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Intra and Interspecific Graft Compatibility Studies and Standardization of Grafting Parameters for Sweet Pepper (*Capsicum annuum* L. var. *grossum* Sendt.)

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ABSTRACT: This research investigated the graft compatibility of various *Capsicum* spp. rootstocks with the popular bell pepper hybrid Massilia RZ F1. Grafting is a technique that combines desirable fruit characteristics of a scion with the disease resistance and stress tolerance of a rootstock, contributing to increased yield and improved quality. The study focused on 25 rootstocks, including different *Capsicum* species, evaluating their compatibility and productivity. Significant variations were observed in seed germination times and seedling growth parameters among the rootstocks. CRS-23 and Massilia RZ F1 exhibited quick germination, showcasing seed vigour. Graft success varied across combinations, with high success observed in combinations involving CRS-1, CRS-2, CRS-6, CRS-8, CRS-11, CRS-12, CRS-13, CRS-14, CRS-15, and CRS-21. Compatibility was reflected in scion girth, rootstock girth, and graft union girth measurements at 15 days after grafting. This study emphasizes the importance of selecting compatible rootstock-scion combinations for successful grafting, highlighting potential options for improved germination, graft success, and desirable growth traits in grafted bell pepper plants.

Keywords: Graft compatibility, Graft success, Bell pepper.

INTRODUCTION

Grafted vegetables are the "physical hybrids" (Kubota *et al*., 2016) resulted from the surgical fusion of two plant parts, typically a scion and a rootstock, to form a single, genetically combined plant. In this technique, the scion is chosen based on its desirable fruit characteristics, while the rootstock is selected for its resistance to soil borne diseases, ability to withstand environmental stress and capacity to absorb nutrients. The skillful union of plant parts ensures the combination of two or more attributes from two or more plants into one. Therefore, these physical hybrids contribute to the production of vegetables by increasing yield, enhancing biotic and abiotic resistance, improving fruit quality and extending crop seasons. This transformation turns ordinary vegetable cultivation into something extraordinary by maintaining the true-to-type characteristics of the scion.

The crucial factor in the production of grafted vegetables is the compatibility between the rootstock and scion, which, in turn, determines the success of grafted plants. The success and survival of grafted plants depend on the strong connection between the rootstock and scion. This connection involves processes like callus formation, vascular bundle differentiation, and establishing connectivity at the graft junction. This cohesion ensures the well-balanced growth of both the scion and rootstock, which is essential for optimal horticultural performance (Ogata *et al*., 2005). When grafts are poorly connected, water and xylem sap transfer at the graft site is restricted. This limitation in hydraulic conductance leads to issues such as reduced stomatal activity, defoliation, reduced shoot vigour (scion growth) and ultimately, lower yield and quality of the produce (Oda *et al*., 2005).

The choice of appropriate and commercially viable rootstock and scion cultivars is an essential stage in the successful production of grafted vegetables. The rootstocks are chosen based on seed purity, seed viability, tolerance to biotic (Naik *et al*., 2021) and abiotic stress, and compatibility with the scion cultivar, whereas the scion cultivar is chosen based on yield, fruit quality and market demand (Bie *et al*., 2017).

Successful grafting requires careful consideration of germination conditions, appropriate rootstock and scion selection and precise timing for grafting. Additionally, factors such as stem girth, number of leaves, and plant height at the grafting stage contribute to the overall success of the grafting process (Johkan *et al*., 2008; Hamdi *et al*., 2010; Rodriquez and Bosland 2010; Jang *et al*., 2012; Soltan *et al*., 2017; Alfaro *et al*., 2021; Phukon *et al*., 2020). There is limited information available regarding the standardized grafting technique protocol in bell peppers. Standardization of grafting parameters helps in reduction of in the risk of failed grafts and maximize the efficient resource usage. Furthermore, it facilitates the scalability of grafted plant production on commercial scale and wide supply and rural entrepreneurship. This, in turn, can lead to cost savings by reducing the need for trial and error in grafting techniques, helping streamline the grafting process and reducing labour and material costs associated with grafting. The objective of the study was to investigate the intra and interspecific graft compatibility of various *Capsicum* spp. rootstocks with the popular bell pepper hybrid. This research was conducted as part of a study on screening different graft combinations of bell pepper for major soil-borne diseases, wherein 25 rootstocks were initially including self and non-grafts were screened. Subsequently, the selected rootstocks, as identified by Sanmathi *et al*. (2023), underwent further evaluation for compatibility and productivity.

