



Brinjal (*Solanum melongena*) rootstocks improve photosynthetic rate, fruit yield and quality parameters in grafted tomato (*Solanum lycopersicum*)

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ABSTRACT

The experiment was conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at ICAR-Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh to study the improvement in yield and quality parameters in tomato (*Solanum lycopersicum* L.) cultivar using brinjal (*Solanum melongena* L.) rootstock. Three improved cultivars of tomatoes i.e. Kashi Aman, Kashi Adarsh and Kashi Chayan were grafted over three brinjal rootstocks, IC-111056, IC-354557, and Surya. Experimental findings revealed that brinjal rootstocks significantly affected photosynthetic traits, root architectures, fruit yields and quality traits of tomatoes. Maximum photosynthetic rate (23.8 $\mu\text{mol}/\text{m}^2/\text{s}$) and stomatal conductance (492.74 $\text{mmol}/\text{m}^2/\text{s}$) were recorded in Kashi Chayan grafted over Surya rootstock, whereas chlorophyll fluorescence yields (Fv/Fm) was significantly higher in Kashi Aman self-rooted plants (0.452–0.457). Grafting tomato onto brinjal rootstocks significantly enhanced most of the yield traits, such as fruit number, weight, size and yields. Surya + Kashi Chayan graft combination registered an enhancement in number of fruits and yields by 8.65% and 8.4%, respectively over self-rooted Kashi Chayan. Significantly higher root volumes were noticed in two graft combinations i.e. IC-354557 + Kashi Aman (28.53 cm^3) and Surya + Kashi Chayan (27.98 cm^3), while 63% and 44.5% higher root length density (RLD) were registered in graft combinations IC-354557 + Kashi Chayan and Surya + Kashi Chayan, respectively over self-rooted Kashi Chayan. Fruit quality such as lycopene and ascorbic acid contents were significantly affected in different rootstocks and scions, whereas fruit acidity was unaffected. From the present study it may be concluded that use of brinjal rootstock Surya significantly improved most of the physiological, yield, root architecture and fruit quality in Kashi Chayan tomato cultivars.

Keywords: Brinjal rootstocks, Fruit quality, Fruit yield, Photosynthesis, Root architecture, Tomato grafting

Tomato (*Solanum lycopersicum* L.) is one of the most produced and consumed vegetable crops worldwide. In India, it is cultivated over 8.49 lakh hectare land with total production of 20.42 million tonnes (MoA and FW 2024). It is rich source of antioxidants such as carotenoids, lycopene, phenols, and flavonoids which play a potential role in prevention of cardiovascular and cancerous diseases (Djidonou *et al.* 2020). The grafting of vegetable seedlings combines desirable traits from the rootstock and scion in a single composite plant that is generally viewed as an alternative to conventional breeding of elite cultivars. This technique provides tolerance to unfavourable conditions, whether biotic or abiotic, through the rootstock attributes and simultaneously allows the expression of the graft's production attributes.

In recent years' tomato grafting has increased worldwide as evidence by the number of publications on tomato grafting which increased at an annual rate of 8.8% (Bento-da-Silva *et al.* 2023). The hardiness, disease resistance or vigour of rootstocks have improved the yield of grafted scions, specifically fresh market tomato cultivars (Oztekin *et al.* 2009, Grieneisen *et al.* 2018). There are conflicting reports regarding changes in fruit quality due to grafting. Studies reported that 65% of the time, grafted plants yielded at par or less than non-grafted or self-grafted plants (Grieneisen *et al.* 2018). Whereas, Bie *et al.* (2017) reported increased yields of grafted tomato ranging from 5.4–80.3%. The reported variation in yields of grafted tomato plants may be primarily related to specific scion/rootstock combinations and the environmental variations in specific production systems.

