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Production ecophysiology of the grafted and non-grafted tomato plants grown in substrate

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ABSTRACT

Grafting can be an ally in the vegetable's soilless cultivation, being the objective of this work evaluate the growth and production, as well as to define the thermal sum and trophic limit of grafted and non-grafted tomato plants cultivated in substrate. The experiments were conducted in a protected environment in the city of Jaguari-RS, in two growing seasons in the years 2019 and 2020. Italian and Gaucho tomato cultivars were used, the rootstock was chosen for giving vigor and longevity to the plants. Yield data were obtained through weekly fruit harvesting, growth data through periodic collections of whole plants and the total biomass obtained at the end of the experiments. Grafted plants show greater vegetative growth regardless of the crop season; however, non-grafted plants are more productive in a growing cycle with restricted light and low temperatures. Grafted plants require a greater thermal sum to complete their phenological stages. The trophic limit for grafted and non-grafted plants of Italian and Gaucho tomato cultivars is 4.8 MJ/m^2/day.

Keywords: *Solanum lycopersicum*, abiotic stress, trophic limit, thermal sum, growth.

RESUMO

Ecofisiologia da produção de plantas enxertadas e de pé franco de tomateiro cultivadas em substrato

A enxertia pode ser uma aliada no cultivo sem solo de hortaliças, sendo o objetivo deste trabalho avaliar o crescimento e a produção, assim como definir a soma térmica e o limite trófico de plantas enxertadas e não enxertadas de tomateiro cultivadas em substrato. Os experimentos foram conduzidos em ambiente protegido na cidade de Jaguari-RS, em duas safras de cultivo nos anos 2019 e 2020. Foram utilizadas cultivares de tomateiro do tipo italiano e gaúcho, o porta enxerto foi escolhido por conferir vigor e longevidade às plantas. Os resultados produtivos foram obtidos por meio da colheita semanal dos frutos, os dados de crescimento por meio de coletas periódicas de plantas inteiras e a biomassa total obtida ao final dos experimentos. As plantas enxertadas apresentam maior crescimento vegetativo independente da safra de cultivo, no entanto, as plantas não enxertadas são mais produtivas em ciclo de cultivo com restrição de luminosidade e baixas temperaturas. As plantas enxertadas exigem maior soma térmica para completar seus estádios fenológicos. O limite trófico para plantas enxertadas e de pé franco das cultivares de tomateiro do tipo italiano e gaúcho é de 4,8 MJ/m^2/dia.

Palavras-chave: *Solanum lycopersicum*, estresse abiótico, limite trófico, soma térmica, crescimento.

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Tomato cultivation is mostly carried out in the field, however, in recent decades, this practice in a protected environment has increased significantly to protect the crop from adversities like weather and improve production. Although in a protected environment, conventional soil cultivation of this crop has faced several problems such as the emergence of different physiological races, strains, or groups of soil pathogens; these difficulties can be solved or reduced with the grafted plants use.

Tomato grafting aims to combine plant resistance, productivity, and fruit quality to improve production in various aspects, being used both in field production and in a protected environment. However, grafting in tomato crops has shown a diversity of responses. Djidonou *et al.* (2016) report increases in production in grafted plants compared to non-grafted ones, while Loos *et al.* (2009) observed that grafted plants can produce more or less than non-grafted ones, depending on the rootstock used. On the other hand, Pedó *et al.* (2013) reported that non-grafted plants were more productive than grafted ones.

Still, when we talk about cropping in soilless systems (hydroponics or substrate systems), the use of grafted plants loses the reason, since these cropping systems are free of pathogenic organisms in the root environment. However, many producers have reported the grafting use in the tomato cultivation in substrate in a protected environment, claiming that grafted plants have greater vigor, productivity and longevity compared to the non-grafted.

Another factor in evidence for the use of grafted tomato plants in soilless cultivation is that this technique can offer other benefits, in addition to the function of giving resistance to soil pests and diseases. Several authors highlight that the grafting use to overcome adverse environmental conditions, such as high and low temperature stresses (López-Marín *et al.*, 2013; Muneer *et al.*, 2016), salinity (İşeri *et al.*, 2015), drought (Altunlu & Gul, 2012; Jimenez *et al.*, 2013) and flooding (Schwarz *et al.*, 2010; Bhatt *et al.*, 2015).

In this sense, by offering conditions for low temperatures tolerance, grafting would be an ally for tomato production in the autumn/winter period in the country's southern region, a time of the year when fruit prices are generally higher than those normally practiced. This value difference is due to stations considered critical for tomato production, low incidence of solar radiation and low temperatures.

