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ORIGINAL ARTICLE

# Influence of Rootstocks on Yield and Quality of Summer Tomato cv. 'BARI Tomato-4'

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## Abstract

The appropriate rootstock is the prerequisite for successful tomato production based on the grafting technique. The present study was conducted to evaluate the suitable rootstock combination(s) on the growth, yield and quality attributes of (Bangladesh Agriculture Research Institute) Tomato-4. The experiment was consisted based on the four scion-rootstock combinations such as $T_0$ = Tomato-4 (Non-grafted plant), $T_1$ = Tomato-4 grafted on the *Sunchalo* rootstock, $T_2$ = Tomato-4 grafted on the brinjal rootstock and $T_3$ = Tomato-4 grafted on the wild tomato rootstock. The results of the grafted plants showed significant variations in all properties compared to non-grafted one except for plant height. The grafted plants on the *Sunchalo* rootstock was found better for a number of branches, clusters, fruits per plant, fruit length, diameter and weight rather than the other grafted and the non-grafted ones. The individual fruit weight ranges from 44.84 (non-grafted) to 57.88 g (grafted with *Sunchalo*) and the total yield (60.87 tons/ha) were found maximum in *Sunchalo* rootstock. Fruit quality properties (i.e. vitamin C, protein, lycopene, and β-carotene contents) were found better with *Sunchalo* rootstock rather than the other treatments. But fruit color, TSS (total soluble solids) and phenols content were not affected by the treatments. It is therefore concluded that grafting on *Sunchalo* rootstock was noted as the best on the basis of morphological, yield contributing and quality traits of the tomato fruit.

**Keywords** Tomato · Rootstock · Grafting · Yield · Quality

## 1 Introduction

Tomato (*Lycopersicon esculentum* Mill.) is one of the most popular and widely consumed vegetable crops in the world due to its valuable nutritional components like ascorbic acid, β-carotene and phenolic compounds to the human diet (Rouphael et al. 2010). The consumption of tomato is not only limited to curry or salad, rather it is widely used as ketchup, sauce, soup, and puree. In Bangladesh, it is the third most important vegetable after potato and brinjal in terms of both production and area (BBS 2015).

Tomato is grown in winter in Bangladesh as the temperature is congenial at that time for optimum growth and yield. Its production in summer is limited due to high temperature, heavy rainfall, and prevalence of severe diseases. But the production of summer tomato is highly remunerative and need-oriented. Application of plant growth regulators (PGRs) is required for fruit setting of summer tomato as pollen viability lost causing the failure of flowering and fruit set (Mahmood and Bahar 2006; Karim et al. 2015). This technology is highly technical, cumbersome, cost intensive and unavailable at farmer's level. BARI was developed heat-tolerant determinate type cultivar so-called " Tomato-4" that can set fruits during the summer season except for any PGRs. During the summer, tomato production in Bangladesh is so far to meet its requirement. Tomato producers are facing critical problems related to soil-borne diseases especially during summer that seriously impacting the yield and quality of fruit (Hasna et al. 2009; Cramer et al. 2011; McAvoy et al.

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2012). The major soil-borne diseases affecting tomatoes are *Fusarium* (*Fusarium oxysporum* f. sp. *lycopersici,* races 1 and 2) and *Verticillium wilts* (*Verticillium dahliae*, races 1 and 2), bacterial wilt (*Pseudomonas syringae* p.v. tomato) and root knot nematodes (*Melodogyne* spp.) (Poffley 2003). A number of methods are available to control soil-borne diseases including (1) host resistance (e.g., use of resistant varieties), (2) cultural control (e.g., crop rotation), (3) organic amendments, (4) physical control methods (e.g., solarization), (5) chemical fumigants (e.g., methyl bromide), and (6) biological control, which is under development (Schafer 1999).

Replacement of resistant rootstock through grafting is considered as an innovative technique to overcome the problems caused by soil-borne diseases (Oda 1999; Hasna et al. 2009). It is also used to improve resistance to abiotic stresses such as salinity, drought, heat and low soil temperature, and enhance the uptake of nutrients and water (Mohammed et al. 2009). This ancient technique began in Japan and Korea in the twentieth century to control soil-borne diseases caused by *Fusarium oxysporum* (Davis et al. 2008) and has been expanded to many vegetables such as eggplant, cucumber, watermelon, etc. Studies in many locations and countries have reported as increased yield and quality for a variety of rootstock-scion combinations (Davis et al. 2008; Mohammed et al. 2009). Khah et al. (2006) showed that tomato grafting on suitable rootstocks has positive effects on its performance. But, some studies also reported a reduction in yield and quality in grafted tomato plants and fruits (Vrcek et al. 2011).

The success of grafting relies on the selection of rootstocks. Therefore, the selection of suitable rootstocks with desired trait should be a key focus for minimizing soil-related problems. In view of the role of grafting technique in summer tomato production, the aim of the present study was to examine the effects of rootstocks on the growth, yield and fruit quality of summer tomato cv. 'BARI Tomato-4'.

## 2 Material and Methods

### 2.1 Experimental Site

The research work was conducted at horticulture farm and laboratory, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh during February–July 2017 in the summer season. The experimental land was medium high and the soil belongs to the Old Himalayan Piedmont Plain (Agro-Ecological Zone-1) (UNDP 1988). Ara and Ostendorf (2017) reported that annual average temperature show a discrepancy from 25.20 to 25.48 °C over Dinajpur, while rainfall displays from 1912 to 2232 mm. Monthly meteorological parameters (i.e. minimum and maximum temperature, precipitation, and relative humidity) are presented in Table 1.