MATERIALS AND METHODS

The experiment was conducted at research block of department of vegetable science, College of Horticulture, Sirsi, Uttara Kannada, Karnataka, during the month of April to June, 2022.

Root stocks and scion used in the experiment: Twenty five accessions including *C. annuum*, *C. chinens* and *C. frutscens* were selected as root stocks (Table 1). The scion used is a popular capsicum hybrid *i.e*., Massilia RZ F1 (Rijk Zwaan India Seeds Pvt. Ltd), highly suitable for protected cultivation.

Grafting procedure followed. Individual rootstock and scion seeds were sown in the cavity of 50-celled portrays filled with cocopeat and *Trichoderma* (2g per kg of cocopeat) mixture. The seedlings required for grafting were grown in a polyhouse until they attained two true leaves, three to four days prior to grafting, the irrigation was reduced to harden them. The digital Vernier callipers, was used to measure the stem girth of the seedlings. Grafting was done in the shade, ideally in the evening hours, mainly during the cool hours of the day. The well-known bell pepper hybrid Massilia (MS) was grafted on different *capsicum* spp. rootstocks and also self-grafted by cleft method of grafting. The non-grafted and self-grafted Massilia were used control.

The rootstock was prepared by giving a vertical cut at five cm above the collar region. At the centre of cut surface of rootstock, horizontal cut of 1.5 to 2 cm was done. A vertical slit was given vertically on the rootstock by removing the plant part three to five cm above collar region. The growing tip of the scion up to a length of six to eight cm was taken, by leaving three to four cm above collar region, all the leaves were trimmed off remaining one or two apical growing leaves. Slant cut of about 1.5 to 2 cm was given at one side of the lower part of the scion and the same level cut was given on the opposite side of the lower portion of the scion, such that a ‘V’ shape or ‘wedge’ shape was formed at the bottom part of the scion. Thus, the prepared scion was inserted into the vertical slit given on the rootstock and the union was kept in position by using grafting clip.

Grafted seedlings were placed within the conventional humidity chamber under shade. To control the temperature and humidity inside the chamber, a single layer of polythene sheet and a single layer of green shade net cloth were placed on top of a single layer of mulch sheet for ten days, water was sprayed three to four times every day to maintain the temperature. The temperature and relative humidity were monitored using digital thermo hygrometer inside the humid chamber. When the temperature exceeded the optimum level, water was sprayed on the walls of the humid chamber. The plants were gradually allowed to harden by removing them from the healing chamber 15 days after grafting, and they were placed under natural climatic conditions. After spending fifteen days in the healing chamber, the grafted seedlings were transferred to the shade net and provided with proper irrigation, gradually reducing it to further harden the plants. Five days after hardening under the shade net, they were transplanted under polyhouse conditions.

Observations recorded. Observations on days taken for seed germination of both rootstocks and scion were recorded. Days taken to attain graftable stem girth. The stem girth of the rootstocks and scion seedlings was measured by using digital vernier callipers, holding them at a distance of five centimetres above the collar region of the seedlings. The number of leaves in the rootstock and scion seedlings was counted and expressed in numbers. Height of the rootstock and scion seedlings was measured with scale and the observations were expressed in numbers.

After grafting, healthy grafts without showing wilting were recorded at 5, 10 and 15 days after grafting. The plants producing new leaves were considered as successful grafts. Percentage graft success was calculated as per the formula mentioned below

$$\text{Per centage of graft success} = \frac{\text{Number of successful grafts}}{\text{Total number of plants grafted}} \times 100$$

At 15 days after grafting, the girth of the rootstock and scion was recorded at one cm above and below the graft union region by holding the digital vernier callipers. Whereas the graft union girth of the graft union region was recorded by holding the digital vernier callipers at the grafted region. The number observed in the callipers were recorded.

