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Yield and Quality Response of Indeterminate Tomatoes to Combined Growing Methods and Rootstock Cultivars

Mampe E. Ndlovu [1], Puffy Soundy [1], Jacob J. De Klerk [2] and Martin M. Maboko [1,2,3,*]

[1] Department of Crop Sciences, Tshwane University of Technology, Private Bag X680, Pretoria 0001, South Africa; ndlovumampe@gmail.com (M.E.N.); soundyp@tut.ac.za (P.S.)
[2] Hygrotech SA Pty Limited, 1st Gerard Braak Street, Pyramid 0120, South Africa; voerenweiding@hygrotech.co.za
[3] Department of Agriculture and Animal Health, University of South Africa, Roodepoort 1709, South Africa
* Correspondence: mabokom@tut.ac.za

Abstract

Limited comparative research exists on evaluating the performance of tomato rootstocks under different growing methods, resulting in growers facing challenges when deciding which rootstock and growing method to use for improved yield. The effect of growing methods (scion of a single stem or double stems and non-grafted plant as the control) and rootstock cultivars (Goldbac, SVTX6258, and Booster) on the yield and quality of tomatoes grown in a plastic tunnel and a shade net structure was investigated. The splice grafting method was followed. In a plastic tunnel experiment, grafting and rootstock cultivar did not significantly affect the total soluble solids (TSS), pH, and electrical conductivity (EC) of the tomato juice, as well as percentage weight loss, yield, and fruit firmness. However, the Booster rootstock with a scion of 2 stems had high fruit Mg, K, P, and Fe contents, while the Goldbac rootstock with a scion of 1 stem and 2 stems had high fruit Ca and Fe contents compared to other treatments. The Goldbac and Booster rootstocks grafted to a scion of 2 stems had a high marketable yield. In a shade net experiment, the Booster rootstock with a scion of 2 stems had a high early harvest and total yield of tomatoes, followed by the Goldbac rootstock with a scion of 2 stems. Higher incidences of fruit cracking were noticed on the Booster rootstock grafted with a scion of a single stem. Generally, grafted plants on Booster and Goldbac had improved Mg, K, and P contents, unlike SVTX6258 with a scion of 1 stem. The Booster rootstock with a scion of 2 stems had significantly higher Mg, K, and P contents, while the sodium (Na) fruit content was high on the SVTX6258 rootstock with a scion of 1 stem. Grafting did not significantly affect fruit physiological disorders, weight loss, and TSS, or pH and EC of tomato juice. Grafting with a scion of two stems at the seedling stage significantly improved the tomato fruit mineral content and the total and marketable yield in a plastic tunnel and a shade net structure.

Keywords: cracking; marketable yield; scion; single stem; double stem

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1. Introduction

In South Africa, most tomatoes are cultivated in open fields, while production under protected environments such as greenhouses or tunnels and shade net structures is continuously growing and gaining interest among tomato growers to accomplish improved growth, yield, and availability of tomatoes [1]. The production of tomatoes in an open field faces biotic challenges such as pests and diseases, as well as abiotic stresses, such as high temperatures that increase the plants' water vapor demand, leading to higher leaf

transpiration rates and stomatal closure and, consequently, a higher leaf temperature and a decline in the net photosynthetic rate [2], leading to seasonal variation in supply. In South Africa, where high temperatures during the summer season are common, heat stress severely constrains crop productivity, necessitating a higher demand for tomatoes. Fluctuations in air temperature in greenhouses, especially those that rely on natural ventilation to cool down, cause heat stress and induce leaf and stem wilting, which has a significant negative effect on the average plant growth, yield, quality, and photosynthesis in tomatoes (ambient temperature over 35 °C) [3,4].

Grafting applications are used in horticultural crops to overcome abiotic and biotic stresses, which are responsible for 70% and 30% of the yield gap, respectively [5,6]. Challenges of abiotic and biotic stresses on tomato production in the country lower the yield and availability of tomatoes in the markets. However, grafting in vegetable production is gaining momentum worldwide to overcome these challenges. Owing to their utilization of the vigorous root system of rootstocks, grafted plants usually show an increased uptake of water and minerals when compared with self-rooted plants [6]. Research has shown that possible mechanisms for increased yield are likely the result of increased water and nutrient uptake by vigorous rootstock genotypes.

Grafting has also been found to have other advantages, such as tolerance to low temperatures, tolerance to the growing problem of soil salinity from overuse of chemical fertilizers and desertification in many agricultural zones, and enhanced inorganic nutrient uptake [7–9]. Grafted plants have been considered to increase yield, resulting in more profit. Using grafted seedlings has become a widespread agricultural practice in many parts of the world [10]. Vegetable grafting has recently increased, primarily for tomatoes and watermelons [10,11]. Grafting on suitable rootstocks positively affects cultivation performance, especially in greenhouse conditions [12]. It may be a groundbreaking method that can offer farmers new profitable commercial prospects, better production stability, increased fruit quality with a longer shelf life, and increased yields [13]. In an experiment conducted to determine the differences in marketable yield between grafted and ungrafted tomato plants, the results indicated an increase in the number of marketable fruits in grafted tomato plants [10,14].

Studies have been carried out to evaluate the growth and yield performance of grafted tomatoes in protected structures (plastic tunnels and shade nets), with limited information on the performance of rootstock cultivars using different growing methods. Generally, tomato growers use rootstock grafted to a scion of 1 stem with limited or no information on the scion of two stems that develop at the cotyledons. This study aimed to compare different rootstocks and cultivation methods to enhance the quality and yield of tomatoes grown in a plastic tunnel and under a shadenet. The outcome of this study could assist tomato growers in identifying rootstock and growing method combinations that would provide a high yield of good quality produce when grown in soil in a plastic tunnel or under a shade net structure.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted during the growing season from December 2021 to April 2022 in a plastic tunnel (10 m width × 20 m length × 4.2 m height) and a 40% white shade net structure at Hygrotech Experimental Farm at 25.5857° S, 28.6411° E, Dewageningsdrift, Moloto Rd, Pretoria, South Africa. The climatic conditions in Dewageningsdrift during the experimental period are shown in Table 1.