### 2.2 Treatment

The single factor experiment was laid out in the Randomized Complete Block Design (RCBD) with four replications. Three grafted and one non-grafted (control) plant listed below, were the four treatments of the experiment,

$T_0$ = BARI Tomato-4 (Non-grafted plant),

$T_1$ = BARI Tomato-4 grafted on the *Sunchalo begun* (*Solanum sisymbrifolium*) rootstock,

$T_2$ = BARI Tomato-4 grafted on the brinjal (*Solanum melongena*) rootstock and

$T_3$ = BARI Tomato-4 grafted on the wild tomato (*Solanum aethiopicum*) rootstock

There were 16 unit plots and the size of each unit plot was 2.6 m × 2.0 m. The distance maintained between two blocks and two plots were 0.5 m and 0.4 m, respectively.

### 2.3 Seedling Raising, Grafting and Plant Establishment

The seeds of BARI Tomato-4 and wild tomato were collected from the East-West Seed Pvt. Ltd. and Syngenta Foundation, Bangladesh, respectively, while the sources of other rootstocks were local. For raising seedling, both seeds of rootstock and scion were sown in 50 × 30 cm sized coco pit tray (104 pits/tray) with coconut dust on the 2nd and 17th February 2017, respectively, at the horticulture farm, HSTU. The grafting was done using the tube method with 30-day-old scion tomato seedlings and 4-day-old rootstock seedlings. The grafted seedlings were kept in a small healing chamber for 7 days covered with a polyethylene sheet to maintain high humidity and to protect from direct sunlight. The seedlings were sprayed with water 3–4 times a day. The polyethylene sheet was removed after a week and kept in a shady place for another 7 days until the graft union was

**Table 1** Meteorological condition over the study area from February–July, 2017 (BMD 2017)

| Month | Relative humidity (%) | Total rainfall (mm) | Temperature (°C) | |
|---|---|---|---|---|
| | | | Minimum | Maximum |
| February | 79.00 | 0.0 | 12.90 | 28.10 |
| March | 74.00 | 8.30 | 17.50 | 32.00 |
| April | 79.00 | 4.00 | 21.60 | 34.30 |
| May | 78.23 | 17.93 | 23.34 | 32.29 |
| June | 80.13 | 14.80 | 26.17 | 33.59 |
| July | 84.00 | 23.00 | 27.40 | 35.20 |

established. After 3 weeks of grafting, the plants were transplanted in the North–South direction in the well-prepared plot where each unit plot contained 16 seedlings with maintaining 65 × 50 cm spacing. Recommended doses of well-rotten cowdung manures and chemical fertilizers were mixed with the soil of each unit plot according to the fertilizer recommendation guide (BARI 2004). Various intercultural operations such as irrigation, gap filling, weeding, stalking and plant protection measures were done when necessary for better growth of the plants.

## 2.4 Data Collection

Ten plants from each unit plot were selected randomly and tagged individual plant. The following morphological, yield contributing and biochemical parameters were recorded.

### 2.4.1 Measurement of Plant Height

The plant heights were measured from the randomly selected ten plants from each unit plot in cm on 30, 45 and 60 DATs from the ground level to the tip of the main stem and the mean value was calculated.

### 2.4.2 Estimation the Number of Branches Per Plant, Flowering Clusters Per Plant, Flowers Per Cluster, Fruits Per Cluster and Marketable Fruits Per Plant

The numbers of branches per plant were measured from the randomly selected ten plants from each unit plot by counting and the mean value was calculated at the time of the final harvest. The numbers of flowering clusters were counted from selected plants and the average number of flowering clusters produced per plant was recorded at the time of the final harvest. The flowers per cluster were calculated by counting manually in the flowering stage of selected plants and data was recorded. The fruits per cluster were counted at the time of the final harvest from the selected plants from each plot by counting manually and the mean data was recorded. For counting marketable fruits per plant, the total numbers of marketable fruits harvested from the ten plants throughout the whole harvest period were counted and the average numbers of fruits per plant were calculated.

### 2.4.3 Measurement of Fruit Length and Diameter

The length of fruit was measured with a digital slide caliper (Guanglu, China) from the neck of the fruit to the bottom of ten selected marketable fruits from each plant of each replication and their average was calculated in mm. The diameter of fruit was measured at the middle portion of ten selected marketable fruits from each treatment of each replication with digital slide calipers (Guanglu, China) and their average was calculated in mm.

### 2.4.4 Calculation the Weight of Individual Fruit, Yield Per Plant and Yield Per ha

Fruit weight was calculated using an electronic balance (G&G, T100, Germany) in g by taking ten fruits in each of the selected plants in each row. Fruit yield per plant was recorded in kg at each harvest and added overall harvests to get the final yield per plant. Total marketable fruit yield per ha was calculated by multiplying of final yield per plot area and was expressed as tons/ha.

### 2.4.5 Measurement of Fruit Color

The fruit color was recorded using a chromameter (Konica Minolta CM 250d, Japan) calibrated against a standard white plate. The chromatic analysis was carried out following the CIE (Commission International de l'Eclairage) system of 1976 as detailed in (Ali et al. 2019). Values of $L^*$, $a^*$, and $b^*$ were measured to describe the three-dimensional color space and interpreted as follows: $L^*$ indicates lightness, read from 0 (completely opaque or black) to 100 (completely transparent or white). The positive $a^*$ value indicates redness (negative $a^*$ indicates greenness) and the positive $b^*$ value yellowness (negative $b^*$ indicates blueness) on the hue-circle (Hutchings 1994). The pericarp color was described in terms of $L$, chroma ($C^*$) and Hue angle ($H^\circ$) as the red color development of the fruit was better described using $C^*$ and $H^\circ$ than $a^*$ and $b^*$. The hue angle ($H^\circ$), hue = arctangent ($b^*/a^*$), represented red–purple ($0^o$), yellow ($90^o$), bluish–green ($180^o$) and blue ($270^o$) (McGuire 1992). The chroma ($C^*$), obtained from $(a^{*2} + b^{*2})^{1/2}$, corresponded to the intensity or color saturation, in which low values represent dull color while high values represent vivid color. The pericarp color was measured only from the central section of each fruit at the harvest stage. The data of each measurement are the average of duplicate measurements at two opposite points on the equator of each fruit.

