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Effect of grafting and number of stems on plant growth, yield and fruit quality of soilless tomatoes

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Abstract

Vegetable grafting has grown considerably and has been a management alternative to overcome adverse soil cultivation conditions. However, many growers have used grafted tomato plants in substrate cultivation, claiming greater plant vigor, fruit yield, and longevity. Thus, the work objective is to evaluate the effect of grafting and the number of stems on plant growth, fruit yield, and quality of the Italian tomato, cultivated in a system of troughs filled with raw rice husk substrate. The experiments were conducted in southern Brazil, in the 2017/18 (long cycle) and 2019/20 (short cycle) crop seasons. The cleft grafting was used. The analyzed variables were the number of leaves, leaf area index, vegetative and fruit dry matter production, plant total dry matter, number of fruits, fruit yield, mean fruit weight, and total soluble solids content (ºBrix). The grafted plants had higher LAI, fruit dry matter production, fruit number, and yield (17 and 19%, respectively, in the first and second crop seasons). The quality of the fruits, concerning the concentration of sugars, was not affected by grafting, and the mean fruit size was increased by 7.9 and 8.1 grams (long and short cycle, respectively). In a long cycle, both for grafted and non-grafted plants, single-stem plant cultivation promotes 13.54% more plant growth and is 4.86% more fruit yield than double-stem plants. In a short cycle, from the point of view of reproductive growth and fruit yield, for both types of plants, cultivation with two stems is like that of single-stem plants.

Keywords: *Solanum lycopersicum* L., rootstock, closed grow system, gullies, raw rice husks.

Introduction

Tomato cultivation (*Solanum lycopersicum* L.) is mostly carried out in the field, preferably in new areas or in places where crop rotation is practiced reducing the incidence of pests and diseases. However, in recent years, greenhouse cultivation has increased significantly to protect the crop from bad weather and prolong the production cycle. However, in conventional soil cultivation, the practice of crop rotation is difficult in protected environments, with the recurrent incidence of problems with soil fertility and the increased incidence of pathogens that limit crop cultivation.
Thus, tomato production faces many challenges to overcome biotic and abiotic stress conditions (Singh et al., 2017). Regarding biotic stresses, problems with diseases of different physiological races and groups of pathogens in a growing area can be solved or mitigated with the use of resistant cultivars. However, this management alternative has limitations, as obtaining new genotypes requires time and high investments. Thus, grafting emerged as an interesting management alternative, based on the use of resistant rootstocks (Goto et al., 2003), becoming a tool with great potential to increase the efficiency of highly productive genotypes with greater resistance to different stresses (Kumar et al., 2017).

In tomatoes, grafting objective to combine plant resistance and fruit quality to improve production in several aspects, providing greater economic returns to the grower. However, currently, the main objective of using grafted tomatoes is still to provide the crop with greater resistance or tolerance to soil pathogens (Peil, 2003). For this reason, the use of grafted plants in soilless cultivation would not be necessary because it is a phytopathogen-free growing system that allows better control over plant growth and development (Du Plooy et al., 2012; Maboco et al. 2017). However, there are many reports from growers indicating the use of grafted tomato plants in soilless cultivation systems. Claims are based on the greater apparent vigor, productivity and longevity of grafted plants compared to non-grafted plants.
The best responses of grafted plants are based on the theory that plants used as rootstocks are selected by crossing genotypes with characteristics of tolerance to a certain factor and that have a more developed and vigorous root system, resistant to pathogens and tolerant to various adverse environmental conditions (Gaion et al., 2017). In this way, there is a greater offer of mineral nutrients for the aerial part of the plants, allowing greater plant growth, increased fruit production, and improvement in fruit quality.

Some authors have already observed positive results with the use of plant grafting, including for overcoming adverse environmental conditions (Lee et al., 2010; Rouphael et al., 2010; Schwarz et al., 2010; Nawaz et al., 2016).
Due to their greater vigor, expressed in greater shoot development and greater leaf area, grafted plants possibly have greater photosynthetic capacity, which, in turn, can lead to a gain in fruit production (Djidonou et al., 2017). Thus, grafted plants could be managed with a greater number of stems than non-grafted plants, which would bring the benefit of reducing costs with the acquisition of seedlings. In this way, preserving the density of stems per square meter, conducting plants grafted with two stems would make it possible to reduce the number of plants by 50%, however, maintaining the production levels per area as with plants cultivated with a single stem.
In the literature, few studies are comparing the grafted and non-grafted plants and the number of stems in association, as well as practically no studies on the use of grafting in soilless cultivation. In this sense, Peil and López-Gálvez (2004) report research related to the growth of additional side shoots throughout the vegetative cycle of grafted and non-grafted tomato plants in an NFT hydroponic system and did not observe the existence of interaction between grafting and a greater number of secondary stems, and no greater productive response of the grafted plants. However, the research did not start with plants with two main stems and the same number per square meter as non-grafted plants, which may have been decisive for the differences in the responses obtained.
In general, dissociated studies are found that evaluate only the grafting factor or only the number of stems of the plant. Research reports on the use of grafted tomato plants in substrate cultivation are unknown. In this context, this work objective to evaluate the effect of grafting and the number of stems on the growth, fruit yield, and quality of tomato fruits in the substrate cultivation system.