Table 1. Climatic data during the experimental period for average temperatures, relative humidity, total rainfall and total evapotranspiration from December 2021 to April 2022.

Month	Temperature (°C)		Relative Humidity (%)		Average Rainfall (mm·Month^{-1})	Total Evapotranspiration (mm·Month^{-1})
	Tmax	Tmin	RHmax	Rhmin		
December	27.69	15.03	96.32	42.8	9.47	3.99
January	29.2	15.81	95.95	38.49	4.91	4.3
February	31.31	14.98	95.6	30.44	7.68	4.83
March	28.91	14.24	95.65	34.18	2.93	3.67
April	24.54	10.14	97.61	38.79	5.32	2.79

Tmax = maximum temperature, Tmin = minimum temperature, RHMax = maximum relative humidity, RHmin = minimum relative humidity.

2.2. Experimental Design and Treatments

Grafting and non-grafting of indeterminate tomato seedlings using the splice grafting method were conducted at a commercial nursery (Multigrow Nursery, Brits, South Africa). Tomato seeds were sown in white peat moss (4 × 4 cm blocks) and covered with coco-peat after seeding. Scion seeds were planted a day after rootstock seeds. The seeds were placed in a germination room at 26.5 °C for 3 days. Thereafter, the seedlings were transferred to a greenhouse, where the temperature was 27 ± 1/17 ± 1 °C (day/night) at a relative humidity of 40/60% (day/night) for 15 days. The seedlings were then grafted and placed in a recovery room for 6 days at a temperature of 22–24 °C and a relative humidity of 56–58%. A fluorescent lamp with red–blue light was used as the light source. An SCX824 scion with two stems was performed at the grafting stage by removing/pinching the growing point shoot to allow two shoots to develop at the two cotyledons (Figure 1A), while in the single-scion treatment, the growing point was not removed (Figure 1B). The seedlings were moved from the recovery room into the greenhouse, separated by a spacing of 5 cm × 5 cm, and kept for 18 days before transplanting.



(**A**) (**B**)

Figure 1. The SCX824 scion with 2 stems (**A**), where the growing point was removed just above the cotyledons to allow 2 stems to develop; in the scion with 1 stem (**B**), the growing point was not removed.

The experiment was performed on three commercial tomato interspecific hybrid rootstock cultivars, Booster (Takki Seed, Kyoto, Japan), SVTX6258, and Goldbac (Seminis, Isando, South Africa), grafted with an SCX824 scion with either 2 stems (Figure 1A) or 1 stem (Figure 1B). The treatments were subjected to a randomized complete block design with four replicates containing 12 plants per plot.

2.2.1. In the Plastic Tunnel

The experiment comprised eight treatments, i.e., three different commercial rootstock cultivars, namely, Booster, SVTX6258, and Goldbac grafted with an SCX824 scion with either 1 stem or 2 stems and ungrafted SCX824 that was pruned to single and double stems. The second stem was selected below the first flower truss on ungrafted tomato plants (SCX824). After choosing the main stems according to the method described in [15], all new side shoots were removed once a week. The plants were trained to 2 stems using the V trellising system and to 1 stem by twisting the trellis twine around the main stem and fixing it to a stay wire at 2.3 m above the ground surface to support the plants.

Ungrafted tomato cultivar SCX824 (control treatment) was pruned to 1 stem and 2 stems (SCX824-1S and SCX824-2S, respectively). The seedlings were transplanted in raised beds at a plant population density of 3 plants·m^{-2}. There were eight data plants in each experimental unit. Drip irrigation with 20 mm non-leakage drippers was used with an application rate of 2 L h^{-1} at a pressure of 100–120 kPa, spaced at 30 cm intervals.

2.2.2. In the Shade Net Structure

The treatments applied were similar to those described in the plastic tunnel, except that plants in this study were not pruned and trellised to either one or two stems. The side shoots that developed below the first flower truss were pruned (to the first fork or split) and thereafter trained with no further pruning. The plants were held by horizontal wires to support them and left to grow upright. The seedlings were transplanted in raised beds at an intra-spacing of 40 cm and inter-row spacing of 150 cm to give a population of 16,000 plants·ha^{-1}. The 7 treatments were subjected to a randomized complete block design with four replicates in each structure.

2.3. Fertigation

The soil texture was sandy loam with 44.1% sand, 41.3% silt, and 4.6% clay and a pH of 6.1. The chemical composition of the soil contained 47 mg·kg^{-1} phosphorus (P), 88 mg·kg^{-1} potassium (K), 8 mg·kg^{-1} sodium (Na), 368 mg·kg^{-1} calcium (Ca), 68 mg·kg^{-1} magnesium (Mg), and 2.41 mg·kg^{-1} sulfur (S). Following transplantation, Kickstarter fertilizer (Hygrotech, Pretoria, South Africa) was applied through drip irrigation at 5 mL·L^{-1} of water to stimulate root development. Fertigation was applied according to the fertilizer recommendations by Hygrotech SA Pty Limited. Two to seven weeks after transplantation, the plants were fertigated with 25 kg Hygroponic (Hygrotech, Pretoria, South Africa) and 25 kg calcium nitrate [$Ca(NO_3)_2$] per ha weekly. On a weekly basis during weeks 8–16, the plants were fertigated with 30 kg Hygroponic, 30 kg $Ca(NO_3)_2$, and 20 kg potassium sulphate (K_2SO_4) per ha^{-1}. During weeks 17–20, i.e., from transplantation to termination, the plants were fertigated with 25 kg Hygroponic (Hygrotech, Pretoria, South Africa), 25 kg $Ca(NO_3)_2$, and 15 kg potassium nitrate (KNO_3). Hygroponic fertilizer comprises nitrogen (N) (68 mg·kg^{-1}), phosphorus (P) (42 mg·kg^{-1}), potassium (K) (208 mg·kg^{-1}), sulfur (S) (64 mg·kg^{-1}), magnesium (Mg) (30 mg·kg^{-1}), zinc (Zn) (149 mg·kg^{-1}), boron (B) (373 mg·kg^{-1}), molybdenum (Mo) (37 mg·kg^{-1}), manganese (Mn) (299 mg·kg^{-1}), and copper (Cu) (22 mg·kg^{-1}).