Intra-specific and inter-specific tomatoes are commonly used as rootstocks for tomato. Brinjal (*Solanum melongena* L.) is also known as potential rootstock for tomato in enhancing yields and quality, particularly under various soil and environmental stress conditions (Bahadur *et al.*

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2015, Bhatt *et al.* 2015, Sanwal *et al.* 2022). The vigorous root system of brinjal helps in better mining of water and nutrients for scion cultivars (Bahadur *et al.* 2015, Latifah *et al.* 2023). The efficiency of grafting depends mainly on rootstock selection and graft compatibility. Therefore, the selection of appropriate and compatible rootstocks is crucial in grafting tomato for improving the yield and quality. However, only a small amount of information is available for compatibility of brinjal rootstock with commercial cultivars (as scion) of tomato. Therefore, this study was undertaken to explore (i) the yield performance of three tomato cultivars grafted on three brinjal rootstocks, and (ii) assess the biochemical and physiological changes resulting from scion-rootstock interactions.

MATERIALS AND METHODS

The experiment was conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at ICAR-Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh. Three tomato cultivars i.e. Kashi Aman, Kashi Adarsh and Kashi Chayan (all open-pollinated determinate cultivars) were grafted over three brinjal rootstock, IC-354557, IC-111056, and Surya. Self-rooted tomato plants of above cultivars were also used as control for comparison. Seeds of above three lines of brinjal were sown in the last week of August at 1.5–2.0 cm depth in small plastic glasses (7 cm² × 9 cm²) filled with soil, cocopeat, perlite and vermiculite (2:1:1:1). After one week, the seeds of scion cultivars of tomatoes were also sown in 48 holes portray filled with above mixture. The seedlings of rootstocks and scions were irrigated daily for the next 25 days. About 4–5 weeks-old-seedlings of brinjal were used as rootstocks, whereas 4-weeks tomato seedlings were used for scions. Splice or side grafting was followed wherein 45° slant-cut was made both in the rootstock and scion to ensure proper pairing. Slanting cut of 5–7 mm was made just above the cotyledonary leaves. Before grafting, only one or two small emerging leaves of scion were retained removing rest of the leaves. The rootstock and scion were clipped together with a silicone grafting clip. Grafted plants were soon transferred to grafting chamber, wherein the maximum temperature ranged between 22–28°C. The relative humidity (RH) was maintained more than 85% during most of the time. To maintain appropriate humidity in the chamber, water misting was done twice a day. The natural light penetrating the grafting chamber (3000–5000 lux) was maintained at 25% of the incoming solar radiation. Grafted seedlings were shifted from grafting chamber to acclimatization chamber after 5–7 days. During acclimatization period, grafted seedlings received 50% solar radiation. The temperature and RH varied from 22–35°C and 70–90%, respectively. Thus, after 12–15 days of grafting, plants were transplanted into well-prepared field. While planting, care was taken to keep the graft union just above the ground while any suckers emerging below the graft union were removed time to time.

Experimental field was supplied with 20 tonnes of farmyard manure, and NPK at 150:60:80 kg/ha. Grafted

plants were transplanted on both side of the furrow irrigated raised bed (height 20 cm, width 90 cm) at spacing of 75 cm × 50 cm. Plants were staked vertically up to height of 125 cm supported with iron poles and GI wires (1.8 mm). Two-hand weeding followed by hoeing and N application was performed at 30 and 60 days after planting (DAP). Physiological parameters such as, photosynthetic rate (Pn), stomatal conductance (Gs) and chlorophyll fluorescence yields (Fv/Fm), were recorded once at 70 DAP with CI-340 Handheld Portable Photosynthesis System (CID Bio-science, Camas, WA, USA). The observations were recorded during 09.30 to 10.30 from upper 3rd or 4th fully developed leaf. Root morphological parameters such as, surface area, volume, diameter and root length density (RLD) were measured by the TIFF-format grey image (400 dpi resolution) captured by flatbed root scanner (Epson Expression 11000XL, Epson, Suwa, Japan).

The results are expressed as means with standard error (S.E.). The significant differences between treatments were determined by Duncan's multiple range tests at a significance level of 0.05 for all the physiological and biochemical parameters. ANOVA and critical difference values were calculated using SPSS. 27.0 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel in built data analysis options.