Results

Vegetative growth variables

The analysis of variance for the 2017/18 season showed a significant effect for the grafting factors and number of stems on all vegetative growth variables, with no interaction between the factors. While for the 2019/20 crop season there was only a significant effect of the grafting factor on the variable dry matter of fruits, and there was a significant interaction between the factors grafting and number of stems on the variables vegetative dry matter and total plant dry matter (Table 1).
In the first cropping cycle (2017/18), the grafted plants had a higher number of leaves, leaf area index (LAI), stem length, dry matter of fruit, vegetative, and total plant (Table 1). In the second cropping cycle (2019/20), grafted plants were superior in terms of LAI and fruit dry matter production. However, grafting did not affect the number of leaves.
Regarding the effect of the number of stems, in the first cycle, the cultivation of plants with a single stem resulted in a greater number of leaves, IAF, stem length, production of fruit, vegetative and total dry matter of the plant concerning the plants conducted with two stems (Table 1). On the other hand, in the second cultivation cycle, the number of stems did not affect the number of leaves, IAF, stem length, and fruit dry matter production.
When observing the total dry matter of the plants, we can see that the partition of this matter occurred differently between the two cycles, with the fraction corresponding to the fruits representing 48% for the first experiment and the vegetative part, which adds leaves, bunch floral and stem, represented 52%. In the second cycles, the fruit partition corresponded to 32% and the vegetative part to 68%.
Table 2 shows the interaction between the factors grafting and the number of stems for the variables vegetative dry matter and total plant, referring to the second cultivation cycle. The grafted and non-grafted plants did not differ from each other when conducted in a single stem concerning both variables. On the other hand, when conducted with two stems, grafted plants accumulated greater dry matter compared to non-grafted plants. For non-grafted plants, conduction on one stem provided greater production of the vegetative and total dry matter of plants than non-grafted plants trained with two stems.

Production variables

Concerning production characters (Table 3), in the 2017/18 season, regardless of the number of stems, the grafted plants had a higher number, yiled, and mean fruit weight (Table 3). In the 2019/20 crop season, the grafted plants were superior in terms of number and fruit yield. In both cycles, grafting did not affect the concentration of total soluble solids of the fruits.
Regarding the plant training with one stem were more productive and had a higher mean fruit weight in the first crop cycle (Table 3). In the second crop season, there were no significant differences for any of the analyzed production variables.
As for the distribution of the harvest throughout the production cycle in the 2017/2018 season (Figure 1), both grafted and non-grafted plants showed gradual increasing production until the middle of 240º DAT, with subsequent stabilization.
Figures 1A and 1B indicate that the grafted plants showed an increase in daily productivity of 454 g m^{-2}, combined with a daily increase of 3.5 fruits m^{-2}. The non-grafted plants presented a lower daily yield gain rate, with an addition of 3.0 fruits and 353 g m^{-2}. The coefficients of determination (R2) were above 0.98 for both variables and plant types, indicating that a large part of the total variation of the factor effect was explained by the change in the independent variable.
In the 2019/2020 crop season, production took place in a linearly increasing fashion (Figures 1C and 1D). The grafted plants continued to show a mean daily gain higher than that of the non-grafted plants. The grafted plants increased daily 0.5 fruits and 208 g m^{-2} and the non-grafted plants 0.4 fruits and 156 g m^{-2} throughout the production cycle. The coefficients of determination (R2) were above 0.95 for both variables and plant types.

Discussion

The results indicated that, regardless of location, season and crop cycle, grafted plants showed greater vegetative and reproductive growth, represented by higher LAI and higher dry matter production of aerial vegetative organs and fruits (Table 1), and better production performance, through the production of a greater number of fruits and, consequently, higher fruit yield (Table 3) compared to non-grafted plants in substrate cultivation. Similar results were obtained by Turhan et al. (2011), in soil cultivation; Rahmatian et al. (2014), and Savvas et al. (2017), in hydroponic cropping systems.

With respect to growth variables (vegetative and reproductive; Table 1), in the 2017/18 season of the long cycle, in which the plants did not have their early apical growth limited by topping, the grafted plants showed much better results than the non-grafted plants for all variables, showing their greater vigor, corroborating similar results obtained by Ntatsi et al. (2014) and Savvas et al. (2017). On the other hand, in the 2019/20 crop year, there was no effect of grafting on the number of leaves variables (Table 1), as plant development was limited by apical pruning. However, the LAI and the dry matter of fruits (Table 1) of the grafted plants continued to be higher, as well as the production of the vegetative dry matter of the grafted plants conducted with two stems (Table 2).

