














Research Article

Analysis of Plant Growth and Yield in Varieties of Tomato (*Solanum lycopersicum* L.) Grafted onto Different Eggplant Rootstocks

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This study aimed to examine plant growth of tomato grafted onto different eggplant rootstocks. We applied a randomized block design comprising twelve treatments with three replicates. Three varieties of tomato—Cervo, Karina, and Timoty—and three rootstocks—Gelatik, EG203 line, and *Solanum torvum*—were selected for this study. Nongrafted tomato plants of the same varieties were used as controls. The variables recorded were the number of branches, the diameter of scions and rootstocks, root length, and root dry weight at 4, 6, 8, and 10 weeks after planting (WAT) and relative growth rate, specific leaf area, and net assimilation rate at 4, 8, and 12 WAT. Grafted tomato plants demonstrated better growth than controls. There was a significant relationship between yield, plant growth parameters, and photosynthetic organs, expressed by higher production, greater scion diameter, longer roots, and increased relative growth rate, leaf area ratio, and net assimilation rate of grafted plants, compared to the controls.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is a vegetable with great potential for development in East Java because of its high economic value [1, 2] and can contribute to the household economy when it is intensively cultivated using appropriate technology [3, 4]. In 2017 and 2018, tomato production in East Java was 15.6 t·ha⁻¹ and 16.5 t·ha⁻¹, respectively. Actual production remains low compared with potential production, which can reach 33–35 t·ha⁻¹. The poor tomato production is due to the development of unfavourable conditions, such as bacterial wilt, fusarium wilt, high humidity, high temperature, and low production technology. Chemicals have been regularly applied by farmers [5] following recommendations from the green revolution era

[6, 7]. However, the application of agrochemicals has caused environmental degradation and problems related to human health [8, 9]. Alternative techniques to control disease are required to minimize dependence on agrochemicals and their adverse impacts.

Biotic and abiotic stresses can significantly decrease productivity and severely impact growth [10, 11]. One of the technologies to solve such problems is grafting. Grafting technology is an alternative technology that combines a high-yield scion and a stress-resistant rootstock to increase production. This technology does not produce plants with entirely new properties, but rather combines the characteristics of two different plants. The idea of grafting tomato onto eggplant is not new and has been successfully performed in the past in tropical conditions [12]. Moreover, it

can increase marketable yield [13], manage soilborne diseases [14], and improve alkalinity tolerance [15], in accordance with the specific characteristics and problems of each agroecosystem. The selection of compatible rootstocks using local genetic resources is expected to address local issues and be more practical than using imported resources.

The assumption underlying this study is that a healthy rootstock root system increases the efficiency of water and nutrient absorption and provides a source of endogenous hormones that increase yield and disease resistance [16–19].

Local varieties have genotypes that adapt easily to the growing environment, such that they are easier to cultivate than varieties originating from other regions [20, 21]. The grafting combination can determine plant resistance, expressed through variation in growth, fruit yield and production quality [22–27]. A previous study comparing self-grafted plants and controls reported only four statistically significant differences out of a total of 53 cases and concluded that the inclusion of self-grafted treatments is unnecessary [28]. However, the range of yield ratios from individual studies suggests that the differences in yields between self-grafted and nongrafted plants of the same variety are sometimes quite dramatic [12]. Plant growth analysis is an explanatory, holistic, and integrative approach to interpreting plant form and function, using simple primary data in the form of observed plant weight, leaf area, volume, and plant content to examine plant development in detail [29]. Studying the assimilation and accumulation of dry matter by plants during growth can provide valuable information on factors that influence plant development and yield [30]. In addition, quantitative plant growth analysis can explain in detail the key ecophysiological processes for increasing crop production [31]. Moreover, plant growth analysis can be used in a range of fields, including plant breeding, plant physiology, and plant ecology [32].

The World Vegetable Center has released eggplant lines EG195 and EG203, compatible with most tomato scions and resistant to inundation, salinity, high temperatures, low temperatures, bacterial wilt, fusarium wilt, and root-knot nematodes. Farmers in Indonesia often have difficulty accessing EG195 and EG203 lines as recommended rootstocks. Therefore, there is a need to identify local and wild eggplants that can be used as alternative rootstocks and determine whether these rootstocks can increase growth and production when combined with tomato.

This study examined the influence of grafting technology on tomato performance (growth and yield) using local eggplant cultivars as rootstocks.

2. Materials and Methods

This study was conducted in the Kediri Regency of Indonesia, where wilt diseases have become the major limiting factor for cultivating tomato.

2.1. Experimental Procedure. Seeds from three types of eggplants were planted at a depth of 1.5–2.0 cm in small pots (7 × 9 cm²) filled with sifted soil. After one week, Cervo,

Karina, and Timoty tomato seeds were also planted in small pots. The rootstocks and scions were irrigated daily for 21 days. Three-week-old eggplant seedlings were used as rootstocks, while two-week-old tomato seedlings were the scions. The cutting on the sides of both the scions and rootstocks followed a 45° slope in suitable transplants to ensure cambium alignment. The grafted plants were inserted into plastic pockets. Grafted plants were immediately put into the grafting chamber with a maximum temperature of 30°C and relative humidity in the range of 80–85%. Interception of light entering the grafting chamber was adjusted to reach no more than 25% of the total incoming sunlight. After 10–12 days in the grafting chamber for the unification process, the seedlings were then transferred to a greenhouse.

2.2. Experimental Design. This experiment applied a randomized block design comprising two factors. The first factor was the grafting technology, comprising four treatments: R0 = nongrafted, R1 = cv. Gelatik, R2 = EG203 line, and R3 = *S. torvum*. The second factor was the tomato variety, comprising three tomato varieties: V1 = cv. Cervo, V2 = cv. Karina, and V3 = cv. Timoty. Thus, there were a total of twelve treatments.

