity due to climatic and seasonal conditions. However, little is known about the response of recently developed Brazilian genotypes, particularly those from Embrapa's breeding program, to different planting dates under local edaphoclimatic conditions. Addressing this gap is crucial for establishing region-specific calendars that optimize yield, fruit quality, and earliness.

Therefore, it is essential to evaluate the interaction between planting time of new genotypes and the production environment, and its impact on agronomic performance and fruit quality. This study aimed to evaluate agronomic and quality-related traits of short-day strawberry cultivars developed by the Embrapa Strawberry Breeding Program under different planting dates.

Materials and Methods

The study was carried out between March and December, during the 2022 and 2023 growing seasons, at an Observation Unit (OU) of Embrapa's Strawberry Breeding Program, located on a rural property situated on Estrada da Gama, 9th District – Monte Bonito, in the rural zone of the municipality of Pelotas, Rio Grande do Sul, Brazil. The experimental area is located at approximately 31°39′ south latitude and 52°25′ west longitude, at an altitude of 64 meters. The soil is classified as a Red-Yellow Ultisol. According to Köppen's classification, the regional climate is humid temperate (Cfa), characterized by hot summers, with an average annual temperature of 17.9 °C and average annual precipitation of 1,500 mm. The mean temperatures recorded during the study period are presented in Table 1.

Table 1
Annual averages of climatic variables recorded by Agrometeorology Laboratory (Agromet) of Embrapa Temperate Agriculture

Month	Tmean (ºC)(1)		Tmax (ºC)		Tmin (ºC)		Pmm		HCH(2)	CH	
	2022	2023	2022	2023	2022	2023	2022	2023		2022	2023
January	24.9	24.6	30.4	31.0	20.6	19.7	130.8	58.6	-	-	-
February	23.4	23.7	29.5	30.1	18.8	18.8	70.4	78.9	-	-	-
March	21.2	24.2	26.9	29.6	16.8	20.6	135.8	153.9	-	-	-
April	18.4	18.8	24.0	24.3	14.2	14.7	190.0	27.6	-	-	-
May	14.5	17.2	19.1	22.0	10.7	13.5	76.2	179.4	28	26	0
June	11.5	14,6	16.0	19.9	7.5	10.4	163.6	68.8	80	99	46
July	14.2	13.5	18.9	17.8	10.4	10.0	246.2	272.2	119	42	68
August	13.2	14.6	18.4	20.9	8.7	9.7	151.0	78.2	64	48	59
September	14.4	15.8	19.5	19.7	10.0	12.2	66.6	451.8	31	11	10
October	17.3	17.2	22.4	21.8	13.0	13.0	150.0	75.8	-	-	-
November	20.3	19.8	25.9	24.7	15.3	15.7	51.0	199.6	-	-	-
December	22.6	22.1	28.6	26.7	17.7	18.3	25.2	131.8	-	-	-
Average	17.9	14.6	23.3	24.0	13.6	14.7					
SPCHA(3)							1,456.8	1,776.6	322	226	183

(1)Tmean (°C) mean average air temperature, Tmax (°C) mean maximum air temperature, Tmin (°C) mean minimum air temperature, Pmm mean precipitation, HCH mean historical chilling hours accumulation (<7.2°C) and CH mean chilling hours (<7.2°C) in the weather stations of Embrapa Temperate Climate. (2)Timeline: 1984-2017. (3)Sum precipitation and chilling hours accumulated.

The experimental design was a randomized complete block design (RCBD) in a factorial scheme: 2 × 4 (genotypes × planting dates) in the 2022 season and 3 × 4 in the 2023 season, with four replications in both years. Each experimental unit consisted of six plants. In 2022, the cultivars BRS Fênix and BRS DC22 were evaluated. In 2023, in addition to these, the cultivar BRS DC09 was included, totaling three genotypes. All cultivars originated from the Embrapa Strawberry Breeding Program. Planting was carried out in a staggered manner. In 2022, transplanting was performed on March 4 and 19, and April 1 and 15. In 2023, planting dates were March 30, April 14, May 2, and May 16.