The grafting did not change the soluble solids content of the fruits (Table 3); therefore, it did not affect the quality of the fruits in terms of sugar concentration. Some previous works already indicated that the use of grafted plants did not differ from self-grafted or non-grafted plants with the effect on the total titratable acidity, lycopene, and β-carotene of the fruits (Djidonou et al., 2016) and in the pH, firmness, titratable acidity, total soluble solids, and maturation index (Gomes et al., 2017). However, the quality of tomato fruits includes other aspects, in addition to the concentration of soluble solids, and may be related to several factors related to the grafting itself, such as characteristics of rootstock cultivars, compatibility and union between rootstock and scion, as well as the occurrence or not of biotic and abiotic stress factors and their duration (Riga, 2015). This contributes to justify the discrepancy observed in the results of no effect of grafting on the soluble solids content, followed in the present work, to researche in which grafting provided a higher concentration of soluble solids, firmness, and vitamin C content (Rahmatian et al., 2014; Riga et al., 2016), or to research in which it negatively affected the concentration of soluble solids, titratable acidity and vitamin C (Turhan et al., 2011; Al-Harbi et al., 2017).

The better responses of grafted plants over non-grafted plants can be attributed to the greater size and vigor of their root system, due to the use of hybrid rootstock obtained by interspecific crossing between *Solanum lycopersicum* and *Solanum habrochaites* (Djidonou et al., 2016; Velasco-Alvarado et al., 2016). This may have ensured a greater capacity to absorb water and mineral nutrients, with positive effects on the production of the dry matter of the aerial organs of plants (Table 1) and, consequently, on the yield components, mainly the number of fruits, and on the case of the 2017/18 crop season, also, mean fruit weight (Table 3).

Additionally, the materials used for plant rootstocks are selected for their characteristics of providing resistance to soil diseases and pests and biotic and abiotic stress conditions, seeking to overcome adverse production conditions. The characteristic of providing greater vigor and vegetative growth (Table 1) is generally intrinsic to cultivars intended for these purposes and, therefore, may promote superior productive results, as effectively occurred in this work (Table 3), even in the absence of stress factors biotic, such as diseases and soil pests, as well as abiotic stresses related to the supply of water and mineral nutrients, since the characteristics of the high frequency of supply of the nutrient solution are characteristic of the substrate cultivation system.

To enable the comparison of results, the conduction on a single stem and two stems were carried out in such a way as to maintain the number of stems per square meter. Thus, in the long cycle (2017/18), the cultivation of single-stem plants presented greater vegetative growth, as it presented a greater number of leaves, IAF, stem length, and vegetative dry matter production (Table 1). As a result, it promoted a higher production of the dry matter of fruits and total plants (Table 1). This provided fruit yield gains, mainly due to the production of fruits with a higher mean weight (Table 3).

However, in the shorter season (2019/20), the effect of the number of stems was practically non-existent, since the cultivation of plants with a single stem was only superior to that of two stems in terms of the production of the vegetative dry matter of the plants non-grafted (Table 2). Thus, the cultivation of plants with two stems resulted in values of the dry matter of fruits and other variables related to vegetative growth (Table 1), as well as fruit yield (Table 3) like those of plants with one stem. Considering that the number of stems did not affect the concentration of total soluble solids (Table 3), it can be said that it did not affect the quality of the fruits in terms of the concentration of sugars, in both cultivation cycles.

Considering that the first cultivation cycle was long, with the plants being conducted up to the 18th truss and, consequently, with the need for lowering the stem around the double row and intensive defoliation of the plants (management known as "Dutch carousel"), plants cultivated with a single stem were more easily managed, which avoided stem breakage when performing this cultural treatment. Thus, the higher cost of acquiring a larger number of seedlings for the cultivation of single-stem plants is possibly offset by the greater efficiency in the employment of labor, associated with an increase in fruit yield of 2.6 kg m^{-2} (Table 3) regarding the cultivation of plants with two stems at half the planting density.

On the other hand, in the 2019/20 crop season, in a short cycle, on what the plants were only conducted up to the 10th truss (when they reached the height of the support wire), the management of lowering the stem was unnecessary, and the cultivation of plants with two stems viable, taking into account that there was no significant difference in fruit yield and mean fruit weight (Table 3) when compared to plants with single stem.

The extended cultivation cycle is a viable technique if the basic requirement of good phytosanitary conditions of the plants is met. However, this type of management can express even more satisfactory yield results under conditions of climate-controlled glasshouse and/or regions with mild winter climates, with a low occurrence of frost. Because, in this way, the plants can maintain their vegetative growth and their production in a constant and growing way. The decrease in incident solar radiation values associated with low temperatures for long periods during the winter decreases the plant growth rate and can significantly affect fruit set and development (De Koning, 1990; Ntatsi, et al., 2014). It is for this reason that from 180º DAT, the number of fruits and the fruit yield of the 2017/18 crop season tended to a certain stability, without major increases during the winter period in Rio Grande do Sul (Figures 1A and 1B).