### 2.4.6 Measurement of Firmness of Fruit

The firmness was expressed as the force required penetrating the fruit a 1.6 cm diameter conical needle penetrating to a depth of 1 cm using a penetrometer (HANDPI, China). For firmness, two measurements were made in the pericarp of the central region of the fruit and the results were expressed as kg/cm$^2$.

#### 2.4.7 Determination of Total Soluble Solids of Fruit

The TSS was recorded using a digital refractometer (Hanna Instruments, Romania). For each fruit, two longitudinal slices (from stem end to calyx-end) were taken. The slices were squeezed longitudinally to get the juice. One drop of the juice was placed onto the refractometer prism plate. The reading on the prism scale was noted up to one decimal place. After each reading, the prism plate was cleaned with distilled water and wiped dry with a soft tissue paper. The recorded data were averaged to calculate the mean value and were expressed as Brix%.

#### 2.4.8 Determination of Total Phenols Concentration

The total phenols concentration was quantified using Folin–Ciocalteu reagent (FC) following Singleton and Rossi (1965) with some modifications as detailed in Awad et al. (2017). The extraction was performed according to Velioglu et al. (1998) using 1 g fresh flesh. The fruit tissues were disrupted into the extraction medium using a homogenizer. The tomato flesh tissue was extracted with 4 ml 80% aqueous methanol containing 2.7% HCl (37%), shaken for 2 h on an orbital shaker (200 rpm) at the room temperature and centrifuged at 5300 rpm for 15 min at 4 °C. The extraction procedure was repeated twice and the supernatants were combined for the total phenolic assay. Three hundred microliter (300 µl) of the extract was added to 2.25 ml of Folin–Ciocalteu reagent, followed by 2.25 ml of sodium carbonate solution (60 g/l). The samples were vortexed and left to stand for 90 min at room temperature. After incubation, absorbance was measured at 765 nm using a UV/VIS spectrophotometer. Then the phenol content was estimated from a standard curve of gallic acid and the results were expressed as mg GAE/100 g of fresh weight (FW).

#### 2.4.9 Determination of Vitamin C Content

The vitamin C content was determined using the spectrophotometric procedure (Bajaj and Kaur 1981). 5 g of the fresh tissue was homogenized with a homogenizer (VELP Scientifica, Italy) in 100 ml oxalic acid–EDTA cold solution. The homogenate was centrifuged at 3000 rpm for 10 min at 4 °C and the supernatant was subsequently filtered with Whatman filter paper. A 5 ml aliquot was then transferred to a 25-ml volumetric flask to which 0.5 ml metaphosphoric acid–acetic acid solution, 1 ml sulphuric acid solution (5%) and 2 ml of ammonium molybdate (5%) reagent were added. The mixture was then adjusted to a volume of 25 ml with distilled water and allowed to stand for 15 min. After that, the absorbance at 760 nm was measured with a UV/VIS spectrophotometer (PG Instrument Ltd. Model T60, UK). The vitamin C concentration was quantified using a standard curve of L-ascorbic acid and expressed as mg/100 g FW.

#### 2.4.10 Determination of Protein Content

The protein concentrations were determined according to Bearden (1978). The protein reagent used in the assay consisted of 0.04 mg/ml Coomassie Brilliant Blue G-250, and 85% *ortho*-phosphoric acid. The extraction was performed as per McCown et al. (1968) using 1 g of the fresh sample. The flesh tissue was extracted with 5 ml of 100 mM Tris–HCl (pH 7.5) using a homogenizer (VELP Scientifica, Italy), the mixture was vortexed vigorously and kept in the refrigerator at 4–5 °C for 1 h. The homogenate was centrifuged at 5300 rpm for 15 min at 4 °C. One hundred microliters (100 µl) of supernatant was diluted with 1400 µl distilled water to which 1.5 ml Bearden solution was added. After vortexing, absorbance was measured at 595 nm using a UV/VIS spectrophotometer (PG Instrument Ltd. Model T60, UK). The protein concentration was calculated using the bovine serum albumin (BSA, Sigma Chemical) as the standard and expressed as mg/100 g FW.

#### 2.4.11 Determination of Lycopene and β-Carotenoids Content

The contents of chlorophyll and β-carotenoid in fruits were quantified using the spectrophotometric method (Nagata and Yamashita 1992). One gram of the fruit tissue was extracted with solvent acetone: hexane (4:6). Then taking the supernatant by measuring the absorbance at 663 nm, 645 nm, 505 nm, and 453 nm using a UV/VIS spectrophotometer (PG Instrument Ltd. Model T60, UK). From these values, the pigment content in tomato fruit like lycopene and β-carotene were estimated using the following equations,

$$\text{Lycopene(mg/100g)} = -0.0458A_{663} + 0.204A_{645} + 0.372A_{505} - 0.0806A_{453},$$

$$\beta - \text{carotene(mg/100g)} = 0.216A_{663} - 1.22A_{645} - 0.304A_{505} + 0.452A_{453},$$

Here,

$A_{663}$, $A_{645}$, $A_{505}$ and $A_{453}$ are absorbance at 663 nm, 645 nm, 505 nm and 453 nm each other. The results were expressed as mg/100 g FW.