Strawberry transplants were produced in a greenhouse at Embrapa Clima Temperado, using the propagative material from mother plants obtained through tissue culture, following the methodology proposed by Durner et al. (2002), Rowley et al. (2010), Cocco et al. (2016), and Antunes et al. (2023).

The experiment was conducted under conventional soil cultivation, using raised beds covered with 50 µm-thick black polyethylene mulch film and protected by low tunnels made of transparent low-density polyethylene film, 100 µm thick. The planting spacing was 35 cm between rows and 40 cm between plants within the row, with three planting rows per bed. Plants were arranged in a staggered (quincunx) configuration. Beds were 1.10 m wide, with 0.5 m-wide paths between beds, resulting in a planting density of 40,460 plants per hectare. Irrigation was performed using a drip system with two drip tapes per bed, with emitters spaced 10 cm apart. Fertigation for growth and maintenance was applied weekly through the irrigation system. Phytosanitary management was carried out by the grower as needed, using products registered and recommended for strawberry cultivation by the Brazilian Ministry of Agriculture and Livestock (MAPA).

In the 2022 season, harvest began on May 9 and ended on December 15. In 2023, harvesting started on June 19 and ended on December 15. Fruits were harvested based on skin coloration, with only those presenting at least 75% red epidermis being collected. Only marketable fruits were considered; those with severe defects or weighing less than 6 grams were discarded. The fruits harvested in each plot were counted and weighed using a digital scale. The following variables were evaluated: beginning of harvest; number of fruits per plant (fruits plant^{-1}); fruit yield (g plant^{-1}); average fruit weight (g fruit^{-1}), calculated as the ratio between total yield and number of fruits per plant; number of runners per plant, counted during routine maintenance; and number of crowns per plant, recorded at the end of the experiment.

Physicochemical quality analyses were conducted only for the 2022 season, on October 14, at the Postharvest Physiology Laboratory of Embrapa Clima Temperado (CPACT). Evaluations included: pulp firmness, which was measured using a TA-XT Plus 40855 texture analyzer (Stable Microsystem, England) with a 2 mm probe, 5 mm penetration depth, pre-test speed of 1.0 mm s^{-1}, test speed of 2.0 mm s^{-1}, post-test speed of 10.0 mm s^{-1}, and force of 5.0 kg, assessed on ten fruits per plot, with readings taken on one side of each fruit. Results were expressed in Newtons (N); titratable acidity, which was measured by titration using 5 mL of juice diluted in 90 mL of distilled water and titrated with 0.1 N sodium hydroxide solution until pH 8.1 was reached, with results expressed as grams of citric acid per 100 grams of pulp (g 100 g^{-1} citric acid); soluble solids content, which was determined using a digital refractometer, with results expressed in degrees Brix (°Brix); soluble solids/titratable acidity ratio (RATIO), calculated as the ratio between TSS and titratable acidity; and skin color, which was measured using two readings on opposite sides of the fruit surface with a Minolta CR-300 colorimeter, recording lightness (L), and chromatic coordinates "a" and "b," from which the hue angle (°Hue) was calculated.

The data obtained were subjected to analysis of variance (ANOVA) using the F-test. When significant differences were detected, means were compared using Tukey's test at a 5% probability level (Ferreira, 2014).

Results and Discussion

Regarding the evaluated variables, a significant interaction between genotypes and planting dates was observed only for the variable harvest onset in the 2022 season. For the other variables — fruit yield, number of fruits per plant, average fruit weight, and number of crowns per plant — no interaction between factors was observed in either of the evaluated seasons.

In the 2022 season, both genotypes and planting dates significantly affected harvest onset (Table 2). In 2023, however, this variable did not differ significantly among genotypes (BRS Fênix, BRS DC22, and BRS DC09), with significant differences observed only among planting dates. In that year, plants transplanted on the first date showed a longer interval between transplanting and harvest onset, indicating the influence of planting schedule on earliness. In general, greater earliness of the cultivars was observed in 2023 compared to 2022.

