Standardization of Rootstocks for Yield and Quality in Sweet Pepper (*Capsicum annuum* L.)

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ABSTRACT

Background: The present study was conducted during *kharif*-2022 (June to September) to assess the graft compatibility of two capsicum hybrids with different chilli rootstocks and their effects on growth, yield and quality.

Methods: The experiment was carried out in FRBD with 16 treatments, including seven rootstocks and two scions, replicated thrice in greenhouse.

Result: Graft success rate varied between 82.67% and 96.67%, with the highest rate observed in commercial capsicum hybrid-1 grafted on CRS-2 and commercial capsicum hybrid-2 on CRS-1. Among all combinations, commercial capsicum hybrid-2 grafted on CRS-7 showed superior performance in plant height (103.47 cm), pericarp thickness (0.53 mm), number of branches (10.13) and earliness in flowering (22.33 days). It also recorded the highest fruit yield per plant (3.43 kg), per plot (34.33 kg) and per hectare (54.74 t/ha). The lowest yield was recorded in non-grafted commercial capsicum hybrid-1 (2.41 kg/plant, 38.39 t/ha). No significant differences were found in TSS content across grafts. However, commercial capsicum hybrid-1 grafted on CRS-6 had the highest titratable acidity (0.17%). The findings confirmed that grafting positively influences growth and yield in capsicum, with commercial capsicum hybrid-2 grafted on CRS-7 emerging as the most promising combination.

Key words: Chilli rootstocks, Growth, Interaction, Scion, Quality parameters, Yield.

INTRODUCTION

Capsicum (*Capsicum annuum* L.), a key vegetable in India from the *Solanaceae* family, 2n=2x=24 (Carrizo *et al*., 2016). Cultivated globally as both vegetable and spice, capsicum is rich in vitamins A, B, C and minerals like calcium, magnesium and phosphorus, along with capsaicinoids and other beneficial compounds (Carvalho *et al*., 2015; Keerthana *et al*., 2022). It is grown year-round across India, but yield is challenged by biotic stresses. One promising technique to enhance the performance of sweet pepper in protected cultivation is grafting. Grafting is a horticultural technique in which the stem of one plant is called rootstock, rootstock joined with the shoot of other plant is called the scion. In this process the two plants grow together as a single entity, combining the desirable traits of both the disease resistance or vigor of the rootstock and the high quality of the scion. The practice of vegetable grafting has ancient origins, dated back to around 2000 B.C. in China. Grafting is increasingly used to combat these issues, especially under intensive cultivation (Abirami *et al.,* 2009, Fisk, 2017; Mamphogoro *et al*., 2020; Kumar, 2020). It improves stress tolerance, fruit quality and yield (Devi *et al*., 2020). Splice grafting is the most common method (Hameed *et al*., 2021), with vascular connectivity forming in 5-8 days. The process includes selecting scion and rootstock, grafting, healing, evaluating success and acclimatizing seedlings (Surve, 2019). This research is to assess the graft compatibility of two capsicum hybrids with different chilli rootstocks and their effects on growth, yield and quality of capsicum.

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MATERIALS AND METHODS

The study was conducted in polyhouse during the *kharif*-2022 (June to September) at Center of Excellence for Vegetables, KVK Baramati, using a FRBD with 16 treatments and 3 replications (10 plants per plot, 1.35 ×0.90 m^2 spacing). Seven wild chilli rootstocks (CRS-1 to CRS-7) and two capsicum hybrids (commercial capsicum hybrid-1 and commercial capsicum hybrid-2) were used. Rootstock seeds were sown 4 weeks before scion seeds in sterilized cocopeat to ensure uniform germination. Wild rootstocks recorded delayed germination (25-30 days) compared to others (Rinku *et al*., 2020). Splice grafting was done using 1.6 mm silicon clips when seedlings reached suitable size. Grafted plants were kept in a healing chamber at 85-90% RH and 28-32°C for 10-12 days. After 25 days of healing, seedlings were transplanted at the 3-4 leaf stage (Zhen *et al*., 2022).