On the other hand, winter is the time of year when the price of tomatoes is traditionally higher in the state, reaching values up to two or three times higher than at other times of

Table 1. Effects of grafting factors and number of stems per plant on the number of leaves, leaf area index (LAI), stem length, dry matter (DM) of fruits, vegetative dry matter (DM) and total dry matter (DM) of tomato plants grown in raw rice husk substrate. 2017/18 crop season (spring/winter) Capão of Leão/RS and 2019/20 crop season (spring/summer) Jaguari/RS.

Factors*	Number of leaves m^{-2}	LAI	Stem length (m)	DM of fruits m^{-2}	Vegetative DM (g m^{-2})	Total DM (g m^{-2})
	ason 2017/18					
Grafting						
Grafted plants	268 A	8.9 A	4.8 A	1226.3 A	1524.0 A	2750.3 A
Non-grafted plants	241 B	6.7 B	4.0 B	1056.8 B	987.3 B	2044.1 B
Number of stems $plant^{-1}$						
Single-stem	279 A	9.2 A	4.8 A	1213.0 A	1508.8 A	2721.8 A
Two-stems	230 B	6.5 B	4.1 B	1070.1 B	1002.5 B	2072.6 B
Mean	255.0	7.8	4.4	1141.5	1255.6	2397.2
CV%	7.9	17.8	10.2	11.2	16.9	13.2
	Crop season 2019/20					
Grafting						
Grafted plants	150^{ns}	5.6 A	-	508.4 A	--	--
Non-grafted plants	150	4.9 B	-	426.9 B	--	--
Number of stems $plant^{-1}$						
Single-stem	150^{ns}	5.5^{ns}	-	486.5^{ns}	--	--
Two-stems	150	5.0	-	448.8	--	--
Mean	150.0	5.3	-	467.7	984.9	1452.4
CV%	2.4	16.3	-	11.1	8.8	12.7

Means followed by the same letter in the column do not differ, at 0.05 of probability, by the F test.
ns: not significant by the F test, at 0.05 of probability. * Plant type (grafted plants and non-grafted plants) and number of stems per plant (plants conducted with single-stem and plants conducted with two-stems).