For vegetables in tropical and subtropical climates, there is a minimum amount of daily global solar radiation necessary for the carbohydrates production by photosynthesis in a sufficient way to promote the plant's growth (significant accumulation of dry matter). This value is called the trophic limit, being referred to by FAO (2013), in a generic way, as 8.4 MJ/m^2/day. However, in the state of Rio Grande do Sul (RS), the months from May to August characteristically present values below this limit, as reported by Beckmann *et al.* (2006) for the region of Pelotas-RS.

Albuquerque Neto & Peil (2012) have already observed the adequate development of the mini-tomato crop in experiments conducted in greenhouses during the winter in Pelotas-RS. Perin *et al.* (2018) determined the value of 3.6 MJ/m^2/day as the trophic limit for two mini-tomato cultivars during autumn/winter in the same location. However, this limit has not yet been determined for other tomato plant groups, with larger fruits, which represent a greater carbohydrates demand for their growth. There are also no studies that indicate whether there are differences between the trophic limits of grafted tomato plants in relation to non-grafted.

In view of all the possible benefits associated with the grafting use in tomato crops, studies related to the ecophysiological behavior and management of grafted tomato plants compared to non-grafted in soilless cropping systems require research to lead to optimization production, including at times of the year previously considered inappropriate for the crop cultivation.

Therefore, the aim of this work was to evaluate the growth, production, fruits quality and to define the thermal sum and the trophic limit of grafted and non-grafted tomato plants cv. Gaucho and Italian, cultivated in substrate under restriction conditions of solar radiation and temperature.

MATERIAL AND METHODS

The experiments were carried out on a private rural property in Jaguari-RS, Brazil (29°30'S, 54°41'W) in the years 2019 and 2020. The first cultivation cycle was transplanted on February 25, 2019, and finished on August 5, 2019 (160 days), with vegetative development in summer and the initiation of productive development in the autumn and winter seasons. The second cycle was transplanted on September 19, 2019, in early spring and carried out until January 27, 2020, early summer (130 days).

The first experiment was carried out under a completely randomized experimental design, in a factorial scheme (2 x 2), resulting from the combination of two levels of cultivar factor (Guará and Rally), and two levels of grafting factor (grafted and non-grafted). Nineteen periodic collections of plants were carried out throughout the crop development cycle for each treatment, with two plants being evaluated per collection. The second experiment was carried out in randomized blocks design with four repetitions (two plants evaluated by replication), in a factorial scheme (2 x 2), because of the level's combination of cultivar and grafting.

The seedlings to carry out the work were purchased from the nursery Oriplanta in Nova Bassano-RS. Tomato seedlings of the cultivar Multifort® (Seminis) were used as rootstock. The grafts and seedlings of non-grafted plants were of the hybrid cultivar Guará® (HM Clause), Italian type, and of the hybrid cultivar Rally® (Topseed), of the Gaucho type, both with indeterminate growth habits. The grafting technique used was the simple English type, the seedlings were cut at an approximate angle of 45° and joined by plastic pressure clips.

The cultivation environment was in a greenhouse model "Ceiling in arch", with a mixed structure covered with a 150 μm-thick low-density polyethylene plastic film; North-South direction, with dimensions of 7 x 30 m, comprising an area of 210 m^2, ceiling height of 3.0 m and maximum height of 4.5 m. The management of the protected environment was carried out daily by opening and closing the side windows and doors of the greenhouse according to the variation of environmental conditions.

The plants were tutored with a raffia ribbon attached to a wire line placed about 2.0 m above the cultivation line and supported by the greenhouse structure. The other cultural treatments (sprouts removal, defoliation, fruit thinning, plant lowering) and phytosanitary treatments were carried out as necessary. Plants were conducted in single stem with spacing between plants of 0.4 m (population of 2.93 plants/m^2). During the experiments, meteorological variables of air temperature and relative humidity inside the greenhouse, and global solar radiation incident inside and outside the greenhouse were monitored daily.

The plants were grown in pots containing eight liters of carbonized rice husks; these were placed on wooden channels (0.30 m wide and 7.5 m long) arranged in double rows, with a distance between double rows of 1.2 m and distance between single lines of 0.5 m. Internally, the channels were coated with double-sided polyethylene film (black and white). The channels were supported by wooden trestles with a maximum height of 0.6 m, installed to provide a slope of 3% for to flow of the nutrient solution to the reservoir, to form a closed-type cultivation system, with reuse of leachate.