RESULTS AND DISCUSSION

Days taken to germination

Significant differences were observed among treatments (Table 1) for days to germination. The combination of CRS-4 (rootstock) and commercial capsicum hybrid-2 (scion) recorded the shortest germination period (5.33 days), while CRS-2 exhibited the longest germination period (13.67 days). The ideal timing for grafting was achieved when the diameters of the rootstock and scion stems in capsicum cultivars were similar (Rodriguez *et al*., 2010). Hossain *et al*. (2019); Pawar *et al*. (2021) and Kumar *et al*. (2018) reported comparable results. The rapid healing in capsicum grafts is due to the plant's fast growth rate, which supports quick callus formation at the graft union. Favorable conditions like warmth and adequate moisture further stimulate cell activity and tissue regeneration, essential for reconnecting vascular systems and promoting nutrient and water flow between rootstock and scion. Healing and union formation generally take up to 10 days after grafting (Keerthana *et al*., 2022). Phukon *et al*. (2020) and Vega-Alfaro *et al*. (2021), who reported healing in 6-8 days. The splice grafting technique, involving precise cuts and attentive aftercare, reduces plant stress and enhances graft health, leading to stronger unions. Commercial rootstocks and breeding lines typically achieve grafting success rates over 80%, highlighting compatibility and boosting plant growth compared to non-grafted plants (Jang *et al*., 2012). These results align with the findings of Oda *et al*. (1996); Lilieth *et al*. (2012); Singh *et al*. (2019) and Pawar *et al*. (2021).

Days taken to reach grafting stage

Significant variation was observed in the number of days required to reach the grafting stage. The commercial capsicum hybrid-1 (control) reached the grafting stage earliest at 14.33 days, while CRS-2 took the longest at 34.33 days (Table 1). These results are consistent with earlier reports stating that, under controlled conditions, grafting in chilli rootstocks and capsicum scions is typically performed 27-34 days after germination (Lee *et al*., 2010; Jang *et al*., 2011).

Observations of grafted plants

Days taken for graft healing

Significant differences were observed among rootstocks in terms of days required for graft healing (Table 2), which can be attributed to better vascular union and compatibility between rootstock and scion of the same species. The shortest graft healing period (5.83 days) was recorded in CRS-1, while the longest (7.00 days) was observed in CRS-2 and CRS-5. Among scions, commercial capsicum hybrid-2 showed faster healing (6.00 days) compared to commercial capsicum hybrid-1, which averaged 7.43 days (Rinku *et al*., 2020). Interaction effects between rootstock and scion combinations also revealed significant variation. The fastest graft healing (5.33 days) was observed in treatments T_8 (commercial capsicum hybrid-2 grafted on CRS-1) and T_{11} (commercial capsicum hybrid-2 grafted on CRS-4). In contrast, the longest healing time (8.33 days) occurred in T_9 (commercial capsicum hybrid-2 grafted on CRS-2). Faster healing is generally attributed to higher graft compatibility and more efficient vascular reconnection (Wuu *et al*., 2016, Rinku *et al*., 2020 and Andrey *et al*., 2021).

Days taken to attain transplanting stage

Statistically significant differences were recorded among chilli rootstocks for the number of days required to reach the transplanting stage. The rootstock CRS-1 reached earliest transplanting stage (10.83 days), while CRS-5 took the longest time (13.00 days). Among the scion varieties, commercial capsicum hybrid-2 reached the transplanting stage more quickly, requiring only 11.19 days, compared to 12.43 days for commercial capsicum hybrid-1. A significant interaction effect was observed among the various grafting combinations (Table 2). The shortest time to transplanting was recorded in treatments T_8 (Hybrid-2 grafted onto CRS-1) and T_{14} (Hybrid-2 grafted onto CRS-7), both reaching transplant in just 10.33 days, respectively. In contrast, the longest duration (13.67 days) was observed in T_2 (commercial capsicum hybrid-1 grafted on CRS-2) (Andrey *et al*., 2021), who highlighted faster development in compatible graft combinations. Moreover, grafted plants generally reached the transplanting stage earlier than non-grafted ones, as supported by earlier studies (Nkansah *et al*., 2013; Hossain *et al*., 2019; Andrey *et al*., 2021). The results revealed significant variation in grafting success, which ranged from 84.00% to 96.50%. Among the rootstocks, CRS-2 recorded the highest graft success (96.50%), while CRS-5 exhibited the lowest (84.00%). In terms of scion effect, commercial capsicum hybrid-2 showed a higher graft success rate (93.24%) compared to commercial capsicum hybrid-1 (91.29%). Significant differences were also observed in the interaction between rootstock and scion combinations. The highest graft success (96.67%) was recorded in T_2 (commercial capsicum hybrid-1grafted on CRS-2) and T_8 (commercial capsicum hybrid-2 grafted on CRS-1). The graft success in certain combinations may be attributed

Table 1: Days taken for germination, to reach grafting stage after sowing of rootstocks and scions.

