Journal of
Agriculture and Biology
ISSN: 3007-1755 (Print), 3007-1763 (Online)

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Research Article

Comparative Evaluation of Self and Cross-Grafting Combinations in Tomato Plants

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ABSTRACT

Tomato production encounters various challenges due to a range of abiotic and biotic stresses. The increased consumption demand of tomato in terms of quality and production needs better strategies to alleviate the effects of different climatic stresses. These stresses can be mitigated by grafting which is an innovative technique in tomato. The present study highlights the effects of tomato grafting by using various scion-rootstock combinations on tomato growth and yield. Three tomato cultivars viz. Roma, Bush beefsteak, and Bushel Boy) were self and cross grafted via cleft grafting method in Completely Randomized Design with three replications. The highest grafting success was observed in cross grafted combination of Bush beefsteak on the Bushel Boy as well as on Roma rootstocks. The taller plants with earlier flowering and fruiting were noticed from the non-grafted plants in comparison to the plants that were grafted. However, maximum fruits per plant were observed from grafted combinations where scion or rootstock of the Bushel Boy was grafted with Bush Beefsteak. Maximum fruit diameter, weight of fruit and yield of fruit per plant was also observed from same grafted combination of Bush Beefsteak grafted on the rootstock of Bushel Boy. It is concluded that scion-rootstock combinations had significant effects on yield related parameters of Tomato. Bush Beefsteak and Bushel Boy proved to have best scion-rootstock combination. Non-grafted plants had earlier flowering and fruiting while grafted plants produced maximum fruits as well as yield per plant in comparison to self and without grafting plants. The Bush Beefsteak and Bushel Boy outperformed.

Keywords: Growth, scion-rootstock combinations, tomato production, vegetable grafting.

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Article History
Received: December 12, 2024
Accepted: March 04, 2025
Published: March 29, 2025

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is the most demanding vegetable crop highly grown across the globe. It holds significant commercial importance worldwide, serving both the fresh fruit market and processed food industries. It is usually considered as a rich source for vitamins A and C, mineral nutrients such as sodium, potassium and iron, sugars, amino acids, dietary fibers and lycopene (Miller et al., 2002; Afzal et al., 2013). Along with their health benefits, tomato cultivation paves way for better economy, providing livelihoods for farmers, suppliers, and traders involved in the tomato supply chain (Goka et al., 2021).

The global production of vegetables is on the rise, driven by population growth, improving living standards, and government health agencies promoting vegetable consumption leading to expanded vegetable cultivation (Wills et al., 2007). Tomatoes are known to be the third most popular vegetable globally and are the most widely produced vegetable crop after potatoes and onions (Babalola et al., 2010; Gowda et al., 2015). China is the top producer of tomato followed by India and Turkey. Pakistan is still far behind in average yield and production securing a 36th position at the world level.

Number of factors are responsible for this low production but the prime cause of hindered production is the inadequate seed quality and limited understanding of varieties because seeds are a basic requirement for getting successful crop production and consistent, high-quality yields (Poštić et al., 2019), but it requires specialized knowledge to produce seeds, which leads the growers to purchase seeds from unverified sources. Even though the hybrid seeds are present yet tomato cultivation suffers because they require thorough care (Imam et al., 2023). Tomato production faces various challenges from a range of abiotic and biotic stresses such as drought, salinity, extreme temperatures, cold, nutrient deficiencies pose challenges, pests, fungal and bacterial infections, nematodes, and viral diseases (Li et al., 2023). Tomato seedlings are prone to be affected by biotic factors, especially the seedlings commonly succumb to damping off, while adult plants face damage from wilt and leaf miner diseases (Jiskani et al., 2007). Traditional methods have proven insufficient to meet growing demands, prompting the adoption of innovative approaches such as grafting which surfaced as a promising tool to rapidly improve performance of high production varieties to enhance adjustability and resilience against various stresses (Kumar et al., 2017). Further the grafting is distributed as self-grafting when the scions and rootstocks are seedlings from the same species, or as cross-grafting when the scion and rootstock are seedlings from different species (Bantis, 2021). Number of vegetables can be grafted but the Cucurbits and solanaceous crops are highly grafted vegetables across the globe (Schwarz et al., 2010) among these vegetables indirect type grafting has been shown to be an effective management technique, especially in Pumpkin plants (Louws et al., 2010). Around 30% of cucumber varieties are grafted onto the rootstock of pumpkin in order to address diseases borne from soil and enhance tolerance to abiotic stress, with growers employing heterografting techniques (Huang et al., 2014). Collectively, grafting commercial tomato cultivars onto carefully chosen rootstocks presents a promising approach as a rapid alternative to the time-consuming traditional breeding methods for enhancing tomato quality (Flores et al., 2010).