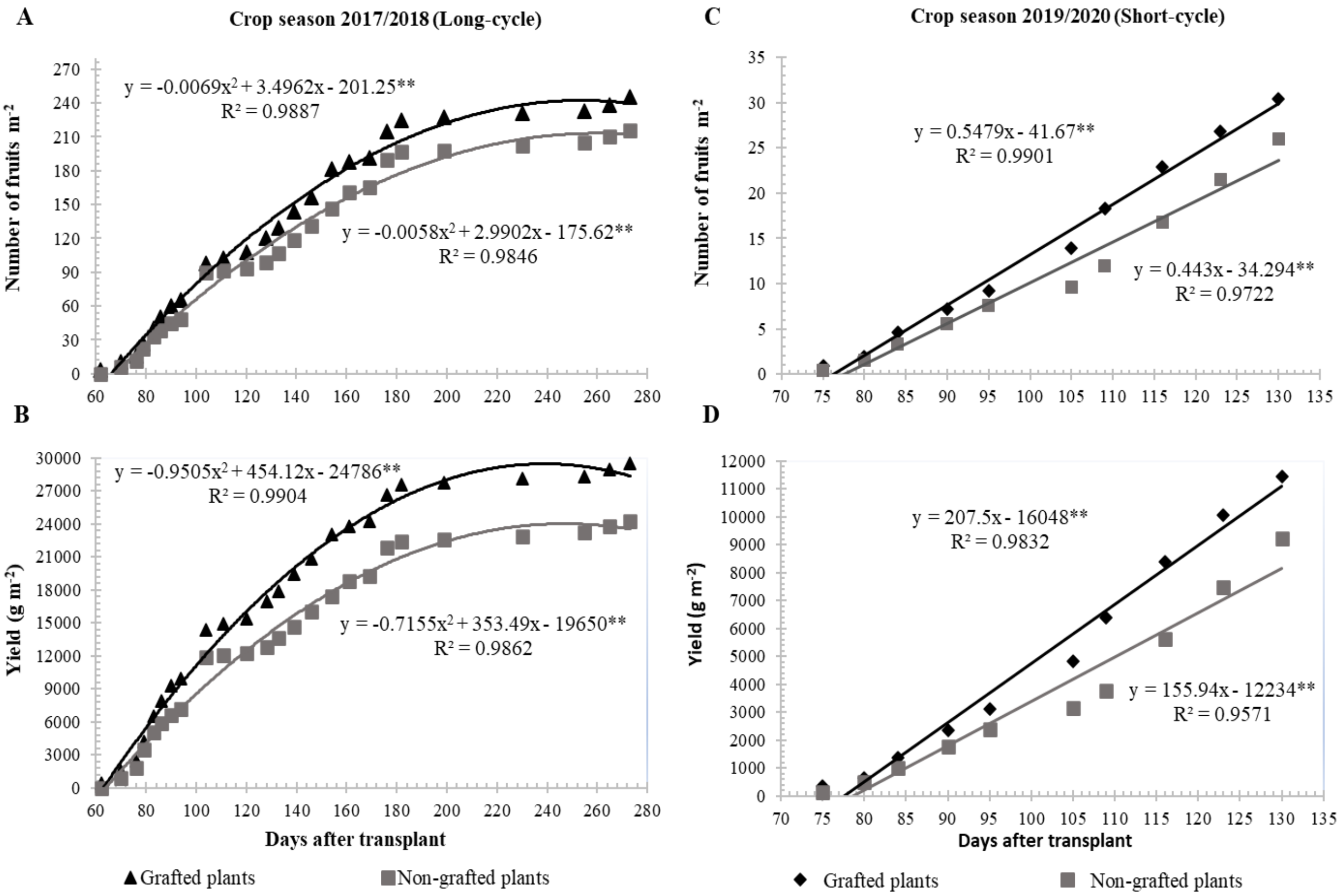

Figure 1. Fruit harvest distribution along the productive cycle of grafted and non-grafted tomato plants, with variation in the number of stems, in the cultivation in raw rice husk substrate. 2017/18 crop season (spring/winter) Capão of Leão/RS and 2019/20 crop season (spring/summer) Jaguari/RS.

Table 2. Interaction of grafting treatment factors and number of stems per plant for the variables vegetative dry matter and total dry matter of tomato plants in a troughs production system in raw rice husk substrate. 2017/18 crop season (spring/winter) Capão of Leão/RS and 2019/20 crop season (spring/summer) Jaguari/RS.

Factors*	Vegetative dry matter (g m^{-2})	
	Single stem conduction	Two stems conduction
Grafted plants	1027.8 Aa	1023.4 Aa
Non-grafted plants	1052.8 Aa	835.7 Bb
	Total dry matter (g m^{-2})	
	Single stem conduction	Two stems conduction
Grafted plants	1590.5 Aa	1522.0 Aa
Non-grafted plants	1531.4 Aa	1165.6 Bb

Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ at 0.05 of probability by Tukey's test. * Plant type factor (grafted plants and non-grafted plants) and number of stems per plant factor (plants conducted on a single-stem and plants conducted with two-stems).

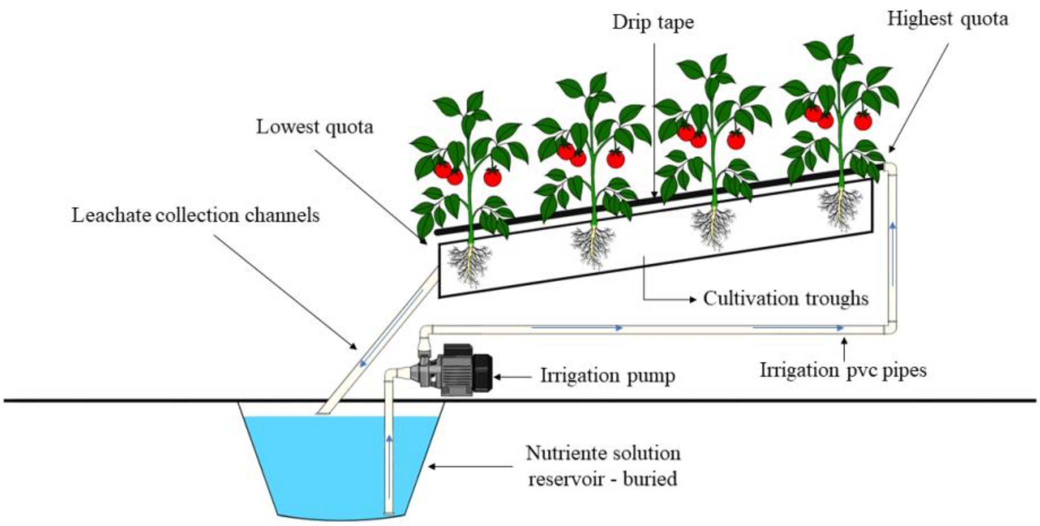

Figure 2. Trough type closed soilless growing system.

Table 3. Effects of grafting factors and the number of stems per plant on the number, yield, mean weight, and total soluble solids (TSS) of tomato fruits cultivated in raw rice husk substrate. 2017/18 crop season (spring/winter) Capão of Leão/RS and 2019/20 crop season (spring/summer) Jaguari/RS.

Factors*	Number of fruits m^{-2}	Yield (kg m^{-2})	Mean weight of fruits (g fruto^{-1})	SST (°Brix)
	Crop season 2017/18			
Grafting				
Grafted plants	243 A	29.2 A	120.9 A	4.2^{ns}
Non-grafted plants	214 B	24.2 B	113.0 B	4.2
Number of stems plant^{-1}				
Single-stem	235^{ns}	28.0 A	119.5 A	4.2^{ns}
Two-stems	222	25.4 B	114.4 B	4.2
Mean	228.0	26.7	116.9	4.2
CV%	10.6	12.8	5.3	3.6
	Crop season 2019/20			
Grafting				
Grafted plants	80 A	11.4 A	144.3^{ns}	4.2^{ns}
Non-grafted plants	68 B	9.2 B	136.2	4.1
Number of stems plant^{-1}				
Single-stem	76^{ns}	10.8^{ns}	143.1^{ns}	4.1^{ns}
Two-stems	72	9.8	137.4	4.2
Mean	74.0	10.3	140.3	4.2
CV%	18.4	18.8	13.4	5.3

