Revista de
CIENCIAS AGRÍCOLAS

e-ISSN Online 2256-2273

Received: February 16 2025 Accepted: February 20 2026 Published: April 15 2026

Research article: Horticulture

Intraspecific hybrid rootstocks in the agronomic performance of salad-type tomato

Portainjertos híbridos intraespecíficos en el rendimiento agronómico del tomate tipo ensalada

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Cite: Campos, L. F. C., Campos, C. M. A., Virgílio, M. L. S., Faria, R. C., & Nascimento, A. R. (2026). Intraspecific hybrid rootstocks in the agronomic performance of tomato salad type. *Revista de Ciencias Agrícolas*, 43(1), e1287. https://doi.org/10.22267/rcia.2026431.287

ABSTRACT

Grafting can either favor or limit growth, productivity, and fruit quality; therefore, choosing the right combination of scion and rootstock is essential for the plant's performance. This study aimed to evaluate the growth and production of tomato hybrids from the salad group grafted onto different rootstock hybrids. Two experiments were conducted using a combination of the salad-type hybrids Valerim and Dylla with five rootstock hybrids: Shield RZ, Green Rise, Green Power, Shincheonggang, and Guardian. The experimental design was randomized blocks, with seven treatments and four replications per treatment. The treatments consisted of combining the rootstocks with each graft (Valerim and Dylla), in addition to autografting the two grafts and the non-grafted seedlings, that is, the two grafts without grafting. Non-grafted seedlings were defined as the control treatment. The interaction with rootstocks or autografting influences the stem growth and diameter up to 30 days after transplantation of the hybrids Valerim and Dylla. However, the rootstocks evaluated did not affect development or compatibility. For the yield parameters, the combinations Valerim/Valerim, Shield RZ, Guardian, and Green Rise presented positive effects. Grafting did not influence the yield parameters of the Dylla hybrid. Likewise, grafting did not influence the physicochemical characteristics of the fruits of the two hybrids, Valerim and Dylla.

Keywords: grafting; physicochemical characteristics; *Solanum lycopersicum*; vegetable production; vegetative growth; yield

RESUMEN

El injerto puede favorecer o limitar el crecimiento, la productividad y la calidad del fruto, por lo que la elección adecuada de la combinación vástago-portainjerto es fundamental para el rendimiento de la planta. El objetivo de este trabajo fue evaluar el crecimiento y producción de híbridos de tomate, del grupo de las ensaladas, injertados sobre diferentes híbridos de portainjertos. Se realizaron dos experimentos, utilizando la combinación de híbridos tipo ensalada, Valerim y Dylla, con cinco híbridos portainjertos: Shield RZ, Green Rise, Green Power, Shincheonggang y Guardião. El diseño experimental fue en bloques al azar, con siete tratamientos y cuatro repeticiones por cada experimento. Los tratamientos consistieron en combinar los portainjertos con cada injerto (Valerim y Dylla), además del autoinjerto de los dos injertos, y las plántulas no injertadas, es decir, los dos injertos sin injertar. Las plántulas no injertadas se definieron como tratamiento de control. El crecimiento y diámetro del tallo, hasta 30 días después del trasplante, de los híbridos Valerim y Dylla estuvo influenciado por la interacción con portainjertos o autoinjerto, pero el desarrollo y la compatibilidad no fueron afectados por los portainjertos evaluados. En cuanto a los parámetros de rendimiento, se observó un efecto positivo en las combinaciones Valerim/Valerim, Shield RZ, Guardião y Green Rise. Los parámetros de rendimiento del híbrido Dylla no fueron influenciados por el injerto. Asimismo, las características físico-químicas de los frutos tanto de los híbridos Valerim como Dylla no fueron influenciadas por el injerto.

Palabras clave: características fisicoquímicas; crecimiento vegetativo; injerto; producción vegetal; rendimiento; *Solanum lycopersicum*

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is grown in all geographic regions of Brazil at different times, under various cultivation systems and different levels of cultural management, standing out as the second most cultivated vegetable in Brazil, being surpassed only by potato (*Solanum tuberosum* L.) (Albuquerque *et al.*, 2018). However, the cultivation of this crop faces many challenges, including abiotic and biotic stresses, which negatively affect yield characteristics and production quality (Bayındır & Kandemir, 2023). Both the public and private sectors are actively working on developing tomato cultivars that can thrive under restrictive conditions. This process involves breeding techniques and biotechnological advancements; however, it demands a significant investment of time (Singh *et al*., 2017).

An alternative approach is the grafting technique, which has emerged as a potential tool to rapidly increase the efficiency of high-yield genotypes, for greater adaptability or resistance to different conditions (Kumar *et al.*, 2017), mainly associated with consequences of intensive cultivation (Lee *et al.*, 2010). The objective of grafting ranges from the use of rootstock resistant or tolerant to soil-borne diseases (Martins, 2012; Shalaby *et al.,* 2022), in addition to controlling salinity problems (Zeist *et al.,* 2023) or even temperature fluctuations (Shehata *et al.*, 2022), as well as improving the use of water and nutrients, increasing plant vigor, extending the harvest period (Rizzo *et al.*, 2004; Zhang *et al.*, 2021), and improving fruit quality (Flores *et al.*, 2010; Zhou *et al.,* 2022). Using resistant rootstocks is the most economical and environmentally sustainable method to combat these stressors (Kabas & Kucukaydin, 2023). Although they have a higher initial cost, grafted seedlings can provide greater economic returns due to their higher survival rate in contaminated soils, better soil utilization, and enhanced nutrient uptake, resulting in increased productivity.