Treatment details	Days taken for germination	Days taken to grafting stage
CRS-1	5.67	27.67
CRS-2	13.67	34.33
CRS-3	6.00	28.00
CRS-4	5.33	28.00
CRS-5	10.33	30.67
CRS-6	8.33	28.00
CRS-7	5.67	27.67
Commercial capsicum hybrid-1 (Control)	5.67	14.33
Commercial capsicum hybrid-2 (Control)	5.33	14.67
Sem±	0.32	0.28
CD at 5 %	0.97	0.83

Table 2: Effect of rootstocks on different growth and yield parameters.

Treatment details	Days taken for graft healing	Days taken to attain transplanting stage	Graft success (%)	Plant height (cm)	No. of branches per plant	Days taken for 50% flowering	No. of fruit per plant	Avg. fruit weight (g)	Pol dia. (cm)	Eq. dia. (cm)	Pericarp thickness (mm)	Yield/ plant (kg)	Yield/ plot (kg)	Yield/ ha (t)	TSS (°Brix)	Titratable acidity (%)
Factor 1: Rootstock effect																
CRS-1	5.83	10.83	96.33	94.09	8.70	22.83	27.54	115.4	6.83	6.68	0.45	3.16	31.56	50.33	4.50	0.13
CRS-2	7.00	12.17	96.50	92.42	8.87	24.33	26.25	107.6	6.67	6.46	0.52	2.81	28.05	44.74	4.82	0.16
CRS-3	6.83	11.83	95.67	96.61	9.20	29.83	26.89	112.3	7.26	6.48	0.47	3.01	30.09	47.99	4.75	0.14
CRS-4	6.83	12.83	89.83	97.40	9.20	29.00	26.14	105.2	6.51	6.48	0.48	2.74	27.40	43.69	4.68	0.15
CRS-5	7.00	13.00	84.00	95.55	8.53	29.83	24.93	112.2	6.64	6.42	0.51	2.78	27.78	44.30	4.33	0.13
CRS-6	6.83	11.00	92.00	101.48	9.37	22.50	26.36	118.5	6.78	6.70	0.45	3.10	30.98	49.40	4.23	0.15
CRS-7	6.67	11.00	91.50	100.21	9.70	24.67	29.88	109.3	7.50	6.68	0.49	3.24	32.40	51.66	4.62	0.12
SEm±	0.25	0.25	0.51	0.28	0.17	0.30	0.36	0.001	0.09	0.07	0.007	0.029	0.29	0.46	0.09	0.005
CD at 5%	0.72	0.74	1.49	0.81	0.50	0.87	1.03	0.003	0.26	0.20	0.02	0.08	0.84	1.34	0.28	0.014
Factor 2: Scion effect																
Commercial capsicum hybrid-	17.43	12.43	91.29	93.94	8.79	27.29	24.88	112.3	7.47	6.36	0.47	2.78	27.75	44.25	4.65	0.15
Commercial capsicum hybrid-	26.00	11.19	93.24	100.13	9.42	26.17	28.61	107.4	6.32	6.69	0.50	3.06	30.62	48.83	4.40	0.13
SEm±	0.13	0.14	0.25	0.14	0.09	0.15	0.18	0.0005	0.04	0.03	0.003	0.014	0.14	0.23	0.04	0.003
CD at 5 %	0.38	0.40	0.79	0.40	0.25	0.43	0.52	0.001	0.12	0.10	0.01	0.042	0.42	0.67	0.14	0.007
Interaction effect																
T_1	6.33	11.33	96.00	88.87	7.93	23.33	26.23	116.3	7.09	6.63	0.45	3.05	30.51	48.65	4.53	0.12
T_2	7.67	13.67	96.67	87.03	8.33	25.33	24.56	109.1	7.14	6.35	0.51	2.67	26.67	42.53	4.90	0.16
T_3	7.33	12.33	94.67	92.23	8.80	30.33	25.89	112.6	7.13	6.28	0.46	2.90	29.01	46.26	4.87	0.16
T_4	8.33	13.33	86.67	95.95	8.93	29.33	24.66	107.3	8.13	6.37	0.48	2.64	26.44	42.16	4.80	0.16
T_5	7.33	13.33	82.67	91.78	8.13	30.33	23.18	113.4	6.95	6.03	0.49	2.66	26.55	42.39	4.63	0.14
T_6	7.33	11.33	91.67	99.53	9.93	22.67	23.45	122.2	7.25	6.54	0.43	2.87	28.70	45.77	4.33	0.17
T_7	7.67	11.67	90.67	98.15	9.27	24.67	27.20	112.3	8.39	6.64	0.45	3.05	30.47	48.58	4.83	0.13
T_8	5.33	10.33	96.67	99.30	9.47	22.33	28.86	113.4	6.57	6.74	0.46	3.26	32.61	52.01	4.47	0.13
T_9	6.33	10.67	96.33	97.82	9.40	23.33	27.95	105.2	6.21	6.56	0.53	2.94	29.44	46.94	4.73	0.16
T_{10}	6.33	11.33	96.67	97.27	9.47	29.33	27.88	112.7	6.39	6.68	0.48	3.12	31.18	49.72	4.63	0.12
T_{11}	5.33	12.33	93.00	102.56	9.60	28.67	27.62	103.5	5.89	6.60	0.49	2.84	28.36	45.22	4.57	0.14
T_{12}	6.67	12.67	85.33	99.33	8.93	29.33	26.68	110.2	6.33	6.81	0.52	2.94	29.41	46.90	4.03	0.12
T_{13}	6.33	10.67	92.33	102.27	8.80	22.33	29.27	114.1	6.31	6.86	0.48	3.33	33.25	53.03	4.13	0.13
T_{14}	5.67	10.33	92.33	103.47	10.13	24.67	32.55	105.3	6.61	6.72	0.53	3.43	34.33	54.74	4.40	0.12