Table 2
Start of harvest, in days after planting and number of crowns per plant

Planting dates	Start of harvest			Number of crowns per plant	
	BRS Fênix	BRS DC 22			
	Season 2022		Season 2023	Season 2022	Season 2023
1st date	96.00 aB	162.75 aA	87.42 a	8.34 a	6.06ns
2nd date	86.50 aB	121.50 bA	73.83 b	8.29 a	6.09
3rd date	87.00 aA	89.00 bA	63.91 c	6.58 ab	5.86
4th date	88.00 aA	83.25 bA	74 b	6.13 b	5.79
Genotypes					
BRS Fênix	-	-	73.38ns	5.38 b	4.29 b
BRS DC22	-	-	76.81	9.29 a	8.92 a
Sel. 09	-	-	74.19	-	4.57 b
C.V. (%)	19.84		7.16	17.54	6.52

Means followed by the same letter do not differ at the 5% probability level according to Tukey's test; ns = not significant; CV (%) = Coefficient of variation; 1 st planting date (03/04/2022; 03/30/2023), 2nd planting date (03/19/2022; 04/14/2023), 3rd planting date (04/01/2022; 05/02/2023), 4th planting date (04/15/2022; 05/16/2023).

In 2022 crop season, 'BRS DC25 Fênix' showed earlier fruiting than 'BRS DC22', particularly in the first two planting dates, confirming its lower sensitivity to photoperiod. In the 2022 season, 'BRS DC22', when planted on the erliest date (March 4), exhibited a delayed onset of harvest compared to plants established on the other dates. This response may be attributed to the characteristics of this genotype, classified as short-day, showing greater sensitivity to photoperiod, in addition to the influence of higher temperatures at the beginning of the cycle, which can interfere with vegetative development (Menzel, 2025).

Similar results were observed by Becker (2017) when evaluating the cultivars

Aromas, Camarosa, Festival, and Oso Grande under different planting dates in Pelotas in 2015 and 2016. It was found that plants transplanted on March 16 and April 1 exhibited longer harvest periods compared to the other planting dates.

The number of crowns was mainly influenced by planting date in 2022, with lower values on the latest date. 'BRS DC22' showed the highest crown production among genotypes. Crowns in strawberry plants consist of a set of short rhizomes from which roots, leaves, and reproductive and propagative structures originate (Vignolo et al., 2016). The number of crowns can vary due to genetic and environmental factors, such as climate and planting time. Moreover, the formation of more crowns may be associated with increased plant productivity (Cocco, 2010; Verma et al., 2024).

According to Durner et al. (2002), the number of crowns per plant is one of the most expressive factors associated with yield, with a positive correlation between fruit production and variables such as number of inflorescences, leaves, and crowns per plant. A higher number of crowns tends to be related to a greater number of fruits per plant, although with a lower average weight. In the case of 'BRS Fênix', which had a higher average fruit weight and a lower number of crowns (Table 2), this relationship was not clearly evident during the 2022 season, possibly due to the larger crown diameter. This suggests that productive capacity may be more closely associated with the amount of reserves stored within the crowns rather than their absolute number.

The inverse relationship between number of crowns and fruit weight suggests a trade-off between sink number and individual fruit size, as observed for 'BRS DC22', in the 2022 season. In both years, fruit production peaked between September and November, regardless of planting date (Figure 1).

In the study by Becker (2017), evaluating the cultivars Aromas, Camarosa, Festival, and Oso Grande, a significant interaction between planting dates and genotypes was observed for the variables average fruit weight and number of fruits per plant, which was not verified in the present study. However, the data corroborate the results obtained in the 2022 season, where an inverse relationship between number of fruits per plant and average fruit weight was verified (Table 3).

Also based on Table 3, planting date significantly influenced fruit production in the 2022 season. On average, plants transplanted on the first date (March 4, 2022) produced more than 100 fruits per plant, differing statistically from the third (April 1, 2022) and fourth (April 15, 2022) planting dates. However, production from the second date (March 19, 2022) did not differ from the first, indicating that earlier planting may favor increased fruit number.

Similar responses have been reported in previous studies evaluating the influence of planting date on strawberry performance. Rahman (2014) and Paul et al. (2017) observed that early planting dates promoted greater vegetative growth, fruit yield, and fruit size, while delayed planting reduced productivity and quality parameters. Likewise, Naidk et al. (2022), working under southern Brazilian conditions, verified that the timing of transplanting strongly affected total and marketable yield, with early-April planting resulting in the best productive performance. These findings are consistent with the results obtained in the present study, in which earlier planting dates favored higher fruit number and total yield, highlighting the importance of defining an appropriate planting window to optimize crop performance.