Along with different methods, it is essential to focus grafting techniques that vary among vegetable plants but there are three main grafting techniques used in tomato: splice grafting, slide grafting and cleft grafting (Soe, 2017). Commercially, tomato grafting is done through splice grafting technique and the majority of eggplant grafting operations (Oda, 2007; Rivard et al. 2010) but if the optimal environmental conditions are not provided for healing there would be low survival rate of splice grafting. Cleft grafting is also found successful in Tomato but it is labor intensive (Soe, 2017). However, choosing the most suitable grafting technique requires careful consideration of the rootstock, plant maturity, number of plants to be grafted, environmental conditions, and healing structures. This study is highly required to search for the grafting techniques utilizing advanced rootstock-scion cultivars to improve tomato development and production.

MATERIALS AND METHODS

This experiment took place in greenhouse at the University of Minnesota, USA, during 2017 to assess grafting for better tomato fruit development and yield. Seeds of three tomato cultivars viz. Roma, Bush beefsteak, and Bushel Boy were selected for the present study. Each cultivar was grafted as self or cross. Non-grafted plants of each cultivar were also maintained as check plants. The grafting combinations were set as follows.

Scion-rootstock Combinations

i. Roma on Bush Beefsteak
ii. Roma on Bushel Boy
iii. Roma on Roma
iv. Roma (non-grafted)
v. Bush Beefsteak on Bushel Boy
vi. Bush Beefsteak on Roma
vii. Bush Beefsteak on Bush Beefsteak
viii. Bush Beefsteak (non-grafted)
ix. Bushel Boy on Beefsteak
x. Bushel Boy on Roma
xi Bushel Boy on Bushel Boy
xii. Bushel Boy (non-grafted)

https://doi.org/10.55627/agribiol.003.01.1223

Seeds of each cultivar were sown in seedling trays (with capacity of 50 seedlings). Total 210 seeds were grown for each variety in growing medium contained peat moss and perlite**.** There were total 12 treatments; 3 for self, 6 for cross graft combinations and 3 for non-grafted of each cultivar. Data was observed on radicle emergence 2 mm (Mohammad et al 2014) after every two days interval until 20 days after sowing. Upon getting the diameter around 1.5 to 2.5 mm of seedlings and had 2-4 leaves (Bumgarner and Kleinhenz, 2015; Rivard and Louws, 2011) grafting on 30th June, 2017. The cleft grafting method was applied for the grafting of different combinations. In the method of cleft grafting, a 5mm horizontal cut below the cotyledon and a vertical insertion of 4mm were done on the rootstock, while the scion was prepared in wedge form and inserted into the vertical cut of the rootstock (Lee *et al*., 2010). Additionally, silicon grafting clips were utilized to cover the severed sections of both the rootstock-scion. Grafted seedlings underwent cleft in a wind-protected greenhouse for optimal conditions. Care included maintaining 24°C temperature and over 80% humidity. After two weeks, they were transferred to 3L pots with a soil-compost mix (1:1) in a greenhouse with temperatures ranging from 15°C to 32.6°C. Successful grafts were gradually acclimated to outdoor conditions for growth assessment and yield evaluation of tomato.

To shift the grafted seedlings in soil, land preparation involved plowing of the soil thoroughly to achieve a fine tilt through five plowings. Raised beds having width of 1.5 feet, were made, with a 0.5-1.0 meter irrigation channel between each bed. Transplantation of seedlings was done in the evening along the sides of the raised beds, spaced 0.5 meters apart. The data was recorded for seed germination, grafting success percentage, flowering and fruit related parameters. For seed germination, growth of the radical, initially measuring 02 mm, was monitored daily for 10 days after planting to assess germination. The percentage of seed germination was determined using the formula devised by Larsen and Andreasen (2004).

$$GP = (\sum n / N) \times 100$$

Where 'n' represents the seeds sprouted during each observation and 'N' denotes the total number of seeds in each treatment. The grafting success was also assessed by the same formula. Observations related to flowering and fruiting were conducted on randomly selected plants, comprising 50% of each treatment group. The time taken for flowering and fruit initiation from the time of planting was recorded. Additionally, the fruits per plant were determined by manual counting harvested fruits at full ripeness and calculating averages. Measurements including fruit length (cm) and for fruit diameter (cm) were made with digital vernier caliper, whereas fruit weight (g) was observed with electronic weighing balance. Yield per plant (kg) was measured by the weight of total harvested fruits from plant, expressed in kilograms. The collected data was manually organized according to treatments, and analysis of variance (ANOVA) was carried out using Statistix (2006) software. Following this, the Least Significant Difference Test (LSD) was applied at a 0.05 probability level to evaluate variances between treatment means.