Means followed by the same letter in the column do not differ, at 0.05 of probability, by the F test. ns: not significant by the F test, at 0.05 of probability. * Plant type factor (grafted plants and non-grafted plants) and number of stems per plant factor (plants conducted on a single-stem and plants conducted with two-stems).

the year. Thus, the low fruit yield, possibly, is still profitable for the maintenance of plants in production even in non-heated glasshouse, if some management measures are taken in the cultivation structure, such as closing and sealing the side curtains and doors in the early afternoon for heat storage. In addition, depending on the size of glasshouse and the conditions of each producer, it is possible to install heaters programmed to start operating during the night or use heating with furnaces to prevent plant death on nights with an expected occurrence of intense frost, and thus reduce yield losses.

Finally, in response to the hypothesis formulated in the introduction, it can be said that, in the long crop season (2017/18) from the point of view of growth and productivity, two-stem grafted plants are lower to single-stem grafted plants. The same can be said for non-grafted plants. Already, in the2019/20 crop season (short cycle), the grafted plants showed conditions to maintain greater growth when conducted with two stems, while the non-grafted plants considerably decreased their vegetative growth (Table 1) when conducted in the same way, but the reproductive growth and the fruit yields (Table 3) were equivalent for the two conductions. Therefore, for short cycles, both for grafted and non-grafted plants, it is possible to choose the cultivation with two stems, with 50% savings in the cost of seedlings, with productive advantages for the grafted plants.

Materials and methods

Characteristics of experimental area

The experiments were conducted in the 2017/18 crop year (long cycle - 273 days), covering the period from Nov 7, 2017, to Aug 7, 2018 (spring/winter), and in the 2019/20 crop year (short cycle – 130 days), from Sept 19, 2019, to Jan 27, 2020 (spring/summer). The first crop season was implanted in the city of Capão of Leão/RS (31°48'S - 52°25'W). The second test was carried in the city of Jaguari/RS (29°30'S - 54°41'W). The cultivation sites are located approximately 400 km away, but both have the same climatic classification, with well-distributed rainfall, hot summer with maximum temperatures in the warmer months above 30 °C, and frost in the winter months and lower temperatures than 10 °C.

The tests were carried out in greenhouses model "Ceiling Arc", with metallic and mixed structure, covered with a 150 µm thick low-density polyethylene plastic film. The greenhouses were arranged in a north-south direction with dimensions of 10 m x 21 m, 5.0 m of maximum height and 3.5 m of right foot, comprising an area of 210 m^2 (intended for the 2017/18 experiment); and 7 m x 30 m, 4.5 m of maximum height and 3.0 m of right foot, comprising an area of 210 m^2 (intended for experiment 2019/20). The management of protected environments was carried out only by natural ventilation, by opening and closing the side windows and greenhouse doors according to the variation of environmental conditions, to maintain the best conditions for the proper development of the crop.

Plant materials

The grafted and non-grafted plants were purchased from the nursery in Nova Bassano/RS (28°43'S - 51°42'W), which specialized in the production of tomato seedlings. Seedlings of the tomato cultivar Multifort® were used as a rootstock, chosen for its vigor and longevity. The graft and non-grafted plants were from the Italian cultivar Giuliana®, with indeterminate growth habits. The grafting technique used was the simple English type, with the seedlings being cut at an approximate angle of 45° and joined by pressure clips.

Plant management

Plants were conducted in such a way as to provide the same stem density per unit area, as follows: single stem in spacing between plants of 0.3 m (population density of 3.9 plants m^{-2}) and two stems in spacing among 0.6 m plants (population density 1.95 plants m^{-2}). The conduction with two stems was obtained from the pinching of the apical meristem of the primary stem above the 4th true leaf, and the first two emitted side shoots were selected.

Plants stake was done with plastic stake attached to a wireline placed about 2.5 m above the cultivation line and supported by the greenhouse structure. In the first cultivation cycle, the plants were not pruned, while in the second cycle, the plants were pruned after the issue of the tenth truss. The other cultural treatments (sprouts, defoliation, fruit thinning, plant lowering) and phytosanitary treatments were carried out, as necessary.

Cultivation system

The cultivation system used was in gullies or troughs, consisting of wood-made gullies (0.30 m wide, with lengths of 7.5 m in the first experiment and 6.0 m in the second experiment) arranged in double rows, with the distance between double lines of 0.50 m; and distance between single lines of 0.2 m. The troughs were supported by wooden trestles with a maximum height of 0.6 m, installed in such a way as to provide a slope of 3% for the nutrient solution to flow to the reservoir (Figure 2). This was made of fiberglass, with a capacity of 1000 L, and buried at the lower end of the cultivation troughs. Internally, the wooden troughs were coated with a double-faced polyethylene film (black/white), to form plastic troughs to convey the leachate to the return pipe. The troughs were filled with raw rice husks (10 cm high layer).