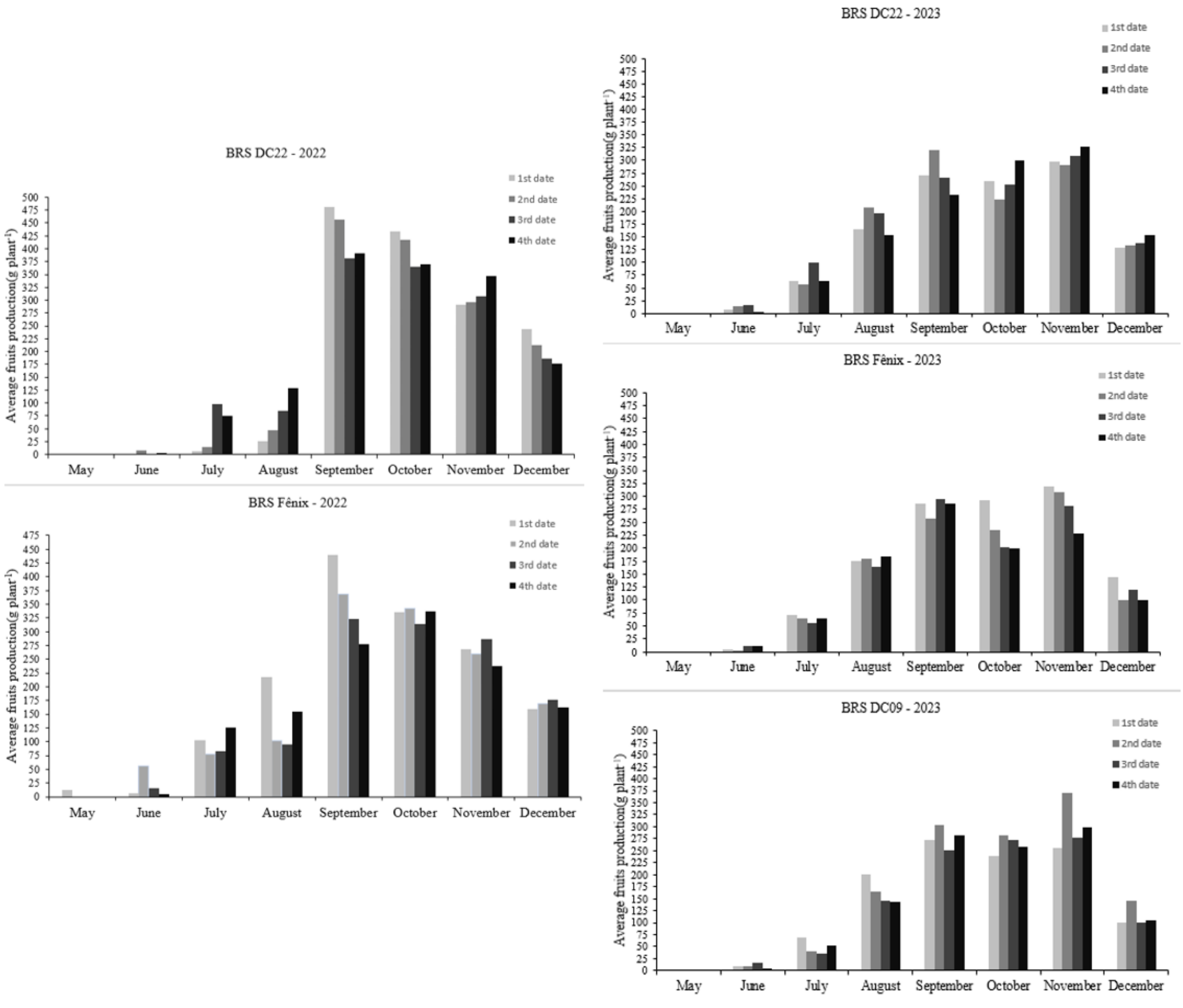

Figure 1. Distribution of strawberry production (g per plant) during 2022 and 2023 seasons.