RESULTS

Results showed that scion-rootstock combinations have a significant impact on the success rate of grafting percentage (Table 1). The success percentage observed in each scion-rootstock combination above than 75% and ranges from 76.83 to 90.50. Maximum sprouting percentage was observed from the graft having Bush Beefsteak scion grafted on the rootstock of Bushel Boy. These results are consistent with the results observed from the graft where same scion cultivar was grafted on the rootstock of Roma. Rest of the grafts have statistically similar results for grafting success.

The data in Table 2 showing significant effects of scion-rootstock combinations on height of plant, initiation of flower and fruit. On the basis of data, non-grafted plants of Bushel Boy produced plants with maximum height (137.50 cm). These results are at par with the result of the graft where Bushel Boy was self-grafted (129.83 cm). The tallest plants of non-grafted Bushel Boy also initiated earlier flowering (29.0 days) and fruiting (40.83 days) than rest of the combinations. Grafting significantly affected the results of fruit development and yield related parameters. The results in Table 3 indicates that fruit per plant were observed maximum from the graft combination where scion of Bushel Boy was grafted on the rootstock of Bush Beefsteak. However, these results are statistically similar with the results obtained from the graft combination having Bush Beefsteak scion grafted on the rootstock of Bushel Boy. Diameter and weight of fruit and fruit yield per plant was observed maximum from similar graft combination of Bush Beefsteak and Bushel Boy. Self-grafted Roma produced less number of fruits (19.33) and yield (1.47 kg) per plant and this is non-significant with non-grafted results of fruits and yield per plant (21.67; 1.52 kg).

Table 1. Effect of grafting methods and scion-rootstock combinations on the success of tomato grafts.

Scion - Rootstock Combinations	Grafting Success (%)
Roma on Bush beefsteak	80.00 cd
Roma on Bushel Boy	80.00 cd
Roma on Roma	76.83 d
Bush beefsteak on Bushel Boy	90.50 a
Bush beefsteak on Roma	85.83 ab
Bush beefsteak on Bush beefsteak	82.17 bcd
Bushel boy on Bush beefsteak	81.67 bcd
Bushel boy on Roma	80.83 bcd
Bushel boy on Bushel boy	85.00 bc
Means	

Table 2. Effect of C on plant height, flower and fruit initiation of tomato grafts.

Scion-Rootstock Combinations	Plant Height (cm)	Flower Initiation (days)	Days to Fruiting
Roma on Bush beefsteak	117.50 CD	35.17 BCDE	50.00 AB
Roma on Bushel Boy	115.17 CD	36.17 ABCD	47.33 ABCD
Roma on Roma	109.67 DE	38.17 ABC	49.00 AB
Roma (Non-grafted)	100.67 EF	34.17 DE	44.17 CDEF
Bush beefsteak on Bushel Boy	113.17 D	38.17 ABC	50.67 A
Bush beefsteak on Roma	97.83 F	39.00 A	47.67 ABC
Bush beefsteak on Bush beefsteak	112.83 D	38.83 AB	44.83 CDE
Bush beefsteak (Non-grafted)	114.50 CD	31.67 EF	43.83 DEF
Bushel boy on Bush beefsteak	124.83 BC	33.67 DE	43.33 EF
Bushel boy on Roma	118.33 CD	34.50 CDE	46.83 BCDE
Bushel boy on Bushel boy	129.83 AB	32.17 EF	49.50 AB
Bushel boy (Non-grafted)	137.50 A	29.00 F	40.83 F

Table 3. Effect of scion-rootstock combinations on fruit yield traits of tomato.

Scion-Rootstock Combinations	Fruits Per Plant	Fruit Length (cm)	Fruit Diameter(cm)	Fruit Weight (g)	Fruit Yield Per Plant (kg)
Roma on Bush beefsteak	30.17 BCD	7.17 A	5.67CDE	101.50 BC	3.08 CD
Roma on Bushel Boy	29.33 CD	6.65 B	4.92 FG	89.33 CD	2.63 DE
Roma on Roma	19.33 G	6.47 B	5.97 FG	76.50 EF	1.47 F
Roma (Non-grafted)	21.67 FG	5.63 CD	4.83 G	68.83 F	1.52 F
Bush beefsteak on Bushel Boy	35.17 AB	5.92 C	6.72 A	135.83 A	4.77 A
Bush beefsteak on Roma	24.11 EFG	5.25 DE	6.07 BC	104.56 B	2.48 DE
Bush beefsteak on Bush beefsteak	26.00 DEF	5.93 C	6.82 A	128.17 A	3.34 C
Bush beefsteak (Non-grafted)	33.17 BC	5.60 CD	6.32 AB	132.33 A	3.67 BC
Bushel boy on Bush beefsteak	40.17 A	5.40 DE	5.38 DEF	102.17 B	4.11 B
Bushel boy on Roma	23.89 EFG	5.36 DE	5.82 BCD	97.96 BC	2.34 E
Bushel boy on Bushel boy	26.83 DE	5.17 E	5.85 BCD	84.33 DE	2.27 E
Bushel boy (Non-grafted)	27.83 DE	5.08 E	5.12 FG	81.00 DEF	2.67 DE