### 2.5 Statistical Analyses

This one-factor analysis of variance (ANOVA) was conducted for all the variables using the Statgraphics Plus Version 2.1 statistical program (STSC 1987). The means were compared using Fisher's Least Significant Difference (Lsd).

## 3 Results and Discussion

### 3.1 Plant Height

The heights of the grafted and non-grafted plants showed significant variation ($p \leq 0.05$) at different DATs (Fig. 1). The non-grafted plants were taller than the grafted ones at 30, 45 and 60 DATs, respectively. At harvest, the tallest plant was measured from $T_0$ (88.6) followed by $T_2$ (85.0), $T_1$ (79.0) and $T_3$ (78.4 cm). However, three different rootstocks exerted statistically insignificant variations among themselves at all the three DATs. Within the grafted plants, in all the cases, $T_2$ resulted taller plants than $T_1$ and $T_3$ (Fig. 1). It became lucid that the plant height decreased due to grafting. Our results are in close conformity with those of Latifah et al. (2019), who reported significant differences between grafted plants. Again, Mohammed et al. (2009) noted insignificant variation in plant height due to grafting in tomatoes up to 45 DAT. But the contrary results were observed by Lee (1994) who found that grafted plants were taller and more vigorous than the non-grafted ones.

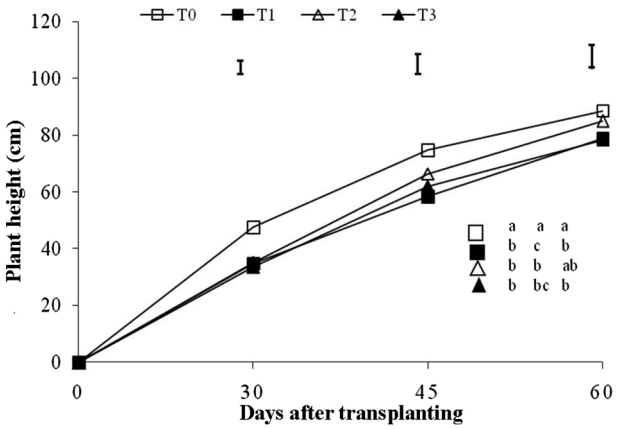


**Fig. 1** Plant height of grafted and non-grafted tomato plants. Vertical bar shows standard deviations ($n=4$) and values followed by the different letter(s) are at 95% level of significance

Oppositely, plant height was insignificant due to grafting under greenhouse conditions whereas in the open-field cultivation, the height of grafted tomato viz. Big red × Heman (BH) was significantly greater than the control and Big red × Primavera (BP) ones at harvest (Khah et al. 2006). These variations might happen due to different varieties and rootstocks.

### 3.2 Number of Branches/Plant, Flowering Clusters/Plant, Flowers/Cluster, Fruits/Cluster and Marketable Fruits/Plant

The number of branches per plant ranged from 3.4 to 3.6 for the grafted and non-grafted plants and also showed statistically insignificant variation (Table 2). However, the maximum number of branches (3.6) among all the treatments was in $T_1$ while in the rest three treatments, the values were equal (3.4). Among the different rootstocks, $T_1$ gave the maximum number of branches (3.6), while the other two rootstocks had the same value (3.4). The number of flowering clusters per plant was insignificant due to different rootstocks and non-grafted plants (Table 2). The grafted plant produced more flowering clusters than the non-grafted one except in $T_3$ (Table 2). However, $T_1$ gave more flowering clusters (9.4) than the rest two rootstocks. Therefore, $T_1$ was better

**Table 2** Variations in morphological parameters of tomato plants as affected by rootstock treatments. Means within each column followed by the same letter(s) are not significantly different at level $P \leq 0.05$ (* defines significant). NS defines not significant

| Treatments | Branches per plant (number) | Flowering clusters per plant (number) | Flowers per cluster (number) | Fruits per cluster (number) |
|---|---|---|---|---|
| $T_0$ | 3.4 a | 8.8 ab | 6.8 b | 4.8 b |
| $T_1$ | 3.6 a | 9.4 a | 7.8 ab | 6.8 a |
| $T_2$ | 3.4 a | 8.8 ab | 7.8 ab | 4.8 b |
| $T_3$ | 3.4 a | 7.8 b | 8.2 a | 5.2 b |
| *F* test | NS | * | * | * |
| Lsd (0.05) | 0.73 | 1.24 | 1.12 | 1.12 |
| CV (%) | 6.48 | 10.60 | 10.93 | 4.91 |

in producing flowering clusters compared to $T_0$. Among all the different rootstocks, $T_1$ resulted in the maximum number of flowering clusters (9.4), while the lowest one (7.8) was in $T_3$. Among the grafted plants, $T_3$ resulted in the minimum clusters per plant (7.8) than the rest two rootstocks. That might occur probably due to the variation in rootstocks.