Table 3

Average fruits production (AFP), average fruit number per plant (NFP), and average fruit weight (AFW) of strawberry genotypes grown under different planting dates in a conventional cultivation system in the Pelotas region, during the 2022 and 2023 growing seasons

Planting dates	AFP (g plant-¹)		NFP		AFW	
	Season		Season		Season	
	2022	2023	2022	2023	2022	2023
1st date	1,509.25 ns	1,142.83ns	100.94 a	71.23 ns	15.88 c	16.35ns
2nd date	1,414.52	1,162.30	92.68 ab	68.31	16.40 bc	17.28
3rd date	1,394.90	1,198.05	80.09 b	72.57	17.58 ab	16.82
4th date	1,358.61	1,212.34	77.61 b	73.54	18.90 a	17.05
Genotypes						
BRS Fênix	1,376.82 ns	1,177.21 ns	66.68 b	71.02 ns	20.73 a	16.89ns
BRS DC22	1,461.82	1,204.57	108.98 a	75.08	13.60 b	16.40
BRS DC09	-	1,154.85	-	68.14	-	17.34
C.V. (%)	14.04	14.66	13.20	21.82	5.74	12.32

Means followed by the same letter do not differ at the 5% probability level according to Tukey's test; ns = not significant; CV (%) = Coefficient of variation; 1 st planting date (03/04/2022; 03/30/2023), 2nd planting date (03/19/2022; 04/14/2023), 3rd planting date (04/01/2022; 05/02/2023), 4th planting date (04/15/2022; 05/16/2023).

The average number of fruits per plant and average fruit weight in 2023 did not show statistically significant differences between planting dates or among cultivars.

In the 2022 season, a greater number of fruits per plant was observed in the 'BRS DC22' cultivar compared to 'BRS Fênix', with a significant difference between genotypes. In contrast, the average fruit weight was inversely proportional, as 'BRS Fênix' produced fewer fruits, but with greater average weight. Fruits of 'BRS DC22' had an average weight of approximately 13 grams, a value similar to that observed by Alves (2023) when studying the same selection under conventional cultivation in Pelotas.

The observed variation in yield and earliness among planting dates can be explained by the environmental conditions prevailing during the early stages of plant establishment. According to the review by Menzel (2023), high temperatures and extended photoperiods accelerate flower induction and fruit development but tend to reduce flower size and fruit weight. This physiological response helps to explain the lower fruit weight observed under later planting dates in the present study, when higher average temperatures occurred. Conversely, moderate temperatures and shorter photoperiods during early planting favor assimilate accumulation and larger fruit size, as also reported by Rahman (2014) and Paul et al. (2017).

The 'BRS Fênix' cultivar presented average weights exceeding 21 grams in the 2023 season, values close to those reported by Delazeri et al. (2024), who, when evaluating the same cultivar under conventional cultivation in Pelotas (RS), found average weights of 20.45 g and 23.46 g, respectively, corroborating the results observed in this study.

Regarding stolon production per plant, it was found that 'BRS Fênix', in the 2022 season, concentrated most of its stolon emission in May (Table 4), at the beginning of the cycle, especially for plantlets transplanted on the first date. This response may be attributed to higher temperatures and longer photoperiods in March and April (Table 1), as well as to the fact that this genotype exhibits lower sensitivity to photoperiod and light variation.

In the 2023 season, 'BRS Fênix' concentrated most of its stolon production at the end of the cycle. 'BRS DC22' also showed greater stolon emission in May 2022, and in both 2022 and 2023, a significant increase in this reproductive structure was observed in December. However, for this cultivar, plants from the first planting date produced fewer stolons compared to the other dates (Table 4). For 'BRS DC09', it was observed that, in the 2023 season, stolon production peaked at the end of the productive cycle.

Considering the effect of high temperatures and extended photoperiods, characteristic of summer in southern Brazil (Table 1), early March planting favors stolon production. This increase in stolon emission implies a greater need for labor to perform cleaning and removal of these vegetative structures. However, this additional management tends to be offset by the higher profitability provided by early fruit production.

