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Pruning inflorescences reduces the yield of neutral-day strawberry cultivars

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Abstract

The lack of information on inflorescence pruning of strawberry cultivars can compromise fruit yield and quality. The aim of this study was to investigate whether inflorescence pruning intensities interfere with the horticultural potential of strawberry cultivars. The treatments studied were three cultivars (‘Albion’, ‘Monterey’, and ‘San Andreas’) and four inflorescence pruning intensities (no pruning, removal of the first inflorescence, removal of the first two inflorescences, and removal of the first three inflorescences). The experiment was laid out in randomized blocks, with four replications. Fruit production and quality were assessed. ‘Monterey’ produced the most fruit and had the highest total strawberry production. Regardless of the cultivar, the total number of fruits and the total yield decreased linearly as the intensity of inflorescence pruning increased. In conclusion, increasing the intensity of inflorescence pruning reduces the productive potential of strawberry plants. Regardless of pruning, ‘Monterey’ has the best productive performance. The chemical quality of strawberries is not influenced by the pruning and cultivars studied.

Keywords: flower thinning, *Fragaria X ananassa Duch.*, production, quality

Introduction

Strawberries (*Fragaria* X *ananassa* Duch.) are appreciated all over the world for their characteristic aroma and flavor and, above all, for the presence of secondary metabolites that have beneficial effects on consumers’ health. Brazil ranks 17th among the largest strawberry producers, with a cultivated area of 5,279 hectares (ha) and a production of 218,881 tons (t), which represents an average yield of approximately 41.5 t ha^{-1} (Antunes et al., 2022). As an initiative to increase this yield in the Brazilian subtropics, producers are opting for cultivars adapted to agroecosystems. However, it is also important to establish appropriate phytotechnical, phytosanitary, and nutritional management throughout the crop cycle.

The lay-flat bag culture system is the most widely adopted in Rio Grande do Sul (RS), Brazil (Alves et al., 2020), for a number of reasons, including the possibility of continuous production. To this end, the use of neutral-day (ND) cultivars is the most suitable. The Californian cultivars ‘Aromas’, ‘San Andreas’, ‘Albion’, ‘Monterey’, and ‘Cabrillo’ are the options available on the Brazilian market.

Strawberry plantations in southern Brazil are established in the fall, from May to June, mostly with plantlets imported from Argentine or Chilean Patagonia (Chiomento et al., 2023a). After the plantlets have been transplanted, the producers begin phytotechnical, phytosanitary, and nutritional management to enhance plant growth and development. These measures, combined with the physiological quality of the plantlets and the micro-meteorological conditions of the growing environment, influence the differentiation of flowering buds (Costa et al., 2021). Plant flowering is an important manifestation of reproductive growth (Zhang et al., 2022). Among the factors that influence this process are

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temperature (Hendry et al., 2021), photoperiod (Song et al., 2013), and endogenous and exogenous hormonal changes (Zhang et al., 2022).

Approximately thirty days after transplanting the strawberry plantlets, inflorescences begin to appear, which coincides with the winter period, when temperatures drop drastically (Trentin et al., 2022; Chiomento et al., 2023b). This fact, coupled with the prioritization of the plants' initial vegetative development (Neri et al., 2012) and the scarcity of information on microclimate management in the agroecosystem, drives producers to prune the first inflorescences that appear. According to producer reports, this phytotechnical management is justified by maintaining the plant's reserves, prioritizing root and aerial part formation, and not directing carbohydrates to the first inflorescences, which are supposed to be affected by low temperatures and not result in good quality fruit.

However, this inflorescence pruning is carried out without any technical criteria, nor is it based on research results. This is due to the scarcity of literature on the effect of inflorescence pruning management on strawberry cultivars in terms of their horticultural potential. Thus, our research will make it possible to know and understand the performance of strawberry cultivars subjected to inflorescence pruning intensities. This will allow us to establish appropriate plant management to maximize fruit production and quality.