Statistical analysis. The mean data for each character were tabulated and analysis was done in SPSS statistics 22 software.

Table 1: Root stocks and scion used in the study.

Sr. No.	Accession	Species and Characters	Source
a. Rootstocks			
1.	CH-1 (CRS-1)	*Capsicum annuum* dwarf statured plants with purplish leaves, bear erect dark purple fruits	Collected from North Eastern states of India
2.	CH-2 (CRS-2)	Local cultivar bear erect green fruits	
3.	CH-3 (CRS-3)	Vigorous growth habit belongs to *Capsicum frutescens*	
4.	CH-4 (CRS-4)	Local cultivar	
5.	CH-5 (CRS-5)	Local cultivar	
6.	CH-6 (CRS-6)	Vigorous growth habit belongs to *Capsicum frutescens*	
7.	CH-7 (CRS-7)	Plants with purplish leaves, bear erect tiny dark purple	
8.	CH-8 (CRS-8)	Vigorous growth habit	
9.	CH-9 (CRS-9)	Naga chilli (*Capsicum chinense*)	
10.	CH-10 (CRS-10)	Vigorous growth habit belongs to *Capsicum frutescens*	
11.	CH-11 (CRS-11)	Dark green fruits turn dark red on ripening, 5-6 cm in length.	
12.	Hosanagara small (CRS-12)	Vigorous growth habit belongs to *Capsicum frutescens*	Collected from (Hosanagara)
13.	Hosanagara medium (CRS-13)	Vigorous growth habit belongs to *Capsicum frutescens*	
14.	Hosanagara white (CRS-14)	Vigorous growth habit belongs to *Capsicum frutescens*	
15.	Hosanagara black round (CRS-15)	Local cultivar with vigorous growth habit with purplish leaves, bear erect tiny dark purple round fruits turns to red after ripening.	
16.	Kashi Anmol (CRS-16)	Improved population derived from two cycles of simple recurrent selection from a Sri Lankan introduction	IIVR, Varanasi
17.	Kashi Ratna (CRS-17)	CMS based F1 suitable for green chilly purpose tolerant to anthracnose and thrips	IIVR, Varanasi
18.	Kashi Abha (CRS-18)	Tolerant to biotic (anthracnose, CLCV, thrips and mites) and abiotic stress (low and high temperature)	IIVR, Varanasi
19.	Solan Bharpur (CRS-19)	Phytophthora tolerant bell pepper variety	College of Horticulture Nauni, Solan (HP), INDIA
20.	DKC 8 (CRS-20)	Improved chilli variety	College of Horticulture Nauni, Solan (HP), INDIA
21.	Sirsi big (CRS-21)	Vigorous growth habit belongs to *Capsicum frutescens*	Local collection of Sirsi
22.	Sirsi small (CRS-22)	Vigorous growth habit belongs to *Capsicum frutescens*	
23.	Bedrock RZ F1 (CRS-23)	Hybrid pepper rootstock with intermediate resistance to nematodes and phytophthora	Rijk Zwaan India Seeds Pvt. Ltd
24.	VNR-Garcia (CRS-24)	Hybrid pepper rootstock tolerant to bacterial wilt, phytopthora and nematodes	VNR Nursery Pvt. Ltd.
25.	Ujjwala (CRS-25)	Resistant to bacterial wilt, mosaic virus and leaf roller attack.	Kerala agricultural university, Trissur.
b. Scion			
1.	Massilia RZ F1 (MS)	Strong and relatively tall plant with a good fruit setting. Large sized deep shiny red blocky fruits with long shelf life. Suitable for green harvest also. Tolerant to nematodes	Rijk Zwaan India Seeds Pvt. Ltd

RESULTS AND DISCUSSION

Seed germination and seedling growth parameters of rootstocks and scion. The choice of appropriate and commercially viable rootstock and scion cultivars is an essential stage in the successful production of grafted vegetables. The rootstocks are chosen based on seed purity, seed viability, tolerance to biotic and abiotic stress, and compatibility with the scion cultivar, whereas the scion cultivar is chosen based on yield, fruit quality and market demand (Bie *et al*., 2017).