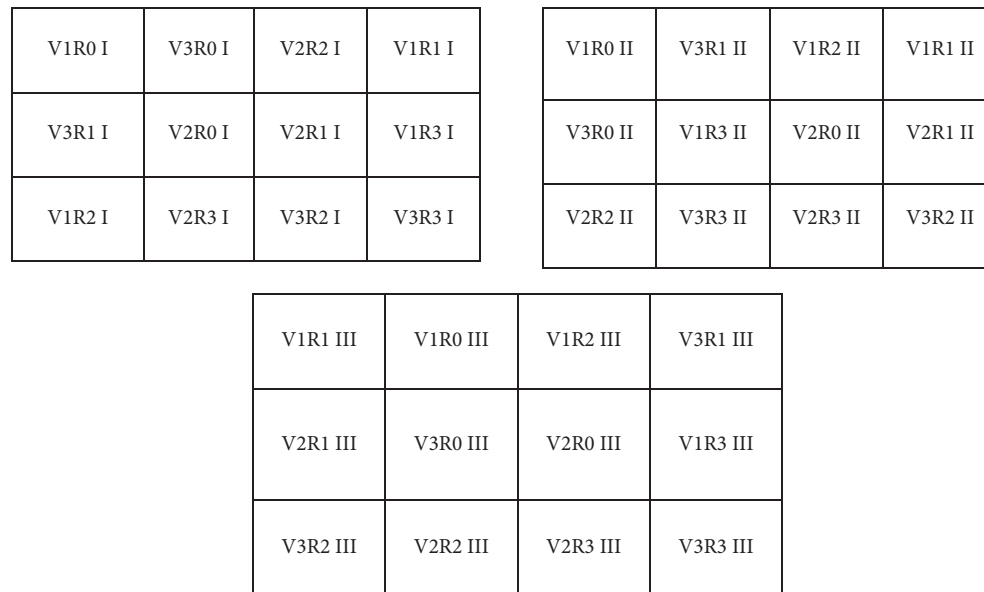
Each 1 m × 5 m experimental unit (bed) comprised 40 plants, with 2 rows of 10 plants, planted within a 50 cm × 70 cm planting space. The distance between beds was 50 cm. The experiment was conducted in three blocks; thus, the total number of grafted plants was 1440. Figure 1 displays the layout of this field experiment.

This study did not use self-grafted tomatoes, since a comprehensive and quantitative review of all published experiments showed that there are no significant differences between nongrafted and self-grafted plants [28].

The study began with rootstock production. *Solanum torvum* was ready to be grafted at 35 days after sowing (DAS), while cv. Gelatik and the EG203 line were ready at 21 DAS. The tomato scions were grafted at 15 DAS. The grafted plants were placed in a grafting chamber for ten days and then transferred to the greenhouse for seven days to strengthen and acclimatize the seedlings.

2.3. Measurement of Growth Parameters. The variables measured in this study included the number of branches, the diameter of scions and rootstocks, root length, and root dry weight, which were observed at 4, 6, 8, and 10 weeks after transplant (WAT). In addition, the plant growth indices—relative growth rate (RGR), specific leaf area (SLA), net assimilation rate (NAR), leaf area ratio (LAR), and dry plant weight—were observed at 4, 8, and 12 WAT. Harvesting was conducted when the fruit had obtained a characteristic red color, commencing when plant age was ±9 WAT and continuing until 20 WAT.

Dry plant weight (g) was obtained by cutting the above-ground part of the plant at the soil surface and drying it in an oven at 75°C for 48 hours to constant weight. The RGR, based on plant dry weight, was calculated using the following formula published by Gardner et al. [33]:



V1R0 = Cervo non-grafted V2R0 = Karina non-grafted V3R0 = Timoty non-grafted
V1R1 = Cervo grafted gelatik V2R1 = Karina grafted gelatik V3R1 = Timoty grafted gelatik
V1R2 = Cervo grafted EG203 V2R2 = Karina grafted EG203 line V3R2 = Timoty grafted EG203
V1R3 = Cervo grafted *S. torvum* V2R3 = Karina grafted *S. torvum* V3R3 = Timoty grafted *S. torvum*

FIGURE 1: Field experimental setup using a randomized block design.

TABLE 1: Summary of F statistics and significance of the effect on plant growth and yield of tomato varieties grafted onto eggplants.

Parameter	Rootstocks (R)	Scions (V)	Interaction (V*R)
Number of branches 4 WAT	2.06 ^{ns}	3.33 ^{ns}	7.57*
Number of branches 6 WAT	0.84 ^{ns}	3.36 ^{ns}	5.31**
Number of branches 8 WAT	1.46 ^{ns}	0.58 ^{ns}	11.9**
Stem diameter of scions 4 WAT	3.24 ^{ns}	24.9**	10.7**
Stem diameter of scions 6 WAT	2.21 ^{ns}	2.34 ^{ns}	5.38*
Stem diameter of scions 8 WAT	13.9**	14.7**	14.5**
Stem diameter of rootstocks 4 WAT	0.57 ^{ns}	5.12**	3.62*
Stem diameter of rootstocks 6 WAT	30.9**	30.7**	2.68*
Stem diameter of rootstocks 8 WAT	0.43 ^{ns}	3.75*	8.12**
Root length 4 WAT	152.**	17.3**	55.3**
Root length 8 WAT	6.48**	2.38 ^{ns}	22.7**
Root length 12 WAT	14.4*	5.56 ^{ns}	28.4**
Root dry weight 4 WAT	68.4**	250. **	81.0**
Root dry weight 8 WAT	23.9**	15.2**	2.93*
Root dry weight 12 WAT	15.6**	13.5**	5.65**
RGR 0-4 WAT	38.1**	10.1**	5.80**
RGR 4-8 WAT	3.12 ^{ns}	66.8**	5.15**
RGR 8-12 WAT	103**	83.9**	100.**
LAR 0-4 WAT	24.1**	36.3**	17.8**
LAR 4-8 WAT	12.6**	109 **	18.0**
LAR 8-12 WAT	1.90 ^{ns}	4.99*	4.34**
NAR 0-4 WAT	1.09 ^{ns}	70.7**	26.4**
NAR 4-8 WAT	0.03 ^{ns}	19.3**	3.15*
NAR 8-12 WAT	1.41 ^{ns}	7.91**	2.76*
SLA 0-4 WAT	16.6**	1.20 ^{ns}	4.61**
SLA 4-8 WAT	0.16 ^{ns}	0.73 ^{ns}	0.00**
SLA 8-12 WAT	41.6**	13.7**	8.16**
Yield production	11.6*	440**	3.25*