A ½ CV motor pump propelled the nutrient solution to the highest end of the troughs through a ½ inch PVC pipe. From this point on, the nutrient solution was supplied through drip tapes directed to the base of the plants, with a flow rate of 1.4 L h^{-1}. The drained nutrient solution returned to the catchment tank, forming a closed system (Figure 2). In the first hours after transplanting, the irrigation system remained working uninterruptedly to avoid possible water stress to the plants. After this period, irrigation was activated for 30 minutes every hour from 8:00 am to 7:00 pm, totaling 12 daily irrigations. During the night, it was activated once, for 15 minutes, to maintain the humidity of the root system.

Nutrient solution

The nutrient solution used for the tomato crop had the following composition: macronutrients (mmol $liter^{-1}$): 14.8 NO_3^-; 1.7 $H_2PO_4^-$; 3.25 SO_4^{-2}; 1.2 NH_4^+; 7.0 K^+; 5.2 Ca^{+2}; 2.2 Mg^{+2}; and micronutrients (mg $liter^{-1}$): 3.0 Fe; 0.5 Mn; 0.05 Zn; 0.6 B; 0.02 Cu and 0.01 Mo. The electrical conductivity (EC) of the solution was maintained at approximately 2.3 dSm^{-1}. To prepare the nutrient solution, rainwater with EC = 0.0 dS m^{-1} was used.

The monitoring of the nutrient solution was done daily and performed by checking the EC values (using a digital manual conductivity meter) and pH (using a digital manual pH meter). The pH value was maintained between 5.5 and 6.5 by adding a correction solution based on sodium hydroxide (1N NaOH), when necessary to increase the pH, or sulfuric acid (H_2SO_4) to decrease its value. The replacement of nutrients or water was carried out through the addition of concentrated stock solution or stored rainwater. Once a month, the catchment tank was cleaned, when the solution level reached the pump's minimum suction limit.

Traits measured

To evaluate the growth of the culture, during and at the end of the cultivation cycle, the quantification of the total accumulated fresh and dry matter of the control plants was carried out, including the fruits harvested during the production process, as well as the leaves from the defoliation. The following variables were analyzed: number of leaves issued, considering those with more than 0.05 m in length; total length of stem and leaf area. The latter was obtained through the square's method, using gridded transparent material (1.0 cm x 1.0 cm) which was placed on the leaves and counted the number of squares totally or more than 50% occupied by the leaves (De Lucena et al., 2011). The leaf area index (LAI) was obtained from the leaf area (cm^2) by multiplying the leaf area per plant by the plant density.

The stem, leaves, and fruit fractions were weighed on a precision scale to obtain the fresh matter and later were dried in an oven with forced air circulation (65 °C) to obtain the dry matter. The vegetative dry matter represents the result of the sum of the dry matter of the leaves and the stem, and the total dry matter, the sum of the vegetative dry matter and the fruits.

To collect data on the production and quality of fruits, weekly harvests of ripe fruits of two plants were carried out per repetition, avoiding the border plants, which were counted and weighed to obtain the number of fruits, yield, the mean weight of fruits, and total soluble solids content (ºBrix). The latter was obtained through monthly analyzes of fruits with 100% of the epidermis showing red color, using a portable refractometer. From the data of the number of harvested fruits and planting density, yield components were determined: number of fruits and crop yield (kg m^{-2}).

Experimental design and statistical analyses

The experiments were implemented in a randomized block design with four replications, in a factorial scheme (two x two), resulting from the combination of two levels of the plant type factor (grafted plants and non-grafted plants) and two levels of the factor pruning or number of stems per plant (plants conducted on a single-stem and plants conducted with two-stems).

The results obtained underwent a previous treatment, for descriptive analysis and inferences of possible 'outliers'. Subsequently, analysis of variance (ANOVA) and the means were compared by Tukey test at a 0.05 probability level for the qualitative treatment factors. For treatment factors of a quantitative nature, regression analysis was performed. All analyzes were performed using the statistical software program GENES 2013 (Cruz, 2013).

Conclusion

Grafted plants have greater vegetative and reproductive growth, as well as higher fruit yield than non-grafted plants in the raw rice husk substrate cultivation system, regardless of the number of stems. The quality of the fruits, concerning the concentration of sugars, is not affected by grafting, and the mean fruit size is favored in a long cycle. And in a long cycle, both for grafted and non-grafted plants, single-stem cultivation promotes greater crop growth and is more productive than plants with two stems. In a short cycle, from the point of view of reproductive growth and fruit yield, for both types of plants, cultivation with two stems is like that of single stem plants.

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References

Al-Harbi A, Hejazi A, Al-Omran A (2017) Responses of grafted tomato (*Solanum lycopersiocon* L.) to abiotic stresses in Saudi Arabia. Saudi J Biol Sci. 24:1274-1280.