The number of flowers per cluster differed significantly ($p \leq 0.05$) between the grafted and non-grafted plants (Table 2). It was highest in $T_3$ (8.2) while the least was in the non-grafted one (6.8). It might be the effects of different rootstocks. Khah et al. (2006) reported that the grafted plants generally showed to have a larger number of flowers. But the authors experienced no significant differences among the various rootstocks they compared. On the other hand, three different rootstocks exerted an insignificant difference as the number of flowers per cluster varied from 7.8 to 8.2. Again, both $T_2$ and $T_1$ produced an equal number (7.8) of flowers per cluster. So, from the production of a number of flowers per cluster, it can be inferred that $T_3$ was better among the three rootstocks compared. The number of fruits/cluster was lucid that the fruit numbers per cluster were influenced significantly ($p \leq 0.05$) due to grafted and non-grafted plants (Table 2). The non-grafted plant had the minimum number of fruits per cluster (4.8) than the grafted ones (6.8) (Table 2). That might be due to the effect of rootstocks. Among the rootstocks, $T_1$ gave the highest number of fruits per cluster (6.8). It might be due to the highest number of flowers/cluster were produced by the same treatment. When $T_2$ and $T_3$ were counted, the lower numbers of fruits per cluster were noted (4.8 and 5.2). The number of fruits per cluster was high with *Sunchalo* rootstock that might be due to the suitability of that rootstock over the others. The total number of fruits per plant ranged from 31.4 to 48.4 and varied notably ($p \leq 0.05$) on account of different rootstocks (Fig. 2). The grafted plant $T_1$ gave the topmost number of fruits (48.4) while the non-grafted plant ($T_0$) produced fruits (39.0) per plant.

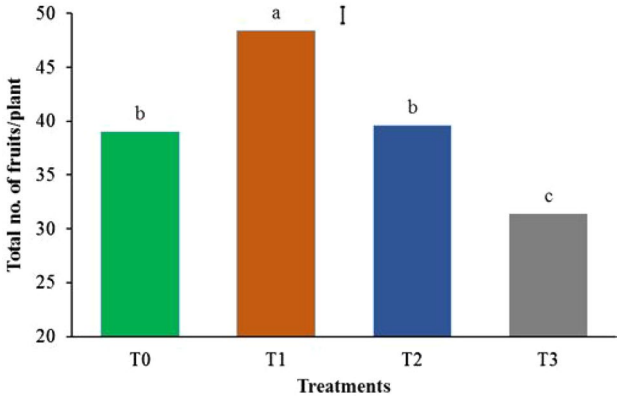


**Fig. 2** Total number of fruits per plant as affected by different rootstock. The vertical bar represents Lsd at 95% level of significance

These results support the findings of Turhan et al. (2011) who claimed that the total number of fruits/plant increased by grafting than without grafting of tomato cvs. Yeni Talya, Swanson and Beril. Oppositely, the three rootstocks had exerted significant difference. The grafted $T_1$ produced the topmost number of fruits/plant (48.4) while the $T_3$ plant had the least number of fruits/plant (31.4). That result depicts that the use of *Sunchalo* rootstock will be better compared to other types of rootstocks.

### 3.3 Fruit Length and Diameter

The length of fruit varied from 44.13 to 41.51 mm and exerted statistically significant variation ($p \leq 0.05$) among the treatments (Table 3). The maximum length (44.13) was found in the grafted plants ($T_1$) while the minimum length (41.51 mm) was in the non-grafted plant. That variation might be due to grafting effect resulting in the variations

**Table 3** Yield contributing parameters of different treatments. Means within each column followed by the same letter(s) are not significantly different at level $P \leq 0.05$ (* defines significant). NS defines not significant

| Treatments | Fruit length (mm) | Fruit diameter (mm) |
|---|---|---|
| $T_0$ | 41.51 b | 45.15 a |
| $T_1$ | 44.13 a | 47.12 a |
| $T_2$ | 42.43 ab | 47.23 a |
| $T_3$ | 42.56 ab | 45.12 a |
| *F* test | * | NS |
| Lsd (0.05) | 2.31 | 2.49 |
| CV (%) | 4.04 | 4.03 |

in enhancing the nutrient and water uptake. Turhan et al. (2011) also reported that in tomato, the fruit length was significantly influenced by grafting. Again, among the grafted plants, the effects of different rootstocks were insignificant in the fruit length. $T_1$ showed the highest fruit length (44.13 mm) whereas $T_2$ and $T_3$ resulted in the almost similar fruit lengths (42.43 and 42.56 mm, respectively). That may happen due to the fact that *Sunchalo* rootstock was more compatible than the other two rootstocks investigated.

The diameter of fruit was varied from 45.12 to 47.23 mm but the variation was statistically insignificant among the four treatments compared (Table 3). The maximum diameter (47.23) was in grafted plant $T_2$, while the minimum (45.15 mm) was with the non-grafted plant. That variation might be due to grafting effect enhancing the water and nutrient uptake by the respective plants. Among the grafted plants, there were insignificant differences in fruit diameter. $T_2$ showed highest fruit diameter (47.23) whereas $T_1$ and $T_3$ were almost similar in their fruit diameters (47.12 and 45.12 mm, respectively). That variation was probably due to the fact that $T_2$ and $T_1$ rootstocks more compatible than $T_3$ rootstock.

