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Evaluation of brinjal and tomato scions for enhancing yield and quality attributes in grafted brimato plants

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ABSTRACT

To meet the growing demand for fresh produce in cities, promoting peri-urban and urban farming is essential to reduce reliance on rural areas for vegetables. One innovative approach, developed at ICAR-IIVR, Varanasi (2019-2022), is the dual grafting of brinjal and tomato on a single brinjal plant, termed 'Brimato' (brinjal + tomato). Using the vigorous, waterlogging and salinity-tolerant brinjal rootstock IC 111056, four brinjal cultivars (Kashi Sandesh, Kashi Uttam, Kashi Manohar, Kashi Vijay) and three tomato cultivars (Kashi Aman, Kashi Chayan, Vani) were grafted as scions. Over three years, experiments showed that the scion cultivars significantly impacted the brimato productivity. Kashi Manohar combined with Kashi Aman or Kashi Chayan yielded the highest brinjal fruit numbers, while Kashi Aman combined with hybrid brinjal Kashi Sandesh resulted in the highest tomato fruit numbers. The highest fruit yield was observed with the Kashi Sandesh + Kashi Chayan combination, yielding 2.58 kg/plant. The Kashi Aman + Kashi Sandesh combination produced a cumulative yield of 5.98 kg/plant. Physiological traits like photosynthetic rate and chlorophyll fluorescence yield varied significantly among scion cultivars, with Kashi Manohar and Kashi Aman scions exhibiting the highest photosynthetic rate. Grafted Brimato plants showed enhanced fruit quality, particularly in vitamin C and β-carotene content. These findings highlight the potential of Brimato plants for urban agriculture, offering a viable solution for sustainable fresh produce supply.

Key words: Brimato, dual grafting, photosynthetic rate, yield, quality traits.

INTRODUCTION

Grafting has been widely used in fruit trees for centuries, but its commercial application in vegetables gained momentum in Japan and Korea during the late 1950s and early 1960s to combat soil-borne diseases in Solanaceous and Cucurbitaceous crops. Similarly, since the mid-1980s, Europe has seen intense development of grafting techniques in vegetables, starting with cucurbits and later Solanaceous plants. In the early 21st century, many American countries adopted grafting as an alternative to methyl bromide for soil disinfection (Belmonte-Ureña *et al*., 8). Today, over 75% of cucurbitaceous seedlings like watermelon and cucumber are grafted in these countries, while grafting rates in Solanaceous vegetables range from 20-40% in tomatoes and brinjal, and 5-10% in capsicum (Lee *et al.*, 12). Despite this, the adoption of grafting in vegetables outside of these regions remains limited.

Inter-specific grafting has emerged as a tool not only for enhancing resistance to biotic and abiotic stresses but also for improving yield and fruit quality. One promising innovation in this field is dual or multiple grafting, which involves grafting two or more scions onto a single rootstock. This method, still underexplored, offers a potential breakthrough for maximizing production from limited space. The "Brimato" (brinjal + tomato), developed at ICAR-IIVR, Varanasi between 2019-2022, exemplifies this by allowing both brinjal and tomato to be harvested from a single plant (Bahadur *et al.*, 3). Such innovations hold immense promise for urban and peri-urban farming, where limited space demands creative solutions for fresh vegetable production.

Despite the potential of dual grafting, there is still limited understanding about the stionic effect, *i.e.,* how rootstock and scion interactions influence yield and quality in Solanaceous crops (Latifah *et al*., 10; 11; Rouphael *et al*., 18; Sanwal *et al*., 19). Very few studies have systematically explored optimal scion-rootstock combinations for dual-grafted vegetables (Qin *et al.*, 16). This study aims to fill that gap by identifying the most suitable brinjal and tomato scion combinations for improved yield and quality traits in Brimato, providing new insights into the potential for large-scale adoption of this technology in urban settings.

MATERIALS AND METHODS

The present study was conducted in Randomised Block Design (RBD) with three replications at ICAR-

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Indian Institute of Vegetable Research, Varanasi during year 2021-22 and 2022-23. Brimato plants were prepared by using brinjal rootstock IC 111056, which has earlier been reported as vigorous rootstock with tolerant to waterlogging and salinity (Bahadur *et al*., 2, 4, 5; Singh *et al*., 20). For evaluation of scions, four cultivars of brinjal and three cultivars of tomato were selected. In brinjal, two round, *i.e.,* Kashi Sandesh (hybrid) and Kashi Uttam, and two long cultivars (Kashi Manohar and Kashi Vijay) were used. In tomato, newly developed open-pollinated varieties, *i.e.*, Kashi Aman, Kashi Chayan and Vani (early variety from M/s VNR Seeds Pvt. Ltd.) were used as scions. A total of 12 graft combinations studied in the present study are presented in Table 1. For quality parameters, ungrafted tomato cultivars were also considered as control.