Cruz CD (2013) GENES - a software package for analysis in experimental statistics and quantitative genetics. Acta Sci Agron. 35:271-276.

De Koning ANM (1990) Long-term temperature integration of tomato. Growth and development under alternating temperature regimes. Sci. Hortic. 45:117–127.

De Lucena RRM, Batista TMV, Dombroski JLD, Lopes WAR, de Oliveira GSR (2011) Measurement of acerola leaf area. Caatinga. 24:40-45.

Djidonou D, Simonne AH, Koch KE, Brecht JK, Zhao X (2016) Nutritional quality of field-grown tomato fruit as affected by grafting with interspecific hybrid rootstocks. Hort Sci. 51:1618-1624.

Djidonou D, Zhao X, Brecht JK, Cordasco KM (2017) Influence of interspecific hybrid rootstocks on tomato growth, nutrient accumulation, yield, and fruit composition under greenhouse conditions. Hort Tech. 26:868-877.

Du Plooy CP, Maboko MM, Van Den Heever E, Chiloane S (2012) Research and technology transfer by Agricultural Research Council to sustain South African hydroponic industry. Acta Hortic. 947:147-151.

Gaion LA, Braz LT, Carvalho RF (2017) Grafting in vegetable crops:a great technique for agriculture. Int J Veg Sci. 24:85-102.

Gomes RF, Castoldi R, Melo DM, Braz LT, dos Santos DMM (2017) Rootstocks for tomato conducted with four stems. Rev Ceres. 64:186-191.

Goto R, Santos HS, Cañizares KAL (2003) Enxertia em hortaliças 1nd ed. UNESP: São Paulo.

Kumar P, Rouphael Y, Cardarelli M, Colla G (2017) Vegetable grafting as a tool to improve drought resistance and water use efficiency. Front Plant Sci. 8(1130):1-9.

Lee JM, Kubota C, Tsao SJ, Bie Z, Hoyos Echevarria P, Morra L, Oda M (2010) Current status of vegetable grafting: Diffusion, grafting techniques, automation. Sci Hortic. 127:93-105.

Maboko MM, Plooy CP, Chiloane S (2017) Yield of determinate tomato cultivars grown in a closed hydroponic system as affected by plant spacing. Hort Bras 35:258-264.

Nawaz MA, Imtiaz M, Kong Q, Cheng F, Ahmed W, Huang Y, Bie Z (2016) Grafting: a technique to modify ion accumulation in horticultural crops. Front. Plant Sci. 7(1457):1-15.

Ntatsi G, Savvas D, Ntatsi G, Kläring HP, Schwarz D (2014) Growth, yield, and metabolic responses of temperature-stressed tomato to grafting onto rootstocks differing in cold tolerance. J Amer Soc Hort Sci. 139:230-243.

Peil RMN, López-Gálvez J (2004) Rendimiento de plantas de tomate injertadas y efecto de la densidad de tallos en el sistema hidropônico. Hort Bras. 22(2):265-270.

Peil RMN (2003) A enxertia na produção de mudas de hortaliças. Cienc. Rural. 33(6):1169-1177.

Rahmatian A, Delshad M, Salehi R (2014) Effect of grafting on growth, yield and fruit quality of single and double stemmed tomato plants grown hydroponically. Hort Environ Biotechnol. 55:115-119.

Riga P (2015) Effect of rootstock on growth, fruit production and quality of tomato plants grown under low temperature and light conditions. Hortic Environ. Biotechnol. 56:626-638.

Riga P, Benedicto L, García-Flores L, Villaño D, Medina S, Gil-Izquierdo A (2016) Rootstock effect on serotonin and nutritional quality of tomatoes produced under low temperature and light conditions. J Food Compos Anal. 46:50-59.

Rouphael Y, Schwarz D, Krumbein A, Colla G (2010) Impact of grafting on product quality of fruit vegetables. Sci Hort. 127:172-179.

Savvas D, Öztekin GB, Tepecik M, Ropokis A, Tüzel Y, Ntatsi G, Schwarz D (2017) Impact of grafting and rootstock on nutrient-towater uptake ratios during the first month after planting of hydroponically grown tomato. J Hortic Sci Biotech. 2017:1-9.

Schwarz, D. Rouphael Y, Colla G, Venema JH (2010) Grafting as a tool to improve tolerance of vegetables to abiotic stresses: thermal stress, water stress and organic pollutants. Sci Hort. 127:162-171.

Singh H, Kumar P, Chaudhari S, Edelstein M (2017) Tomato grafting: a global perspective. Hort Sci. 52:1328-1336.

Turhan A, Ozmen N, Serbeci MS, Seniz V (2011) Effects of grafting on different rootstocks on tomato fruit yield and quality. Hort Sci. 38:142-149.

Velasco-Alvarado MJ, Castro-Brindis R, Castillo-González AM, Avitia-García E, Sahagún-Castellanos J, Lobato-Ortiz R (2016) Mineral composition, biomass and fruit yield in grafted tomato (*Solanum lycopersicum* L.). Interciencia. 41:703-708.