2.4. Data Collection

Fruits were hand-harvested once every week at the mature-pink stage without a calyx. Fruits were graded into extra-large- (85–95 mm), large- (76–84 mm), medium- (55–75 mm), small- (50–54 mm), and extra-small-sized fruit (<50 mm) based on fruit diameter. Fruit mass and total marketable and unmarketable yield (extra-small-sized fruits and physiological disorders such as BER, fruit crack, sunburn, catface, zippering, and rain check) were

recorded. The early marketable and total early yields were recorded from the first three harvests, i.e., 70, 77, and 84 days after transplantation. Fruit firmness was measured using an Effegi-type Bishop FT 327 firmness tester with an 11.3 mm diameter plunger as described in [16]. Five ripe fruit samples per treatment and replicate were harvested and sent to NviroTech Laboratories, Hartbeespoort, South Africa, for percentage moisture and fruit mineral content analyses (P, Ca, Mg, S, K, Na, Mn, Cu, Zn, Mo, and B) on a dry weight basis. The percentage moisture was determined on freeze-dried samples. The sample analysis was carried out with an aliquot of a digested solution using inductively coupled plasma optical emission spectrometry (ICP-OES) as described in [17].

Five fruits per experimental unit were harvested at the mature red stage when ready for consumption, washed with distilled water, and then wiped with paper towels. The tomato fruits were sliced into small pieces and placed in a laboratory blender to produce a puree. The puree was then filtered through a cheesecloth to produce tomato juice. The total soluble solids (TSS), pH, and electrical conductivity (EC) of the tomato juice were determined. The pH and EC of the tomato juice were measured using a Combo pH and EC meters (Hanna Instruments Inc., Port Louis, Mauritius). The TSS of the tomato juice was determined using a PAL-1 refractometer (ATAGO, Kobe, Japan). Fruit weight loss was determined using the method described in [18], where five tomatoes from each treatment were marked and weighed on a digital weighing scale.

$$\%\text{weight loss} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100$$

The tomatoes were stored at room temperature (25 °C) and weighed at 3-day intervals for 15 days for weight loss determination. At 133 days (19 weeks) after transplantation (at the termination of the experiment), data on plant height (using a measuring tape) and stem diameter (using a Vernier caliper) were measured, and the number of trusses was counted. Stem diameter was taken 30 cm above the soil surface, and the average stem diameter was taken on plants with a scion of 2 stems. The plants were then placed in an oven at a temperature of 60 °C for 72 h for plant dry mass determination.

2.5. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using the GenStat Windows (2022) statistical package. The differences between the combined treatments were tested using the least significant difference (LSD) method. Differences were judged significant at $p < 0.05$ according to the *F*-test. The *F*-protected LSD values were calculated at the 0.05 probability level.

3. Results and Discussion

3.1. Plastic Tunnel Experiment

The results show significant differences in plant height, stem diameter, number of trusses, and plant fresh mass as affected by treatments (Table 2). The tallest plants were on the Booster rootstock with a scion of either 1 stem or 2 stems, although not significantly different from Goldbac with a scion of either 1 stem or 2 stems. The ungrafted plants pruned to either 1 or 2 stems, including SVTX6258 grafted to a scion of 1 or 2 stems, were shorter. Generally, the Goldbac and Booster rootstocks were vigorous and exhibited taller plants compared to the ungrafted plants and the SVTX6258 rootstock. The ungrafted plants pruned to 1 stem or 2 stems had a significantly greater stem diameter, although not significantly different from the rootstock cultivars grafted with a scion of 1 stem. The rootstocks with a scion of 2 stems had thinner stem diameters. Competition for assimilates could result in reduced stem diameter on plants with two stems compared to a scion of a

single stem. A higher number of fruit trusses on the rootstock cultivars (Goldbac, Booster, and SVTX6258) with a scion of 2 stems could be explained by the fact that such plants with 2 stems bear more trusses than plants with a single scion. Plant fresh mass was significantly greater on the Goldbac and Booster rootstocks when grafted with a scion of 2 stems (Table 2). This could be due to the larger rootstock's root system of Booster and Goldbac being capable of absorbing water and nutrients efficiently, consequently improving vigorous growth [6,14]. The biomass increase in grafted plants is consistent with previous findings, in which vigorous interspecific hybrid tomato rootstocks were used to promote plant growth [14,19]. Plant dry mass was not affected by the combined rootstock cultivar and growing method.

Table 2. Effect of the combined rootstock cultivar and growing method on tomato growth parameters at 133 days after transplantation in a plastic tunnel.