Firstly, seeds of rootstock were sown in small plastic glasses filled with soil, sand, vermicompost and cocopeat (2:1:1:1), whereas scion cultivars were sown in small earthen pots (10 inch) during last week of August. The grafting operation was performed when rootstock and scion seedlings were 25-30 day-old, having 2.0-3.0 mm diameter. On rootstock, brinjal scion was grafted just 1-2 cm above the cotyledonary leaf by splice or side grafting, whereas tomato scion was grafted near the cotyledonary leaf by apical wedge or cleft grafting method. For accommodating brinjal scion, 5-7 mm of slant cut (45° angle) was made at the top of rootstock, whereas similar length slanting cut was also made in brinjal scion. Similarly, tomato scion was grafted by opening about 0.3-0.5 mm deep and longitudinal slit in rootstock, whereas in tomato scion about 5 mm slanting cut was made from both sides making wedge shape. The graft unions were

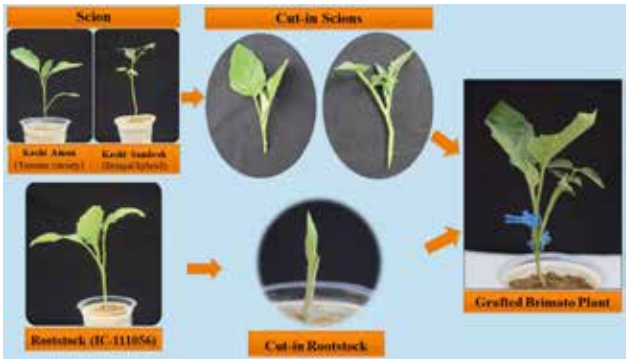

Fig. 1. Illustration of technique for grafted brimato seedling production.

secured with plastic grafting clips (Fig. 1). The grafted plants were shifted immediately inside the grafting chamber for next 4-5 days, wherein the maximum temperature was maintained between 22-28°C with relative humidity (RH) more than 85%. The light interception in the grafting chamber varied between 3000-3500 lux. To maintain appropriate temperatures and humidity, water misting was done 2-3 times daily. Thereafter, the healed grafted plants were kept in partial shade for another 7 days with relatively less RH and higher temperatures for acclimatization. Before transplanting to the field, the grafted plants were exposed to full sunlight for hardening to another 5 days, and during hardening, the grafting clips were removed. In this way, it took 20-25 days long duration from grafting operation to transplanting in the field. As far as the nutrition was concerned, 150 kg N, 80 kg P and 100 kg K were applied per hectare, beside application of 20 tonnes of FYM at the time of planting. Brimato seedlings were transplanted in field during the last week of September. Plants

Table 1. Treatment details showing different graft combinations of brinjal and tomato genotypes.

Sl. No.	Symbol	Treatment details
1.	IC56 + (KA+KS)	IC-111056 + (Kashi Aman + Kashi Sandesh)
2.	IC56 + (KA+KU)	IC-111056 + (Kashi Aman + Kashi Uttam)
3.	IC56 + (KA+KM)	IC-111056 + (Kashi Aman + Kashi Manohar)
4.	IC56 + (KA+KV)	IC-111056 + (Kashi Aman + Kashi Vijay)
5.	IC56 + (KC+KS)	IC-111056 + (Kashi Chayan + Kashi Sandesh)
6.	IC56 + (KC+KU)	IC-111056 + (Kashi Chayan + Kashi Uttam)
7.	IC56 + (KC+KM)	IC-111056 + (Kashi Chayan + Kashi Manohar)
8.	IC56 + (KC+KV)	IC-111056 + (Kashi Chayan + Kashi Vijay)
9.	IC56 + (V+KS)	IC-111056 + (Vani + Kashi Sandesh)
10.	IC56 + (V+KU)	IC-111056 + (Vani + Kashi Uttam)
11.	IC56 + (V+KM)	IC-111056 + (Vani + Kashi Manohar)
12	IC56 + (V+KV)	IC-111056 + (Vani + Kashi Vijay)