RESULTS AND DISCUSSION

Physiological parameters: Physiological parameters, such as photosynthesis rate (Pn), stomatal conductance (Gs) and chlorophyll fluorescence yields (Fv/Fm) significantly varied due to different brinjal rootstocks (Fig. 1). Maximum Pn (23.8 μmol/m²/sec) was recorded in Surya + Kashi Chayan combination, whereas the minimum Pn was recorded in Surya + Kashi Adarsh (12.72 μmol/m²/sec). Kashi Chayan grafted over Surya registered 39.8%, 26.8% and 13.3% higher Pn over self-rooted Kashi Aman, Kashi Adarsh and Kashi Chayan, respectively. In the present study, remarkably higher Gs was registered in Surya + Kashi Chayan combination (492.74 mmol/m²/s) followed by Kashi Adarsh self-rooted (323.46 mmol/m²/sec). In other graft combinations significantly lower Gs values were noticed which varied between 70.44–221.12 mmol/m²/sec). Likewise, Gao *et al.* (2016) observed that the stomatal conductance (gs) of the eggplant graft combination, Jiza Long + Hirasasu was 39.1% higher than that of the self-rooted control under low temperature stress. Photosynthetic efficiency of photosystem II (PS-II) indicated as the ratio of fluorescence variable (Fv) and fluorescence maximum (Fm) was significantly influenced by various brinjal rootstocks. A significantly higher Fv/Fm was recorded in IC-111056 + Kashi Aman (0.452), Surya + Kashi Aman (0.452), Kashi Aman self-rooted (0.457) and Surya + Kashi Chayan (0.455). In corroboration to our findings, Bhatt *et al.* (2015) also reported that photosynthesis rate, stomatal conductance and chlorophyll fluorescence showed a lesser decline in tomato grafted on brinjal rootstocks under flooding situation as compared to self-grafted and un-grafted plants. Similarly, the findings from grafting cucumber onto fig-

leaf gourd rootstock indicate that both the rootstock and the scion influence stomatal performance, resulting in a heightened CO₂ assimilation rate and reduced stomatal resistance compared to non-grafted and/or self-grafted plants (Rouphael *et al.* 2008, Zheng *et al.* 2009).

Fruit yield attributes: Fruit yield traits such as number of fruits, weight, size and yield were significantly affected due to brinjal rootstocks (Table 1). Maximum number of fruits per plant were registered in tomato when Surya was used as rootstock for Kashi Chayan (96.00) followed by IC-354557 for Kashi Adarsh (94.60). These rootstocks enhanced number of fruits by 8.65% and 4.41% in Kashi Chayan and Kashi Adarsh, respectively. In present study, significantly higher fruit fresh weight was observed in Kashi Chayan grafted over Surya (78.85 g) or IC-111056 (78.58 g). Fruit size in term of polar and equatorial diameters were also significantly improved in tomato by using brinjal rootstocks. It has been noticed that Kashi Aman grafted over IC-111056 or Kashi Chayan on Surya registered maximum polar diameter of fruits with 14.8% and 9.1% enhancement, respectively over self-rooted plants. Fruit equatorial diameter was reported maximum in self-rooted Kashi Chayan (52.88 mm) followed by IC-111056 + Kashi Aman (52.08). As far as fruit yield is concerned, the maximum yields of 6.68 kg/plant were obtained in Kashi Chayan tomato grafted over Surya rootstock with enhancement by 12.1%, 27.7% and 8.4% over self-rooted Kashi Aman, Kashi Adarsh and Kashi Chayan, respectively. A study conducted by Bayındır and Kandemir (2023) involved four brinjal rootstock candidates *Solanum melongena* × *Solanum aethiopicum*, AGR-703 F₁ eggplant rootstock (*S. melongena* × *S. aethiopicum*), and Yavuz F₁ tomato rootstock (*Solanum lycopersicum* × *Solanum pimpinellifolium*) grafted with Fulya F₁ and Berat-45 F₁ tomato cultivars. Results indicated that all rootstocks utilized for grafting exerted a positive influence on various yield components of the tomato plants. Likewise, both fruit yield and fruit weight increased in grafted eggplants (Bidhan Suphala + Utkal Anushree) over non-grafted plants

in a study conducted by Jamir *et al.* (2023). Eggplants demonstrate greater efficiency in water uptake compared to tomato root systems, which could contribute to higher yields observed with grafting. This improvement in yield is primarily attributed to enhanced water and nutrient uptake, along with increased CO₂ assimilation (Schwarz *et al.* 2010). Similar observations have been made in non-grafted watermelon plants compared to those grafted on pumpkin rootstocks (Colla *et al.* 2010). Additionally, cucumber plants grafted on pumpkin rootstocks exhibited higher shoot yields, likely attributed to their ability to sustain higher net CO₂ assimilation.