The fertigation system consisted of a fiberglass reservoir with 1,000 L capacity, buried at the lower end of the cultivation channels. A motor-pump set of ½ CV, boosted the nutrient solution to the highest quota end of the channels, through a ½ inch PVC pipe. From that point onward, the nutrient solution was supplied through drip tapes directed towards the plant's base, with drippers spaced at 0.40 m and an individual flow rate of 1.4 L/h. Fertigation was carried out by automatic activation through a timer every 1.5 hours, with 15-minute pulses between 7:00 am and 7:00 pm, totaling nine daily irrigations. During night, the system was activated once for 5 min to maintain the root system humidity.

To calculate the nutrient solution used, referenced solutions and some used by farmers were taken into account, resulting in the following macronutrient composition (mmol/liter): 14.8 of NO_3^-; 1.7 of $H_2PO_4^-$; 3.25 of SO_4^{-2}; 1.2 of NH_4^+; 7.0 of K^+; 5.2 of Ca^{+2}; 2.2 of Mg^{+2}; and micronutrients (mg/liter), 3.0 of Fe; 0.5 of Mn; 0.05 of Zn; 0.6 of B; 0.02 of Cu and 0.01 of Mo, with electrical conductivity (EC) of approximately 2.3 dS/m.The fertilizers used in the solution were calcium nitrate from Norway, ammonium sulphate, potassium nitrate, magnesium sulphate, potassium monophosphate, potassium sulphate, manganese sulphate, zinc sulphate, copper sulphate, boric acid, sodium molybdate and chelated iron 6%. The nutrient solution was prepared with rainwater with EC = 0.0 dS/m.

The nutrient solution was monitored daily by measuring EC (using a digital manual conductivity meter) and pH (using a digital manual pH meter). The EC entering the fertigation system depended on the leachate return EC, measured before the first irrigation, and could vary from 0.0 to 2.3 dS/m, to avoid substrate salinization. The pH was maintained between 5.5 and 6.5 by adding a correction solution based on sodium hydroxide (NaOH 1N) and sulfuric acid (H_2SO_4).

In the summer/autumn experiment, periodic collections of whole plants were made to define the trophic limit for the crop. The evaluations began on the day of transplantation to obtain the seedlings initial matter. From the second collection, the plants were collected randomly (raffle), always respecting the treatments, and dispensing the plants in the parcel edges. The variables analyzed were: production; mean weight of fruits, dry matter and fruit size; total soluble solids content (TSS; ºBrix), obtained with a portable refractometer by analyzing fruits with 100% of the red-colored epidermis; number of leaves issued, considering those with more than 0.05 m in length; leaf area measured using the squares method according to Lucena *et al.* (2011); plant height; fresh matter of each of the plant fractions (fruits, leaves and stems); and dry matter obtained by drying the material to a constant weight in an oven with forced air circulation (65°C). The absolute growth rate (AGR) and relative growth rate (RGR) variables were calculated according to the method described by Benincasa (2003).

The commercial fruits were harvested weekly, and those harvested in the intervals between the plant collections were counted and weighed to obtain the productive data, and dry matter data referenced to the respective plants for further summation at the time of the total collection of the plants. The non-commercial fruits obtained in the collections of the whole plants had their dry matter allocated in the variable of dry matter of the fruits.

In the second experiment, the productive and qualitative fruits data were collected during the harvests and the biomass data only at the end of the experiment, using the same methodology as in the first experiment.

Incident global solar radiation data inside and outside of the greenhouse were obtained using handcrafted solarimeter tubes with printed circuit boards (Duarte *et al.*, 2010), installed in the same direction (north/south) inside the protected environment (over the crop canopy), and outside the environment, avoiding any type of shading.

The air temperature was obtained by a set of dry bulb and wet bulb thermometers (model 107 temperature probe). Data were collected and stored by a data acquisition system (datalogger CR1000), obtaining daily values of incident solar radiation (Gi). The thermal sum data were obtained according to the calculation methodology and base and optimal temperature values used by Schmidt *et al.* (2017).

After obtaining the final data, they underwent prior treatment for descriptive analysis and inferences of possible ‘outliers’. Subsequently, variance analysis (ANOVA) and Tukey and Scott-Knott mean comparison tests were performed at 5% probability of error. All analyzes were performed using the GENES software (Cruz, 2013).

RESULTS AND DISCUSSION

According to statistical analysis, all variables followed the normal distribution of errors by the Shapiro-Wilk test (w>p). The variance analysis showed significant differences for the grafting treatment, depending on the variables and the growing season. The coefficients of variation (CV%) fluctuated from 3.4% to 13.9% for the productive variables and from 3.0% to 13.7% for the growth variables.

Grafting did not increase productivity for the cultivar Guara (Table 1) in the first trial. On the contrary, grafted plants produced 0.9 kg/plant less. This same response was observed for dry fruit matter. Regarding the variables of mean weight matter, total soluble solids and fruit dimensions, there was no significant difference between grafted and non-grafted plants. For cultivar Rally there were no significant differences between grafted and non-grafted plants for all variables (Table 1).