were spaced at 90 cm × 60 cm distance in raised bed with the provision of drip irrigation system. Two hand weedings followed hoeing were performed at 30 and 60 days after planting. Brimato plants also pruned and staked to obtain potential yields. For initial 45 days, only single stem of brinjal and tomato was maintained, and any extra growth, appearing in any of the scions was pruned to maintain the proportional growth in both the groups of scions. Simultaneously, no sucker was allowed to grow below the graft union. Harvesting of both brinjal and tomato started at 70 days after planting (Fig. 2). A total of 4-5 harvestings in both brinjal and tomato were made till the end of March. For recording yields and quality attributes, three plants were selected in each replication. Photosynthetic parameters such as, net photosynthesis rate (*Pn*) and maximum quantum yield of PSII chemistry, denoted by *Fv/Fm*, were measured in top third fully expanded leaf with CI-340 Handheld Photosynthesis System (CID Bio-Science, Inc USA) (Bahadur *et al*., 1). Chlorophyll content index (CCI) was measured by SPAD 502 chlorophyll meter (Spectrum Technology, Inc USA). Lycopene, β-carotene and vitamin C contents were estimated by the method described by Ranganna (17). TSS was measured by hand held digital refractometer.

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

RESULTS AND DISCUSSION

Studies indicate that grafting is a highly effective technique for enhancing yield, disease resistance, and quality in various vegetable crops (Bahadur and Kumar, 2; Bahadur *et al*., 7). Rootstocks are believed to boost fruit yield and quality by being resistant to soil borne stresses, efficient in nutrient uptake, and plant vigour regulator (Bahadur *et al*., 2; Singh *et al*., 21). Three years of experimental research on brimato revealed that the scion cultivars significantly influence its productivity (Table 2). The highest number of brinjal fruits was obtained with Kashi Manohar in combination with Kashi Aman (22.33) or Kashi Chayan (21.00). For tomatoes, the highest number of fruits was recorded with Kashi Aman in combination with hybrid brinjal Kashi Sandesh (53.67), followed by Vani + Kashi Uttam (52.62). Fruit

Fig. 2. Field view of brimato production.

Table 2. Stionic effect of brinjal and tomato for fruit production in brimato (pooled data of two years).

Treatment	Fruits/ plant		Fruit yield (kg/ plant)		Cumulative yield (kg/ plant)
	Brinjal	Tomato	Brinjal	Tomato	
IC56 + (KA + KS)	6.67^{de}	53.67^{a}	2.38^{ab}	3.60^{a}	5.98
IC56 + (KA + KU)	6.00^{de}	47.67^{abc}	2.26^{ab}	2.94^{b}	5.20
IC56 + (KA + KM)	22.33^{a}	49.33^{ab}	2.32^{ab}	3.06^{b}	5.38
IC56 + (KA + KV)	17.33^{bc}	48.67^{ab}	1.75^{bc}	2.94^{b}	4.69
IC56 + (KC + KS)	7.33^{d}	38.33^{d}	2.58^{a}	2.90^{b}	5.48
IC56 + (KC + KU)	4.67^{de}	40.00^{cd}	1.45^{cd}	2.89^{b}	4.34
IC56 + (KC + KM)	21.00^{ab}	41.00^{bcd}	2.04^{abc}	3.01^{b}	5.05
IC56 + (KC + KV)	15.67^{c}	38.67^{d}	1.44^{cd}	2.78^{b}	4.22
IC56 + (V + KS)	3.33^{de}	49.33^{ab}	0.85^{de}	2.91^{b}	3.76
IC56 + (V + KU)	2.33^{e}	52.67^{a}	0.68^{e}	3.20^{ab}	3.88
IC56 + (V + KM)	7.33^{d}	43.67^{bcd}	0.80^{de}	2.80^{b}	3.60
IC56 + (V + KV)	5.33^{de}	43.33^{bcd}	0.48^{e}	2.81^{b}	3.29