Note. * and ** denote significance at 5% and 1%, respectively; ns denotes a nonsignificant result.

TABLE 2: Effect of grafting on the number of branches.

Treatment	R0	R1	R2	R3
<i>Number of branches 4 WAT</i>				
V1	2.33 ab	2.00 a	2.11 ab	2.78 bc
V2	4.00 d	2.70 b	2.00 a	3.22 c
V3	5.00 e	2.45 ab	2.22 ab	2.67 ab
LSD 5%	0.68			
CV (%)	28.7			
<i>Number of branches 6 WAT</i>				
V1	9.00 ab	7.11 a	7.45 a	8.00 ab
V2	16.8 d	15.44 cd	10.9 ab	18.1 d
V3	12.2 bc	9.11 ab	8.44 ab	8.89 ab
LSD 5%	4.5			
CV (%)	35.7			
<i>Number of branches 8 WAT</i>				
V1	15.1 d	13.2 cd	8.22 a	9.00 ab
V2	11.2 bc	9.78 ab	8.55 ab	9.56 ab
V3	9.0 ab	11.4 bc	10.0 ab	13.22 cd
LSD 5%	2.97			
CV (%)	32.1			

Numbers in the same column followed by the same letter are not significantly different based on LSD test at significant level of 5%. LSD is least significant difference; CV is coefficient of variation.

$$\text{RGR} = \frac{1}{w} \times \frac{dw}{dt} (\text{g cm}^{-2} \text{day}^{-1}), \quad (1)$$

where w is total plant dry weight, dw is the increase in biomass, and dt is the number of days after planting. Calculation of the photosynthetic variables, specific leaf area (SLA), leaf area ratio (LAR), and net assimilation rate (NAR) was performed according to the following formulae:

$$\text{SLA} = \frac{\text{LA}}{W} (\text{cm}^{-2} \text{g}^{-1}), \quad (2)$$

$$\text{LAR} = \frac{\text{LA}}{W} (\text{cm}^{-2} \text{g}^{-1}), \quad (3)$$

$$\text{NAR} = \frac{1}{\text{LA}} \times \frac{dw}{dt} (\text{g cm}^{-2} \text{day}^{-1}), \quad (4)$$

where LA is leaf area per plant and W is total dry weight of the leaf area (for SLA) or total plant dry weight (for LAR and NAR).

The data were recorded and subjected to a two-way analysis of variance (ANOVA) at the significance level of 0.05. Significance of interactions was determined using the F-test. If the significance of F was less than 0.05, pairwise comparisons were made using the least significant difference (LSD) test at a significance level of 0.05 [34].

3. Results and Discussion

3.1. Interaction between Grafting and Variety. The interaction between scion and rootstock affected all measured variables, as presented in Table 1. For several variables, one of the factors was not significantly affected by treatment (Table 1). Initial plant growth was measured at 4 WAT.

TABLE 3: Effect of grafting on diameter of scions and rootstocks.

Treatment	R0	R1	R2	R3
<i>Stem diameter (cm) tomato scions 4 WAT</i>				
V1	0.35 a	0.56 b	0.56 b	1.07 c
V2	0.49 ab	0.59 b	0.55 b	0.62 b
V3	0.49 ab	0.56 b	0.59 b	0.61 b
LSD 5%	0.14			
CV (%)	13.6			
<i>Stem diameter (cm) eggplant rootstocks 4 WAT</i>				
V1	0.35 a	0.4 ab	0.41 ab	0.38 a
V2	0.493 b	0.37 a	0.32 a	0.36 a
V3	0.49 b	0.367 a	0.6 a	0.40 ab
LSD 5%	0.0824252			
CV (%)	12.42			
<i>Stem diameter (cm) tomato scions 6 WAT</i>				
V1	0.84 ab	1.02 cde	1.00 bcd	0.98 bcd
V2	0.69 a	0.97 bcd	0.91 bc	1.03 cde
V3	0.98 bcd	1.03 cde	1.09 de	1.18 e
LSD 5%	0.17			
CV (%)	20.00			
<i>Stem diameter (cm) eggplant rootstocks 6 WAT</i>				
V1	0.84 e	0.67 bcd	0.68 bcd	0.78 de
V2	0.69 bcd	0.53 a	0.51 a	0.59 ab
V3	0.98 f	0.63 bc	0.63 bc	0.71 cd
LSD 5%	0.09			
CV (%)	8.45			
<i>Stem diameter (cm) tomato scions 8 WAT</i>				
V1	0.98 a	1.01 a	1.12 ab	1.11 ab
V2	1.73 c	0.98 a	0.93 a	1.14 ab
V3	1.06 a	1.17 ab	1.16 ab	1.33 b
LSD 5%	0.24			
CV (%)	24.4			
<i>Stem diameter (cm) eggplant rootstocks 8 WAT</i>				
V1	0.98 de	0.74 bc	0.80 cd	0.82 cd
V2	1.73 f	0.60 abc	0.50 a	0.79 bcd
V3	1.06 e	0.7 bc	0.74 bc	0.82 cd
LSD 5%	0.19			
CV (%)	26.3			
<i>Stem diameter (cm) tomato scions 10 WAT</i>				
V1	0.92 ab	2.91 e	1.20 cd	1.21 cd
V2	0.81 a	0.92 ab	1.01 abc	1.31 d
V3	1.03 bc	1.17 cd	1.28 d	1.36 d
LSD 5%	0.21			
CV (%)	19.80			
<i>Stem diameter (cm) eggplant rootstocks 10 WAT</i>				
V1	0.92 gh	0.77 cdef	0.69 cdef	0.89 fg
V2	0.81 efg	0.49 a	0.54 ab	0.78 def
V3	1.03 h	0.66 bcd	0.64 bc	0.83 fg
LSD 5%	0.13			
CV (%)	20.5			