Table 2: Continue....

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T_{15}	-	-	-	97.98	9.00	32.33	23.86	101.6	7.71	6.07	0.50	2.41	24.1	38.39	4.30	0.16
T_{16}	-	-	-	99.03	9.53	29.33	28.05	94.1	6.22	6.57	0.53	2.64	26.37	42.05	4.23	0.14
SEm±	0.35	0.36	0.72	0.39	0.24	0.42	0.50	0.10	0.13	0.10	0.01	0.04	0.41	0.66	0.14	0.007
CD at 5 %	1.01	1.05	2.10	1.15	0.71	1.23	1.47	0.30	0.36	0.29	0.03	0.12	1.19	1.90	NS	0.02

T_1: Commercial capsicum hybrid-1 grafted on CRS-1, T_2: Commercial capsicum hybrid-1 grafted on CRS-2, T_3: Commercial capsicum hybrid-1 grafted on CRS-3, T_4: Commercial capsicum hybrid-1 grafted on CRS-4, T_5: Commercial capsicum hybrid-1 grafted on CRS-5, T_6: Commercial capsicum hybrid-1 grafted on CRS-6, T_7: Commercial capsicum hybrid-1 grafted on CRS-7, T_8: Commercial capsicum hybrid-2 grafted on CRS-1, T_9: Commercial capsicum hybrid-2 grafted on CRS-2, T_{10}: Commercial capsicum hybrid-2 grafted on CRS-3, T_{11}: Commercial capsicum hybrid-2 grafted on CRS-4, T_{12}: Commercial capsicum hybrid-2 grafted on CRS-5, T13: Commercial capsicum hybrid-2 grafted on CRS-6, T14: Commercial capsicum hybrid-2 grafted on CRS-7, T15: Control (commercial capsicum hybrid-1), T16: Control (commercial capsicum hybrid-2).

to better physiological and anatomical compatibility between rootstock and scion (Saraswat *et al*., 2020 and Rathod *et al*., 2017). In contrast, the lowest graft success (82.67%) was observed in T_5 (commercial capsicum hybrid-1 grafted on CRS-5).