In the second cultivation cycle, there

Table 1. Main effects of cultivars and grafting factor on yield, mean weight and dry matter of fruits, total soluble solids (TSS) and fruit size of tomato plants in two growing seasons in potted production system with rice husk substrate. Jaguari, UFPel, 2019/2020.

Crop	Cultivars	Grafting	Fruit yield (kg/plant)	Mean weight of fruits (g)	Fruits dry matter (g/plant)	TSS (ºBrix)	Fruit size (mm)	
							Height	Width
Summer/Winter 2019	Guará	Grafted	4.2 b*	120.0 ns	193.8 b	6.2 ns	71 ns	49 ns
		Non-grafted	5.1 a	113.0	253.8 a	5.5	72	46
	Rally	Grafted	4.7 ns	195.8 ns	226.2 ns	6.0 ns	50 ns	64 ns
		Non-grafted	5.4	200.0	274.1	6.0	48	66
	CV (%)		17.4	11.4	16.5	6.1	3.4	2.4
Spring/Summer 2019/2020	Guará	Grafted	6.1 ns	152.3 ns	328.3 ns	6.0 ns	98 ns	65 ns
		Non-grafted	5.7	146.7	308.4	5.2	96	62
	Rally	Grafted	6.7 ns	222.1 ns	264.1 ns	5.9 ns	68 ns	88 ns
		Non-grafted	6.2	216.5	245.7	5.8	64	86
	CV (%)		13.8	11.9	13.9	5.2	4.9	3.4

Means followed by the same lowercase letter, in the column, do not differ at 5% probability, by Tukey test. ns not significant.

was no significant difference between grafted and non-grafted plants, for both cultivars, for any of the variables (Table 1). The spring/summer cropping cycle was more productive than the summer/winter cycle, both in terms of production per plant and in relation to fruit size.

Regardless of the cultivation cycle and cultivars (Table 1), grafting did not show a positive effect of higher fruit production. Likewise, it did not affect the soluble solids content of the fruits, according to the work of Buller *et al.* (2013). The non-expression of superior results by the grafted plants is since the soilless cultivation is a production system free of pathogens and soil diseases and for this reason the grafted and non-grafted plants were under the same favorable development conditions. With easily available water and nutrients, both plant types equaled their productive potentials and, thus, grafting did not express its superiority compared to non-grafted plants (Lang & Nair, 2019).

On the other hand, the grafted plants showed greater vegetative growth (Table 2), expressed in a greater leaves number, vegetative dry matter, root dry matter and total dry matter for both cultivars in the first summer/winter assay. In the second experiment, there were no significant differences between grafted and non-grafted plants for most variables, only root dry matter was approximately 7 g/plant higher in grafted plants for both cultivars.

On the other hand, the grafted plants characteristically presented a more vigorous root system than the non-grafted (Table 2), as well as greater growth of aerial vegetative organs, corroborating the results found by Mohammed *et al.* (2009) and by Soare *et al.* (2018), who also observed greater growth of grafted plants compared to non-grafted. This greater characteristic of vigor is expressed due to the selection and genetic improvement of plants and, therefore, it is intrinsic to the rootstock,

Table 2. Main effects of cultivars and grafting factor on the leaves number, leaf area index (LAI), plant height, vegetative, root and total dry matter of tomato plant in two growing seasons in potted production system with rice husk substrate. Jaguari, UFPel, 2019/2020.

Crop	Cultivars	Grafting	Nº leaves/ plant	LAI	Plant height (m)	Vegetative dry matter** (g/plant)	Root dry matter (g/plant)	Total dry matter*** (g/plant)
Summer/ Winter2019	Guará	Grafted	50 a*	4.3 a	3.8ns	239.7 a	68.5 a	502.0 a
		Non-Grafted	46 b	3.5 b	3.8	176.6 b	59.0 b	489.4 b
	Rally	Grafted	51 a	4.9 ns	3.4 ns	216.1 a	69.1 a	511.4 a
		Non-Grafted	47 b	4.9	3.3	167.9 b	59.4 b	501.4 b
	CV (%)		1.2	4.9	3.0	5.5	3.0	2.9
Spring/ Summer 2019/2020	Guará	Grafted	37 ns	3.4 ns	2.4 ns	190.5 ns	48.9 a	567.7ns
		Non-Grafted	36	3.3	2.3	174.6	42.1 b	525.1
	Rally	Grafted	37 ns	4.4 ns	2.3 ns	180.2 ns	49.4 a	493.7 ns
		Non-Grafted	37	4.2	2.2	165.7	42.4 b	453.8
	CV (%)		3.0	13.7	4.1	11.8	3.5	11.2