Significant differences were observed in the days taken for seed germination (Table 2). Notably, among the various rootstock seeds, CRS-23 and the bell pepper hybrid MS exhibited significantly quicker germination. CRS-23 and MS are hybrid rootstocks, which are generally the result of crossing two genetically distinct parent plants. which indicated the seed vigour manifested by heterosis.

Conversely, the rootstock seedlings of CRS-14 displayed a significantly prolonged germination period. CRS-14 is a bird's eye chilli (*Capsicum frutescens*) rootstock. The bird's eye pepper is known for its higher pungency. The pungency of bird's eye pepper is governed by its capsaicin content. Seeds with greater amounts of capsaicin were found to have thicker seed coats, which can lead to slower imbibition of water into the seed and delay germination in wild-type *Capsicum* species (Bernau *et al*., 2020). Dutta *et al*. (2015) reported that bird's eye chilli (*Capsicum frutescens* L.) seeds from the eastern Himalayan region of India had a mean germination time ranging from 13.53 days to 21.63 days. Over all the days taken for seed germination were found similar to the findings reported by Gisbert *et al*. (2011); Haque *et al*. (2016); Yuvraj (2023); Jang *et al*. (2011); Verdugo *et al*. (2001); Yamamoto and Nawata (2006).

The bell pepper scion MS, exhibited the shortest period to reach the grafting stage. In contrast, CRS-12, CRS-13, CRS-14, CRS-21, and CRS-22 required a significantly longer duration to reach this stage. Similar observations were noted by Phukon *et al*. (2020). It is worth noting that during this stage, the seedlings experienced severe winter conditions, which may have contributed to their slow growth rate. The accessions belonging to *Capsicum frutescens i.e*. CRS-12, CRS-13, CRS-14, CRS-21, and CRS-22 are known to be sensitive to temperature fluctuations. Exposure to temperatures outside their optimal range can result in slow growth, with high temperatures inhibiting seed germination and cold temperatures slowing down seedling growth (Deli and Tiessen 1969). Delayed germination and slow growth rate may be characteristic features of these seedlings. Additionally, these seedlings may have higher nutrient requirements, which may not have been adequately met, further contributing to their slow growth rate. Conversely, the bell pepper MS, exhibited early germination and rapid seedling growth, requiring fewer days to reach the graftable stage, possibly due to hybrid vigour. Similar findings have been reported by Yuvraj (2023).

Stem girth is an important factor in grafting experiments because it can affect the success of the graft union and overall plant growth. A thicker scion stem generally provides a larger vascular connection area, which can enhance the flow of water, nutrients and photosynthates between the scion and rootstock. This improved vascular connection promotes better graft compatibility and can lead to higher graft survival rates and overall plant health (Smith and Beres 2005). The highest stem girth was recorded in CRS-19 and CRS-13 rootstock seedlings, on par measurements noted in CRS-9, CRS-8, CRS-7, CRS-18, CRS-25, CRS-26, CRS-15, CRS-21 CRS-13 and CRS-14 rootstock seedlings. In contrast, the hybrid scion seedlings of MS displayed a slightly smaller stem girth at the grafting stage. Different plant varieties and hybrids may exhibit varying stem growth and girth. The genetic makeup of the hybrid scion MS may naturally result in a slightly smaller stem girth compared to certain rootstock varieties like CRS-19 and CRS-13. These findings are in line with the study conducted by Camposeco *et al*. (2018); Albornoz *et al*. (2020).

The highest number of leaves was recorded in CRS-6 rootstock seedlings closely followed by CRS-9. Conversely, the lowest number of leaves were observed in CRS-12, CRS-23 and CRS-13. The CRS-6 and CRS-9 rootstocks may have faster growth rates during the seedling stage, allowing them to produce more leaves by the time they reach the grafting stage. In contrast, rootstocks like CRS-12, CRS-23 and CRS-13 had fewer leaves due to their slower growth rate.