### 3.4 Weight of Individual Fruit, Yield Per Plant and Yield Per ha

The average weight of individual fruit varied from 44.84 to 57.88 g and that variation was notable ($p \leq 0.05$) (Table 4). The maximum weight of individual fruit was measured from $T_1$ (57.88) and the least weight was from $T_0$ (44.84 g). So, the least fruit weight resulted from the non-grafted plant. That might occur due to the effect of grafting. Turhan et al. (2011) opined that the fruit weight was meaningfully influenced by grafting. In a similar study, Khah et al. (2006) claimed that fruit weight of grafted plants was higher than with the non-grafted plants. The findings of Pogonyi et al. (2005) and Ibrahim et al. (2014) are also support with the present findings. Among the grafted plants, $T_1$ produced fruits with higher weight (57.88 g) while the individual fruit weight of $T_2$ and $T_3$ were 48.0 and 48.4 g in turn. The output of *Sunchalo* rootstock was better than the other types of rootstock that might be due to the suitability of this rootstock. The total yield per plant ranged from 1.67 to 2.68 kg. In the grafted treatments, the total fruit yield per plant increased significantly than the non-grafted plants except in $T_3$ (Table 4). The non-grafted plant gave 1.71 kg tomatoes/plant and the grafted plant in $T_1$ produced the maximum yield per plant (2.68 kg). So, the high yield in the grafted plant might be due to the positive effect of the rootstock. Marsic and Osvald (2004) and Ibrahim et al. (2014) had also reported the same type of results in grafted and non-grafted tomato plants; they concluded that the higher yield of fruit from grafted tomato plants was most likely an effect of the vigorous root system of the rootstock. The results of the present experiment show that tomato plants grafted on suitable rootstocks exerted positive effects on the fruit yield. Within the three rootstocks compared, $T_1$ had the highest yield/plant (2.68 kg) followed by $T_2$ (1.96 kg) and the $T_3$ had the lowest yield rate (1.67 kg). That might be due to the effects of grafting was positive in *Sunchalo* than the brinjal and the wild tomato rootstocks. The effects of rootstocks on the fruit yield of tomato plants were also observed by Turhan et al. (2011).

The fruit yield per ha ranged from 35.26 to 60.87 tons and that varied between the grafted and non-grafted plants (Fig. 3). The non-grafted plant gave 40.06 tons tomato fruits per ha and the grafted plant on $T_1$ was found to result in the maximum yield per ha (60.87 tons). So, such variations in the yield might be due to the effects of grafting and rootstocks. Marsic and Osvald (2004), Ibrahim et al. (2014), Al-Harbi et al. (2018) and Milenkovic et al. (2018) reported the same type of results in grafted and non-grafted tomato plants; they experienced that the higher yield of fruit from grafted tomato plants was most likely due to the effects of the vigorous root system of the rootstock used.

**Table 4** Yield contributing parameters of tomato plants as affected by three different grafted treatments. Means within each column followed by the same letter(s) are not significantly different at level $P \leq 0.05$ (* defines significant)

| Treatments | Individual fruit weight (g) | Fruit yield per plant (kg) |
|---|---|---|
| $T_0$ | 44.84 b | 1.71 c |
| $T_1$ | 57.88 a | 2.68 a |
| $T_2$ | 48.0 b | 1.96 b |
| $T_3$ | 48.4 b | 1.67 c |
| *F* test | * | * |
| Lsd (0.05) | 4.21 | 0.21 |
| CV (%) | 6.31 | 7.07 |

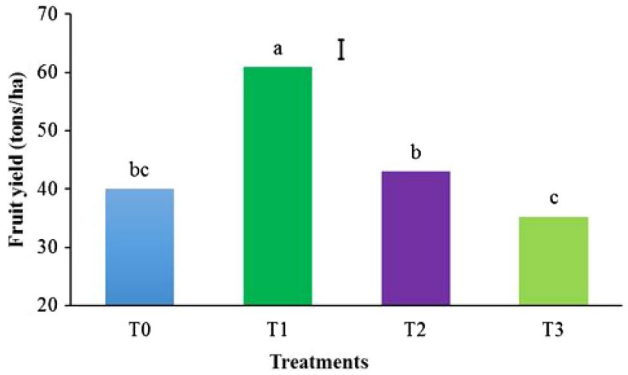


**Fig. 3** Per hectare fruits yield of tomato due to different grafting treatments. The vertical bar represents Lsd at 95% level of significance

The results of the present experiment show that tomato plants grafted on suitable rootstocks had positive effects on the fruit yield. Again, within the three rootstocks used, $T_1$ had the highest fruit yield per ha (60.87 tons) and $T_3$ had the lowest fruit yield per ha (35.26 tons). $T_2$ gave the medium amount of fruit per ha (42.97 tons). Those variations could be due to the fact that the effects of grafting were positive in *Sunchalo* than brinjal and wild tomato rootstock. Lee (1994) claimed that the increased yield of grafted plants was probably due to the enhanced water and mineral uptake by the various rootstocks.

### 3.5 Fruit Color

The statistical analysis of fruit color clarified that there was insignificant variation among the lightness ($L$) of all the treatments (Table 5). All the grafted and non-grafted plants showed nearly similar lightness of the fruits. The non-grafted one showed the highest $L$ value (41.59) and all the three rootstocks showed the least $L$ value pointing the fact that the lighter red color was found in non-grafted fruit compared to the all grafted plants. In contrast, in connection with the chroma ($C^*$) and hue ($H^\circ$) angles, significant differences were found between the grafted and non-grafted plants. The non-grafted plant showed the lowest $C^*$ value (44.21) and the highest $H^\circ$ value (45.29) with BARI 4 tomato plant which meant intensity of red color was low. But the grafted plants showed comparatively higher $C^*$ value (49.21) and the minimum $H^\circ$ value of different rootstocks than non-grafted fruits which meant better intense in red color of fruit produced by grafted plants which is desirable. So, grafting enhanced the fruit appearance and made that attractive.