Therefore, based on the hypothesis that inflorescence pruning reduces fruit yield, we investigated whether inflorescence pruning intensities modify the horticultural potential of strawberry cultivars.

Materials and Methods

Plantlets of strawberry cultivars classified as ND in terms of flowering, from the Chilean nursery (33° 50' 15.41" S; 70° 40' 03.06" W), Agrícola Llahuen S.A., constituted the plant material for the research. The work was carried out in the municipality of Passo Fundo (28° 15' 41" S; 52° 24' 45" W), RS, Brazil, from May (fall) 2021 to March (fall) 2022, in a greenhouse (430 m^2) installed in a northeast-southwest direction. The galvanized steel structure, with a semicircular roof, was covered with low-density polyethylene film (150 microns) with an anti-ultraviolet additive.

The treatments, laid out in a bifactorial design, were three cultivars ('Albion', 'Monterey', and 'San Andreas') subjected to four intensities of inflorescence pruning (no pruning, removal of the first inflorescence, removal of the first two inflorescences, and removal of the first three inflorescences). The experimental design used was randomized blocks, with four replications. Each plot consisted of six plants (6 plants per plot x 4 replications = 24 plants per treatment; n = 288).

The plantlets were transplanted in May 2021 into containers measuring 1 m long x 0.5 m wide, filled with Dallemole® substrate. This substrate is made up of pine bark, rice husk, rice ash, and class A organic compost. The plants were distributed at a spacing of 0.17 m, with one row of plants per container. The physical and chemical characterization of the substrate is shown in **Table 1**.

Table 1. Physical and chemical properties of the Dallemole® substrate.

Physical properties[1]						
D		TP	AE	RAW	BW	RW
(kg m^{-3})		--------- (m^3 m^{-3}) ------------				
212		0.885	0.502	0.144	0.017	0.222
Chemical properties[2]						
N	P_2O_5	K_2O	OC	pH	EC	C/N
----- % (m m^{-1}) -----					mS cm^{-1}	ratio
0.82	0.58	<0.25	26.10	5.6	1.05	33.42

[1]D: density; TP: total porosity; AE: aeration space; RAW: easily available water; BW: buffer water; RW: remaining water. [2]N: nitrogen; P_2O_5: phosphorus pentoxide; K_2O: potassium oxide; OC: organic carbon; pH: hydrogen potential; EC: electric conductivity; C/N ratio: relationship between carbon and nitrogen.

The irrigation used in the experiment was localized, using an automated system with drip strips (1.41 L h^{-1} per dripper). The irrigation regime consisted of activating the system seven times a day, with a total wetting time of 14 minutes. Nutrient solutions were supplied to the plants on a weekly basis.

The inflorescences were pruned from July 21 (winter) to September 16 (spring) 2021. Pruning took place as soon as the primary flower of the inflorescence was at stage 60 and the secondary (and tertiary, when present) flowers were at stage 55 (**Figure 1**), according to the phenological scale proposed by Meier et al. (1994)

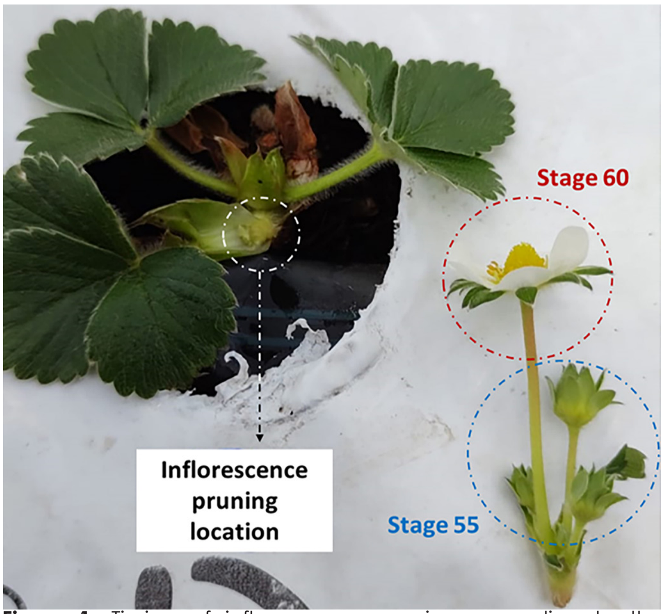

Figure 1. Timing of inflorescence pruning according to the strawberry phenological scale proposed by Meier et al. (1994).

and the Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie (BBCH) coding.