Treatment	Plant Height (m)	Stem Diameter (cm)	Number of Trusses per Plant^{-1}	Plant Fresh Mass (kg Plant^{-1})	Plant Dry Mass (kg Plant^{-1})
SCX824-1S	2.25 ^{cd}	1.62 ^{a}	5.22 ^{c}	0.66 ^{c}	0.17
Booster-1S	2.72 ^{ab}	1.55 ^{ab}	5.67 ^{c}	0.69 ^{c}	0.13
Goldbac-1S	2.59 ^{abc}	1.56 ^{ab}	5.44 ^{c}	0.76 ^{bc}	0.14
SVTX6258-1S	2.15 ^{d}	1.37 ^{abc}	6.44 ^{bc}	0.59 ^{c}	0.13
SCX824-2S	2.41 ^{bcd}	1.64 ^{a}	6.56 ^{bc}	0.77 ^{bc}	0.15
Booster-2S	2.97 ^{a}	1.25 ^{c}	8.78 ^{a}	1.06 ^{a}	0.17
Goldbac-2S	2.57 ^{abcd}	1.33 ^{bc}	8.56 ^{a}	0.98 ^{ab}	0.19
SVTX6258-2S	2.47 ^{bcd}	1.22 ^{c}	8.22 ^{ab}	0.77 ^{bc}	0.17
LSD 0.05	0.42	0.27	1.90	0.23	ns

Values in a column followed by the same letter are not significantly different ($p < 0.05$), using Fisher's protected *t*-test ($n = 4$); Goldbac, Booster, and SVTX6258 are rootstocks with 1S = scion with 1 stem and 2S = scion with 2 stems; SCX824-1S and SCX824-2S, ungrafted plants (SCX824) pruned to 1 (1S) and 2 stems (2S), respectively; ns = non-significant.

Early yield parameters were not significantly affected by the combined rootstock cultivar and growing method (Table 3). However, the grafted plants with a scion of 1 stem and 2 stems showed an increased tendency towards a high early yield, especially on SVTX6258 with a scion of 2 stems, compared to the ungrafted plants. The total yield was not affected by the treatments (Table 3). Non-significant results could be because the rootstock with a scion of 2 stems or the ungrafted plants with 2 stems might have been confined in a small area of 3 plants·m^{-2} with a high number of stems·m^{-2}, resulting in a densely populated area. The plants at 3 plants·m^{-2} with a scion of two stems might have contributed to the dense shoots per area and enhanced competition among the plants for space and solar radiation, consequently reducing the photosynthetic rate. The total marketable yield and number of marketable fruits were significantly higher on the Booster rootstock with a scion of 2 stems, even though it did not differ significantly from the Goldbac rootstock with a scion of 2 stems compared to other treatments (Table 3). This could be due to the high plant fresh mass and number of trusses on the Booster and Goldbac rootstocks with a scion of 2 stems, as shown in Table 2. Similarly, tomato plants with double stems were reported to produce more fruits per plant than single-stem plants [20,21]. It has been reported that vigorous rootstocks improve fruit yield, probably by enhancing water and nutrient uptake and transport to the scion [8,14]. However, grafted plants with a scion of 2 stems, including ungrafted plants with 2 stems, might require reduced plant density below 3 plants·m^{-2} in a plastic tunnel to enhance light penetration and air ventilation among the plants for increased yield. One report [22] attributed the reduced number of fruits at high plant density to the development of fewer inflorescences and flowers and a lower fruiting rate. Grafting treatments did not influence the unmarketable yield, although the number of unmarketable fruits was higher on the rootstocks with a scion of 2 stems and the ungrafted plants with 2 stems (Table 3).

The number of extra-large-, large-, medium-, and extra-small-sized tomatoes were not affected by grafting and rootstock cultivar (Table 4). However, the number of small-sized fruits was significantly higher on the grafted plants with a scion of 2 stems (Booster, SVTX6258, and Goldbac) and the ungrafted plants pruned to 2 stems (SCX824). The fruit mass of small-sized and medium-sized fruits was greater on the Booster and Goldbac rootstock cultivars when grafted with a scion of 2 stems (Booster and Goldbac) compared to the other treatments (Table 4). Tomato plants with many stems increase shading and competition for assimilates, consequently producing a high number of reduced fruit sizes [20,21]. A rootstock grafted to two scions, coupled with the right plant density under a plastic tunnel, could reduce the cost effectiveness of grafting and improve tomato fruit size and yield.

Incidences of fruit cracking, catface, rotten and nipple fruits were not affected by the combined rootstock and growing method (Table S1, Supplementary Data).

The Booster rootstock with a scion of 2 stems had a significant effect on Mg (0.19%), K (3.82%), P (0.42%), and Fe (55.67 mg·kg^{-1}) fruit contents ($p < 0.05$) (Table 5). The Goldbac rootstock with a scion of 1 stem had a significantly higher Ca content (0.1%), even though it did not differ significantly from the other treatments, except for the ungrafted plants with 1 stem and the Booster rootstock with a scion of 1 stem and 2 stems (Table 5). The improved fruit mineral content could be associated with the higher rate of water and mineral uptake from the soil by larger roots of rootstocks [19,23] as well as the improved growth and development compared to ungrafted plants [14,23]. No significant differences were observed in the Na, S, Mn, Cu, Zn, Mo, and B tomato fruit mineral contents and fruit moisture (Table 5).

Grafting did not significantly affect the total soluble solids (6.3–7.0%Brix), pH (4.1–4.3) and electrical conductivity (3.4–3.8 mS·cm^{-1}) of the tomato juice, and fruit firmness (1.3–1.5 kPa) (Table S2, Supplementary Data).

3.2. Shade Net Experiment

Plant growth parameters, i.e., plant height (1.96–2.18 m), stem diameter (1.7–2.0 cm), number of trusses (9–15·plant^{-1}), plant fresh mass (0.7–1.1 kg·plant^{-1}), and plant dry mass (0.09–0.11 kg·plant^{-1}) were not significantly affected by the growing method and rootstock cultivar (Table S3, Supplementary Data).