Each rootstock interacts uniquely with the graft, influencing plant performance under varying environmental conditions. Consequently, selecting an appropriate graft and rootstock combination is essential to achieving the desired outcomes (Goto *et al*., 2013; Lee *et al*., 2023). This combination regulates hormonal signals, photosynthesis, and the transport of nutrients and water, thus altering the plant's structure and growth performance (Huang *et al*., 2025). Furthermore, grafting can also extend the growing period of tomato plants, making them more vigorous in the final stage of development, which is suitable for situations requiring long-term cultivation (Lee *et al*., 2022). Vigorous rootstocks can induce more vigorous plants that produce more fruit and have higher yields (Balliu *et al*., 2024; Hashem *et al*., 2024). While some grafting combinations promote vegetative growth and development, others may have the opposite effect, potentially restricting growth (Huh *et al*., 2003), reducing yield (Yetisir *et al*., 2003), and affecting fruit quality (Davis *et al*., 2008).

Thus, this study is based on the importance of understanding the result of the interaction between the graft and rootstock for the tomato cultivation, which provides adequate crop development and greater yield, with a consequent increase in producer profitability. In this regard, the present study aimed to evaluate the growth and production of tomato hybrids from the salad group grafted onto different rootstock hybrids.

MATERIALS AND METHODS

Study area and experimental conditions

The experiment was conducted in the vegetable garden of the Horticulture Sector, School of Agronomy, Federal University of Goiás (UFG), in Goiânia, Goiás, at the geographic coordinates of: 16º35'46" S and 49º16'52" W, at a mean altitude of 741 m.

According to the Köppen-Geiger classification, the climate is of the Aw type (tropical with dry season in winter) (Dubreuil *et al*., 2018). The experimental period was from May to August 2020. Meteorological data of maximum, minimum, and mean temperatures (Fig. 1) were collected at one-hour intervals throughout the experimental period using a portable weather station, Davis Vantage Vue Pro 2, model 6250.

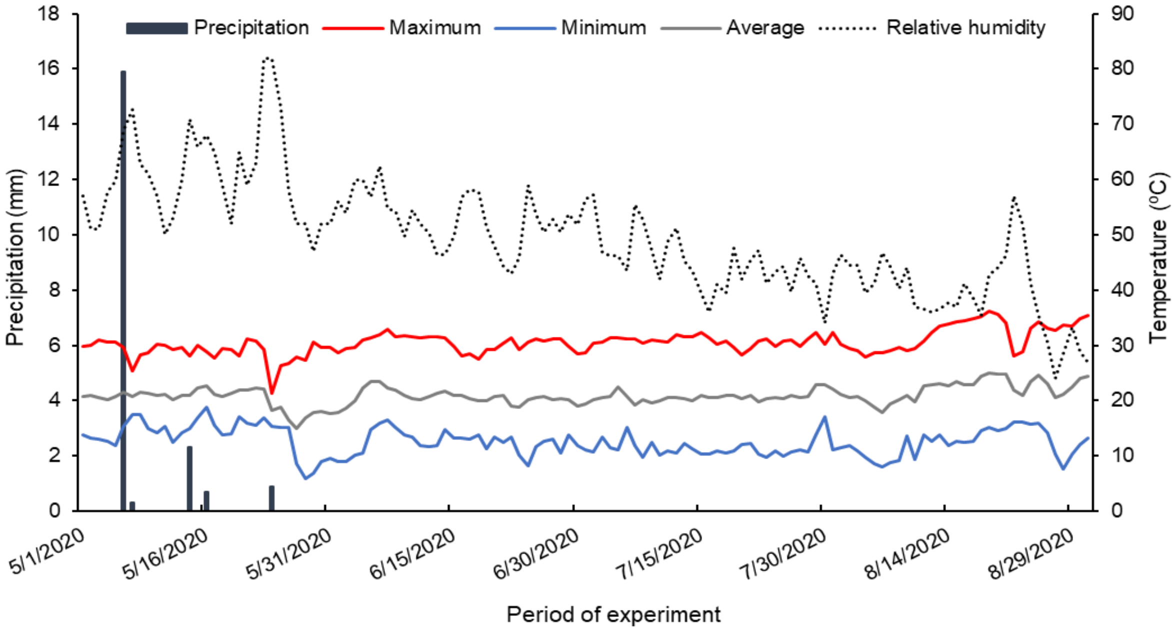


Figure 1. *Precipitation, minimum, maximum, and average air temperature, and relative humidity during the experiment*.

The soil of the area was classified as a Dystrophic Red Latosol (a type of Oxisol), whose chemical and physical characteristics prior to the establishment of the experiment, at a depth of 0–20 cm, were as follows: pH ($CaCl_2$) = 5.5; P (Melich 1) = 90.0 mg/dm3; K = 0.164 cmolc/dm3; Ca = 3.9 cmolc/dm3; Mg = 1.2 cmolc/dm³; Ca+Mg = 5.1 cmolc/dm³; Al = 0 $cmol_c$/dm³; H+Al = 2.2 cmolc/dm³; Na = 1 mg/dm³; B = 0.26 mg/dm³; Cu = 1.1 mg/dm³; Fe = 51 mg/dm³; Mn = 22 mg/dm³; Zn = 3.4 mg/dm³; V% = 70%; CEC = 7.46 cmolc/dm³; Organic matter = 16 g/kg^{-1}; clay = 390 g kg^{-1}; silt = 250 g kg^{-1}; and sand = 360 g kg^{-1}.