### 3.6 Firmness of Fruit

There was a significant variation for the fruit firmness among the grafted and the non-grafted tomato fruits (Table 6). The firmness of non-grafted fruits was higher (1.27 kg/cm$^2$), while the grafted fruits was comparatively lower firmer. So, the grafting did not affect the firmness. This result is in agreement with those of others as Romano and Paratore (2001) reported that fruit qualitative characteristics were not affected by grafting in tomato. Oppositely, the three rootstocks had the more or less equal firmness trend of fruits. The maximum firmness (1.20) was observed in $T_1$ while the least (1.02 kg/cm$^2$) in $T_3$. The $T_2$ treatment was found to possess the medium firmness (1.10 kg/cm$^2$). Those variations could be due to the effects of different rootstocks used.

### 3.7 Total Soluble Solids (TSS)

There was an insignificant difference for the TSS contents among the four treatments compared as the grafted and the non-grafted plants also showed a more or less similar trend of TSS content in their fruits (Table 6). The non-grafted BARI Tomato-4 plant gave the highest value of TSS (5.62)

**Table 5** Effect of three rootstocks on color attributes ($L$, $C^*$ and $H^\circ$) of tomato fruits. Means within each column followed by the same letter(s) are not significantly different at level $P \leq 0.05$ (* defines significant). NS defines not significant

| Treatments | Lightness ($L$) | Chroma ($C^*$) | Hue angle ($H^\circ$) |
|---|---|---|---|
| $T_0$ | 41.59 a | 44.21 b | 45.29 a |
| $T_1$ | 40.23 a | 48.84 a | 39.57 b |
| $T_2$ | 39.83 a | 49.21 a | 41.49 b |
| $T_3$ | 39.89 a | 48.73 a | 39.78 b |
| $F$ test | NS | * | * |
| Lsd (0.05) | 2.39 | 2.5 | 2.91 |
| CV (%) | 4.40 | 4.54 | 4.50 |

**Table 6** Biochemical parameters of tomato fruits as affected by grafting treatments. Means within each column followed by the same letter(s) are not significantly different at level $P \leq 0.05$ (* defines significant). NS defines not significant

| Treatments | Firmness (kg/cm$^2$) | TSS (% Brix) | Phenol contents (mg GAE/100 g FW) |
|---|---|---|---|
| $T_0$ | 1.27 a | 5.62 a | 82.50 a |
| $T_1$ | 1.20 ab | 5.58 a | 82.00 a |
| $T_2$ | 1.10 bc | 5.44 a | 82.97 a |
| $T_3$ | 1.02 c | 5.34 a | 80.74 a |
| *F* test | * | NS | NS |
| Lsd (0.05) | 0.13 | 0.48 | 5.84 |
| CV (%) | 8.68 | 5.14 | 2.63 |

while the plants grafted on $T_3$ gave the lowest value (5.34). The experimental result is as per with the result of Khah et al. (2006) regarding fruit qualitative characteristics who stated that there were no significant differences in TSS contents under open field and greenhouse grown grafted and non-grafted tomato cvs. Big Red, Heman, and Primavera. All the three grafted plants had nearly equal TSS contents as the highest value (5.58) was found in T1 and lowest was in T3 (5.34). That might be due to no effect of different rootstocks in case of TSS. The findings of Khah et al. (2006) also support the present findings.

### 3.8 Total Phenols Concentration

The total phenols concentration of the tomato fruits ranged from 80.74 to 82.97 mg GAE/100 g FW among the grafted and the non-grafted plants and there were no significant variations (Table 6). $T_2$ plants had the maximum phenols concentration (82.97 mg GAE/100 g FW) whereas $T_1$ plants had the minimum phenols. The similar contents of the phenolic compounds in tomato fruits in the present study clarify that grafting had no effects on it. But contrary results from Vrcek et al. (2011) and Soare et al. (2019) indicated that the total phenolic compound varied within the fruits of the grafted and the non-grafted tomato plants. That could be due to different growing conditions and varietal effects. Again, among the three rootstocks, $T_2$ had better phenol contents (82.97 mg GAE/100 g FW) than both $T_1$ and $T_3$ rootstocks. The phenol contents in the $T_1$ were nearly equal (82.0) to $T_2$ but the lowest value (80.74 mg GAE/100 g FW) was found in $T_3$. It might be due to the effects of different rootstocks.

### 3.9 Vitamin C Content

The vitamin C content varied from 26.88 to 44.38 mg/100 g FW and a highly significant difference was noted among the fruits harvested from the graft and the non-grafted plants (Fig. 4). The highest vitamin C (44.38 mg/100 g FW) was found in the grafted plant of *Sunchalo* whereas the second highest value (38.13 mg/100 g FW) was found from the fruits of the non-grafted plant. Vitamin C in grafted plants of suitable rootstocks was better than those from the non-grafted ones due to the increases the concentration of active oxygen after grafting (García-Sánchez et al. 2007). This result is in agreement with those of Balliu et al. (2007) who reported higher vitamin C contents in grafted tomato plants compared to the non-grafted ones. But some contrary results were found from those of Gioia et al. (2010), Vrcek et al. (2011) and Turhan et al. (2011) all of whom argued that the total vitamin C content was reduced by grafting as compared to the non-grafted plants, the grafted plants accumulated less vitamin C in their different tomato fruit tissue. The trend of vitamin C content is independent to graft or without grafted plant as a mixed result is noted in the above graph. Different rootstocks exhibited a wide range of variation as $T_1$ had better vitamin C content (44.38 mg/100 g FW) while $T_2$ was the lowest performer (26.88 mg/100 g FW). The rest one, i.e. $T_3$ was found to produce the medium value (30.28 mg/100 g FW). The total vitamin C contents in the fruits of $T_2$ and $T_3$ were significantly lower compared to the fruits of those of non-grafted ones. Similar findings were reported by Turhan et al. (2011). Those variations could be due to the fact that