Table 4
Distribution of the number of stolons produced per plant throughout the cultivation cycle in percentage (%), and total number of stolons per plant of the cultivars BRS DC25 Fênix, BRS DC22, and BRS DC09 grown at different planting dates in the Pelotas region, during the 2022 and 2023 growing seasons

		April		May		June		July		August		October		November		December		Total	
		2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
BRS Fênix	1st date	9.00	-	44.00	25.00	15.50	19.64	0.98	-	-	1.79	3.40	-	10.72	17.86	15.68	35.71	27.61	28.00
	2nd date	2.00	-	39.00	5.00	9.08	28.10	0.98	-	-	3.27	2.44	-	21.39	16.99	25.20	47.06	10.24	38.25
	3rd date	1.00	-	10.00	0.00	2.33	0.00	0.52	-	-	0.00	3.24	-	37.69	32.94	45.85	67.06	7.72	21.25
	4th date	0.00	-	0.00	0.00	0.00	0.00	0.00	-	-	9.80	31.74	-	32.30	15.69	35.96	74.51	7.12	25.50
BRS DC22	1st date	7.00	-	38.00	13.00	13.33	4.00	0.00	-	-	1.33	0.00	-	21.15	12.00	20.13	69.33	7.80	18.75
	2nd date	1.00	-	45.00	10.00	8.87	1.27	0.00	-	-	0.00	1.91	-	10.44	11.39	32.44	77.22	8.91	19.75
	3rd date	0.00	-	0.00	0.00	0.00	0.00	0.00	-	-	0.00	1.30	-	32.55	14.06	66.15	85.94	3.84	16.00
	4th date	0.00	-	0.00	0.00	0.00	0.00	0.00	-	-	0.00	3.86	-	28.44	21.35	67.70	78.65	6.47	22.25
BRS DC09	1st date	-	-	-	3.00	-	2.20	-	-	-	2.20	-	-	-	16.48	-	75.82	-	22.75
	2nd date	-	-	-	5.00	-	12.78	-	-	-	3.01	-	-	-	19.55	-	60.15	-	33.25
	3rd date	-	-	-	0.00	-	0.00	-	-	-	0.00	-	-	-	36.64	-	63.36	-	32.75
	4th date	-	-	-	0.00	-	0.00	-	-	-	0.81	-	-	-	42.28	-	56.91	-	30.75

When analyzing production distribution throughout the harvest months, it is noted that the evaluated cultivars showed production peaks between September and November (Figure 1). However, a considerable amount of production was already recorded in July and August, indicating early performance for the Southern region. This period is strategic, as there is a market shortage of strawberries, since producers who depend on imported plantlets have not yet started harvesting. Plantlets from Argentina and Chile usually arrive in Brazil from the second half of May, delaying the start of production in those areas.

According to Cocco (2014) and Cocco et al. (2015), strawberry production in Rio Grande do Sul usually concentrates between September and November, although this period may vary depending on the cultivar used and the origin of the plantlets. During this interval, most fields are in full harvest, which tends to lower the price paid to the producer per kilogram of fruit. Therefore, anticipating the beginning of harvest to May and June represents an early production strategy, enabling commercialization during a period of low supply, when prices are still high. In this context, proper planting date planning, combined with genotype selection, can enhance production efficiency and maximize economic returns for growers.

In the 2023 season, due to higher maximum average temperatures during the earliest planting dates, the planting date factor did not significantly influence some parameters that had been affected in the previous season. Thus, management strategies based on the appropriate choice of cultivar and the definition of the ideal planting period should be adjusted according to the prevailing climatic conditions of each season, in order to ensure greater productive efficiency and economic return. The consistency of these results with those obtained by Naidk et al. (2022) in southern Brazil reinforces the practical importance of adjusting planting dates according to regional climatic conditions. Proper scheduling of transplanting allows growers to anticipate fruit production to periods of higher market value, as also emphasized by Cocco (2014) and Cocco et al. (2015). Thus, defining an optimal planting window combined with genotype selection represents an effective strategy to maximize production efficiency and economic returns under subtropical conditions.