* Means followed by the same lowercase letter, in the column, do not differ at 5% probability, by the Tukey test. ** Vegetative dry matter = leaves + stems. *** Total dry matter = leaves + stems + roots + fruits. ns not significant.

aiming to give it a more robust root system for greater expansion in the soil and greater capacity to absorb water and nutrients in different situations from biotic (caused by pests and diseases) or abiotic (water stress and soil salinity) stresses. For these reasons, grafted plants are more vigorous than non-grafted, as observed by Urlic *et al.* (2020) in soil cultivation.

In the same sense, the cultivation system in pots used in these experiments may have limited the expression of greater growth of the root system of the grafted plants, negatively affecting their vegetative and productive development compared to non-grafted. Another factor to consider, specifically for summer/winter cultivation, would be the fact that the rootstock does not present characteristics to overcome adverse environmental conditions, such as low temperatures (minimum below 10ºC) and solar radiation mean lower to 8.4 MJ/m²/day, for example. And for this reason, the grafted plants were less productive in the first cropping cycle, while in the second cycle, spring/summer, under more suitable climate conditions for the crop, the grafted plants showed, although not significantly, greater productive magnitude compared to non-grafted.

Regarding plant responses to meteorological variables (Figure 1), grafted plants had a longer cycle, which expressed in terms of thermal time resulted in higher thermal sum values to reach each stage of development, compared to non-grafted plants, on both crops. In the summer/winter experiment, the mean temperature during the transplanting and harvesting phases was 22.4ºC, with a minimum of 11.5ºC and a maximum of 37.4ºC. The non-grafted plants needed 71 days and 836 degrees days from transplanting to fruit harvest and the grafted plants 75 days and 882 degrees days. In the spring/summer experiment, the mean temperature was 23.3ºC with a minimum and maximum of 4.8ºC and 40.5ºC, respectively, the non-grafted plants needed 68 days and 718 degrees days to fulfill the cultivation cycle and grafted plants 71 days and 759 degrees days.

Despite being a vegetable with wide climate adaptation, the tomato crop is strongly influenced by air temperature conditions, requiring temperatures between 11 and 24ºC for its proper development, in addition to a certain thermal amplitude, with a considerable reduction in temperatures during the night (Schmidt *et al.*, 2017). In this sense, the thermal sum calculation

Table 3. Mean for the different evaluation periods of daily global solar radiation incident on the crop (Gi), minimum (Min), maximum (Max) and mean (Mea) air temperatures, total dry matter (DM), dry matter increase (DMI), absolute (AGR) and relative (RGR) growth rates of two tomato cultivars (Rally® and Guará®) grafted (G) and non-grafted (NG), throughout the summer/winter. Jaguari, UFPel, 2019.

Collects	Gi	Temperature (°C)			TOTAL DM (g)		DMI	AGR	RGR
	(MJ/m²/day)	Min	Max	Mea	G	NG			
0	0	0.0	0.0	0.0	0.27 I	0.14 H	0.0 E	0.0 D	0.00 E
14	12.3	18.2	31.5	23.9	5.50 I	3.08 H	4.1 E	0.3 D	0.22 A
28	15.1	17.5	29.7	22.8	51.8 H	41.6 G	42.4 B	3.0 B	0.17 B
42	11.1	18.1	29.7	22.9	74.9 G	78.8 F	30.2 C	2.2 C	0.04 B
56	10.7	16.3	28.8	21.6	161.1 F	127.2 E	67.3 A	4.8 A	0.04 B
70	6.8	16.7	26.8	21.5	202.5 E	170.1 D	42.2 B	3.0 B	0.02 C
77	4.9	15.8	25.4	19.4	208.6 E	197.2 C	17.8 D	2.5 B	0.01 D
84	5.5	13.8	24.2	18.1	218.7 E	212.4 C	12.5 D	1.8 C	0.01 D
91	4.3	14.6	23.7	18.3	206.7 E	195.6 C	0.6 E	0.1 D	0.00 E
98	3.3	14.5	21.8	17.3	208.9 E	196.6 C	3.1 E	0.5 D	0.00 E
105	5.3	11.7	23.9	16.5	219.4 E	203.7 C	11.3 D	1.6 C	0.01 D
112	4.8	17.3	28.3	21.5	240.9 D	206.3 C	17.3 D	2.5 B	0.01 D
119	6.6	12.4	26.5	18.3	268.8 C	239.9 B	30.7 C	4.4 A	0.02 C
126	4.7	11.5	25.3	17.4	256.9 C	237.8 B	1.3 E	0.2 D	0.00 E
133	6.8	3.1	24.6	10.8	290.9 B	259.2 B	27.8 C	4.0 B	0.01 D
140	5.1	9.5	24.4	15.5	292.3 B	250.9 B	1.1 E	0.2 D	0.00 E
147	6.8	8.9	26.1	15.1	300.5 B	253.6 B	6.2 E	0.9 D	0.00 E
154	2.4	13.7	19.8	15.9	292.1 B	252.0 B	1.6 E	0.2 D	0.00 E
161	6.3	8.3	25.4	14.7	342.5 A	298.2 A	48.3 B	6.9 A	0.02 C
CV (%)					6.6		57.2	71.0	30.0