Growth parameters

Plant height

Plant height varied significantly among rootstocks, with CRS-6 recorded maximum height (101.48 cm) and CRS-2 shortest (92.42 cm) (Table 2). Among scions, commercial capsicum hybrid-2 (100.13 cm) was recorded maximum height than commercial capsicum hybrid-1 (93.94 cm). The graft combinations also differed significantly; T_{14} (commercial capsicum hybrid-2/CRS-7) and T_{11} (commercial capsicum hybrid-2/CRS-4) had the greatest heights (103.43 cm and 102.56 cm), while T_2 (commercial capsicum hybrid-1/ CRS-2) and T_9 (commercial capsicum hybrid-2/CRS-2) were shortest (87.03 cm). Grafted plants showed greater height than non-grafted controls (Colla *et al*., 2008; Soltan *et al*., 2017; Rinku *et al*., 2020).

Number of branches per plant

The number of primary branches per plant differed significantly among rootstocks, with CRS-7 having the highest (9.70) and CRS-1 the lowest (8.70). Among scions, commercial capsicum hybrid-2 produced more branches (9.42) than commercial capsicum hybrid-1 (8.79). Significant differences were also found in graft combinations, with T_{14} (commercial capsicum hybrid-2 on CRS-7) recording the most branches (10.13) and T_1 (commercial capsicum hybrid-1on CRS-1) the fewest (7.93) (Table 2). Grafted commercial capsicum hybrid-2 plants showed more branches than non-grafted controls, consistent with Salehi *et al*. (2009) and Rathod (2017).

Days taken for 50% flowering

Days to 50% flowering varied significantly among rootstocks, with CRS-6 requiring the fewest days (22.50) and CRS-3 and CRS-5 the most (29.83) (Table 2). Among scions, commercial capsicum hybrid-2 flowered earlier (26.17 days) than commercial capsicum hybrid-1 (27.29 days). Interaction effects showed the earliest flowering in T_8 (commercial capsicum hybrid-2 /CRS-1) and T_{13} (22.33 days), comparable to T_1 (commercial capsicum hybrid-1/ CRS-1), T_6 (commercial capsicum hybrid-1/CRS-6) and T_9 (commercial capsicum hybrid-2 /CRS-2) all at 23.33 days. The latest flowering occurred in non-grafted commercial capsicum hybrid-1 (T_{15}) at 32.33 days. Delayed flowering in non-grafted plants is likely influenced by rootstock–scion interactions (Nkansah *et al*., 2017; Maurya *et al*., 2019; Saraswat *et al*., 2020).

Yield parameters

Number of fruits per plant

The number of fruits per plant, closely linked to total yield, varied significantly among rootstocks. The CRS-7 produced the highest fruit number (29.88), likely due to its vigorous

wild root system, while CRS-3 had the lowest (24.93) (Table 2). Among scions, commercial capsicum hybrid-2 recorded more fruits (28.61) than commercial capsicum hybrid-1 (24.88). The graft combination T_{14} (commercial capsicum hybrid-2 /CRS-7) recorded the highest fruit count (32.55) and T_5 (commercial capsicum hybrid-1/CRS-5) recorded the lowest fruit count. Increased fruit number in grafted plants is attributed to vigorous rootstocks enhancing cytokinin and gibberellin levels, boosting fruit load (Jang *et al*., 2011; Rinku *et al*., 2020; Andrey *et al*., 2021).

Average fruit weight

Rootstock CRS-6 produced the highest average fruit weight (118.5 g), while CRS-4 had the lowest (105.2 g). Among scions, commercial capsicum hybrid-1 showed greater fruit weight (112.3 g) than commercial capsicum hybrid-2 (107.4 g) (Table 2). The graft combination T_6 (commercial capsicum hybrid-1/ CRS-6) recorded the highest fruit weight (122.2 g) and the lowest was in non-grafted commercial capsicum hybrid-2 (94.1 g). Grafted plants recorded significantly heavier fruits compared to controls (Turhan *et al*., 2011; Andrey *et al*., 2021).