Regarding average fruit weight, it was observed that at the beginning of the cycle, particularly in July, the fruits had greater weight (Table 5). This may be associated with the lower number of fruits produced per plant in this initial period, as reported by Neri et al. (2012). In general, regardless of planting date, there was a tendency for average fruit weight to decrease starting in September, coinciding with the period of highest fruit production per plant. This increase in the number of sinks results in greater competition for photoassimilates (Gonçalves et al., 2016), in addition to the effect of higher temperatures, which, according to Menzel (2023), contribute to a reduction in fruit weight. According to Carvalho et al. (2013), fruit size is a highly relevant commercial attribute, directly influencing its acceptance in the fresh market, since larger fruits are more appealing to consumers.

Table 5

Distribution of average fruit mass (grams per fruit) of the cultivars BRS DC25 Fênix, BRS DC22, and BRS DC09 grown at different planting dates in the Pelotas region, during the 2022 and 2023 growing seasons

		April		May		June		July		August		October		November		December	
		2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
BRS Fênix	1st date	9.00	-	44.00	25.00	15.50	19.64	0.98	-	-	1.79	3.40	-	10.72	17.86	15.68	35.71
	2nd date	2.00	-	39.00	5.00	9.08	28.10	0.98	-	-	3.27	2.44	-	21.39	16.99	25.20	47.06
	3rd date	1.00	-	10.00	0.00	2.33	0.00	0.52	-	-	0.00	3.24	-	37.69	32.94	45.85	67.06
	4th date	0.00	-	0.00	0.00	0.00	0.00	0.00	-	-	9.80	31.74	-	32.30	15.69	35.96	74.51
BRS DC22	1st date	7.00	-	38.00	13.00	13.33	4.00	0.00	-	-	1.33	0.00	-	21.15	12.00	20.13	69.33
	2nd date	1.00	-	45.00	10.00	8.87	1.27	0.00	-	-	0.00	1.91	-	10.44	11.39	32.44	77.22
	3rd date	0.00	-	0.00	0.00	0.00	0.00	0.00	-	-	0.00	1.30	-	32.55	14.06	66.15	85.94
	4th date	0.00	-	0.00	0.00	0.00	0.00	0.00	-	-	0.00	3.86	-	28.44	21.35	67.70	78.65
BRS DC09	1st date	-	-	-	3.00	-	2.20	-	-	-	2.20	-	-	-	16.48	-	75.82
	2nd date	-	-	-	5.00	-	12.78	-	-	-	3.01	-	-	-	19.55	-	60.15
	3rd date	-	-	-	0.00	-	0.00	-	-	-	0.00	-	-	-	36.64	-	63.36
	4th date	-	-	-	0.00	-	0.00	-	-	-	0.81	-	-	-	42.28	-	56.91

For fruit firmness (Table 6), there was no interaction between factors, and no significant differences were observed among the means. Firmness, according to Schiavon et al. (2021), is one of the most important attributes determining fruit quality. Greater firmness implies higher resistance to mechanical damage, allowing for longer-distance transport, longer marketing periods, and better postharvest quality retention. It is important to highlight that pulp firmness is an intrinsic characteristic of each genotype and is also directly related to crop management practices, including the fruit's harvest stage, plant nutritional status, irrigation, air temperature, among other factors.

Table 6
Flesh firmness (N), lightness (L), skin color (ºHue), total soluble solids (ºBrix), pH, total titratable acidity (TTA), and ratio (TSS/TTA) of the cultivars BRS DC25 Fênix and BRS DC22 grown at different planting dates in the Pelotas region during the 2022 growing season

Planting dates	N	L	ºHue
1st date	1.48 ns	30.68 ns	29.76 ns
2nd date	1.49	30.71	32.53
3rd date	1.48	30.83	30.79
4th date	1.32	31.49	29.50
Genotypes			
BRS Fênix	1.37 ns	31.37 a	30.32ns
BRS DC22	1.50	30.49 b	30.96
C.V. (%)	13.02	2.31	12.92