Root architecture: Root morphological traits, such as surface area, volume, root length density (RLD) and root diameter varied significantly due to influence of different rootstocks. Significantly higher root surface areas in tomato were recorded under IC-354557 + Kashi Aman (1562.78 cm²), IC-111056 + Kashi Chayan (1617.85 cm²), IC-354557 + Kashi Chayan (1579.74 cm²) and Surya + Kashi Chayan (1582.14 cm²). Root volumes were significantly higher in two graft combination i.e. IC-354557 + Kashi Aman (28.53 cm³) and Surya + Kashi Chayan (27.98 cm³), however graft combinations, Surya + Kashi Aman and IC-111056 + Kashi Chayan also had higher root volume over rest of the graft combinations. All the self-rooted tomato cultivars registered significantly lower root volume as compared to the grafted plants. Among graft combinations, IC-354557 + Kashi Chayan showed maximum RLD (8510.74 cm/m³), registering 63% enhancement over self-rooted Kashi Chayan. While, other two rootstocks i.e. IC-111056 and Surya also registered higher root volume by 50.8% and 44.5% respectively than self-rooted Kashi Chayan. All brinjal rootstocks exhibited significantly higher root volume over self-rooted tomatoes (Table 2). A significant variation (0.51–0.79 mm) in average root diameter was observed in different rootstocks. Maximum root diameter of 0.79 mm was observed in IC-354557 + Kashi Aman combination, whereas Surya + Kashi Aman and Surya + Kashi Chayan

Table 1 Yield and yield attributes of grafted and non-grafted tomato plants

Graft combination	Yield/plant (kg)	No. of fruits/plant	Fruit weight (g)	Polar diameter (mm)	Equatorial diameter (mm)
IC-111056 + Kashi Aman	5.95 ± 0.53 ^{ab}	86.40 ± 5.30 ^{bcd}	75.84 ± 5.83 ^a	48.24 ± 1.35 ^a	52.08 ± 2.48 ^{ab}
IC-354557 + Kashi Aman	5.48 ± 0.48 ^{ab}	83.20 ± 4.40 ^{cd}	58.22 ± 2.76 ^{cd}	42.50 ± 0.90 ^{bcd}	43.12 ± 1.25 ^{cd}
Surya + Kashi Aman	5.16 ± 0.31 ^b	86.80 ± 4.29 ^{bcd}	56.21 ± 2.68 ^d	42.24 ± 0.74 ^{bcd}	40.80 ± 0.75 ^d
Kashi Aman	5.96 ± 0.41 ^{ab}	91.80 ± 8.59 ^{ab}	63.34 ± 2.19 ^{bcd}	42.08 ± 0.92 ^{bcd}	43.52 ± 0.77 ^{cd}
IC-111056 + Kashi Adarsh	5.92 ± 0.36 ^{ab}	85.60 ± 5.49 ^{bcd}	64.78 ± 1.71 ^{bcd}	40.60 ± 1.73 ^{cd}	42.72 ± 1.35 ^{cd}
IC-354557 + Kashi Adarsh	5.70 ± 0.39 ^{ab}	94.60 ± 8.61 ^a	62.88 ± 2.29 ^{bcd}	41.20 ± 0.57 ^{bcd}	45.00 ± 1.13 ^c
Surya + Kashi Adarsh	5.12 ± 0.54 ^b	89.00 ± 9.80 ^{abc}	60.43 ± 2.62 ^{bcd}	38.92 ± 0.52 ^d	41.04 ± 0.79 ^d
Kashi Adarsh	5.23 ± 0.20 ^{ab}	90.60 ± 3.41 ^{ab}	58.90 ± 3.16 ^{cd}	40.16 ± 0.63 ^{cd}	42.12 ± 0.36 ^{cd}
IC-111056 + Kashi Chayan	6.01 ± 0.29 ^{ab}	87.00 ± 6.53 ^{bcd}	78.58 ± 4.20 ^a	41.16 ± 1.23 ^{bcd}	48.76 ± 1.55 ^b
IC-354557 + Kashi Chayan	6.29 ± 0.41 ^{ab}	93.20 ± 11.83 ^{ab}	70.72 ± 4.31 ^{ab}	43.20 ± 0.30 ^{ab}	50.20 ± 0.68 ^{ab}
Surya + Kashi Chayan	6.68 ± 0.81 ^a	96.00 ± 12.37 ^a	77.85 ± 2.15 ^a	46.16 ± 0.68 ^a	49.56 ± 1.20 ^{ab}
Kashi Chayan	6.16 ± 0.40 ^{ab}	90.20 ± 8.56 ^{ab}	68.32 ± 3.79 ^{abc}	42.32 ± 0.83 ^{bcd}	52.88 ± 1.0 ^{6a}