Crop management

The soil was prepared conventionally using a harrow and a bed former. To correct the soil, 800 kg ha^{-1} of dolomitic limestone was applied, while fertilization at planting involved 1,667 kg ha^{-1} of NPK 04-30-10, supplying 67, 500, and 167 kg ha^{-1} of N, P, and K, respectively. Cover fertilization was administered through fertigation, beginning ten days after transplanting. This process included the application of MAP Crystal, potassium chloride, calcium nitrate, potassium nitrate, magnesium sulfate, potassium sulfate, boric acid, and zinc sulfate, distributed in three weekly applications throughout the tomato growth cycle. The applied doses of each nutrient were: 132 kg ha^{-1} of N; 200 kg ha^{-1} of P; 477 kg ha^{-1} of K; 109 kg ha^{-1} of Ca; 22 kg ha^{-1} of Mg; 93 kg ha^{-1} of S; 4 kg ha^{-1} of Bo; and 2 kg ha^{-1} of Zn. The soluble fertilizers were previously dissolved in a 500-liter water tank, and the solution was subsequently pumped into the drip irrigation system. Foliar application of calcium-boron-based fertilizer (NutrireCaB®) was carried out weekly as a supplement, from the beginning of flowering until fruit formation.

Pests and diseases were monitored, and control was carried out according to the level of infestation, following the recommendations of the integrated pest and disease management for tomato crops (Zambolim & Quezado-Duval, 2022). Fungicides and insecticides were applied alternately with different active ingredients, as needed. To control spontaneous plants, the beds were covered with white polyethylene plastic film (mulching) with a black background, 25 µm thick and 1.40 m wide. Furthermore, mechanical weeding was carried out between the rows.

The rootstock and graft seedlings were produced in an agricultural greenhouse in 200-cell trays filled with commercial coconut fiber substrate. Grafting was performed 21 days after sowing (DAS) using the lateral slit type (45º). In both parts, the cut was made below the cotyledonary leaf. A silicone clip was used to join the two plants. The grafted plants remained in a humid chamber under 100% shade for five days and then were acclimatized in a greenhouse for 23 days until planting.

The plants were tutored with ribbons. These were tied to wires, tensioned above the flowerbeds, and fixed to posts at the ends and in the middle of the flowerbeds, with a spacing of 5 m. The plants in all treatments were grown with two stems. Sprouting occurred once a week, from 30 days after transplanting until apical pitching (or tipping), when the plant reached approximately 1.80 m in height.

Experimental design and treatments

Two experiments were carried out using the combination of salad-type Valerim and Dylla with five rootstock hybrids: Shield RZ, Green Rise, Green Power, Shincheonggang, and Guardião (Table 1). The experimental design was developed in randomized blocks, with seven treatments in four replications in each experiment. The treatments consisted of combining the rootstocks with each graft (Valerim and Dylla) and the self-grafting of the two grafts and the non-grafted seedlings, i.e., the two grafts without grafting. Non-grafted seedlings were defined as the control treatments.

The experimental plot comprised ten plants arranged in double rows spaced at 0.70 m and with a spacing between plants of 0.50 m. The spacing between beds of 1.0 m wide by 0.20 m high was 1.50 m, forming a density of 18,182 plants/ha^{-1}. The six central plants in each plot were defined as useful.

Table 1. *Information on the strength and vigor of the grafts and rootstocks used in this study*

Rootstock	Resistance*	Vigor*	Enterprise
Shincheonggang	ToMV:0-2/ Rs/ Fol:0-2/ For/ Va:0/ Vd:0/ Ma/ Mi/ Mj	Low	Seminis
Green Power	RS/PL/Fol 1 & 5/Fol 3/For/Vd/Ma/Mi/Mj	Medium	Takii Seeds
Green Rise	RS/PL/FOL 1 & 7/FOL 5/For/Vd/Ma/Mi/MJ	Medium/High	Takii Seeds
Guardião	Rs/ Fol 1 and 3/ For/ Vd/ Ma/ Mi/ Mj	Medium/Low	Takii Seeds
Shield RZ	ToMV:0-2/ Fol:0-2/ For/ Va:0/ Vd:0/ Ma/ Mi/ Mj	Medium	Rijk Zwaan
Grafts			
Valerim	Vd:1; Fol:1, 2; ToMV estirpe Tm1; Mi 1-4; Mj; TSWV; ToSRV.	-	Sakata
Dylla	TSWV; TYLCV; Fol: 1-3; Va; Vd; TMV; ToMV.	-	Syngenta

*Information provided by the companies. Aal (*Alternaria alternata* f. sp. Lycopersici); Fol = *Fusarium oxysporum* f. sp. *lycopersici*; For = *Fusarium oxysporum* f. sp. *radicis-lycopersici*; Ma = *Meloidogyne arenaria*; Mi = *Meloidogyne incognita*; Mj = *Meloidogyne javanica*; Pd = *Phytophthora drechsleri*; Pl = *Pyrenochaeta lycopersici*; Pst = *Pseudomonas syringae* pv. tomato; Rs = *Ralstonia solanacearum*; TSWV (*Tomato spotted wilt virus*); TYLCV (*Tomato yellow leaf curl virus*); ToMV = *Tomato mosaic virus*; Va = *Verticillium albo-atrum*; Vd = *Verticillium dahlia*.