The air temperature inside the greenhouse was monitored using a mini weather station (**Figure 2**). Evaluations began after the plants had set fruit. Attributes relating to fruit production and quality were assessed.

Between August (winter) 2021 and March 2022, with approximately ten monthly harvests, we assessed the total number of fruits per plant (TNF, number per plant) and the total fruit production per plant (TP, grams per plant), carried out at commercial maturity (≥85% reddish visual color). We also determined the average fresh fruit mass (AFFM, grams) by the ratio between TP and TNF.

In November (spring) 2021, the total soluble solids content (TSS, %) and total titratable acidity (TTA, % of citric acid) were evaluated using 15 fruits from each treatment for each repetition (Zenebon et al., 2008). To assess the taste of the fruit, the TSS/TTA ratio was determined.

The data obtained was submitted to analysis of variance (Anova) and regression. When there was isolated significance for the qualitative factor (cultivars), the means of the treatments were compared using the Tukey test, with a 5% probability of error. All the analyses were carried out using Costat® software (CoHort Software, 2003).

Results and Discussion

There was no significant effect for the interaction between cultivars and inflorescence pruning intensities. Statistical differences were only observed for the cultivars in relation to TNF and TP. 'Monterey' produced the most fruit and had the highest total yield compared to 'Albion' and 'San Andreas' (**Table 2**).

As inflorescence pruning intensities are a quantitative factor, we carried out a regression analysis of variance, which indicated a significant effect for the linear regression model in relation to the TNF and TP attributes (**Table 3**).

The coefficient of determination (R^2) from the regression analysis between inflorescence pruning intensity and TNF was 0.97, indicating that 97% of TNF was explained by this factor. We also found that TNF decreased linearly with increasing pruning intensity (**Figure 3**A). In addition, the R^2 obtained in the regression between pruning intensities and TP was 0.93, indicating that 93% of the yield was explained by pruning intensities. We also observed that TP decreased linearly as the intensity of inflorescence pruning increased (Figure 3B).

There was no significant effect, either interactive or in isolation, for the treatments studied in relation to the fruit quality attributes (**Table 4**).

There was no interaction between strawberry cultivars and inflorescence pruning intensities in terms of yield potential. However, among the ND cultivars studied, we identified the one with the highest yield. In Brazil, 'Albion' and 'San Andreas' occupy approximately 65% of the total area under strawberry cultivation (Chiomento et al., 2021). However, 'Monterey' produced the most strawberries and had the highest yield (Table 2). This indicates that producers should strategically plan the establishment of their commercial crops based on the adaptability and stability of cultivars (Chiomento et al., 2023b).

Despite the better phytosanitary quality and robustness of 'Albion' and 'San Andreas' against biotic stresses (Kilic et al., 2021), factors that explain the spread of