Numbers in the same column followed by the same letter are not significantly different based on LSD test at significant level of 5%. LSD: least significant difference; CV: coefficient of variation.

Nongrafted control plants produced a higher number of branches than plants grafted onto rootstocks of cv. Gelatik, EG203 line, and *S. torvum*. When plants are grafted, the scion and the rootstock are cut before the grafting. The tissues in the stem vessels and around the cutting fuse with one another when the scion and rootstock are attached [35, 36]. This process inhibits the initial growth of grafted

plants compared to the control. Gaps in the linkage area may interrupt the transportation of water, nutrients, growth regulators, and photosynthates [37]. Therefore, the initial nutrient absorption process was smoother in control plants compared to grafted tomato plants.

3.2. Number of Branches. The results show an interaction between rootstock and scions on the number of branches (Table 2). The tomato cv. Karina grafted onto “Gelatik” and *S. torvum* rootstocks, as well as the nongrafted control, produced more branches at 6 WAT than other scion varieties in any grafting treatment. Grafted “Karina” plants grew more branches, possibly influenced by genetic factors of this variety [38]. The genetic pattern determines the potential for plants to grow optimally. At 4 WAT and 6 WAT, there was no significant difference in the number of branches produced by Cervo and Timoty varieties grafted onto “Gelatik,” EG203 line, and *S. torvum* rootstocks. In some cases, these were not different from nongrafted “Cervo” and “Timoty” plants. By 6 WAT, the grafted plants of “Cervo” and “Timoty” had adapted well and produced similar numbers of branches to nongrafted plants. At 6 WAT, there was no significant difference in branch production between nongrafted “Karina” and “Karina” grafted onto “Gelatik” and *S. torvum* rootstocks. At 8 WAT, “Timoty” grafted onto *S. torvum* and “Cervo” grafted onto “Gelatik,” as well as the control plants, produced more branches than other treatments.

3.3. Diameter of Scions and Rootstocks. Table 3 shows the interaction between tomato scion and eggplant rootstock on the diameter of scions and rootstocks. Scion diameter is always significantly higher than rootstock diameter. It is due to inflammation in the joint area, which accelerates the growth of the scion parts [39, 40]. This swelling indicates the success of the grafting process. The results show that the node in the seam area supports scion growth, which is a sign of conformity [32].

The scion diameters of “Cervo,” “Karina,” and “Timoty” grafted on “Gelatik,” EG203 line, and *S. torvum* were higher than the diameters of the nongrafted plants at 4 WAT, but this was significant only for “Cervo” (Table 3). At 4 WAT, the rootstock diameter of “Karina” was lower in all grafted treatments than in the control, and the rootstock diameter of “Timoty” was lower in “Gelatik” and EG203 line than in the control. At 6 WAT, the scion diameters of “Cervo,” “Karina,” and “Timoty” grafted onto the rootstocks of “Gelatik” eggplant, EG203, and *S. torvum* were higher than the scion diameters of the control plants, and this was significant for “Cervo” on “Gelatik,” “Karina” on all rootstocks, and “Timoty” on *S. torvum*. In contrast, the rootstock diameters of “Cervo,” “Karina,” and “Timoty” grafted onto “Gelatik,” EG203 line, and *S. torvum* were lower than the rootstock diameter of the control. This was significant for “Cervo” and “Karina” on “Gelatik” and EG203 and for “Timoty” on all grafted rootstocks.

At 8 WAT, the scion diameter of “Cervo” did not differ between grafted and nongrafted plants. In contrast, the scion

TABLE 4: Effect of grafting on root length.

Treatment	R0	R1	R2	R3
<i>Root length (cm) 4 WAT</i>				
V1	5.73 b	11.1c	1.97 a	1.64 a
V2	33.6 e	0.81 a	0.31a	3.41 ab
V3	16.9d	2.24 ab	2.99 ab	1.93 a
LSD 5%	3.2935973			
CV (%)	28.22			
<i>Root length (cm) 8 WAT</i>				
V1	20 de	20 de	20.4 de	16.9 cd
V2	11 abc	5.2 a	7.89 ab	40.0 f
V3	16.9 cd	25.2 e	20.8 de	13.0 bcd
LSD 5%	6.94			
CV (%)	22.6			
<i>Root length (cm) 12 WAT</i>				
V1	18,0 d	13.03 cd	27.6 e	17.6 d
V2	9.67 abc	3.23 a	5.82 ab	38.3 f
V3	14.7 cd	18.4 d	18.8 d	10.8 bc
LSD 5%	6.17			
CV (%)	22.3			

Numbers in the same column followed by the same letter are not significantly different based on LSD test at significant level of 5%. LSD: least significant difference; CV: coefficient of variation.

diameter of “Timoty” grafted onto *S. torvum* was higher than that of nongrafted plants, while the scion diameter of “Karina” grafted onto all three rootstocks was lower than that of nongrafted plants. At 10 WAT, the scion of “Cervo” tomato grafted onto “Gelatik” eggplant produced the largest diameter, and scion diameter of “Cervo” in all three grafting treatments was significantly larger than for the control. Scion diameter of “Karina” grafted onto the *S. torvum* rootstock and scion diameter of “Timoty” grafted onto the EG203 and *S. torvum* rootstocks was significantly larger than scion diameter of control plants.