yields of both brinjal and tomato varied significantly with different scion combinations. The highest fruit yield was harvested in Kashi Sandesh grafted with Kashi Chayan (2.58 kg/plant); however, this yield was comparable to the Kashi Aman + Kashi Sandesh combination (2.38 kg/plant). Regarding the total yield of brimato, the maximum cumulative yield of 5.98 kg was obtained with the scion combination of Kashi Aman and Kashi Sandesh, followed by Kashi Chayan + Kashi Sandesh (5.48 kg/plant). Earlier, Bahadur *et al*. (3) recorded an average yield of 2.56 kg of brinjal and 2.68 kg of tomato fruits from a single plant, when Kashi Aman and Kashi Sandesh were used as scions. They also reported the marketable fruit yields of 35.7 tons of brinjal and 37.3 tons of tomato per hectare of brimato cultivation, with a net profit of Rs 6.44 lakhs/ha and a B:C ratio of 1.91 (Bahadur *et al*., 6).

Plant physiological traits such as photosynthetic rate, chlorophyll fluorescence yield, and chlorophyll content index (CCI) varied significantly with different scion cultivars (Table 3). The chlorophyll content, which has a direct influence on the photosynthetic efficiency of leaves, is a major index of photosynthetic capacity and can be considered a source of food and energy (Musa *et al*., 14). The highest quantum yield of PSII chemistry, denoted by *Fv/Fm*, was highest in the Kashi Sandesh (0.648) and Kashi Aman (0.637) scion combination, both in brinjal and tomato. Across the variety and scion combinations, tomato scions exhibited approximately 52% higher CCI value than brinjal. Among brinjal scions, the maximum CCI (31.49) was observed in Kashi Manohar with Kashi Aman. In tomato, the highest CCI (51.00) was registered in Kashi Chayan combined with Kashi Uttam. Similarly, Liu *et al*. (13), in an experiment on tomatoes, found that the chlorophyll content was significantly higher in grafted tomatoes compared to non-grafted ones. The photosynthetic rate may be considered as the amount of food manufactured, and energy released to other parts of the plant (Musa *et al*., 14). Photosynthesis rates varied significantly between brinjal and tomato in the present study, with brinjal generally exhibiting higher rates than tomato. In this study, the highest photosynthesis rate in brinjal scions was recorded in Kashi Manohar (20.70 µmol/m²/sec), Kashi Vijay (20.26 µmol/m²/sec), followed by Kashi Sandesh (17.97 µmol/m²/sec) when combined with the tomato scion Kashi Aman. For tomato scions, the highest photosynthesis rate was observed in Kashi Aman, when paired with brinjal cultivars Kashi Manohar (13.88 µmol/m²/sec), Kashi Vijay (13.24 µmol/m²/sec), and Kashi Sandesh (11.45 µmol/m²/sec). Kumar *et al*. (9) reported that better uptake of nutrients in grafted seedlings leads to improved photosynthesis, which is also evident in the present study as well.

The interplay between rootstock and scion has been widely documented across various crops. In this study, it was observed that the fruit quality was significantly influenced by the different scions used for the production of grafted Brimato plants (Fig. 3). Fruit quality plays a crucial role in determining fruit marketability, and grafting can influence the characteristics associated with fruit quality (Walubengo *et al*., 22). The highest ascorbic acid

Table 3. Stionic effect of brinjal and tomato on photosynthetic parameters in brimato (pooled values of two years data).

Treatment	Maximum quantum yield of PSII (*Fv/ Fm*)		Chlorophyll content index (CCI)		Net photosynthesis rate, (*Pn*) (µmol/ m²/ sec)	
	Brinjal	Tomato	Brinjal	Tomato	Brinjal	Tomato
IC56 + (KA + KS)	0.648^{abc}	0.637^{ab}	25.13^{b}	39.16^{bc}	17.97^{e}	11.45^{bc}
IC56 + (KA + KU)	0.499^{a}	0.467^{bcde}	21.91^{bc}	38.17^{bc}	15.35^{a}	9.16^{cde}
IC56 + (KA + KM)	0.585^{ab}	0.578^{a}	31.49^{a}	30.82^{cd}	20.70^{abcd}	13.88^{ab}
IC56 + (KA + KV)	0.619^{cd}	0.553^{de}	21.73^{bc}	34.83^{bc}	20.26^{abc}	13.24^{ab}
IC56 + (KC + KS)	0.530^{abc}	0.544^{bcd}	24.16^{b}	42.46^{b}	17.69^{bcde}	17.35^{a}
IC56 + (KC + KU)	0.473^{bcd}	0.495^{abc}	24.47^{b}	51.00^{a}	14.88^{cde}	7.64^{de}
IC56 + (KC + KM)	0.441^{cd}	0.399^{e}	22.84^{b}	38.60^{bc}	12.51^{cde}	9.20^{bcd}
IC56 + (KC + KV)	0.487^{ab}	0.397^{cde}	22.67^{b}	40.82^{b}	11.06^{de}	7.43^{cde}
IC56 + (V + KS)	0.513^{abc}	0.474^{abcd}	19.24^{bc}	25.34^{de}	14.19^{cde}	10.12^{bcd}
IC56 + (V + KU)	0.525^{bcd}	0.479^{bcde}	18.70^{bc}	21.47^{e}	16.92^{ab}	10.00^{bcd}
IC56 + (V + KM)	0.490^{abc}	0.527^{ab}	19.76^{bc}	23.99^{de}	13.89^{cde}	9.46^{bcd}
IC56 + (V + KV)	0.365^{d}	0.321^{e}	16.10^{c}	19.49^{e}	8.80^{e}	6.14^{e}