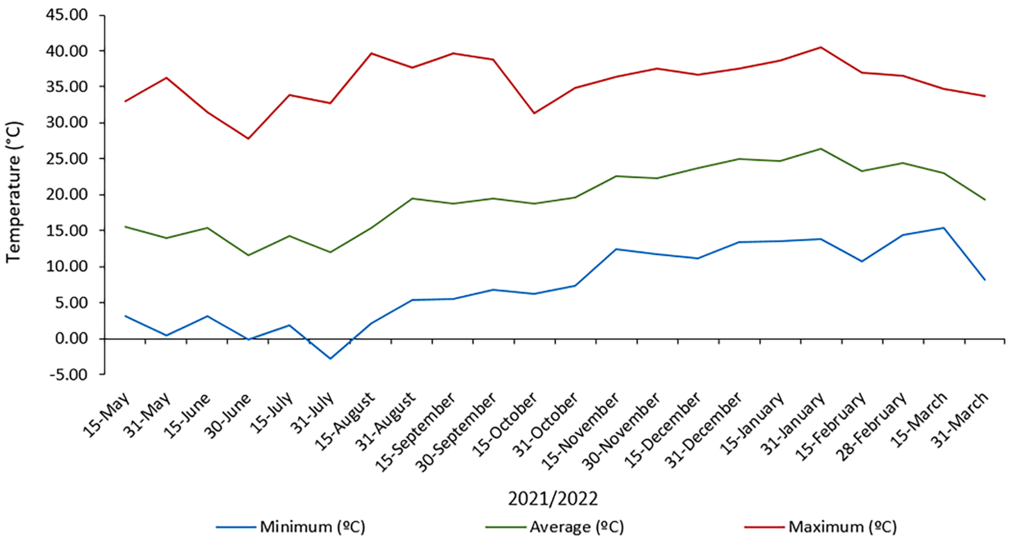

Figure 2. Minimum, average, and maximum temperatures inside the greenhouse during the experiment.

Table 2. Yield of neutral-day strawberry cultivars.

Cultivars	TNF (number per plant)[1]	TP (grams per plant)	AFFM (grams)
‘Albion’	16.35±6.76 b	213.64±31.13 b	13.20±4.23
‘Monterey’	20.59±5.95 a	265.65±29.58 a	12.89±3.08
‘San Andreas’	17.91±5.43 b	226.64±30.73 b	12.86±5.19
Significance	**	**	NS
Mean	18.28	235.31	12.98
CV (%)[2]	16.72	16.16	8.16

Data was presented as mean ± standard deviation. **: significant at the 1% probability level ($p < 0.01$). NS: treatment effect not significant (Tukey's test, $p > 0.05$). [1]TNF: total number of fruits; TP: total production; AFFM: average fresh fruit mass. [2]CV: coefficient of variation.

Table 3. Summary of analysis of variance for regression of yield of strawberry cultivars in relation to inflorescence pruning intensities.

Causes of variation[1]	DF[2]	Mean square		
		TNF (number per plant)[3]	TP (grams per plant)	AFFM (grams)
x^1	1	264.97**	34,468.86**	2.87^{ns}
x^2	1	4.38^{ns}	$2{,}279.48^{ns}$	0.45^{ns}
Residue	45	14.89	2,241.51	1.14
Total	47			
R^2		0.97	0.93	0.61
Mean		18.28	235.31	12.98

[1]x^1: linear regression; x^2: second-order polynomial regression. [2]DF: degrees of freedom. [3]TNF: total number of fruits; TP: total production; AFFM: average fresh fruit mass. [ns]Treatment effect not significant (Tukey's test, $p > 0.05$). **Significant at the 1% probability level ($p < 0.01$).