At 8 WAT, the rootstock diameter of nongrafted tomatoes was significantly larger than the rootstock diameters of “Cervo,” “Karina,” and “Timoty” grafted onto the rootstocks of “Gelatik,” EG203, and *S. torvum*, except for “Cervo” grafted onto EG203 and *S. torvum*. This trend was maintained at 10 WAT. At this stage, only the rootstock diameter of “Cervo” grafted onto *S. torvum* was not smaller than the rootstock diameter of the control. This difference in plant growth is due to an unbalanced distribution of assimilates between the scions and rootstocks [41].

3.4. Root Length. Table 4 shows the effect of the interaction between tomato scion and eggplant rootstock on root length. Plant resistance is closely related to the root system, which supplies nutrients and water to the plant. At 4 WAT, the length of the roots produced varied. The nongrafted tomato plants of “Karina” and “Timoty” produced longer roots than the grafted plants, while for “Cervo” this was true only for plants grafted onto “Gelatik.” At 8 WAT, there was no difference in root length between “Cervo” grafted onto “Gelatik,” EG203 line, and *S. torvum* and the nongrafted “Cervo” control. “Karina” grafted onto *S. torvum* produced the longest roots of any scion-rootstock interaction, while

TABLE 5: Effect of grafting on root dry weight.

Treatment	R0	R1	R2	R3
<i>Root dry weight (g) 4 WAT</i>				
V1	0.87 a	0.4 a	0.30 a	0.41 a
V2	9.28 c	0.27 a	0.09 a	0.29 a
V3	4.11 b	0.32 a	0.46 a	0.59 a
LSD 5%	0.71			
CV (%)	28.8			
<i>Root dry weight (g) 8 WAT</i>				
V1	3.03 bc	2.93 bc	3.13 c	4.27 e
V2	3.03 bc	1.73 a	2.33 ab	3.40 cd
V3	4.13 e	3.60 cde	3.20 c	4.00 de
LSD 5%	0.67			
CV (%)	12.29			
<i>Root dry weight (g) 12 WAT</i>				
V1	2.66 bcd	2.00abc	4.60 e	4.40 e
V2	2.67 bcd	1.13 a	1.83 ab	3.20 d
V3	3.57 de	2.80 bcd	3.03 cd	3.20 d
LSD 5%	0.94			
CV (%)	19.1			

Numbers in the same column followed by the same letter are not significantly different based on LSD test at significant level of 5%. LSD: least significant difference; CV: coefficient of variation.

the other grafting treatments for this variety were not different from the control. “Timoty” grafted onto “Gelatik” produced longer roots than the other grafting treatments as well as the nongrafted “Timoty” control.

At 12 WAT, root length of “Cervo” grafted onto the EG203 line was longer than for the other grafting treatments and the control. “Timoty” grafted onto “Gelatik” and EG203 line produced longer roots than “Timoty” grafted onto *S. torvum* and the nongrafted “Timoty” control. In contrast, “Karina” grafted onto *S. torvum* produced longer roots than all other scion-rootstock interactions, while the other grafting treatments for this variety were not different from the control. During the experimental setup, the “Karina” plants were attacked by a virus. Still, they were very resistant to diseases in the soil so that at the beginning of 4 WAT growth, the nongrafted “Karina” plants had longer roots than all other tomato-eggplant interactions.

3.5. Root Dry Weight. Table 5 presents the effect of the interaction between tomato scion and eggplant rootstock on root dry weight. At 4 WAT the nongrafted plants of “Karina” and “Timoty” produced higher root dry weight than other treatments, while at 8 WAT and 12 WAT, there was no clear difference between nongrafted and grafted plants of these two varieties.

There were no clear trends in root dry weight at 8 WAT among the different treatments [42].

3.6. Relative Growth Rate (RGR). RGR is the primary indicator of plant growth related to plant productivity, which is influenced by plant genetic and environmental factors. It is significant for plants because it affects many ecological processes. The RGR of each treatment can be used to determine overall differences among treatments on plant

TABLE 6: Effect of grafting on RGR.

Treatment	R0	R1	R2	R3
<i>RGR (g.cm⁻² day⁻¹) 0–4 WAT</i>				
V1	0.03 d	0.03 cd	0.02 b	0.03 d
V2	0.02 b	0.02 bc	0.02 a	0.02 a
V3	0.03 bcd	0.03 bc	0.03 bcd	0.02 b
LSD 5%	0.04			
CV (%)	8.35			
<i>RGR (g.cm⁻² day⁻¹) 4–8 WAT</i>				
V1	0.12 a	0.14 b	0.15 bc	0.15 bc
V2	0.12 a	0.13 a	0.15 bc	0.16 c
V3	0.12 a	0.15 bc	0.15 bc	0.16 c
LSD 5%	0.74			
CV (%)	9.8-			
<i>RGR (g.cm⁻² day⁻¹) 8–12 WAT</i>				
V1	-0.97 bc	-0.15 f	-0.91 c	-0.53 e
V2	-0.49 e	-1.10b	-0.67 d	-0.50 e
V3	-0.12 a	-0.10 bc	-0.10 b	-0.52 e
LSD 5%	0.09			
CV (%)	-7.46			

Numbers in the same column followed by the same letter are not significantly different based on LSD test at significant level of 5%. LSD: least significant difference; CV: coefficient of variation.

performance. The accumulation of dry matter shows the plant’s ability to obtain energy from sunlight through photosynthesis, as influenced by the environment.