This variation can be attributed to several factors. Certain rootstock varieties may naturally exhibit faster growth rates during the seedling stage, allowing them to reach a taller height by the time of grafting. Factors such as efficient nutrient absorption and hormonal balance can influence these growth rates. In this experiment, the hybrid scion used for grafting was sown later than the rootstocks. Consequently, these scion seedlings experienced faster growth and reached the optimal stem girth required for grafting at an earlier stage compared to the other rootstocks. This earlier readiness for grafting led to the measurement of shorter plant height in the hybrid bell pepper at the grafting stage.

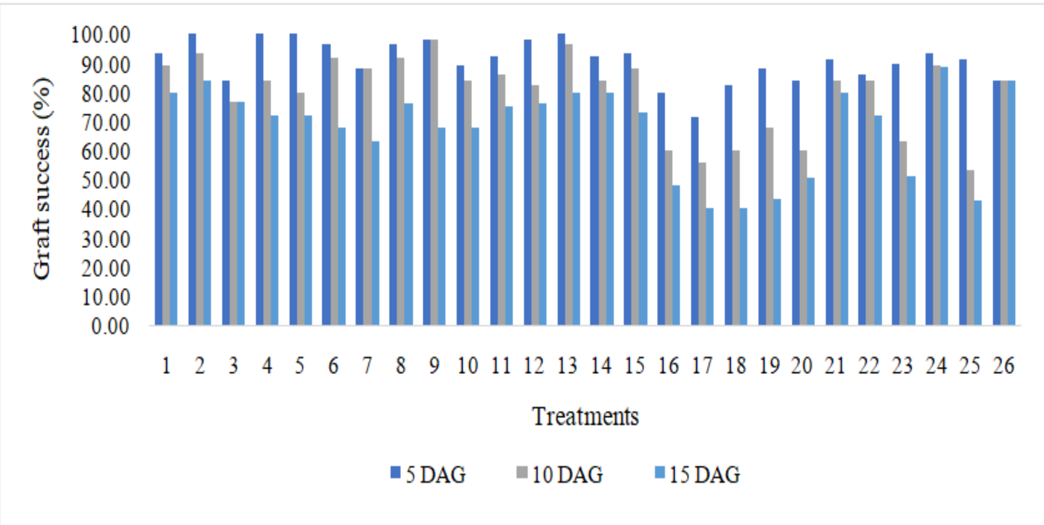
Graft success at different intervals of healing. The highest graft success (Fig. 1) was observed in graft combinations of MS with CRS-1, CRS-2, CRS-6, CRS-8, CRS-11, CRS-12, CRS-13, CRS-14, CRS-15, and CRS-21 at both 5 and 15 days intervals, it can be attributed to their favourable genetic traits and compatibility with the bell pepper scion MS. These rootstocks likely possess characteristics that promote efficient graft union formation and scion-rootstock interaction, resulting in higher graft success percentage. Similar graft success per cent were noted by Hamdi *et al*. (2010); Jang *et al*. (2011); Soltan *et al*. (2017); Naik *et al*. (2020); Phukon *et al*. (2020). Conversely, rootstocks like CRS-16, CRS-17, CRS-18, CRS-19 and CRS-25 recorded lower graft success it may be due to lack of callus formation (Lee, 2006), limited hydraulic conductance (Oda *et al*., 2005) and certain genetic attributes leading to incompatibility with the scion. The stable performance of the self-grafted MS combination (84 %) at both time points can be attributed to the genetic uniformity of the scion and rootstock in this combination, which contributed to more graft success.

The initiation of graft union formation typically begins around 5 days after grafting. In highly compatible combinations, this process is characterized by the production of callus tissue at the graft site during the initial days (5 days after grafting). However, the determination of a successful graft combination may require a longer observation period, typically around 15 days after grafting. This extended period allows for a more accurate assessment of graft success. This difference in observation at 5 and 15 days after grafting can indeed contribute to variations in graft success percentages among seedlings. In some cases, the initial signs of callus formation may be promising at 5 days, but the ultimate success or failure of the graft may become more evident by the 15 days after grafting.