Vegetative growth variables

The stem length (cm) was obtained by directly measuring from the base of the plant to the insertion of the last true leaf. It was determined thirty and sixty days after transplantation (DAT). The stem elongation rate (SER; Eq. (1)) was calculated by the following equation (Mahmoud, 2020):

$$SER = \frac{(L2 - L1)}{(t2 - t1)} \quad \text{Eq. 1}$$

Where L2 and L1 are the length of the stem at 30 and 60 DAT, respectively, and (t2 − t1) is the time elapsed in this period (30 days).

Thirty and sixty days after transplanting, the rootstock stem (RSD) and the graft (GD) diameters were also determined and measured with a digital caliper, approximately 1 cm below and above the grafting point. The Compatibility Index (CI) was calculated through the relation between the diameters of the graft stem and the rootstock stem. The ideal index was considered to be close to 1 (one) (Farias *et al*., 2013).

Yield and fruit quality variables

Yield variables. To collect yield data, weekly harvests were carried out on six central plants of each plot, discarding the two plants at each end. The fruits were counted and weighed to obtain data on the number of fruits per plant, production (kg plant^{-1}), and average mass (g^{-1}) of fruits. Before being weighed, the marketable fruits were classified according to the largest transverse diameter as: giant (> 100 mm), large (80<100 mm), medium (65<80 mm), and small (50<65 mm) (Brasil, 1995).

Fruit physicochemical characteristics. For the quality analysis, a sample of ten fruits was collected in the middle third of the plants for each plot. The average mass of the fruits, as well as longitudinal and transverse diameters, was measured with a digital caliper. The fruits were cut transversely to verify pericarp thickness, and the thickness was measured at two opposite points in the equatorial region of each fruit using a digital caliper. The evaluation of fruit firmness was determined by the Intrutherm PTR-300 digital penetrometer device, with a penetration tip of 11 mm and accuracy of ± 0.5%, in the equatorial region of the fruit. The results were expressed in Newtons (N). A digital refractometer (Reichert RI-Chek) determined the soluble solids content, and the results were expressed in °Brix.

Statistical analyses

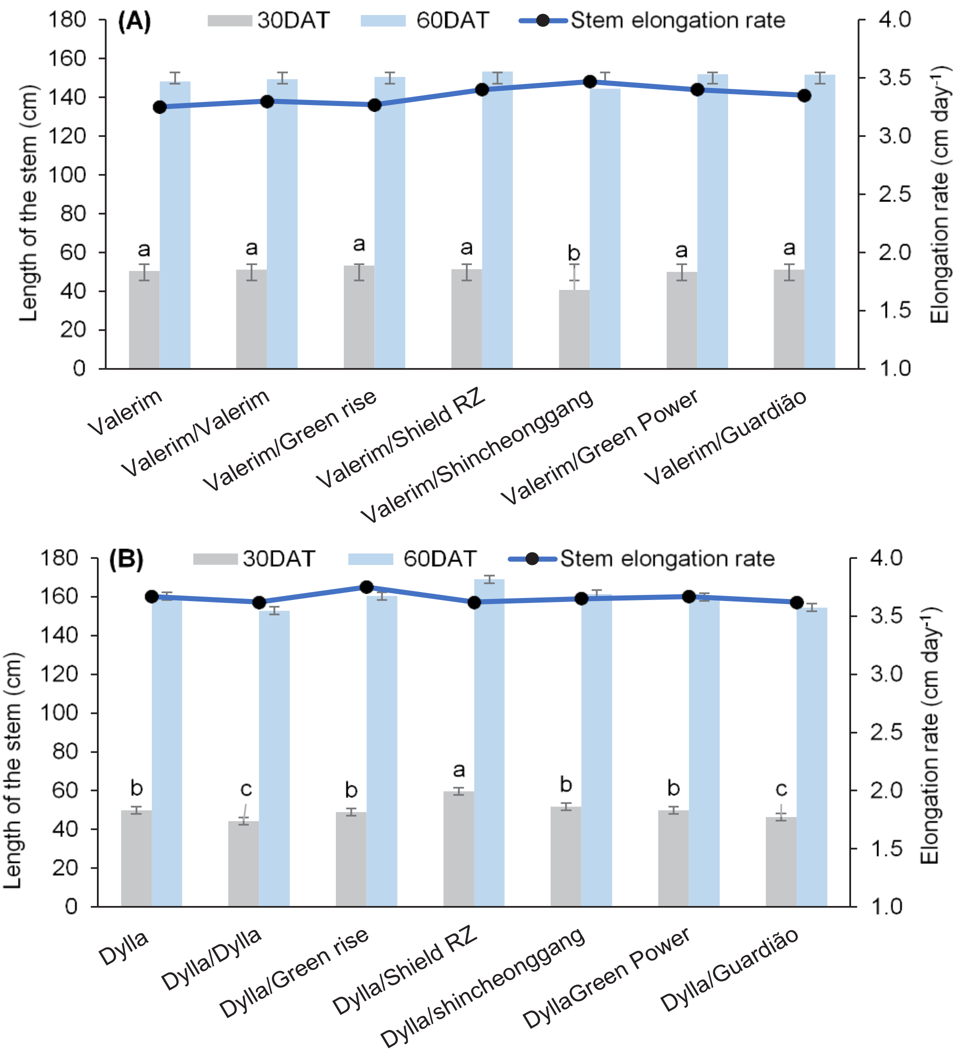
A Shapiro-Wilk normality test was performed to verify the assumptions for the Analysis of Variance (ANOVA). The production data and number of fruits were transformed into √Y + 0.5 - SQRT (Y + 0.5) to satisfy the normality test. The data were transformed for statistical analysis, but the means presented are the original. The data were subjected to ANOVA ($p < 0.05$), and when significant, means were grouped using the Scott-Knott test (Scott & Knott, 1974) at a 5% probability level. The statistical software SISVAR, version 5.7 (Sisvar, Lavras, MG, Brazil), was used for the statistical analysis.