The growing method and rootstock cultivar affected the early yield and total yield. The early and total yield parameters, including the total yield, the total number of fruits per plant, the marketable yield, and the number of marketable fruits per plant, were significantly higher on the Booster rootstock with a scion of 2 stems, although not significantly different from the Goldbac rootstock with a scion of 2 stems (Table 6). Although plants were not pruned in this study, it appears that the Booster and Goldbac rootstocks with two scions from the seedling stage produced a higher yield compared to the rootstock grafted to a single scion and the ungrafted plants. Generally, the rootstocks grafted to 1 scion performed similarly to the control (ungrafted plants) except for the Goldbac rootstock with a single scion. The SVTX6258 rootstock performed poorly in improving tomato yield. It could be that the rootstock has a poor root system unable to enhance tomato yield. Early harvest is advantageous for tomato growers because it allows them to supply tomato fruits earlier to the market. The ungrafted plants showed an increased tendency towards low total and early yield compared to the grafted plants. Higher yields can benefit the farmer in the form of increased profits. However, growers need to consider the high cost of grafted seedlings as this technique is labor-intensive, can have a longer production period, and incurs additional cost of rootstock seeds [24]. The unmarketable yield was not affected by the rootstock cultivar and growing method.

Table 3. Effect of the combined rootstock cultivar and growing method on the early and total yield of tomatoes grown in a plastic tunnel.

Treatment	Early Harvest						Total Harvest					
	Total Yield (kg Plant^{-1})	Total Number of Fruits Plant^{-1}	Marketable Yield (kg Plant^{-1})	Number of Marketable Fruits Plant^{-1}	Unmarketable Yield (kg Plant^{-1})	Number of Unmarketable Fruit Plant^{-1}	Total Yield (kg Plant^{-1})	Total Number of Fruits Plant^{-1}	Marketable Yield (kg Plant^{-1})	Number of Marketable Fruits Plant^{-1}	Unmarketable Yield (kg Plant^{-1})	Number of Unmarketable Fruits Plant^{-1}
SCX824-1S	2.184	13.67	2.066	12.70	0.129	13.67	4.072	34.08 ^{bc}	3.667 ^{b}	28.72 ^{bc}	0.406	34.08 ^{bc}
Booster-1S	2.309	16.02	2.184	15.08	0.126	16.02	3.608	30.15 ^{c}	3.353 ^{b}	26.72 ^{c}	0.255	30.15 ^{c}
Goldbac-1S	2.639	18.82	2.450	17.40	0.189	18.82	4.267	34.80 ^{bc}	3.718 ^{b}	28.85 ^{bc}	0.549	34.80 ^{bc}
SVTX6258-1S	2.311	15.83	2.114	14.43	0.197	15.83	3.555	30.52 ^{c}	3.256 ^{b}	26.58 ^{c}	0.299	30.52 ^{c}
SCX824-2S	2.013	15.21	1.874	14.04	0.139	15.21	4.396	38.86 ^{abc}	4.003 ^{b}	32.77 ^{abc}	0.393	38.86 ^{abc}
Booster-2S	2.558	17.74	2.40	16.29	0.162	17.74	5.499	46.08 ^{a}	5.066 ^{a}	39.42 ^{a}	0.433	46.08 ^{a}
Goldbac-2S	2.409	15.38	2.251	14.19	0.158	15.38	4.695	41.77 ^{ab}	4.133 ^{ab}	35.22 ^{ab}	0.562	41.77 ^{ab}
SVTX6258-2S	3.836	27.20	3.590	25.38	0.246	27.20	4.221	40.05 ^{abc}	3.831 ^{b}	33.55 ^{abc}	0.389	40.05 ^{abc}
LSD 0.05	ns	ns	ns	ns	ns	ns	ns	10.03	1.025	8.094	ns	10.03

Values in a column followed by the same letter are not significantly different ($p < 0.05$), using Fisher's protected *t*-test ($n = 4$); Goldbac, Booster, and SVTX6258 are rootstocks with 1S = scion with 1 stem and 2S = scion with 2 stems; SCX824-1S and SCX824-2S, ungrafted plant (SCX824) pruned to 1 (1S) and 2 stems (2S), respectively; ns = non-significant. Early harvest was the first 3 harvests (70–84 days after transplantation) and the total harvest was 10 harvests (70–133 days after transplantation).

Table 4. Effect of the combined rootstock cultivar and growing method on the fruit size of the tomatoes grown in a plastic tunnel.

Treatment	Fruit number·Plant^{-1}					Fruit Mass (kg·Plant^{-1})				
	XL	L	M	S	XS	XL	L	M	S	XS
SCX824-1S	0.60	3.29	18.90	5.93 ^{c}	3.44	0.234	0.609	2.339 ^{b}	0.485 ^{bcd}	0.125
Booster-1S	0.28	2.11	19.26	5.69 ^{c}	2.15	0.066	0.393	2.492 ^{b}	0.402 ^{d}	0.068
Goldbac-1S	0.72	3.03	19.41	5.07 ^{c}	2.58	0.154	0.556	2.539 ^{b}	0.469 ^{bcd}	0.095
SVTX6258-1S	0.37	2.43	17.16	6.62 ^{bc}	2.17	0.099	0.453	2.257 ^{b}	0.447 ^{cd}	0.080
SCX824-2S	0.43	2.60	21.93	7.81 ^{abc}	4.33	0.123	0.462	2.829 ^{b}	0.590 ^{bcd}	0.152
Booster-2S	0.60	2.31	25.98	10.52 ^{a}	4.63	0.125	0.430	3.652 ^{a}	0.859 ^{a}	0.169
Goldbac-2S	0.63	2.67	22.92	9.01 ^{ab}	4.06	0.151	0.484	2.842 ^{ab}	0.657 ^{abc}	0.183
SVTX258-2S	0.46	1.75	22.10	9.25 ^{ab}	4.63	0.129	0.317	2.701 ^{b}	0.685 ^{ab}	0.167
LSD 0.05	ns	ns	ns	2.83	ns	ns	ns	0.8128	0.2286	ns

Values in a column followed by the same letter are not significantly different ($p < 0.05$), using Fisher's protected *t*-test ($n = 4$); Goldbac, Booster, and SVTX6258 are rootstocks with 1S = scion with 1 stem and 2S = scion with 2 stems; SCX824-1S and SCX824-2S, ungrafted plant (SCX824) pruned to 1 (1S) and 2 stems (2S), respectively; ns = non-significant; fruit size in diameter: XL = extra-large (85–95 mm), L = large (76–84 mm), M = medium (55–75 mm), S = small (50–54 mm), and XS = extra-small (<50 mm).