Table 2: Seed germination and seedling growth parameters of *Capsicum* spp. used as root stock and scion.

Treatments	Days taken for seed germination	Days taken to reach grafting	Stem girth at the stage of grafting (mm)	Number of leaves at the stage of grafting	Plant height at the stage of grafting (cm)
T_{1}:CRS-1	12.20^{e}	47.40^{cde}	2.81^{i}	7.10^{fg}	18.20^{c-f}
T_{2}:CRS-2	12.30^{e}	47.30^{cd}	2.82^{hi}	7.40^{c-g}	18.90^{ab}
T_{3}:CRS-3	11.30^{cd}	47.60^{cde}	2.90^{e-i}	7.30^{d-g}	17.85^{e-h}
T_{4}:CRS-4	12.00^{de}	47.40^{cde}	2.91^{e-i}	7.40^{c-g}	17.95^{d-g}
T_{5}:CRS-5	12.20^{e}	47.40^{cde}	2.89^{e-i}	8.00^{bc}	17.35^{ij}
T_{6}:CRS-6	11.80^{de}	47.40^{cde}	2.93^{c-g}	8.70^{a}	19.10^{a}
T_{7}:CRS-7	11.80^{de}	48.20^{de}	2.95^{a-e}	7.90^{bcd}	18.40^{cd}
T_{8}:CRS-8	11.50^{cd}	48.10^{de}	2.94^{b-e}	7.60^{b-f}	17.85^{e-h}
T_{9}:CRS-9	11.40^{cd}	47.70^{cde}	2.94^{a-e}	8.10^{b}	17.50^{g-j}
T_{10}:CRS-10	11.50^{cd}	48.20^{de}	2.90^{e-i}	7.90^{bcd}	18.10^{def}
T_{11}:CRS-11	11.30^{cd}	47.80^{de}	2.90^{e-i}	7.30^{d-g}	18.30^{cde}
T_{12}:CRS-12	14.20^{f}	52.20^{f}	2.87^{f-i}	6.90^{g}	16.05^{m}
T_{13}:CRS-13	14.40^{f}	53.30^{f}	3.02^{abc}	6.80^{g}	16.40^{lm}
T_{14}:CRS-14	15.20^{g}	53.20^{f}	3.02^{abc}	7.20^{efg}	16.40^{lm}
T_{15}:CRS-15	12.00^{de}	48.60^{de}	2.99^{a-e}	8.00^{bc}	17.90^{efg}
T_{16}:CRS-16	10.40^{b}	47.60^{cde}	2.86^{f-i}	7.90^{bcd}	17.05^{jk}
T_{17}:CRS-17	11.00^{bc}	48.60^{de}	2.93^{c-g}	7.90^{bcd}	17.35^{ij}
T_{18}:CRS-18	10.80^{bc}	47.40^{cde}	2.95^{a-e}	7.80^{b-e}	17.40^{hij}
T_{19}:CRS-19	11.00^{bc}	47.40^{cde}	3.03^{a}	7.60^{b-f}	17.80^{f-i}
T_{20}:CRS-20	11.30^{cd}	48.40^{de}	2.87^{f-i}	7.90^{bcd}	18.55^{bc}
T_{21}:CRS-21	14.20^{f}	52.70^{f}	3.01^{a-d}	7.10^{fg}	17.10^{kl}
T_{22}:CRS-22	14.30^{f}	52.90^{f}	2.92^{d-h}	7.00^{fg}	16.65^{kl}
T_{23}:CRS-23	8.50^{a}	46.40^{bc}	3.03^{ab}	6.90^{g}	17.80^{f-i}
T_{24}:CRS-24	11.30^{cd}	48.10^{de}	2.84^{ghi}	7.80^{b-e}	18.00^{def}
T_{25}:CRS-25	11.50^{cd}	48.70^{e}	2.95^{a-e}	7.00^{fg}	18.60^{bc}
T_{26}:RootstockMS	8.50^{a}	45.60^{b}	2.95^{a-e}	7.40^{c-g}	15.30^{n}
T_{27}:ScionMS	8.90^{a}	44.10^{a}	2.93^{c-g}	7.30^{d-g}	14.20^{o}
SEm±	0.21	0.39	0.03	0.19	0.14
CD	0.60**	1.13**	0.09**	0.55**	0.40**
CV	2.50	1.14	1.42	3.58	1.13