RESULTS

Vegetative growth

Grafting had a significant effect only on stem length evaluated 30 days after transplanting, both for Valerim hybrids and for Dylla (Figure 2A and 2B). The Valerim/Shincheoggang combination had the lowest mean (40.77 cm), 80.7% lower than the non-grafted Valerim, for which there was no significant difference from the other combinations (Figure 2A). The Dylla autograft and the Dylla/Guardian combination showed the lowest mean, and the Dylla/Shield RZ combination had the highest mean for stem length (Figure 2B). The results can be related to the rootstock's vigor. Shincheoggang has low vigor, while Shield RZ is medium (Table 1).

There was no significant difference among the hybrids and their combinations in stem length evaluated at 60 DAT, with mean values of 150 and 160 cm for Valerim and Dylla, respectively. There was also no significant difference in the stem elongation rate, with a mean of 3.35 and 3.66 cm day-1 for Valerim and Dylla, respectively (Figure 2).

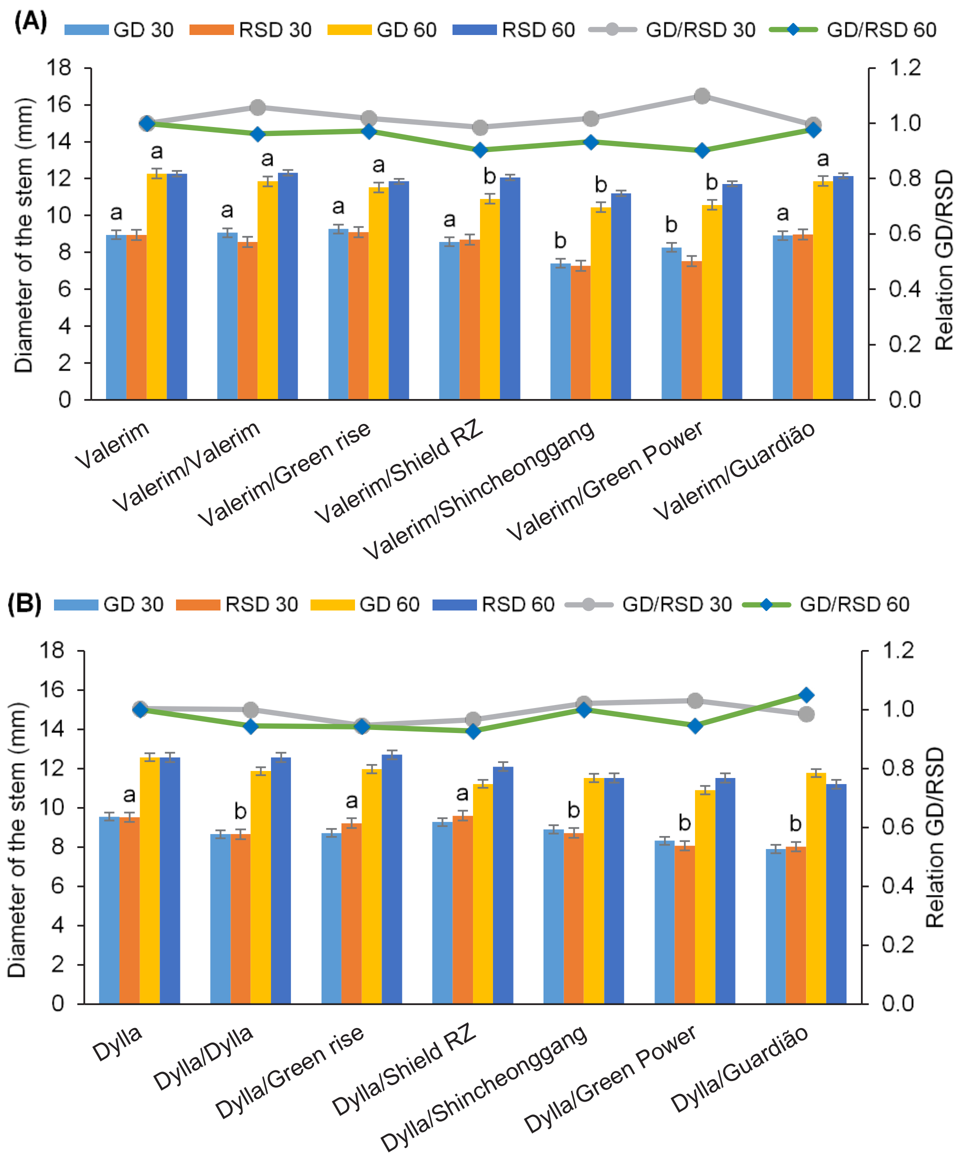


Note. Vertical bars represent the standard error (S.E.), and columns with equal letters represent values that do not differ statistically, according to the Scott and Knott test (1974) ($p < 0.05$).