Means followed by the same letter in the column do not differ from each other according to Scott-Knott test.

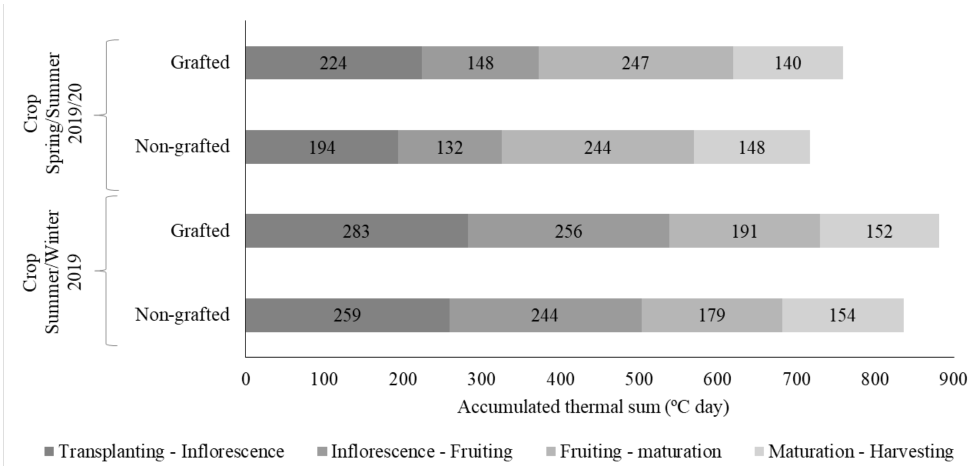

Figure 1. Thermal sum of grafted and non-grafted tomato plants, quantified by development stages in two growing seasons in potted production system with rice husk substrate. Jaguari, UFPel, 2019.

makes air temperature readings standard, transforming them into degrees days and providing a physiological measure that estimates the available energy to the plant each day (Palaretti *et al.*, 2012). And, as shown in the Figure 1, the harvest beginning in both seasons occurred approximately 70 days after transplanting. However, it was observed that plant behavior throughout the phases was different, as the crops were grown at different times of the year, and in which temperatures showed different variations. Additionally, the grafted plants had a delay in their initial development of a few days, due to the practice of grafting, which changes the final plant morphology. Argericha & Smith (2019) observed the same behavior in their assays.

Regarding the summer/winter crop (Figure 2), throughout the cycle, measurements inside the greenhouse indicated daily mean values of global solar radiation incident on the crop canopy of less than 8.0 MJ/m^2/day from the 70th day after transplantation (DAT), with the occurrence of a minimum temperature of 0.0ºC and a minimum mean temperature of 10.8°C, with temperature events below 10ºC in 30 days during the months July and August.

In this season, plants showed growth expressed in dry matter accumulation, increasing throughout the cycle, but with some stability periods. The grafted plants showed higher mean values of root accumulated dry matter (Guará 49.5 g/plant and Rally 52.0 g/plant) and vegetative organs (Guará 135.9 g/plant and Rally 116.9 g/plant) compared to non-grafted plants [root (Guará 44.0 g/plant and Rally 47.4 g/plant) and vegetative organs (Guará 105.8 g/plant and Rally 100.4 g/plant)]. On the other hand, non-grafted plants presented higher accumulated mean values of fruits dry matter (Guará 30.4 g/plant and Rally 32.4 g/plant) compared to grafted plants (Guará 22.5 g/plant and Rally 28.0 g/plant).