**(p<0.01), Different letters reveal significant differences according to Duncan's test p=0.05.



DAG: Days after grafting

Fig. 1. Graft success percent of bell pepper scion (MS) grafted on different *Capsicum* spp. root stocks at different intervals of graft healing.

Grafted seedlings growth at 15 days after grafting. Significantly higher scion girth was recorded in non-grafted MS, on par observations noted in MS grafted on CRS-5, CRS-7, CRS-8, CRS-9, CRS-13, CRS-14, CRS-21, CRS-23 and grafted on itself (Table 3). The high compatibility of these rootstocks with the scion, may have resulted in significant increase in scion girth at 15 days after grafting, suggests that the grafting process likely did not induce stress on the scion. Instead, it appears to have had a positive effect on scion growth. Contrarily, lower scion girth was observed in MS grafted on CRS-12. It could be due to differences in the compatibility and physiological interactions between the scion and the rootstock.

The bell pepper scion MS grafted on CRS-14 exhibited a significantly highest rootstock girth, on par observations noted in self-grafted MS, MS grafted on CRS-1, CRS-2, CRS-3, CRS-7, CRS-8, CRS-11 and CRS-12. Similarly, the self-grafted MS and MS grafted on CRS-1, CRS-2, CRS-3, CRS-7, CRS-8, CRS-11, and CRS-12 also exhibited comparable girth measurements, indicating compatibility and synergic interactions between the scion and these rootstocks. Conversely, the lower girth measurements observed in the graft combinations of MS with CRS-16 and CRS-17 could be due to difference in compatibility, physiological constraints between the scion and thin stem characteristics of the seedlings.

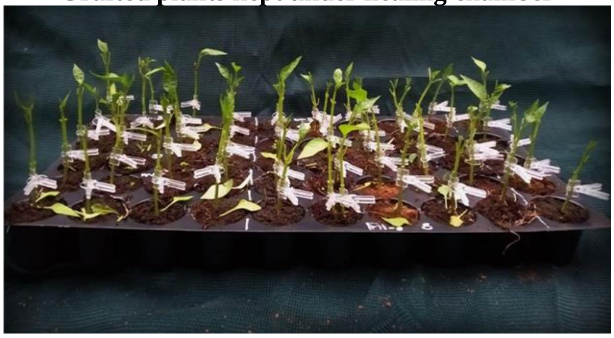
The significant differences in graft union girth were observed among the bell pepper scion MS grafted on various rootstocks, it can be attributed to the stem girth characteristics of the grafting partners. In the case of MS grafted on CRS-14, exhibited a significantly larger graft union girth, it is likely that both the scion and rootstock had higher stem girth characteristics. This compatibility in stem girth may have contributed to the successful graft union development by the formation of callus resulting larger graft union girth. Conversely, the significantly less graft union girth were observed in the graft combinations of MS with CRS-16, CRS-17 and CRS-18, it may be due to the smaller stem girth of these rootstocks. These rootstocks may inherently possess thinner stems, leading to the development of thinner plants and subsequently smaller graft unions.

Table 3: Girth of scion, root stock and graft union of bell pepper scion (MS) grafted on different *Capsicum* spp. root stocks at 15 days after grafting.