Figure 2. *Stem length at 30 and 60 days after transplantation (DAT) and stem elongation rate for the hybrids Valerim and Dylla grafted on different rootstocks.*

For the stem diameter of the Valerim hybrid, there was a significant effect only for the graft diameter (DE), at 30 and 60 DAT (Figure 3A). The lowest means refer to the combinations Valerim/Shincheoggang and Green Power, at 30 and 60 DAT, and Valerim/Shield RZ at 60 DAT. The other treatments showed no significant difference. These results indicate that the graft had a diameter greater than the diameter of the rootstock (DPE) at 30 DAT. However, at 60 DAT, the opposite was observed; with DPE exceeding ND. Despite this, there was no significant difference in the DE/DPE ratio, indicating good compatibility between the parts (Figure 3A).

For the Dylla hybrid, only the diameter of the rootstock (DR) at 30 DAT presented a significant result. The Dylla/Dylla, Shincheoggang, Green Power, and Guardian combinations presented lower averages. The DPEs were slightly smaller than the graft diameters. However, these results did not influence the compatibility between the parties, as verified by the DE/DPE ratio (Figure 3B).



Note. Vertical bars represent the standard error (S.E.), and columns with equal letters represent values that do not differ statistically, according to the Scott and Knott test (1974) ($p < 0.05$).

Figure 3. *Graft stem diameter (GD) and rootstock stem diameter (RSD) and GD/RSD relation, at 30 and 60 days after transplantation (DAT), for the hybrids Valerim and Dylla grafted on different rootstocks.*

Yield of fruits

For the production and number of non-commercial fruits, the Valerim/Shield RZ combination provided the lowest averages, standing out from the other treatments that did not differ from each other (Table 2). Compared to non-grafted Valerim, this combination showed a 48% and 43% reduction in the production and number of non-commercial fruits. The combinations that presented the highest average number of fruits of medium size were the autografting of Valerim/Valerim, Guardian, and Green Rise (Table 2). The increments observed were 43%, 28%, and 22%, respectively.

Table 2. *Production and number of fruits per plant and per class (medium, small, and non-commercial fruit), for the Valerim hybrid grafted onto different rootstocks.*

Treatments	Medium	Small	Commercial total	Non-commercial
	Production (kg plant^{-1})			
Valerim	2.075	0.950	3.000	0.435 a
Valerim/Valerim	2.650	0.925	3.575	0.473 a
Valerim/Green rise	2.225	0.925	3.175	0.578 a
Valerim/Shield RZ	1.925	1.175	3.050	0.209 b
Valerim/Shincheonggang	1.925	0.725	2.625	0.535 a
Valerim/Green Power	1.650	1.025	2.625	0.592 a
Valerim/Guardião	2.400	1.150	3.550	0.592 a
CV (%)	22.43	24.63	19.10	18.04
p-value	0.123	0.203	0.196	0.033
	Number of fruits per plant			
Valerim	11 b	9	20	4 a
Valerim/Valerim	16 a	8	24	3 a
Valerim/Green rise	14 a	8	22	4 a
Valerim/Shield RZ	13 b	10	22	2 b
Valerim/Shincheonggang	12 b	6	18	4 a
Valerim/Green Power	11 b	10	21	5 a
Valerim/Guardião	15 a	9	24	4 a
CV (%)	16.85	23.06	13.03	16.22
p-value	0.025	0.146	0.093	0.034

Note. Means followed by distinct letters in the column differ from each other by the Scott-Knott test at a 5% probability. C.V.: Coefficient of variation; $p < 0.05$: significant.

For the Dylla hybrid, there was no significant difference for any of the production variables and the number of fruits per plant, according to the evaluated classes (Table 3).

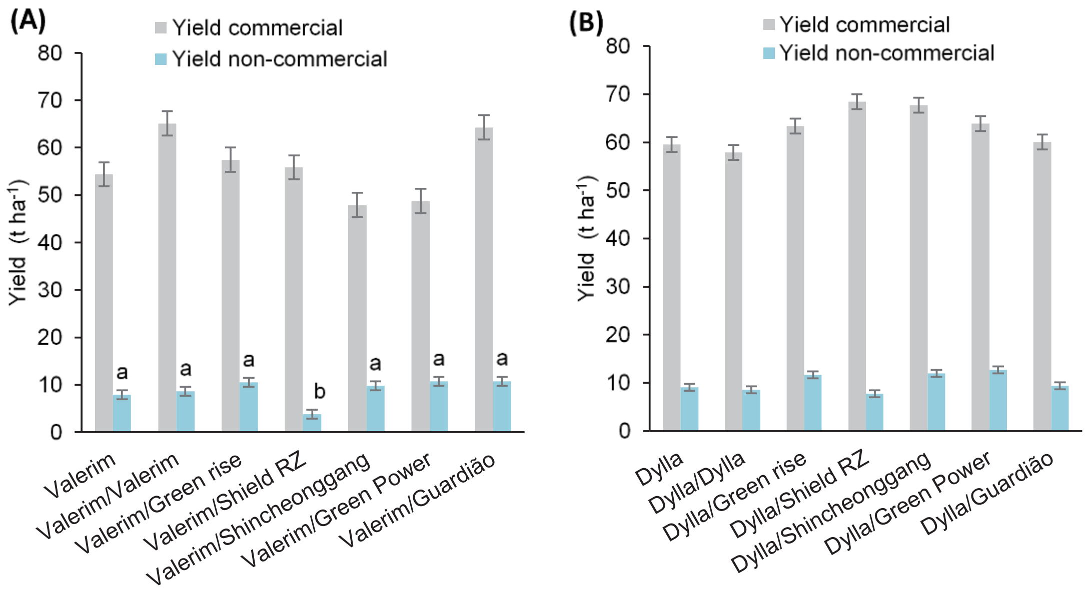
Table 3. *Production and number of fruits per plant and per class (medium, small, and non-commercial fruit), for the Dylla hybrid grafted onto different rootstocks.*