The rootstock cultivars with a scion of 2 stems (Booster and Goldbac) had a significantly higher number and greater fruit mass of medium-sized fruits. The rootstock and growing method did not affect the extra-large-, large-, small-, and extra-small-sized fruit mass (Table S4, Supplementary Data).

In Table 7, incidences of blossom end rot, zippering, catface, rotten and nipple fruits were not affected by the rootstock and growing method. However, the incidence of fruit cracking was greater on the Booster rootstock with a scion of 1 stem and on the Goldbac rootstock with a scion of 2 stems (Table 7). Fruit cracking occurs when rapid changes in soil moisture levels cause fruits to expand quicker than the tomato skin can grow [25]. In this instance, fruit cracking was possibly due to the fact that the shade net structure had no waterproofing, resulting in the high soil moisture content caused by rainwater, which was absorbed by the larger roots of the rootstock (Table 1). A larger root system of the rootstocks might have encouraged more water uptake and increased turgor pressure of the fruits' internal cells, resulting in the change of the mechanical texture properties of the tomato pericarp tissue, and then predisposing the fruits to cracking [26]. According to [27], a sudden change in the internal turgor pressure of a tomato fruit leads to initial cracks in the pericarp layer, then extends into the pulp layer, resulting in macroscopic cracks. It has been reported that good water management practices are key in managing the incidence of fruit cracking [28].

Davis et al. [29] reported that grafting influences the absorption and translocation of phosphorus (P), nitrogen (N), magnesium (Mg), and calcium (Ca). This statement agrees with the findings in this experiment (Table 8), which indicated that grafting significantly affected the Mg, K, Na, and P fruit contents ($p < 0.05$). Generally, the grafted plants had improved Mg, K, and P contents except for SVT6258 grafted to a single stem. The Booster rootstock with a scion of 2 stems had the highest Mg, K, and P, while the Na fruit content was greater on the SVTX6258 rootstock with a scion of 1 stem (Table 8). No significant differences were found in the fruit mineral content, namely, Ca, S, Fe, Mn, Cu, Zn, Mo, and B, and the fruit moisture content. Gebologlu et al. [30] also reported the non-significant effect of the rootstock on the levels of micronutrient contents of Fe, Cu, Zn, Mn, B, and Mo in tomatoes.

Table 5. Effect of the combined rootstock cultivar and growing method on the fruit mineral content of the tomatoes grown in a plastic tunnel.

Treatment	Ca (%)	Mg (%)	K (%)	Na (mg kg^{-1})	S (%)	P (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mo (mg kg^{-1})	B (mg kg^{-1})	Moisture (%)
SCX824-1S	0.12 ^{cd}	0.15 ^{cd}	3.19 ^{b}	929.70	0.13	0.32 ^{c}	45.00 ^{ab}	16.33	7.67	16.00	4.58	19.67	94.78
Booster-1S	0.13 ^{bcd}	0.17 ^{b}	3.27 ^{b}	574.70	0.13	0.38 ^{ab}	53.67 ^{a}	15.00	8.67	15.00	5.34	19.33	95.01
Goldbac-1S	0.16 ^{a}	0.15 ^{cd}	3.28 ^{b}	707.00	0.14	0.35 ^{bc}	52.00 ^{a}	16.67	8.00	17.67	4.76	19.00	95.01
SVTX6258-1S	0.13 ^{abc}	0.15 ^{cd}	3.12 ^{b}	1003.70	0.13	0.33 ^{bc}	47.33 ^{ab}	15.67	8.00	16.33	4.59	20.00	94.77
SCX824-2S	0.14 ^{abc}	0.16 ^{bc}	3.19 ^{b}	824.70	0.14	0.36 ^{bc}	39.00 ^{b}	12.33	7.67	16.00	4.49	20.33	94.78
Booster-2S	0.10 ^{d}	0.21 ^{a}	3.82 ^{a}	746.00	0.15	0.42 ^{a}	55.67 ^{a}	17.67	9.67	18.67	5.22	19.33	94.90
Goldbac-2S	0.15 ^{ab}	0.16 ^{bc}	3.33 ^{b}	1054.70	0.14	0.35 ^{bc}	55.33 ^{a}	16.00	8.33	17.33	4.61	19.00	95.05
SVTX6258-2S	0.14 ^{abc}	0.14 ^{d}	3.06 ^{b}	1144.30	0.12	0.31 ^{c}	38.00 ^{b}	12.33	7.33	13.67	5.33	20.00	94.91
LSD 0.05	0.024	0.016	0.3405	ns	ns	0.052	12.37	ns	ns	ns	ns	ns	ns

Values in a column followed by the same letter are not significantly different ($p < 0.05$), using Fisher's protected *t*-test ($n = 4$); Goldbac, Booster, and SVTX6258 are rootstocks with 1S = scion with 1 stem and 2S = scion with 2 stems; SCX824-1S and SCX824-2S, ungrafted plant (SCX824) pruned to 1 (1S) and 2 stems (2S), respectively; ns = non-significant.

Table 6. Effect of the combined rootstock cultivar and growing method on the early and total yield of the tomatoes grown in a shade net.