Polar diameter

Significant differences in polar diameter were observed among rootstocks, with CRS-7 having the highest (7.50 cm) and CRS-4 the lowest (6.51 cm). Among scions, commercial capsicum hybrid-1 recorded greater polar diameter (7.47 cm) than commercial capsicum hybrid-2 (6.32 cm) (Table 2). Graft combinations also varied significantly; T_7 (commercial capsicum hybrid-1/CRS-7) showed the largest polar diameter, comparable to T_4 (commercial capsicum hybrid-1/ CRS-4, 8.13 cm), while T_9 (commercial capsicum hybrid-2/ CRS-2) had the smallest (6.21 cm). Fruits from grafted plants exhibited larger polar diameters than non-grafted ones (Rinku *et al*., 2020).

Equatorial diameter of fruit

Equatorial diameter varied significantly among rootstocks, with CRS-6 having the highest (6.70 cm) and CRS-5 the lowest (6.42 cm). Among scions, commercial capsicum hybrid-2 showed greater equatorial diameter (6.69 cm) than commercial capsicum hybrid-1 (6.36 cm) (Table 2). The highest equatorial diameter was in T_{13} (commercial capsicum hybrid-2/CRS-6, 6.86 cm), comparable to several other graft combinations, while the lowest was in T_5 (commercial capsicum hybrid-1/CRS-5, 6.03 cm). Grafted plants had larger equatorial diameters than non-grafted, likely due to increased growth hormone accumulation from rootstocks (Kumar *et al*., 2016; Hossain *et al*., 2019).

Pericarp thickness

Pericarp thickness, important for shelf life, varied significantly among rootstocks (Table 2). CRS-2 showed the highest thickness (0.52 mm), while CRS-1 had the lowest (0.45 mm) Pericarp thickness. Among grafts, T_9 (commercial capsicum hybrid-2/CRS-2), T_{14} (commercial capsicum hybrid-2/CRS-7) and T_{16} (non-grafted commercial capsicum hybrid-2) recorded the highest thickness (0.53 mm) and T_6 (commercial capsicum hybrid-1/CRS-6) the lowest (0.43 mm). Increased pericarp thickness in grafted plants may result from rootstock-scion interactions (Neymar *et al*., 2018).

Yield per plant

Yield attributes are key to assessing capsicum productivity and depend on graft compatibility and other factors. Fruit yield per plant varied significantly among rootstocks, with CRS-7 producing the highest yield (3.24 kg) and CRS-4 the lowest (2.74 kg) (Table 2). Among scions, commercial capsicum hybrid-2 recorded more yield (3.06 kg) than commercial capsicum hybrid-1 (2.78 kg). The highest yield (3.43 kg) was in T_{14} (commercial capsicum hybrid-2/CRS-7), while the lowest (2.41 kg) was in non-grafted commercial capsicum hybrid-1 (T_{15}). CRS-7 rootstock grafted with commercial capsicum hybrid-2 showed superior yield, likely due to better graft compatibility and environmental adaptation (Kumar *et al*., 2016; Soltan *et al*., 2017).

Yield per plot

Among rootstocks, CRS-7 recorded the highest fruit yield per plot (32.40 kg), while CRS-4 had the lowest (27.40 kg). commercial capsicum hybrid-2 scion produced significantly higher yield (30.62 kg) than commercial capsicum hybrid-1 (27.74 kg) (Table 2). The highest yield per plot was in T_{14} (commercial capsicum hybrid-2/CRS-7) with 34.33 kg, closely followed by T_{13} (commercial capsicum hybrid-2/CRS-6) at 33.25 kg. The lowest yield (24.1 kg) was in non-grafted commercial capsicum hybrid-2 (T_{15}). CRS-7 grafted with commercial capsicum hybrid-2 consistently showed superior plot yields (Soltan *et al*., 2017; Andreas *et al*., 2019).