Table 2 Effect of different rootstocks on tomato root morphology

Graft combination	Root surface area (cm ²)	Root volume (cm ³)	Root length density (cm/m ³)	Root diameter (mm)
IC-111056 + Kashi Aman	1292.73 ± 82.71 ^c	22.88 ± 0.94 ^c	6323.86 ± 334.54 ^{def}	0.66 ± 0.02 ^{bc}
IC-354557 + Kashi Aman	1562.78 ± 149.50 ^a	28.53 ± 1.54 ^a	7003.90 ± 204.86 ^{bcd}	0.79 ± 0.05 ^a
Surya + Kashi Aman	1488.04 ± 9.77 ^{ab}	26.31 ± 0.45 ^{ab}	6900.86 ± 273.12 ^{bcd}	0.72 ± 0.01 ^b
Kashi Aman	1092.64 ± 32.41 ^{de}	19.51 ± 0.70 ^d	5135.61 ± 98.44 ^f	0.66 ± 0.02 ^{bc}
IC-111056 + Kashi Adarsh	1170.31 ± 37.68 ^{cde}	18.81 ± 0.23 ^d	5585.07 ± 276.28 ^{ef}	0.65 ± 0.02 ^{bcd}
IC-354557 + Kashi Adarsh	1330.95 ± 40.51 ^{bc}	18.50 ± 0.70 ^d	6582.71 ± 445.33 ^{cde}	0.58 ± 0.01 ^{de}
Surya + Kashi Adarsh	1087.28 ± 17.53 ^{de}	16.09 ± 0.12 ^{ef}	5292.61 ± 114.20 ^f	0.61 ± 0.01 ^{cd}
Kashi Adarsh	1036.50 ± 25.62 ^e	13.95 ± 0.15 ^f	5569.09 ± 532.25 ^{ef}	0.51 ± 0.02 ^e
IC-111056 + Kashi Chayan	1647.85 ± 40.50 ^a	26.39 ± 0.56 ^{ab}	7870.37 ± 378.21 ^{ab}	0.66 ± 0.02 ^{bc}
IC-354557 + Kashi Chayan	1579.74 ± 32.57 ^a	24.23 ± 1.27 ^{bc}	8510.74 ± 673.77 ^a	0.65 ± 0.04 ^{bc}
Surya + Kashi Chayan	1582.14 ± 27.02 ^a	27.98 ± 0.68 ^a	7544.13 ± 448.76 ^{abc}	0.70 ± 0.02 ^b
Kashi Chayan	1255.65 ± 20.81 ^{cd}	17.16 ± 0.50 ^{de}	5218.98 ± 70.05 ^f	0.61 ± 0.01 ^{cd}

combinations also registered significantly higher root diameter (9.17% and 14.7% higher, respectively) over their self-rooted plants. Bayındır and Kandemir (2023) observed a significantly stronger relationship between yield characteristics of grafted tomato plants (grafted onto eggplant) and certain root traits such as total root length, root surface area, root dry weight, and the length ratio of roots. As a result, it was suggested that these parameters be carefully examined and considered in rootstock breeding programmes, as they may play a crucial role in enhancing tomato yields through grafting techniques.