Regarding plant growth, this occurred significantly until 70 DAT, due to a higher incident solar radiation period (greater than 8.4 MJ/m^2/day) and higher temperatures mean at 20ºC, in addition to this period coinciding with the phase of greater vegetative development than productive (Figure 2). From 70th DAT, solar radiation and temperatures decreased, as well as the plants also reduced their growth speed and began the maturation and fruit harvesting period. Solar radiation influences photo-assimilates production, whose demand is greater the larger the plant and fruit size (Reis *et al.*, 2013). Temperature affects photosynthesis reactions speed, and plant transpiration (Delgado-Tobón *et al.*, 2020). Both variables are key parts in the plant growth process, since the larger the plants, the greater their need for carbohydrates and energy to maintain their metabolic functions and continue to accumulate dry matter, in addition to influencing the development speed and the fruit size.

The grafted plants, due to the characteristics conferred by the rootstock with a more developed root system and greater aerial part vigor, present a greater demand for carbohydrates to maintain their metabolism and express their potential growth. For this reason, the greater vigor of plants was not expressed in greater productive results under restricted solar radiation conditions (below 8 MJ/m^2/day) and mild mean temperatures (between 11 and 20ºC), during the autumn/winter period (after 70 DAT), as shown in Figure 2. In this sense, the rootstock used in these experiments was not presented as a viable alternative for management in the autumn/winter conditions of Rio Grande do Sul.

However, these unsatisfactory results in production terms do not mean that the grafting technique in tomato crops is not efficient, since many studies bring positive results with this technique, as observed by Turhan *et al.* (2011), Ntatsi *et al.* (2014), Al-Harbi *et al.* (2017) and Soare *et al.* (2018). However, it is a fact that, especially in Brazil, there is a need to evolve in terms of rootstock cultivars improvement and, more specifically, cultivars for