DISCUSSION

Tomato grafting was initially introduced to mitigate the effects of Fusarium wilt (Khah et al., 2006). However, the applications of grafting have expanded significantly over time. For instance, grafts have been employed to confer resistance to extreme temperatures, both low and high (López-Marín et al., 2013; Fu et al., 2021), to enhance nutrient absorption, to stimulate endogenous hormones (Flores et al., 2010), to improve water-use efficiency (Cohen and Naor, 2002) and to enhance vegetable resistance to stresses caused by environmental issues such as drought, salinity, and flooding (Bhatt et al., 2015; Kumar et al., 2015).

Grafting success is the fundamental parameter for evaluating successful grafting. It is influenced by factors including seedling performance during the process of grafting, scion-rootstock compatibility (Bumgarner and Kleinhenz, 2015). In this study, different grafting success was attained from each scion-rootstock combination and each combination showed more than 70-90% grafting success. These results allign with the results of Mahbou et al. (2022), who observed grafting success rates between 90 and 100% by using cleft grafting method in tomato. The highest success rate was observed through cross-grafting Bush beefsteak onto Bushel Boy rootstock. Self-grafted combinations also showed favorable results. Similar findings were seen in the study of Bharathi et al. (2020) who observed higher grafting success rates from 88.76 to 86.77% by grafting Shivam onto *Solanum sisymbrifolium.* Dhivya (2014) also observed 90.67 grafting success when tomato plants were grafted with rootstock *Solanum torvum* 15 days' post grafting. This cross grafting success may be due to the cell division occurring at the graft union between the scion-rootstock, followed by the establishment of vascular connections (Tamilselvi and Pugalendhi, 2017), this successful union helps in better plant establishment which makes the plant highly resistant to abiotic and biotic stresses, subsequently justifying cross grafting (Nordey et al., 2020).

The significant differences in plant height between grafted and non-grafted plants are primarily due to grafting process. Non-grafted plants had the highest plant height as compared to the grafted ones. Contradictory results were observed by Khah et al*.* (2006) their study reported significant differences between non-grafted and grafted plants of tomato varieties under open field conditions. The grafted combination of Big Red and Heman produced taller plants of 75 cm. Grafted plant took maximum days compared to non-grafted. The shock or stress caused by the grafting wound at the time of rootstock and scion union could be the reason of delay in flower initiation. Delayed flowering and fruiting is a common phenomenon caused by grafting of the scion. Khah et al*.* (2006) reported that once the graft union is successfully established, nutrient flow resumes, and physiological processes begin, leading to a delay in flowering compared to the normal flowering of these cultivars. Similarly, Ibrahim et al*.* (2001) reported that grafted plants took more days to flower than non-grafted plants.

The yield of tomato is mainly based on the fruits number, size and weight. In the current study fruits' number, diameter, weight and yield varied with the scion and rootstock combinations. Bush beefsteak as scion or rootstock proved better results with Bushel Boy. This increase in fruits count, weight and yield in grafted plants attributed to the influence of a vigorous rootstock. Kacjan Marsic and Osvald (2004) observed higher fruit count per plant in the grafted plants than to the non-grafted ones. This increase in yield is because of the grafting (Gisbert et al*.*, 2011). The increase in yield of grafted tomato is mainly due to maximum fruit biomass and more fruit count per plant than nongrafted plants. Bharthi et al. (2020) observed that cross grafted plants exhibited improved yield, with a similar enhancement in tomato plants. This increase might be due to the enhanced vigor of the scion, achieved through grafting with a robust and effective rootstock. (Milenković et al., 2020).

CONCLUSIONS

Non-grafted plants had earlier flowering and fruiting while grafted plants produced maximum number of fruits plant^{-1} and yield as compared to self and non-grafted plants. The maximum yield was recorded from scion-rootstock combination of Bush beefsteak on Bushel boy rootstock.

ACKNOWLEDGEMENTS

The author extends sincere gratitude and recognizes the invaluable contributions of the entire team of researchers for their steadfast support and technical guidance throughout the study.

AUTHOR CONTRIBUTIONS

All the authors contributed equally to this research.

COMPETING OF INTEREST

No conflicts of interest have been disclosed by the authors.

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