Treatment	Early Harvest						Total Harvest					
	Total Yield (kg Plant^{-1})	Total Number of Fruits Plant^{-1}	Marketable Yield (kg Plant^{-1})	Number of Marketable Fruits Plant^{-1}	Unmarketable Yield (kg Plant^{-1})	Number of Unmarketable Fruits Plant^{-1}	Total Yield (kg Plant^{-1})	Total Number of Fruits Plant^{-1}	Marketable Yield (kg plant^{-1})	Number of Marketable Fruits Plant^{-1}	Unmarketable Yield (kg Plant^{-1})	Number of Unmarketable Fruits Plant^{-1}
SCX824	1.622 ^{c}	11.30 ^{c}	1.503 ^{c}	10.33 ^{c}	0.119	11.30 ^{c}	6.081 ^{d}	51.75 ^{c}	4.980 ^{d}	39.88 ^{c}	1.101	51.75 ^{c}
Booster-1S	2.183 ^{bc}	14.96 ^{bc}	1.958 ^{c}	13.31 ^{bc}	0.225	14.96 ^{bc}	7.464 ^{bcd}	64.02 ^{bc}	5.939 ^{cd}	48.38 ^{bc}	1.525	64.02 ^{bc}
Goldbac-1S	2.674 ^{bc}	18.01 ^{bc}	2.512 ^{bc}	16.58 ^{bc}	0.163	18.01 ^{bc}	8.192 ^{abc}	69.91 ^{b}	6.801 ^{abc}	54.97 ^{b}	1.391	69.91 ^{b}
SVTX6258-1S	2.552 ^{bc}	14.87 ^{bc}	2.373 ^{c}	13.62 ^{bc}	0.179	14.87 ^{bc}	6.419 ^{cd}	56.18 ^{c}	5.629 ^{cd}	45.18 ^{bc}	0.791	56.18 ^{c}
Booster-2S	3.924 ^{a}	27.96 ^{a}	3.675 ^{a}	26.17 ^{a}	0.249	27.96 ^{a}	9.658 ^{a}	86.63 ^{a}	8.332 ^{a}	70.81 ^{a}	1.326	86.63 ^{a}
Goldbac-2S	3.219 ^{ab}	22.39 ^{ab}	3.008 ^{ab}	20.76 ^{ab}	0.212	22.39 ^{ab}	8.944 ^{ab}	69.54 ^{b}	7.623 ^{ab}	55.54 ^{b}	1.321	69.54 ^{b}
SVTX6258-2S	2.437 ^{bc}	17.93 ^{bc}	2.262 ^{bc}	16.47 ^{bc}	0.175	17.93 ^{bc}	7.203 ^{bcd}	63.47 ^{bc}	6.097 ^{bcd}	50.10 ^{bc}	1.106	63.47 ^{bc}
LSD 0.05	1.079	8.35	1.021	7.805	ns	8.35	1.784	13.28	1.557	11.66	ns	13.28

Values in a column followed by the same letter are not significantly different ($p < 0.05$), using Fisher's protected *t*-test ($n = 4$); 1S = scion with 1 stem, 2S = scion with 2 stems; SCX824 = ungrafted cultivar; ns = non-significant. Early harvest was the first 3 harvests (70–84 days after transplantation) and the total harvest was 10 harvests (70–133 days after transplantation).

The fruit weight loss of ripe harvested tomatoes was monitored for 16 days at normal room temperature. The percentage of fruit weight loss during the storage duration was not dependent on the rootstock/growing method combination used (Table 9). This could be because the fruits obtained from the scion and ungrafted plants (SCX824) had a tough skin/texture that decelerated the ripening process [31]. The results differ from those reported in [18], which showed that ungrafted control fruits had a higher percentage of weight loss at the ripe stage. The results also contrast with [32], which reported a higher percentage of fruit weight loss from grafted plants than ungrafted plants.

The combined rootstock cultivar and growing method did not affect the total soluble solids, pH, and electrical conductivity of the tomato juice (Table 10). Fruit firmness was significantly improved on the Goldbac rootstock with a scion of 1 stem, although not significantly different from the SVTX6258 rootstock with a scion of 1 stem (Table 10). This result agrees with those of Nkansah et al. [33], who observed that grafting tomatoes onto African eggplant significantly improved firmness. The influence of rootstocks on fruit firmness may be ascribed to a variation in cellular morphology, cell turgor, and chemical and mechanical properties of fruit cell walls as a result of increasing synthesis of endogenous hormones, changing water relationships, and the nutritional status of the scion [34].

Table 7. Effect of the combined rootstock cultivar and growing method on fruit physiological disorders of the tomato plants grown in a shad enet.

Treatment	Cracking		Blossom End Rot		Zippering		Catface		Rotten		Nipple	
	Number Plant^{-1}	Weight (kg Plant^{-1})	Number Plant^{-1}	Weight (kg Plant^{-1})	Number Plant^{-1}	Weight (kg Plant^{-1})	Number Plant^{-1}	Weight (kg Plant^{-1})	Number Plant^{-1}	Weight (kg Plant^{-1})	Number Plant^{-1}	Weight (kg Plant^{-1})
SCX824	2.35 ^{bc}	0.30 ^{bc}	0.00	0.00	0.77	0.10	0.39	0.09	3.62	0.41	0.03	0.003
Booster-1S	4.14 ^{a}	0.51 ^{a}	0.00	0.00	1.34	0.17	0.47	0.11	6.92	0.64	0.03	0.004
Goldbac-1S	2.44 ^{bc}	0.30 ^{bc}	0.00	0.00	0.79	0.10	0.42	0.14	7.57	0.68	0.15	0.019
SVTX6258-1S	1.73 ^{c}	0.18 ^{c}	0.00	0.00	0.92	0.12	0.36	0.09	2.55	0.22	0.05	0.006
Booster-2S	1.77 ^{c}	0.21 ^{c}	0.00	0.00	1.10	0.13	0.42	0.09	7.62	0.52	0.16	0.026
Goldbac-2S	3.46 ^{ab}	0.40 ^{ab}	0.31	0.03	0.67	0.08	0.49	0.11	5.70	0.69	0.05	0.009
SVTX6258-2S	1.87 ^{bc}	0.24 ^{bc}	0.00	0.00	1.18	0.14	0.26	0.05	6.13	0.50	0.05	0.007
LSD 0.05	1.63	0.18	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Values in a column followed by the same letter are not significantly different ($p < 0.05$), using Fisher's protected *t*-test ($n = 4$); 1S = scion with 1 stem, 2S = scion with 2 stems; ns = non-significant.