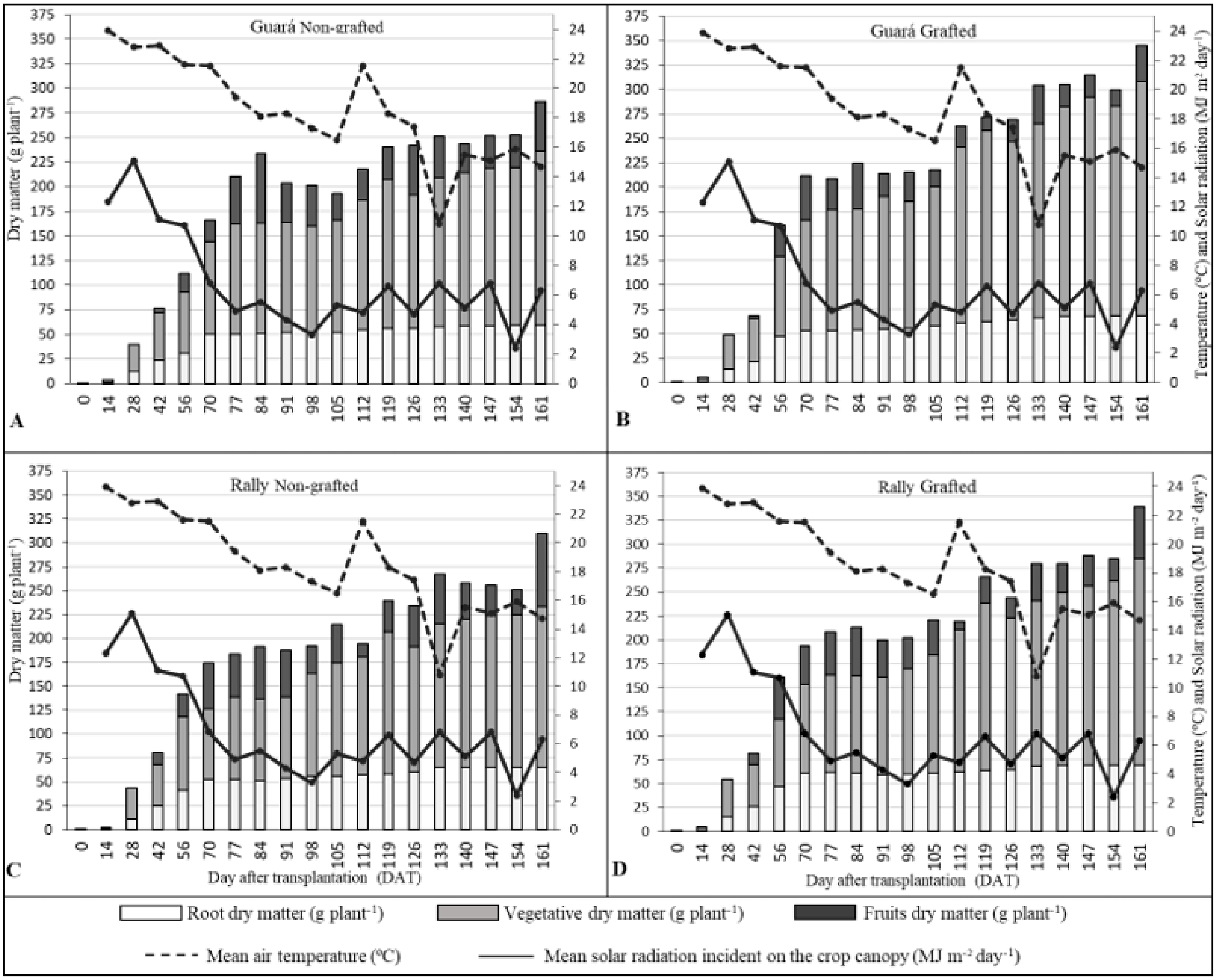

Figure 2. Daily mean values of temperature and global solar radiation incident inside the greenhouse and dry matter production of different plant organs of two tomato cultivars (Rally and Guará), grafted (B and D) and non-grafted (A and C), in summer/winter cropping cycle, in potted production system with rice husk substrate. Jaguari, UFPel, 2019.

use in soilless cultivation systems and to overcome abiotic stresses, such as low radiation incidence, temperature extremes and salinity of the culture medium, for example.

In Table 3, the data of average solar radiation incident inside the cultivation environment and of the minimum, average and maximum temperatures associated with the responses of the culture in relation to the production of total dry matter (DM), dry matter increase (DMI), absolute (AGR) and relative (RGR) growth rates, throughout the cultivation cycle of the first trial (summer/winter 2019 crop). The grafted and non-grafted plants showed statistical difference between them for the variable total dry matter, being presented separately. On the other hand, there was no significant difference between the types of plants for the variables of dry matter increase (DMI), absolute (AGR) and relative (RGR) growth rates, so the values were presented as a general average.

Plants showed lowest DMI, AGR and RGR values at 91, 98, 126, 140, 147 and 154 DAT, with values lower than 6.2 g/plant/period, lower than 0.9 g/plant/period and equal to 0.00 g/g/period for each of the variables, respectively (Table 3). The plants presented significant minimum values of RGR in the periods 77, 84, 105, 112 and 133 DAT, with minimum mean values of daily incident solar radiation equal to and superior to 4.8 MJ/m^2/day. This value can be considered the trophic limit for the cultivation of Rally and Guara tomato cultivars.

Regarding plant growth in the autumn/winter period (Table 3), it was found that plants can maintain their metabolism and express some growth type in the form of dry matter accumulation in this period of restricted solar radiation conditions and minimum temperatures. The literature mentions 8.4 MJ/m^2/day, also known as the trophic limit of these crops, as the minimum value of solar radiation necessary to increase the dry matter of vegetables in tropical and subtropical climates. However, it was verified (Table 3) and already observed by Perin *et al.* (2018) for mini-tomato crop, that this value can be significantly lower. In this experiment, using grafted and non-grafted plants of two tomato cultivars, conducted on a single stem and planting density of 2.93 plants/m^2, the minimum significant value of RGR coincided with 4.8 MJ/m^2/day of solar radiation incident inside the cultivation environment (mean LAI recorded in this period was 35404). The trophic limit value may vary depending on the way the plants are conducted and the spacing used and may be greater for denser crops and with greater LAI.

Thus, it can be stated, as already observed by Albuquerque Neto & Peil (2012), that the tomato crop presents growing conditions during the autumn/winter period of Rio Grande do Sul under radiation conditions incident global solar with values inferior to 8.4 MJ/m^2/day. However, it is necessary to note that other minimum conditions need to be met, such as maintaining temperatures under conditions that allow the proper plants development, not inferior to 0.0ºC for their survival and above 10ºC for proper setting and fruits development and significant plants growth (Shamshiri *et al.*, 2018). Another factor to concern is the planting density, since in low incidence of solar radiation periods, increasing the spacing between plants allows greater insolation of the crop canopy, improving its photosynthetic capacity and its growth.

Without the heating used to maintain temperatures above 10ºC, plant production in this critical period is low, due to the high flower abortion rate and poor fruit formation. On the other hand, producers who can carry out heating of the cultivation environment will probably achieve superior results, as the conditions will allow adequate fruit set and growth, ensuring yields within the expected by the culture.

Therefore, it can be concluded that grafted plants have greater vegetative growth than the non-grafted, regardless of growing season. Non-grafted plants are more productive in a growing cycle with restricted light and low temperatures; on the other hand, under more suitable temperature and light conditions, grafted plants can be equal and have the potential to present greater productive magnitude than non-grafted plants. Finally, the trophic limit for grafted and non-grafted plants of Rally and Guara tomato cultivars is 4.8 MJ/m^2/day.

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