Yield per hectare

Rootstock CRS-7 recorded the highest fruit yield per hectare (51.66 t/ha), while CRS-4 had the lowest (43.69 t/ha). Commercial capsicum hybrid-2 (48.83 t/ha) recorded significantly more yield than commercial capsicum hybrid-1 (44.25 t/ha) (Nimbrayan *et al*., 2016; Nkansah *et al*., 2017 and Hameed *et al*., 2021) (Table 2). Use of bell pepper rootstocks improves vigor and tolerance to abiotic and biotic stresses, increasing yield up to 30% compared to non-grafted plants (Nimbrayan *et al*., 2016; Nkansah *et al*., 2017; Neymar *et al*., 2018; Hameed *et al*., 2021).

Qualitative parameters

Total soluble solids (°Brix)

Higher sugar and acid content enhances fruit flavor and quality. The highest Total Soluble Solids content (4.82 °Brix) was recorded in rootstock CRS-2, while the lowest (4.23 °Brix) was in CRS-6 (Table 2). Among scions, commercial capsicum hybrid-1showed significantly higher TSS (4.65 °Brix) than commercial capsicum hybrid-2 (4.40 °Brix). The highest TSS in graft combinations was observed in T_2: commercial capsicum hybrid-1grafted on CRS-2 (4.90 °Brix), followed by T_3, T_7 and T_4; however, interaction effects were non-significant. Increased TSS in grafted capsicum fruits compared to self-grafted plants is attributed to elevated phenolic compounds (Josefa *et al*., 2013; Neymar *et al*., 2018).

Titratable acidity (%)

Titratable acidity, reflecting citric acid content, directly influences capsicum fruit flavor and organoleptic properties. Among rootstocks, the highest acidity (0.16%) was recorded in CRS-2 and the lowest (0.12%) in CRS-7 (Table 2). Scion commercial capsicum hybrid-1 showed significantly higher acidity (0.15%) compared to commercial capsicum hybrid-2 (0.13%). In graft combinations, the highest titratable acidity (0.17%) was observed in T_6 (commercial capsicum hybrid-1 grafted on CRS-6), comparable to T_2, T_3 and T_4 treatments (0.16%). The lowest acidity (0.12%) occurred in T_1, T_{10}, T_{12} and T_{14} combinations. Grafting enhances titratable acidity likely through rootstock effects on organic acid accumulation or improved nutrient uptake *via* vigorous roots (Nina *et al*., 2021).

Benefit cost ratio (B:C ratio)

The benefit-cost ratio (B:C) of different graft combinations the highest B:C ratio (2.01) was observed in T_{14} (commercial capsicum hybrid-2 grafted on CRS-7), followed by T_{13} (commercial capsicum hybrid-2 grafted on CRS-6) with 1.94 (Table 2). The lowest B:C ratio (1.49) was recorded in non-grafted commercial capsicum hybrid-1. Grafted capsicum demonstrates greater feasibility and productivity under polyhouse conditions due to controlled environments (Sreedhara *et al*., 2013; Kumar *et al*., 2016).

CONCLUSION

The rootstock CRS-1 demonstrated superior graft compatibility, evidenced by the shortest graft healing time, earliest transplanting stage and highest graft success. Among graft combinations, commercial capsicum hybrid-1 grafted on CRS-2 and commercial capsicum hybrid-2 grafted on CRS-1 showed the highest graft success (96.67%), shortest graft healing (5.33 days) and earliest transplanting (10.33 days), with earlier 50% flowering compared to non-grafted plants. commercial capsicum hybrid-1 grafted on CRS-6 recorded the highest average fruit weight (122 g).

Rootstocks CRS-6 and CRS-7 significantly enhanced growth, yield and quality parameters. CRS-7 outperformed CRS-6 and other rootstocks in plant height, branch number, fruit number, pericarp thickness and fruit yield per plant, plot and hectare. Commercial capsicum hybrid-2 grafted on CRS-7 exhibited the lowest disease incidence, including fusarium wilt, damping off, leaf curl, mosaic, thrips and no root knot nematode occurrence. Fruit color and shape remain unchanged by grafting.

Overall, commercial capsicum hybrid-2 grafted on CRS-7 showed superior performance in plant height (103.47 cm), pericarp thickness (0.52 mm), fruit number (32.55/plant), primary branches (10.13/plant), fruit yield (3.43 kg/plant; 34.33 kg/plot; 54.74 t/ha), lowest disease incidence and highest benefit-cost ratio (2.01).

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Conflict of interest

The authors declare that there is no conflict of interest.

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