Table 6 shows the effect of the interaction between tomato scion and eggplant rootstock on the RGR. At 4–8 WAT, the RGR of grafted plants was higher than the RGR of control plants. These results are consistent with research results showing no significant difference between self-grafted and nongrafted plants of the tomato cv. “Big Red” in terms of the ratio of total plant dry weight to total fresh weight of cv. hybrid tomato plants [43]. During the grafting process, callus tissue forms at the joint between the scion and the rootstock, allowing differentiation of new cells into xylem and phloem, which have the same conductance properties, as the original vascular vessels for transporting material from the rootstock to the scion [44]. This adaptation process results in reduced water flow from roots to shoots (decreased hydraulic conductance) through the callus region and limited transport of photosynthetic products from shoots to roots [45]. Nevertheless, the grafted plants do not show a clear trend of slower growth than nongrafted plants at 0–4 WAT. It is known that plant strength is closely related to the root system, which supplies water and nutrients to the scion [42].

At 8–12 WAT, the RGR decreased in all treatments. This was due to a decrease in photosynthesis so that vegetative growth as expressed by leaf area, plant height, dry root weight, and total plant dry weight also decreased [46]. “Cervo” tomato grafted onto “Gelatik” rootstock produced the highest RGR. In contrast, “Karina” grafted onto *S. torvum* rootstock produced the lowest RGR of the grafted treatments. This low RGR is due to the lower growth of vegetative organs such as leaf area, dry root weight, and plant dry weight. Differences in growth period and environmental conditions can affect RGR [47]. In particular, larger plants

TABLE 7: Effect of grafting on leaf area ratio.

Treatment	R0	R1	R2	R3
<i>LAR (cm²g⁻¹) 4 WAT</i>				
V1	40.8 bcd	35.8 bc	30.8 ab	19.6 a
V2	45.4 cd	47.9 cd	28.9 ab	72.7 e
V3	40.1 bcd	50.15 d	40.5 bcd	89.1 f
LSD 5%	11.7			
CV (%)	15.3			
<i>LAR (cm²g⁻¹) 8 WAT</i>				
V1	29.2 bc	27.5 abc	27.2 abc	19.1 a
V2	38.8 d	35.4 cd	51.7 e	75.1 f
V3	24.1 ab	24.7 ab	24.9 ab	30.5 bc
LSD 5%	7.89			
CV (%)	13.7			
<i>LAR (cm²g⁻¹) 12 WAT</i>				
V1	23.0 bc	28.5 c	27.6 c	21.4 bc
V2	24.4 bc	26.0 bc	11.2 a	19.2 b
V3	22.6 bc	23.1 bc	25.0 bc	27.5 c
LSD 5%	7.08			
CV (%)	17.9			

Numbers in the same column followed by the same letter are not significantly different based on LSD test at significant level of 5%. LSD: least significant difference; CV: coefficient of variation.

tend to have a lower RGR because of the possibility of their position being shaded [47].

3.7. Leaf Area Ratio (LAR). Leaf area ratio determines light interception and is an essential parameter in determining plant productivity [48]. It expresses the potential for photosynthesis per unit of plant biomass [49]. The LAR was measured at 0–4 WAT, 4–8 WAT, and 8–12 WAT. At 0–4 WAT, for “Cervo,” the LAR of scions grafted onto the three rootstocks (“Gelatik,” EG203 line, and *S. torvum*) was lower than the LAR of the nongrafted control plants, but this was only significant for *S. torvum*. This pattern repeated itself at 4–8 WAT. However, at 8–12 WAT, the LAR for “Cervo” grafted onto “Gelatik,” EG203 line, and *S. torvum* was not significantly different from the LAR of nongrafted control plants (Table 7).

In 0–4 WAT, the LAR of “Karina” scions grafted onto rootstocks of the EG203 line was lower than the LAR of “Karina” on rootstocks of “Gelatik” and nongrafted control plants, but the LAR of “Karina” scions grafted onto *S. torvum* rootstocks was higher than the LAR of “Gelatik” and nongrafted control plants. At 4–8 WAT, the LAR of nongrafted “Karina” and “Karina” scions grafted onto “Gelatik” was the lowest, LAR of scions grafted onto EG203 line was intermediate, and LAR of scions grafted onto *S. torvum* was the highest. At 8–12 WAT, the LAR of “Karina” scions grafted onto rootstocks of EG203 line was lower than the LAR of “Karina” scions grafted onto “Gelatik” and *S. torvum* rootstocks and nongrafted control plants.

At 0–4 WAT, the LAR of “Timoty” grafted onto *S. torvum* rootstock was higher than that of the control by 122%. At 4–8 WAT and at 8–12 WAT, the LAR of grafted “Timoty” plants was not significantly different from the LAR of the control plants.

TABLE 8: Effect of grafting on net assimilation rate.

Treatment	R0	R1	R2	R3
<i>NAR (g 100 cm⁻² day⁻¹) 0–4 WAT</i>				
V1	0.07 c	0.08 c	0.07 c	0.15 d
V2	0.05b	0.05 b	0.06 bc	0.02 a
V3	0.07 bc	0.05 b	0.07 bc	0.03 a
LSD 5%	0.00019			
CV (%)	16.7			
<i>NAR (g 100 cm⁻² day⁻¹) 4–8 WAT</i>				
V1	0.06 bcd	0.06 bcd	0.05 bcd	0.08 e
V2	0.04 abc	0.04 ab	0.04 abc	0.02 a
V3	0.05 bcd	0.06 cde	0.06 de	0.05 bcd
LSD 5%	0.02			
CV (%)	20.9			
<i>NAR (g 100 cm⁻² day⁻¹) 8–12 WAT</i>				
V1	6.25 a	6.32 ab	5.95 a	6.48 ab
V2	6.82 abc	6.26 ab	7.68 c	7.09 bc
V3	6.85 bc	6.29 ab	6.27 ab	6.44 ab
LSD 5%	0.76			
CV (%)	6.89			

Numbers in the same column followed by the same letter are not significantly different based on LSD test at significant level of 5%. LSD: least significant difference; CV: coefficient of variation.