Treatments	Medium	Small	Commercial total	Non-commercial
	Production (kg plant^{-1})			
Dylla	2.100	1.175	3.250	0.475
Dylla/Dylla	1.800	1.375	3.150	0.475
Dylla/Green rise	2.050	1.425	3.500	0.650

Treatments	Medium	Small	Commercial total	Non-commercial
	Production (kg plant^{-1})			
Dylla/Shield RZ	2.000	1.725	3.750	0.450
Dylla/Shincheonggang	2.125	1.625	3.725	0.675
Dylla/Green Power	1.950	1.525	3.500	0.700
Dylla/Guardião	1.900	1.400	3.300	0.525
CV (%)	20.15	20.55	12.32	26.79
p-value	0.911	0.255	0.355	0.119
	Number of fruits per plant			
Dylla	11	11	22	5
Dylla/Dylla	10	13	23	5
Dylla/Green rise	12	14	26	6
Dylla/Shield RZ	12	17	29	5
Dylla/Shincheonggang	12	15	27	6
Dylla/Green Power	12	15	27	6
Dylla/Guardião	12	14	26	5
CV (%)	20.47	21.74	13.64	27.33
p-value	0.638	0.272	0.118	0.551

Note. Means followed by distinct letters in the column differ from each other by the Scott-Knott test at a 5% probability. C.V.: Coefficient of variation; $p < 0.05$: significant.

For both hybrids, commercial yield was not affected by the grafting treatments (Figure 4A and 4B). For non-commercial yield, the combination of the hybrid Valerim/Shield RZ showed a lower average than the other treatments (Figure 4A), while there was no significant difference for the Dylla hybrid (Figure 4B). The average commercial yield was 56 and 63 tha-1 for the hybrids Valerim and Dylla, respectively.



Note. Vertical bars represent the standard error (S.E.), and columns with equal letters represent values that do not differ statistically, according to the Scott and Knott test (1974) ($p \leq 0.05$).

Figure 4. *Yield for the hybrids Valerim and Dylla grafted on different rootstocks*

Physicochemical characteristics

For the variables of fruits' physicochemical characteristics, there was no significant effect of the grafting treatments for both hybrids Valerim and Dylla (Table 4).

Table 4. *Average fruit mass per class (medium, small, and non-commercial (NC)), firmness (FIR), pericarp thickness (PET), transverse diameter (TD), and longitudinal diameter (LD) of fruits and soluble solids content (SSC), for the Valerim and Dylla hybrids grafted on different rootstocks.*

Treatments	Medium	Small	NC	FIR	PET	TD	LD	SSC
		g		N		mm		ºBrix
Valerim	180.9	108.3	123.9	4.6	7.0	54.9	70.7	4.8
Valerim/Valerim	161.8	120.6	163.8	4.7	7.1	55.7	73.0	4.9
Valerim/Green rise	156.5	110.4	148.3	4.6	6.1	54.0	73.2	5.0
Valerim/Shield RZ	153.4	120.6	133.7	4.4	6.2	57.2	72.3	4.9
Valerim/ Shincheonggang	160.9	115.2	123.6	4.8	6.6	53.6	73.3	5.1
Valerim/Green Power	156.7	103.8	112.9	4.4	7.1	54.5	66.5	5.0
Valerim/Guardião	162.6	121.2	141.5	4.7	6.5	52.7	70.6	5.1
CV (%)	10.63	8.16	17.02	10.57	16.65	7.33	6.88	2.58
p-value	0.394	0.091	0.085	0.902	0.746	0.768	0.466	0.054
Treatments								
Dylla	192.5	103.4	98.4	4.1	5.7	51.1	69.5	4.7
Dylla/Dylla	185.9	104.4	102.0	4.0	5.8	55.2	77.0	4.7
Dylla/Green rise	164.8	105.5	112.7	3.9	5.9	50.7	71.6	4.9
Dylla/Shield RZ	162.8	101.6	92.6	3.6	5.8	49.6	70.9	4.9
Dylla/Shincheonggang	181.2	108.5	112.0	3.9	6.1	54.4	76.2	5.0
Dylla/Green Power	158.4	105.1	110.2	3.9	5.7	54.6	74.0	4.8
Dylla/Guardião	154.7	101.4	100.7	3.9	6.5	54.5	75.3	5.0
CV (%)	11.67	4.39	17.66	10.12	14.76	6.17	8.08	4.23
p-value	0.091	0.367	0.654	0.695	0.879	0.121	0.505	0.231

Note: C.V.: Coefficient of variation; N = Newton; $p < 0.05$: significant.

DISCUSSION

The results of this study indicated that the rootstocks evaluated only influenced the initial growth of the plants (30 DAT), even for indications of vigor other than the rootstock. At a certain point (at 60 DAT), the plants showed similar growth. By evaluating nine rootstocks, Riga (2015) found that all combinations of rootstocks significantly reduced plant height, compared to non-grafted plants, evaluated at 46 DAT. In the same study, the author reported that the rootstocks increased graft diameter between 19% and 23%. Other studies have concluded that grafting is linked to increased plant vigor, which is reflected in larger stem diameters and greater plant height (Lee *et al*., 2010; Hashem *et al*., 2024). However, in this study, the graft combinations did not yield consistent results regarding plant growth or stem diameter, aligning with the findings of Riga (2015) and Rahmatian *et al*. (2014).