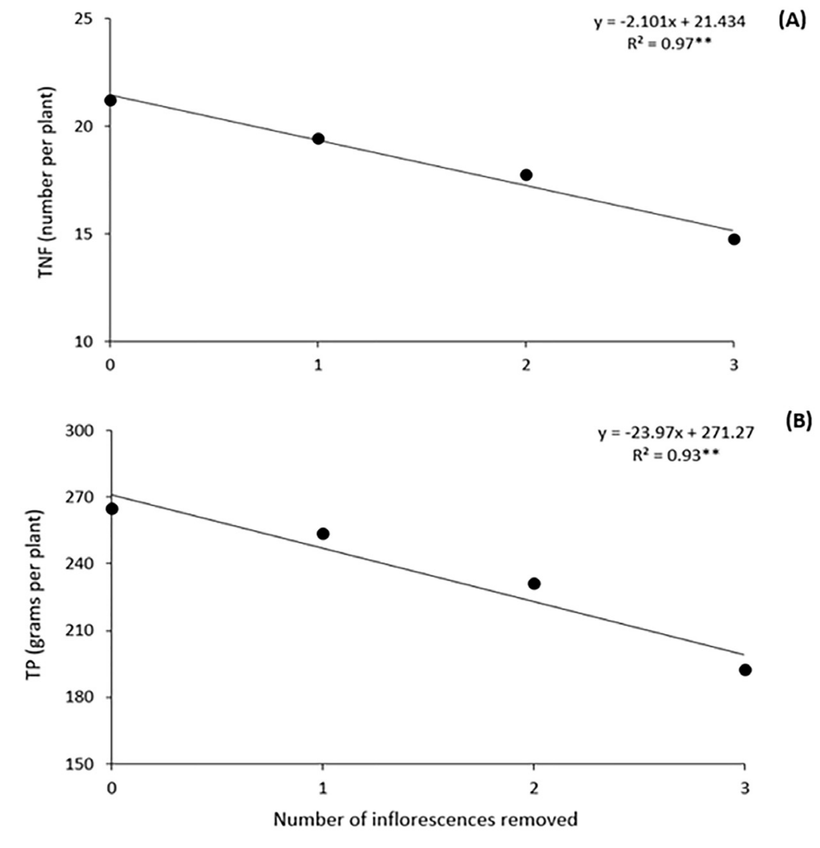

Figure 3. Total number of fruits (A) and total production (B) of strawberry cultivars subjected to inflorescence pruning intensities. **Significant at the 1% probability level (p < 0.01).

both materials, the lack of information on the productive potential of the other strawberry cultivars available on the market, such as ‘Monterey’, is still the main reason for this scenario. Scientists and extension agents should therefore disseminate technical and research-based information to producers in order to intensify local, regional, and global agricultural development (Chiomento et al., 2023a).

The literature reports different yield performances from strawberry cultivars. Chiomento et al. (2021), in a study conducted in soil and greenhouse, showed that the production of marketable fruit (grams per plant) was 295, 420, and 316 for ‘Albion’, ‘Monterey’, and ‘San

Table 4. Fruit quality of neutral-day strawberry cultivars subjected to inflorescence pruning intensities.

Cultivars	TSS (%)[1]	TTA (%)	TSS/TTA
'Albion'	7.24±1.14	0.72±0.03	10.97±3.02
'Monterey'	7.37±2.05	0.67±0.02	12.20±3.15
'San Andreas'	8.03±1.89	0.75±0.03	11.40±2.94
Significance	NS	NS	NS
Inflorescences removed			
0	7.87±1.27	0.77±0.02	11.02±2.88
1	7.70±1.06	0.69±0.02	12.26±3.61
2	7.40±1.15	0.67±0.01	11.75±2.78
3	7.20±1.79	0.71±0.04	11.06±3.17
Significance	NS	NS	NS
Mean	7.55	0.71	11.52
CV (%)[2]	21.03	32.27	32.42

Data was presented as mean ± standard deviation. NS: treatment effect not significant (Tukey's test, $p > 0.05$). 1TSS: total soluble solids; TTA: total titratable acidity; TSS/TTA: flavor. 2CV: coefficient of variation.

Andreas', respectively. On the other hand, in substrate and greenhouse cultivation, production (grams per plant) was 265, 325, and 234 for 'Albion', 'Monterey', and 'San Andreas', respectively (Chiomento et al., 2023a). These results corroborate the productive potential of 'Monterey' (Table 2). The low production of 'Albion' and 'San Andreas' (Table 2) may be related to the unsuitability of these materials to the management to which they were subjected. Furthermore, these discrepancies in the performance of the cultivars suggest that the yield of the materials may be influenced by edaphoclimatic factors (Trentin et al., 2022), biogeographical factors (Schiavon et al., 2022), ecophysiological factors (Costa et al., 2021), and the management applied during cultivation, such as inflorescence pruning.