(vitamin C) content in tomato fruit was observed when Kashi Chayan (31.85 mg/100 g) or Vani (31.20 mg/100 g) cultivars were used in combination with Kashi Sandesh, followed by Vani combined with Kashi Uttam (30.77 mg/100 g). Compared to ungrafted tomatoes, grafted Kashi Chayan and Vani showed 34.7 and 45.8% higher vitamin C content, respectively, while grafted Kashi Aman had Vitamin C content comparable to ungrafted Kashi Aman. The significant impact of grafting on the ascorbic acid content in tomato fruit is evident from the results. This effect may be attributed to the improved growth of plants, leading to enhanced accumulation of nutrients and better water uptake from the soil, as also reported by Singh *et al*. (20) in tomatoes grafted onto brinjal rootstock.

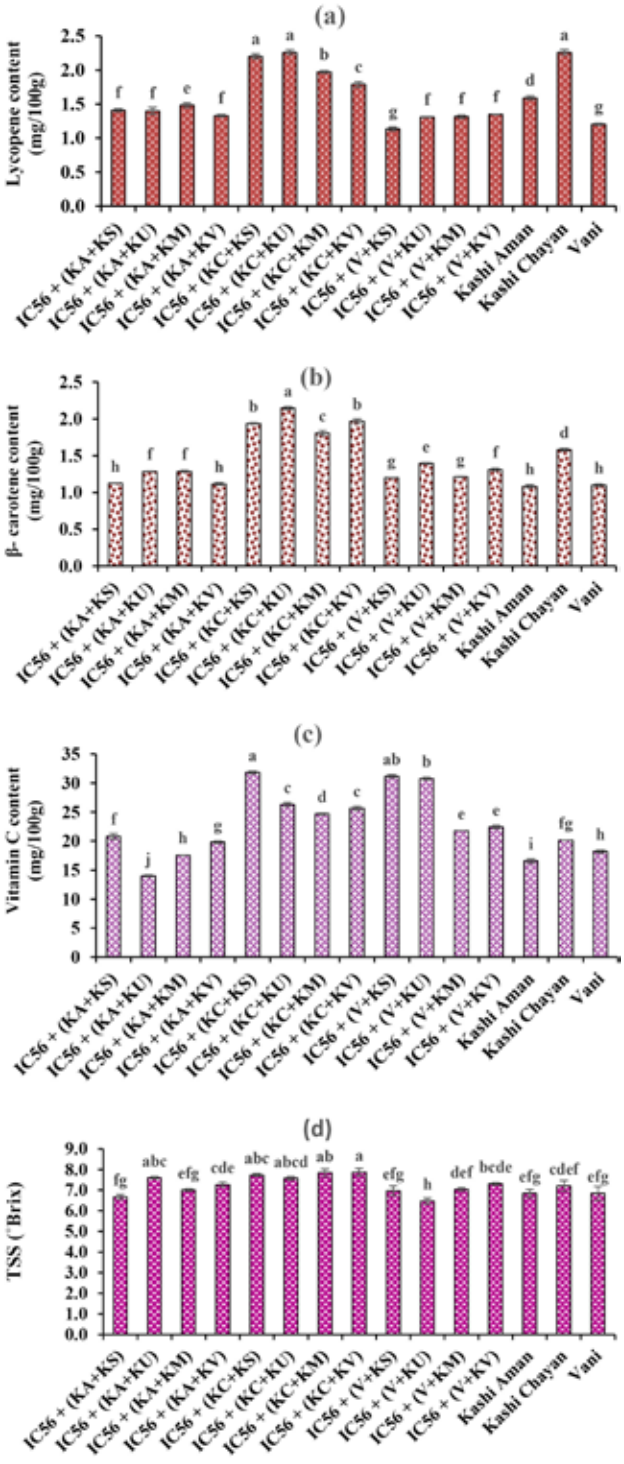

Fig. 3. Quality parameters, namely, Lycopene (a), β-carotene (b), Vitamin C (c), and TSS (d) of grafted tomato fruits.

The primary carotenoids present in tomato fruit are lycopene and β-carotene. Lycopene is a bright red carotenoid pigment found in tomatoes, known for its antioxidant properties. Lycopene content in tomato fruit varied significantly among different tomato scions (Fig. 3). However, grafting brinjal and tomato onto brinjal rootstock did not affect lycopene content compared to the ungrafted control. Regardless of brinjal scions, the tomato cultivar Kashi Chayan had the highest lycopene content (1.97-2.26 mg/100 g), while Kashi Aman and Vani scions had significantly lower lycopene content, ranging between 1.31-1.48 mg/100 g. Earlier, Latifah *et al*. (10) reported that the lycopene content was affected by genotype but not by the growing environment and the grafting technology. Based on these observations, it can be concluded that no significant differences were observed between grafted and non-grafted plants in terms of lycopene contents. From the Fig. 3, it is evident that the highest β-carotene content (2.147 mg/100 g) was recorded in Kashi Chayan combined with the brinjal cultivar Kashi Uttam. In general, significantly higher β-carotene contents were observed in the fruits of grafted Kashi Chayan scions (1.964 mg/100 g), regardless of brinjal cultivars. Grafted Kashi Chayan showed a 24.2% higher β-carotene content than their respective non-grafted plants, while no significant variations were observed in β-carotene content