Table 8. Effect of the combined rootstock cultivar and growing method on the fruit mineral and percentage moisture contents of the tomatoes grown in a shade net.

Treatment	Ca (%)	Mg (%)	K (%)	Na (mg kg^{-1})	S (%)	P (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mo (mg kg^{-1})	B (mg kg^{-1})	Moisture (%)
SCX824	0.14	0.15 ^{c}	3.49 ^{b}	395.30 ^{b}	0.15	0.39 ^{bc}	74.33	16.67	7.67	17.33	3.96	19.00	94.63
Booster-1S	0.16	0.17 ^{ab}	3.94 ^{a}	240.70 ^{d}	0.16	0.46 ^{a}	66.00	14.33	8.67	16.3	3.71	19.33	94.72
Goldbac-1S	0.17	0.17 ^{ab}	3.91 ^{a}	334.00 ^{bc}	0.17	0.39 ^{bc}	68.67	14.00	8.33	19.00	3.73	20.00	94.72
SVT6258-1S	0.17	0.16 ^{bc}	3.49 ^{b}	502.70 ^{a}	0.17	0.36 ^{c}	56.00	12.67	8.33	18.33	3.51	19.00	94.44
Booster-2S	0.16	0.18 ^{a}	4.12 ^{a}	310.70 ^{cd}	0.17	0.45 ^{a}	56.00	13.33	9.33	17.00	4.42	19.33	94.72
Goldbac-2S	0.18	0.17 ^{abc}	4.08 ^{a}	371.30 ^{bc}	0.17	0.44 ^{ab}	59.00	13.33	8.33	15.33	4.07	19.67	94.80
SVT6258-2S	0.17	0.17 ^{ab}	3.84 ^{ab}	573.00 ^{a}	0.18	0.42 ^{ab}	75.33	15.33	9.00	18.00	3.69	19.33	94.35
LSD 0.05	ns	0.019	0.376	82.6	ns	0.0565	ns	ns	ns	ns	ns	ns	ns

Values in a column followed by the same letter are not significantly different ($p < 0.05$), using Fisher's protected *t*-test ($n = 4$); 1S = scion with 1 stem, 2S = scion with 2 stems; ns = non-significant.

Table 9. Effect of the combined rootstock cultivar and growing method on fruit weight loss of the tomatoes grown in a shade net.

Treatment	Fruit Weight Loss (%)				
	Day 3	Day 6	Day 9	Day 12	Day 15
SCX824	2.54	3.64	4.72	5.92	6.98
Booster-1S	1.72	2.92	4.37	5.28	6.67
Goldbac-1S	1.69	2.86	4.38	5.73	7.76
SVTX6258-1S	2.06	3.17	4.45	8.77	5.91
Booster-2S	1.62	2.75	4.23	5.35	7.61
Goldbac-2S	1.91	3.26	4.84	5.98	7.29
SVTX6258-2S	1.59	2.60	4.10	4.95	5.84
LSD 0.05	ns	ns	ns	ns	ns

1S = scion with 1 stem, 2S = scion with 2 stems; ns = non-significant.

Table 10. Effect of the combined rootstock cultivar and growing method on the total soluble solids, pH, and electrical conductivity of the extracted tomato juice and firmness of the tomatoes grown in a shade net.

Treatment	Total Soluble Solids (%Brix)	pH	Electrical Conductivity ($mS \cdot cm^{-1}$)	Firmness (kPa)
SCX824	7.0	4.5	4.05	1.44 ^{b}
Booster-1S	6.8	4.4	4.30	1.59 ^{b}
Goldbac-1S	7.2	4.5	3.98	1.87 ^{a}
SVT6258-1S	7.3	4.4	3.95	1.64 ^{ab}
Booster-2S	6.9	4.4	4.38	1.42 ^{b}
Goldbac-2S	7.4	4.5	4.50	1.54 ^{b}
SVT6258-2S	6.8	4.4	4.15	1.58 ^{b}
LSD 0.05	ns	ns	ns	0.2373

Values in a column followed by the same letter are not significantly different ($p < 0.05$), using Fisher's protected *t*-test ($n = 4$); 1S = scion with 1 stem, 2S = scion with 2 stems; ns = non-significant.

4. Conclusions

The results show that tomato grafting on the Booster and Goldbac rootstocks with a scion of 2 stems had positive effects in improving the early harvest in a 40% white shade net structure and the marketable yield in a plastic tunnel, while the fruit mineral content of the tomatoes was significantly higher in both growth structures. The combined growing method and rootstock cultivar had a limited effect on fruit size. Fruit mass of the medium-sized fruits was greater on the Booster and Goldbac rootstocks with a scion of 2 stems in both the plastic tunnel and shade net structures. It is, therefore, recommended that the Booster and Goldbac rootstocks grafted with a scion of 2 stems at the nursery be recommended to tomato growers for early harvest, improved marketable yield, and fruit mineral content. More studies on plant density should be conducted to optimize the yield of grafted plants with a scion of 2 stems when grown in a plastic tunnel.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae11070758/s1, Table S1: Effect of combined rootstock cultivar and grafting method on fruit physiological disorders of tomato grown in a plastic tunnel; Table S2: Effect of combined rootstock cultivar and growing method on total soluble solids, pH and electrical conductivity of extracted tomato juice and firmness of tomatoes grown in a plastic tunnel; Table S3: Effect of combined rootstock cultivar and growing method on plant growth parameters of tomato grown in a shade net; Table S4: Effect of combined rootstock cultivar and growing method on tomato fruit size grown in a shade net.

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