Increasing the intensity of inflorescence pruning linearly reduced the yield potential of 'Albion', 'Monterey', and 'San Andreas' (Figure 3). The development of the entire aerial part of the plant influences the number of flower buds and, consequently, the number of fruits formed (Antunes et al., 2016). Therefore, removing the inflorescences in the first reproductive phenological stages of the strawberry (stages 55 and 60, for example) resulted in losses in the final yield.

The relationship between the source (organ of net export of carbon skeletons) and the drain (organ of net import of photosynthetic compounds) regulates vegetative growth and the development of flowers and fruit (Hansen, 1989). In general, the source-drain interface that marks fruit growth is also determined by the plant's fruit/leaf ratio. Thus, plant manipulations that modify this ratio can interfere with yield (Sønsteby et al., 2021), such as pruning inflorescences.

The negative effect of inflorescence pruning on the strawberry's productive potential can be explained by the stress the plants have been subjected to, causing them to change their growth pattern. For example, the additional reduction in plant energy occurs because the starch reserves, stored in the removed organ, are lost (Lacan, 2013). Due to the physiological stage at which the plantlets were received (**Figure 4**), their productive potential was already pre-established (differentiation of flowering buds in the nursery). Thus, the inflorescences removed were pre-formed while still in the nursery. Strawberry production is also determined by the photoassimilates stored in the crown of the plants (Deggerone et al., 2023). These reserves, in the form of carbohydrates, are associated with the temperatures recorded during the plantlets development period, while still in the nursery (Costa et al., 2017).

Figure 4. Strawberry plantlets, bare root, received from the Chilean nursery (Agrícola Llahuen S.A.).

ND strawberry cultivars show a thermoperiodic response to flowering (Durner, 2015). The differentiation of flowering buds in this group of cultivars occurs via an intrinsic stimulus from the plant (autonomous flowering pathway) or when there are several cycles of temperatures below 10ºC (Costa et al., 2021). As the common goal of plants is to perpetuate the species, pruning the inflorescences stimulated differentiation and the subsequent development of new flowering buds. Considering that the ontogeny and anthesis of strawberry flowers are regulated by temperature (Durner, 2016), the lack of cold in the subsequent production period, starting in September (Figure 2), may have negatively affected the formation of new flower buds and, consequently, the size of the flowers and the caliber of strawberries, which reduced production per plant.

The literature reports that the first strawberry inflorescence produces the most flowers (Ridout et al., 1999) and is therefore considered the most complex (Labadie et al., 2019). In addition, variations in the complexity of the first two inflorescences emitted significantly affect the number of flowers produced by the plant (Labadie et al., 2023). This is a key factor in establishing phytotechnical management to control yield. In addition, strawberry breeding programs should focus on the complexity of the first inflorescences in order to control the intensity of the first flowering (Gaston et al., 2021).

In this context, our results suggest that growers should not prune the first inflorescences emitted by ND strawberry plants, 'Albion', 'Monterey', and 'San Andreas' cultivars, to yield detriment. This will make it possible to boost strawberry production and will contribute substantially to increasing producers' incomes. In a scenario of optimizing management to improve plant performance, we technically support that maintaining the first flowers is a viable strategy to improve the final production result, as well as reducing the demand for labor during the strawberry cultivation cycle. In any case, it is always important to carefully evaluate the context in which plant management should be carried out.

Conclusions

Increasing the intensity of inflorescence pruning linearly reduces the productive potential of 'Albion', 'Monterey', and 'San Andreas'. In addition, regardless of the removal of the first three inflorescences, 'Monterey' has the best productive performance and should be an option for obtaining maximum yield. Strawberry chemical quality is not influenced by inflorescence pruning or by the cultivars studied.

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