3.8. Net Assimilation Rate (NAR). Table 8 presents the effect on NAR of grafting the tomato varieties onto the eggplant rootstocks. The NAR expresses the increase in plant dry biomass per unit leaf area and is a complex physiological variable related to photosynthesis and respiration [50]. Most of NAR is the net result of carbon gain (photosynthesis) and loss of carbon (respiration, evaporation) expressed per unit leaf area [47]. NAR is the highest when the plants are still young because at that stage, they are more efficient at absorbing sunlight directly [46].

There was an effect of the interaction between tomato and eggplant rootstocks on NAR. At 0–4 WAT, “Cervo” grafted onto *S. torvum* rootstock had higher NAR than “Cervo” controls and other grafted treatments. In contrast, “Timoty” and “Karina” grafted onto *S. torvum* had lower NAR than the other treatments.

At 8–12 WAT, NAR of “Cervo” grafted onto “Gelatik”, EG 203 line, and *S. torvum* lines was not significantly different from NAR of the control. Many experts argue that rootstock characteristics significantly affect the growth and yield of grafted plants [33, 51, 52]. The rootstock’s strength and compatibility are influenced by the connection of the scion and rootstock, and its appearance is influenced by different environmental conditions, giving different effects [42, 44]. The NAR of “Timoty” scion grafted onto “Gelatik”, EG203 line, and *S. torvum* was not significantly different than the NAR of the control.

3.9. Specific Leaf Area (SLA). The SLA ratio describes the efficiency of leaf area formation for every unit of available carbohydrate. This index contains information on leaf thickness that reflects photosynthetic organelle units and photosynthetic rate. Leaf thickness differences are often observed between environments with different light quanta.

TABLE 9: Effect of grafting on specific leaf area.

Treatment	R0	R1	R2	R3
<i>SLA (cm²g⁻¹) 4 WAT</i>				
V1	256 def	114 abc	171 bcde	141 abc
V2	107 abc	169 bcde	52.1 a	79.7 ab
V3	162 bcde	266 ef	192 cdef	288 f
LSD 5%	90.3			
CV (%)	31.9			
<i>SLA (cm²g⁻¹) 8 WAT</i>				
V1	239 ab	339 bc	337 bc	270 abc
V2	366 c	209 a	218 a	286 abc
V3	302 abc	301 abc	295 abc	360 c
LSD 5%	92.8			
CV (%)	18.6			
<i>SLA (cm²g⁻¹) 12 WAT</i>				
V1	343 ab	529 bc	1077 de	1164 e
V2	215 ab	333 ab	157 a	168 a
V3	257 ab	1033 de	881 de	794 cd
LSD 5%	284			
CV (%)	28.9			

Numbers in the same column followed by the same letter are not significantly different based on LSD test at significant level of 5%. LSD: least significant difference; CV: coefficient of variation.

TABLE 10: Effect of grafting on production (t.ha⁻¹).

Treatment	R0	R1	R2	R3
V1	24.53 b	34.27 de	35.50 e	30.25 cd
V2	4.46 a	4.51 a	4.57 a	4.69 a
V3	22.13 b	29.47 c	30.12 c	30.74 cd
LSD 5%	3,8			
CV (%)	11			

Leaf area growth determines light interception and is an important parameter in determining plant productivity [48].

Table 9 shows the effect of tomato grafted onto eggplant rootstock on SLA. At 0–4 WAT, the SLA of grafted “Cervo” plants was lower than the SLA of the control, but this was not significant for EG203 line. In contrast, grafted “Timoty” plants at 0–4 WAT had higher SLA than control “Timoty plants,” but this was significant only for *S. torvum*.

At 4–8 WAT, the SLA of “Cervo” and “Timoty” plants grafted onto all three eggplant rootstocks was no different to SLA of the controls. In contrast, the SLA was lower in “Karina” plants grafted onto “Gelatik” and EG 203 line eggplant rootstocks compared to the control. At 8–12 WAT, SLA of “Cervo” and “Timoty” plants grafted onto the three eggplant rootstocks was higher than the control (only “Cervo” on “Gelatik” was not significant).

3.10. Production. The interactive effect of tomato scions and eggplant rootstocks on production is shown in Table 10.

The combinations of “Cervo” scion grafted onto EG203 rootstock and “Cervo” on “Gelatik” produced the highest yields. The yield level of “Cervo” grafted onto *S. torvum*, and “Timoty” grafted onto *S. torvum* was not significantly different from the yield of “Cervo” on “Gelatik.” For these two tomato varieties, tomato plants grafted onto eggplant

rootstocks produced higher yields than nongrafted plants. This indicates that the absorption of water and nutrients is higher in grafted plants. This finding is consistent with a study showing that the number of fruits and yield of rootstock *S. incanum* with *S. melongena* was significantly higher than for nongrafted or self-grafted “Black Beauty” eggplant [53]. Similarly, the rootstock *S. melongena* with *S. aethiopicum* had a much higher number of fruits and yield than “Black Beauty” grafted onto *S. macrocarpon* rootstock. There was no significant difference in the number of fruits and yield between control plants and the “Black Beauty” self-grafted eggplant.

Studies show that vascular vessels are formed during the grafting process, which connects the rootstock to the scion, affecting the translocation of air and nutrients and other physiological properties [54, 55]. Nevertheless, grafted plants demonstrate improved resistance acquired from the rootstock root system. Thus, they show increased absorption of water and nutrients and subsequently higher yield [56].