between grafted and non-grafted plants of Kashi Aman and Vani. Conversely, in the majority of cases involving grafted tomato, the β-carotene content remains unchanged between grafted and non-grafted plants (Pugalendhi *et al*., 15). The total soluble solids (TSS) content also varied significantly among the grafted plants. TSS content in tomato fruits was highest in the combinations of Kashi Chayan + Kashi Vijay (7.87°B) and Kashi Chayan + Kashi Manohar (7.83°B) compared to non-grafted Kashi Chayan (7.20°B). Grafted Kashi Aman and Vani registered TSS content comparable to their ungrafted controls. The results are in agreement with the findings of Pugalendhi *et*

al. (15), wherein they noted that the fruits harvested from TNAU tomato hybrid CO3 grafted onto *Solanum sisymbriifolium* rootstock exhibited the highest TSS content (5.79°Brix), followed by var. Shivam grafted onto *Solanum sisymbriifolium* rootstock (5.75°Brix).

The study showed significant variation in fruit yields of brinjal and tomato with different scion combinations. The highest fruit yield in brinjal was from Kashi Sandesh (2.58 kg) grafted with Kashi Chayan, whereas the maximum yield in tomato was registered in Kashi Aman (3.60 kg) in combination with Kashi Sandesh. But, the maximum cumulative yield of brimato, *i.e*., 5.98 kg was obtained in Kashi Aman + Kashi Sandesh, followed by 5.48 kg with Kashi Chayan + Kashi Sandesh. The highest ascorbic acid content in tomato was observed with Kashi Chayan and Vani when combined with Kashi Sandesh. The highest β-carotene content was in Kashi Chayan with Kashi Uttam. Generally, grafted Kashi Chayan had significantly higher β-carotene than non-grafted plants, while Kashi Aman and Vani showed no significant difference between grafted and non-grafted plants. This suggests that using tomato Kashi Chayan and brinjal Kashi Sandesh is a promising combination for harnessing the dual benefits of both vegetables from the same plant.

AUTHORS' CONTRIBUTION

Conceptualization of the original idea (AB); experiment designing, field experiment and data collection (AB, AKS and VKP); statistical analysis and interpretation (RK, AB); manuscript preparation (AB, HK and RK). Administrative supports (TKB).

DECLARATION

The authors do not have any conflict of interests or competing interests.

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