Fruit quality attributes: Fruit quality traits such as lycopene and ascorbic acid contents were significantly affected by brinjal rootstocks. Whereas, rootstocks did not influence acidity significantly. Significantly higher lycopene contents were recorded in IC-111056 + Kashi Chayan (3.89 mg/100 g) and self-rooted Kashi Chayan (3.88 mg/100 g) (Fig. 2). Kashi Aman grafted or self-rooted had the minimum lycopene contents (1.45–1.62 mg/100 g). Ascorbic acid content (vitamin C) in fruits was also the

maximum and significantly higher in IC-111056 + Kashi Chayan (17.04 mg/100 g), whereas the minimum ascorbic acid was registered in IC-111056 + Kashi Aman (15.63 mg/100 g) and self-rooted Kashi Aman (15.68 mg/100 g). Fruit acidity was unaffected in any of the tomato cultivars grafted on brinjal rootstocks in this study, and it ranged between 0.92–0.99%. Researchers have noted diverse impacts of grafting on tomato fruit quality. Kumar *et al.* (2015) illustrated that rootstock can positively influence fruit quality traits including peel colour, fruit shape index, titratable acidity, soluble solids content, and dry matter content. Conversely, Turhan *et al.* (2011) observed that while grafting did not alter tomato fruit quality attributes such as lycopene content and pH, it resulted in decreased levels of vitamin C, titratable acidity, and soluble solids content in grafted plants. Recently, in the study conducted by Latifah *et al.* (2023), grafting scion cvs. Cervo and Timoty onto *S. torvum* rootstocks resulted in a 30% increase in yield compared to non-grafted plants. Furthermore, grafted tomatoes exhibited an enhanced shelf-life and total dissolved

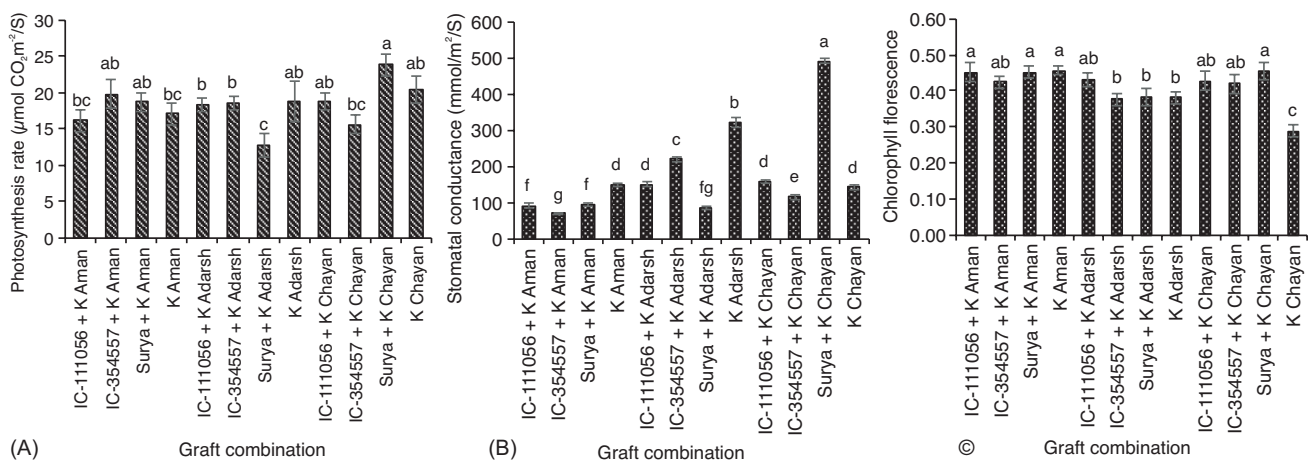


Fig. 1 (A) Photosynthesis rate; (B) stomatal conductance; and (C) Chlorophyll fluorescence yields of tomato leaves at fruiting stage. Bars representing mean values with same alphabets on the top are not significantly different ($P < 0.05$) by Duncan multiple range test at a particular time of measurement.