Nongrafted “Karina” and “Karina” grafted onto the three rootstocks resulted in low production. This is because cv. Karina is susceptible to viruses and was attacked by viruses during the research. The plant apex is attacked by a virus that causes stunted growth, and photosynthate translocation from the stem to the rootstock is blocked, causing a decrease in yield and poor fruit quality [57].

Table 11 presents correlations among the different plant growth indices (RGR, LAR, NAR, SLA, and production). Relative growth rate at 0–4 WAT is negatively correlated with LAR at 4–8 WAT (-0.754) and NAR at 8–12 WAT (-0.466) and positively correlated with LAR at 8–12 WAT (0.44), NAR at 0–4 WAT (0.527) and 4–8 WAT (0.453), SLA at 0–4 WAT (0.346) and production (0.562). It shows a direct and mutually supportive relationship among RGR, LAR, NAR, and SLA. Meanwhile, RGR at 4–8 WAT had a significant positive correlation only with SLA at 8–12 WAT. The RGR at 9–12 WAT had a significant positive correlation with NAR at 4–8 WAT and 8–12 WAT. Previous research has shown that NAR is the most critical predictor of RGR [49]. Fast-growing plants always have a high NAR, and plants with high assimilation rates always grow fast.

The NAR at 0–4 WAT was positively correlated with NAR at 4–8 WAT (0.470), SLA at 8–12 WAT (0.412), and production (0.374). At 4–8 WAT, NAR had a significant positive correlation with SLA at 8–12 WAT (0.474) and production (0.491). The NAR at 8–12 WAT was significantly negatively correlated with SLA at 8–12 WAT (-0.470) and production (-0.489). The RGR is mainly affected by NAR at high radiation and by SLA at low radiation [39]. Specific leaf area has been shown to decrease when light availability decreases [58, 59].

The LAR at 0–4 WAT was negatively correlated only with NAR at 0–4 WAT (-0.775). At 4–8 WAT, LAR had a significant positive correlation only with NAR at 8–12 WAT (0.345) as well as significantly negative correlations with LAR at 8–12 WAT (-0.369), NAR at 0–4 WAT (-0.475) and 4–8 WAT (-0.733), SLA at 0–4 WAT (-0.428), and 8–12 WAT (-0.532) and production (-0.650). Subsequently, LAR at 8–12 WAT had a significant negative correlation with

TABLE 11: Correlation of RGR, LAR, NAR, SLA at 4, 8, and 12 WAT and yield.

WAT	RGR 0-4	RGR 4-8	RGR 8-12	LAR 4 WAT	LAR 4 WAT	LAR 12 WAT	NAR 4 WAT	NAR 8 WAT	NAR 12 WAT	SLA 4 WAT	SLA 8 WAT	SLA 12 WAT	Yield
RGR 0-4	1	-0.323	0.03	-0.29	-0.754**	0.449**	0.527**	0.453**	-0.466**	0.346*	0.023	0.325	0.562**
RGR 4-8		1	-0.201	0.217	0.005	-0.158	-0.74	0.289	0.161	-0.047	0.048	0.424**	0.216
RGR 8-12			1	-0.079	0.156	0.151	0.026	-0.352**	-0.68**	0.117	0.218	0.192	0.146
LAR 0-4				1	0.327	0.186	-0.775**	-0.268	0.083	0.26	0.174	-0.18	-0.142
LAR 4-8					1	-0.369*	-0.475**	-0.733**	0.345**	-0.428**	-0.71	-0.532**	-0.65**
LAR 8-12						1	-0.19	0.043	-0.622**	0.288	0.256	0.306	0.424**
NAR 0-4							1	-0.47**	-0.194	-0.117	-0.137	0.412*	0.374*
NAR 4-8								1	0.023	0.174	-0.73	0.474**	0.491**
NAR 8-12									1	-0.39	-0.084	-0.47**	-0.489**
SLA 0-4										1	0.145	0.509**	0.522**
SLA 4-8											1	0.22	0.347**
SLA 8-12												1	0.747**
Yield													1

NAR at 8-12 WAT (-0.622) and was positively correlated with production (0.424).

At 0-4 WAT, SLA had a significant positive correlation with SLA at 8-12 WAT (0.509) and production (0.522). Meanwhile, at 4-8 WAT and 8-12 WAT, SLA had a significant positive correlation with production (0.347 and 0.747, respectively). A study by Amarullah et al. [60] concluded that the initial vegetative growth phase was associated with a high assimilation rate for root formation, while the optimum vegetative growth phase significantly affected final yield.

The resulting yield production is strongly influenced by several components of growth and photosynthetic organs. According to Table 11, higher scion stem diameter, root length, RGR, LAR, NAR, and SLA produce a higher yield. The carbon used in photosynthesis is distributed to plant organs to produce sucrose and starch. Since the supply of carbon decreases at night because of the respiration process, the remaining carbon forms new biomass [53]. The surplus carbon is used for leaf thickening and leaf area growth and for promoting further plant growth depending on the plant's developmental phase. Previous research has shown that plant development influences optimal production in the early growth phase and the maximum vegetative phase and depends on the variety used [60].

4. Conclusions

The initial growth of grafted tomato plants was lower than that of the nongrafted control tomato plants, but the grafted tomato plants grew faster than the control plants during the

course of the experiments. There was a significantly positive relationship between production and several parameters of plant growth and photosynthetic organs. Higher values of scion stem diameter, root length, RGR, LAR, NAR, and SLA increased production. The tomato cv. Cervo grafted onto EG203 line and eggplant cv. Gelatik produced the largest stem diameter, longest roots, fastest RGR, highest LAR, highest NAR, and highest yield. The eggplant cv. Gelatik is a local eggplant variety that has potential as a rootstock for tomato, increasing SLA, LAR, and RGR, thus supporting increased yields. Thus, it is recommended to use this rootstock for tomatoes grown by local farmers in Indonesia.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

All authors declare that there are no conflicts of interest regarding the publication of this paper.

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