Evaluating the growth and production of the grafted plant is a good indicator of the compatibility between the graft and the rootstock (Goldschmidt, 2014). In this study, the non-grafted plants served as a comparison parameter, so that no signs of incompatibility were found during the production cycle for the grafted plants, which developed and obtained results similar to non-grafted plants. Sirtoli *et al*. (2011) evaluated the number of nodes up to the first cluster and found no delay in the growth and development of grafted plants compared to non-grafted plants.

The production and number of non-commercial fruits were lower in Valerim/Shield RZ. The combinations of Valerim/Valerim, Guardian, and Green Rise had better results for the number of medium-sized fruits. For the Dylla hybrid, there was no significant difference for any of the production or yield variables. By evaluating the cultivar Débora Victory grafted on the rootstocks TD1 and Woodstock, Luciano *et al*. (2019) found a positive influence on yield since the rootstocks promoted greater fruit dry matter than when the non-grafted plant was used. Masterson *et al*. (2016) found that interspecific hybrid rootstock Maxifort and Trooper Lite significantly increased yield, ranging from 18% to 126% for grafted plants compared to non-grafted plants. Evaluating grafting with ‘DR0141TX’ and ‘Estamino’, Gong *et al*. (2022) found an increase of 103.8% and 122.6% in commercial production compared to the non-grafted control, and these two rootstocks also increased by 44.0% and 57.3%, respectively, in commercial production compared to the less vigorous ‘Shield’ rootstock, corroborating the results of the present study. Other studies also found that the yield of grafted plants was higher than that of non-grafted plants (Casals *et al*., 2018; Alagöz & Ozer, 2019; Bayındır & Kandemir, 2023; Hashem *et al*., 2024).

For hybrids and grafting combinations, the variables of the physicochemical characteristics of fruits had no significant effect (Table 4). Supporting these findings, Jenkins *et al*. (2022) and Walubengo *et al*. (2022) also reported no significant effects of grafting on tomato fruit quality. Hashem *et al*. (2024) did not see significantly higher values for fruit quality characteristics but found that Maxifort and KFS-16 achieved satisfactory results for soluble solids content. This same behavior was evidenced in the present study, with values ranging from 4.82 to 5.12ºBrix for Valerim and 4.67 to 4.95ºBrix for Dylla. However, some studies suggest that grafting can noticeably improve tomato fruit quality, leading to firmer, heavier fruits with larger diameters compared to non-grafted or self-grafted plants (Moncada *et al*., 2013; Riga, 2015; Mahmoud, 2020).

Grafting plays a crucial role in intensive vegetable production (Zhou *et al*., 2022). However, its impact on fruit development, yield, and quality remains inconsistent, as studies have reported varying results. These differences are often linked to the specific graft/rootstock combinations used (Kyriacou *et al*., 2017; Bayındır & Kandemir, 2023) as well as environmental factors such as climate, cultivation practices, stress duration and intensity, and the availability of water and nutrients (Riga, 2015). Thus, it is necessary to evaluate the grafting in different environments and conditions, so that the interaction between the factors can be evaluated more consistently. It is suggested to carry out further studies concerning the variables studied and in different years of production or growing seasons.

This study contributes to the advancement of knowledge about tomato grafting, especially the use of intraspecific hybrids as rootstocks, by demonstrating that the technique does not always result in increased vigor or productivity when performed between genetically close genotypes and cultivated under conditions without limiting stresses (Singh *et al*., 2017; Gong *et al*., 2022; Babar *et al*., 2023). From a practical point of view, the findings suggest that, in environments with low stress pressure, the use of grafted seedlings may not justify the investment solely based on the expectation of higher productivity, contributing to guiding the more judicious use of the technique and the development of rootstocks with greater functional divergence and adaptive potential.

CONCLUSIONS

The interaction with rootstocks or autografting influences the stem growth and diameter up to 30 days after the hybrids Valerim and Dylla are transplanted. However, the rootstocks evaluated did not affect development or compatibility.

The combinations of Valerim/Valerim, Shield RZ, Guardian, and Green Rise presented positive effects for the yield parameters. Grafting did not influence the yield parameters of the Dylla hybrid. Likewise, grafting did not influence the physicochemical characteristics of the fruits of both hybrids Valerim and Dylla. The absence of grafting effects on vigor and productivity suggests that the combinations evaluated are functionally compatible and that under the experimental conditions, the original root system of the cultivars was already sufficient to express their productive potential.

AUTHOR CONTRIBUTIONS

Conceptualization, L.F.C.C. and A.R.N.; Methodology, L.F.C.C.; Formal Analysis, L.F.C.C. and C.M.A.C.; Investigation, L.F.C.C., C.M.A.C., M.L.S.V. and R.C.F.; Resources, A.R.N.; Data Curation, L.F.C.C., C.M.A.C. and M.L.S.V.; Writing -Original Draft Preparation, L.F.C.C.; Writing- Review & Editing, R.C.F. and A.R.N.; Visualization, A.R.N.; Supervision, A.R.N.; Project Administration, L.F.C.C.

ACKNOWLEDGMENTS

The authors are grateful for the granting of a scholarship with the support of the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES).

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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