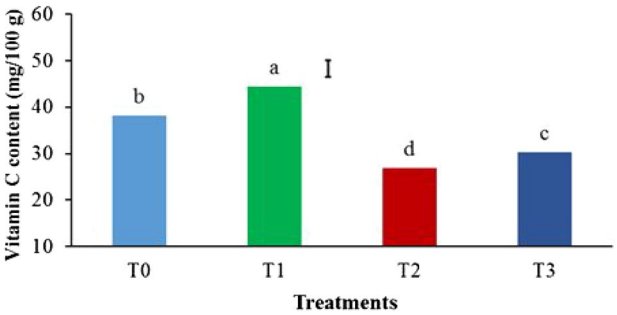


**Fig. 4** Vitamin C contents in the tomato fruits from the four treatments. The vertical bar represents Lsd at 95% level of significance

the grafted plants were initially under stress following the grafting operation. Oppositely, Miskovic et al. (2009) and Pogonyi et al. (2005) reported no or inconsistent effects of grafting on the vitamin C contents of tomato fruits.

### 3.10 Protein Content

The protein contents among the fruits of the grafted and the non-grafted plants varied from 3.54 to 3.72 mg/100 g FW and there was a variation (Table 7). The maximum protein content (3.72 mg/100 g FW) was obtained from the fruits of the grafted plants and the minimum (3.54 mg/100 g FW) from the non-grafted one. These variations could be due to grafting effects. In contrast, within the fruits of the three rootstocks, there were more or less similar trends in the protein contents (Table 7). The $T_1$ treatment was found to produce the highest protein (3.72 mg/100 g FW) and the other two types, i.e. $T_2$ and $T_3$ had the equal value of protein content (3.58 mg/100 g FW). That might be due to no effect of different rootstocks in tomato fruit production.

### 3.11 Lycopene and β-Carotene Content

The lycopene contents in the fruits from the four treatments varied from 0.063 to 0.076 mg/100 g FW, which exhibited significant difference (Table 7). The maximum lycopene content (0.076 mg/100 g FW) was found in the fruits of grafted plants ($T_2$) whereas the minimum (0.057 mg/100 g FW) was in the fruits of the non-grafted plants of $T_0$. Contradictory results also reported by Turhan et al. (2011), Mohammed et al. (2009) and Khah et al. (2006), they concluded that the grafted plants minimized or had no significant effect in case of lycopene contents. Helyes et al. (2008) studied from their experiment that lycopene content of tomato fruits decreased by grafting which was found contradictory might be due to different conditions and variety. Different rootstocks showed significant variation in respect of lycopene content in fruits. $T_2$ and $T_1$ rootstocks were the same than the lowest one of $T_3$ which was presented in Table 7. Romano and Paratore (2001) reported that qualitative parameters were not affected by grafting of tomato. Moreover, different rootstocks had no positive effects on lycopene content of tomato fruits (Turhan et al. 2011).

The β-carotene of tomato fruits varied from 0.137 to 0.156 mg/100 g FW and was significantly variable in grafted and non-grafted plants (Table 7). The maximum β-carotene (0.156 mg/100 g FW) was weighed from the fruits of grafted plants and the minimum (0.137 mg/100 g FW) was weighed from the non-grafted plants. It might be due to the effects of grafting. This result supports the findings of Khah et al. (2006). But, it was disagreed by Mohammed et al. (2009) who found significantly decreased in β-carotene of tomato in case of using He-man and Syria rootstocks. The contradictory result might be due to different varieties and growing conditions.

Among different rootstocks, amount of β-carotene was high with $T_2$ than $T_1$ and $T_3$ (Table 7). Variability was also noted in different rootstocks in case of their β-carotene contents (Mohammed et al. 2009).

## 4 Conclusions

A wide variation existed among the grafted and non-grafted plants for growth, yield and fruit quality of tomato. The most of the traits of growth (except for plant height), yield and fruit quality were significantly influenced by grafting. The individual fruit weight, total yield per plant and hectare had the significant topmost values (57.88 g, 2.68 kg and 60.87 ton, respectively) of the plants grafted on the *Sunchalo* than the non-grafted ones and other two rootstocks. Besides, the plants grafted on the *Sunchalo* were the most acceptable in

**Table 7** Biochemical parameters of tomato fruits as affected by grafting treatments. Means within each column followed by the same letter(s) are not significantly different at level $P \leq 0.05$ (* defines significant)

| Treatment | Protein content (mg/100 g FW) | Lycopene content (mg/100 g FW) | β-Carotene content (mg/100 g FW) |
|---|---|---|---|
| $T_0$ | 3.54 b | 0.057 ab | 0.137 b |
| $T_1$ | 3.72 a | 0.067 ab | 0.146 ab |
| $T_2$ | 3.58 ab | 0.076 a | 0.156 a |
| $T_3$ | 3.58 ab | 0.063 b | 0.142 ab |
| *F* test | * | * | * |
| Lsd (0.05) | 0.15 | 0.01 | 0.017 |
| CV (%) | 2.77 | 11.62 | 6.85 |

terms of the biochemical quality, especially vitamin C and protein contents compared to other treatments. So, it can be concluded that the *Sunchalo* rootstocks were found better performance in respect of most of the parameters than the brinjal and the wild tomato rootstocks. Such information might be beneficial for growers, postharvest technologist, nutritionists and consumers. Additional research works in term of different seasons, varieties, locations and more types of rootstocks are suggested for morphological traits, yield and quality attributes assessment of tomato cv. BARI Tomato-4.

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