Planting dates	TSS (ºBrix)	pH	TTA	Ratio (TSS/TTA)
1st date	7.63ns	3.34 b	0.99 a	7.84 b
2nd date	7.32	3.37 b	0.89 b	8.36 b
3rd date	7.38	3.40 ab	0.86 b	8.64 b
4th date	7.92	3.49 a	0.78 b	9.95 a
Genotypes				
BRS Fênix	7.48 ns	3.44 a	0.82 b	9.19 a
BRS DC22	7.65	3.36 b	0.94 a	8.20 b
C.V. (%)	4.84	1.53	6.62	6.91

Means followed by the same letter do not differ at the 5% probability level according to Tukey's test; ns = not significant; CV (%) = Coefficient of variation; 1st planting date (03/04/2022; 03/30/2023). 2nd planting date (03/19/2022; 04/14/2023). 3rd planting date (04/01/2022; 05/02/2023). 4th planting date (04/15/2022; 05/16/2023).

With respect to colorimetric parameters (Table 6), no significant interaction was observed between genotypes and planting dates. For skin lightness, there was also no significant interaction between the studied factors. Among genotypes, 'BRS Fênix' stood out compared to 'BRS DC22', presenting fruits with greater brightness (Table 3). Both genotypes presented higher values for these variables compared to those reported by Alves (2023) for the cultivar Camino Real, grown under conventional systems in the municipality of Pelotas. Strawberry color results from the presence of anthocyanins, natural pigments derived from sugars. The presence of these pigments indicates the degree of fruit ripeness, and fruits with shinier skin tend to be more attractive and preferred by consumers (Cantillano & Silva, 2010; Nunes et al., 2021).

For the remaining fruit quality parameters, no significant interaction was observed between genotypes and planting dates for soluble solids, titratable acidity, and the soluble solids/titratable acidity ratio (SS/TA) (Table 6). For soluble solids, no statistical differences were found between genotypes or planting dates; however, the values obtained are noteworthy. According to Chitarra and Chitarra (2005), the soluble solids content in strawberries can range from 4 to 11 ºBrix, depending on the variety and cultivation conditions. Even so, the balance between sugar content and acidity is also decisive for fruit quality and flavor. Johnson and Hoffmann (2024) reported values ranging from 6.1% to 8.0% in seven strawberry cultivars in the United States, thus close to the values obtained in this experiment. According to Camargo et al. (2018), characteristics such as TA values directly influence the flavor, aroma, and sensory quality of fruits.

For pH, no significant interaction occurred between the factors. Among genotypes, higher values were observed for the cultivar 'BRS Fênix'. Regarding planting dates, plantlets from the fourth planting date showed higher pH values compared to those from the first and second dates, while the third did not differ from the others. According to Azevedo (2007), although climatic factors may affect fruit quality traits, genetic factors are the most decisive for variations in pH.

Considering the SS/TA ratio, an important indicator of fruit quality, the cultivar BRS DC22 showed lower values than BRS DC25 Fênix, indicating higher acidity. Among planting dates, the first date presented higher titratable acidity and, consequently, a lower SS/TA ratio compared with the others. These differences may be related to fruit size, as plants from the earliest plantings produced smaller fruits during the evaluation period. Nunes et al. (2021) reported TA values between 5.35 and 7.73 in Brazilian cultivars, lower than those observed in this study. According to Chitarra and Chitarra (2005), the balance between soluble solids and acidity determines sweetness, flavor, and overall consumer acceptance.

Conclusions

The agronomic performance of the cultivars depended on the interaction between genotype and planting date, especially during the 2022 season.

Early planting of 'BRS DC25 Fênix' (starting on March 4th) promoted early fruit production and fruits with higher average weight.

'BRS DC22' did not benefit from early planting and is recommended for cultivation from April 1st onward in the Pelotas/RS region.

'BRS DC09' showed performance similar to that of 'BRS DC25 Fênix' and 'BRS DC22' during the 2023 season.

Regarding fruit quality, 'BRS DC25 Fênix' exhibited superior traits in terms of skin brightness and SS/TA ratio.

Fruit firmness and colorimetric parameters were not significantly influenced by planting dates or genotypes.

In the 2023 season, higher average temperatures during early development reduced the influence of planting date on most parameters, highlighting the role of climatic conditions in plant physiological responses.

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