Treatments	Scion girth (mm)	Root stock girth (mm)	Graft union girth (mm)
T_{1}: MSonCRS-1	2.99^{cde}	3.28^{abc}	3.47^{b-f}
T_{2}: MSonCRS-2	3.03^{b-e}	3.19^{a-h}	3.44^{b-f}
T_{3}: MSonCRS-3	2.98^{cde}	3.08^{b-i}	3.36^{d-h}
T_{4}: MSonCRS-4	2.96^{cde}	2.98^{f-i}	3.29^{e-h}
T_{5}: MSonCRS-5	3.10^{a-d}	3.03^{c-i}	3.40^{c-h}
T_{6}: MSonCRS-6	2.95^{de}	3.01^{d-i}	3.30^{e-h}
T_{7}: MSonCRS-7	3.12^{a-d}	3.17^{a-h}	3.48^{b-e}
T_{8}: MSonCRS-8	3.12^{a-d}	3.21^{a-g}	3.51^{bcd}
T_{9}: MSonCRS-9	3.06^{a-e}	3.03^{c-i}	3.37^{c-h}
T_{10}: MSonCRS-10	2.92^{de}	3.05^{c-i}	3.30^{e-h}
T_{11}: MSonCRS-11	2.93^{de}	3.26^{a-d}	3.43^{b-g}
T_{12}: MSonCRS-12	2.86^{e}	3.16^{a-h}	3.34^{d-h}
T_{13}: MSonCRS-13	3.18^{abc}	3.22^{a-f}	3.55^{abc}
T_{14}: MSonCRS-14	3.24^{ab}	3.42^{a}	3.68^{a}
T_{15}: MSonCRS-15	2.97^{cde}	3.04^{c-i}	3.33^{d-h}
T_{16}: MSonCRS-16	2.93^{de}	2.89^{i}	3.23^{h}
T_{17}: MSonCRS-17	2.94^{de}	2.90^{i}	3.23^{h}
T_{18}: MSonCRS-18	2.92^{de}	2.92^{hi}	3.24^{h}
T_{19}: MSonCRS-19	2.97^{cde}	3.03^{c-i}	3.32^{d-h}
T_{20}: MSonCRS-20	2.97^{cde}	2.96^{f-i}	3.29^{e-h}
T_{21}: MSonCRS-21	3.07^{a-e}	3.05^{c-i}	3.39^{c-h}
T_{22}: MSonCRS-22	2.99^{cde}	2.94^{hi}	3.28^{fgh}
T_{23}: MSonCRS-23	3.11^{a-d}	3.12^{b-i}	3.45^{b-f}
T_{24}: MSonCRS-24	2.99^{cde}	2.96^{ghi}	3.30^{e-h}
T_{25}: MSonCRS-25	3.02^{b-e}	2.99^{e-i}	3.33^{d-h}
T_{26}: Self-graftedMS	3.14^{a-d}	3.34^{ab}	3.59^{ab}
T_{27}: Non-graftedMS	3.25^{a}	3.25^{a-e}	3.25^{gh}
SEm±	0.06	0.08	0.05
CD	0.19*	0.22**	0.16**
CV	3.01	3.53	2.29

*(p<0.05),**(p<0.01). Different letters reveal significant differences according to Duncan's test p=0.05.

Grafted plants kept under healing chamber



New leaf emergence in successful grafts

Seedling growth observations

CONCLUSIONS

In summary, this experiment suggests that the choice of rootstock and grafting combination can significantly influence the success of the grafting process, as well as the subsequent growth and development of the grafted seedlings. It appears that CRS-23 and MS are promising rootstock and scion options for quick germination and grafting. Additionally, the combination of MS with various rootstocks, such as CRS-1, CRS-2, and others, results in high graft success percentages, which is crucial for successful grafting. The selection of the appropriate rootstock is also essential for achieving desirable girth measurements in grafted seedlings.

Authors contribution. S.A.T.S.N., S.H. and C.N.H. developed the plan; S.A.T.S.N., S.H. and C.N.H. conducted the greenhouse and laboratory experiments, and wrote the initial draft of the research paper; G.M., M.K.S., S.M. helped in the laboratory analysis and data interpretation; S.A.T.S.N. and S.H. improved data presentation in tables, graphs, texts significantly and critically revised and improved the manuscript. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest. None.

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