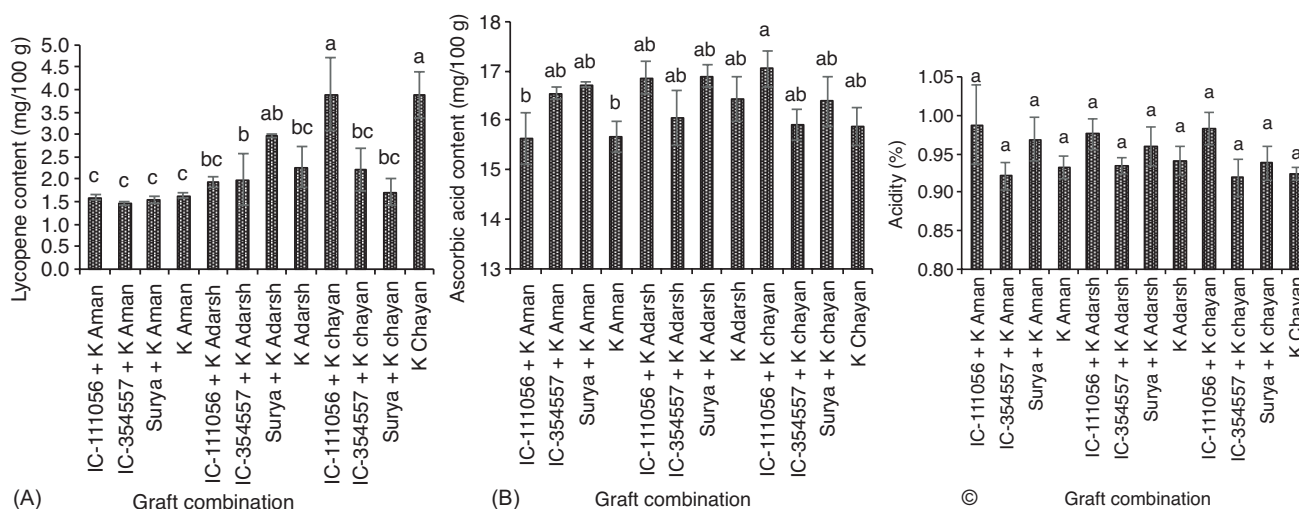


Fig. 2 (A) Lycopene content; (B) Ascorbic acid content; and (C) Acidity of tomato fruits.

Bars representing mean values with same alphabets on the top are not significantly different ($P < 0.05$) by Duncan multiple range test at a particular time of measurement.

solids by more than 10% and increased red colour intensity (a+) by over 16%, with higher lycopene contents. However, grafting technology did not affect the vitamin C content. Likewise, Naik *et al.* (2021) observed that the grafting effect on fruit chemical quality attributes in cherry tomatoes was generally not significant. However, they found promising results for certain graft combinations, such as grafting Sheeja onto *S. pimpinellifolium* 'Sopim' for total soluble solids, 'Sheeja' onto *S. torvum* 'Sotor' for lycopene content, and 'Cheramy' onto *S. melongena*, 'Ponny' for total phenols. Chavez-Mendoza *et al.* (2013) also reported that grafting in capsicum significantly increased β -carotene and vitamin C content, and improved the antioxidant capacity, but no effect on the total phenol or lycopene contents was observed.

The grafting of three improved tomato cultivars, Kashi Aman, Kashi Adarsh, and Kashi Chayan on three different brinjal rootstocks, IC-111056, IC-354557, and Surya resulted in notable impacts on photosynthetic traits, root architectures, fruit yields, and quality traits of tomatoes. The study revealed significant effects of brinjal rootstock on photosynthetic parameters, with Surya rootstock combined with Kashi Chayan showing the highest rates. Grafting on brinjal rootstocks also improved fruit number and yield in Surya + Kashi Chayan combination. Root architecture was also positively influenced by grafting, with certain combinations showing higher volumes and density. Fruit quality, particularly lycopene and ascorbic acid contents, were significantly affected by both rootstocks and scions, while acidity remained unchanged. Overall, the study showed that the utilization of brinjal rootstock Surya notably improved physiological characteristics, yield parameters, root architecture, and fruit quality in Kashi Chayan tomato cultivars.

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