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MAXIMIZING SEED YIELD AND ECONOMICS THROUGH STEM-TRAINING INTERVENTIONS IN INDETERMINATE TOMATO

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Abstract

The study was carried out under open-field conditions to explore the impact of stem training on indeterminate tomato cultivar (Solan Lalima) during 2023 and 2024. The treatment comprised of three levels of training system (i.e., two, four and no stem. The results revealed that a two-stem training system improved the phenological traits, *viz*., plant height, number of flowers and fruits/cluster, enhanced fruit setting by 35% coupled with a faster progression to the red-ripe stage. Likewise, it displayed a profound effect on enhancing the seed yield contributing attributes such as fruit count/plant, fruit weight, fruit yield and seed number/fruit. Adoption of a two-stem training system increased the seed yield (kg/ha) by 7.69% with a benefit-cost ratio of 1 : 2.19 as against only 1 : 1.86 in untrained plants. It could be suggested that commercial seed production of indeterminate tomato could be improved by the two-stem training under open-field conditions.

Introduction

Plant architecture plays a crucial role in crop productivity due to its direct effect on flower, fruit, and seed production. By affecting light absorption, air flow, nutrient distribution, altering the relative growth and spatial arrangement of vegetative and reproductive organs within the plant canopy, plant architecture ultimately influences yield and quality (Tieman *et al*. 2017, Zhu *et al*. 2018). In tomato (*Solanum lycopersicum* L.), traits related to plant architecture include growth habit, flowering time, lateral branching, stem and leaf development, plant height, and inflorescence structure (Du *et al*. 2025). Tomato displays three distinct growth habits: determinate (or self-pruning), indeterminate, and semi-determinate (Vicente *et al*. 2015). Growth habit is predominantly controlled by allelic variation in the recessive self-pruning (sp.) locus, which is also part of the gene SINGLE FLOWER TRUSS (SFT) (Schwarz *et al*. 2014, Finzi *et al*. 2017). Alternation between vegetative and reproductive phases presents themselves as modular units (called sympodia) and is responsible for shoot determinacy in tomato (Jiang *et al*. 2025). In indeterminate genotypes, after a series of 6-12 internodes with leaves, the vegetative apical meristem transforms into floral (Samach and Lotan 2007). However, vegetative growth persists through the uppermost axillary meristem, which laterally displace the inflorescence and initiate a new sympodium with three leaves and an inflorescence (Lifschitz and Eshed 2006). This pattern continues repeatedly, generating multiple sympodial units that results in a higher number of flower clusters. Indeterminate tomato cultivars are favoured in the fresh market for their sustained vegetative growth along with continuous flower and fruit development. Generally, lateral shoots/suckers of indeterminate tomato cultivars need to be removed before elongation to minimise competition between vegetative and reproductive organs and for diverting photosynthates towards the main-stem inflorescences. If lateral shots are not pruned off, uneven distribution of photosynthates and vital resources occurs, negatively affecting fruit production and quality (Ohta and Ikeda 2015). Acknowledging the crucial role of sucker management in an indeterminate tomato variety, stem training was adopted. The number of stems allowed to grow as leaders during plant growth is known as stem training. Franco *et al*. (2009) stated that adoption of

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proper training and pruning techniques creates balance in source-sink relationship and carbon-nitrogen (C/N) ratio, that enhance capacity to bear a heavy crop load. Several studies also affirm that pruning excessive foliage in tomato benefits fruit productivity, seed yield, and quality by influencing the light utilization pattern as well as source-sink balance (Kumar *et al.* 2014, Nipa *et al.* 2020). Moreover, well-trained plants ensure adequate air circulation within the canopy, allowing the leaves to dry faster and thereby reducing the risk of pests and diseases. Henceforth, a standard training system needs to be established for achieving its full potential. Thus, the study aims to identify the best training system for maximising the seed yield and economic returns in an indeterminate tomato cultivar.

Materials and Methods

The study was carried out under open field conditions at Dr. Y. S. Parmar University of Horticulture and Forestry during the summer months of 2023 and 2024. Seeds of indeterminate tomato cv. Solan Lalima were sown in nursery and seedlings at 4-5 leaf stage were transplanted at a spacing of 90 × 30 cm. The experiment was arranged as a randomized complete block design consisting of stem training methods at three levels. These were the two-stem (T1), four-stem (T2) and no-training (T3: control) and they were replicated thrice, with each replication consisting of twelve plants. Two-stem training method was achieved by retention of the first two stems (or branches) that appear. These two stems were then trained to grow upward and the rest of the side shoots are customarily removed on a regular basis to maintain only these two primary stems to bear fruits for seed production. On the other hand, in Four-stem training, first 4 stems were selected to grow and bear fruit for seed production. All other side shoots or branches that emerge from the plant are pruned regularly. The No-stem method was achieved by allowing it to grow naturally following its inherent growth patterns without any training (Fig. 1). The retained stems were supported with plastic wires and tied to a support structure to ensure upright growth and prevent toppling. The data obtained for different characteristics were statistically analysed to find out the statistical significance using KAU-GRAPES version 1.10.

Fig. 1. Different training strategy adopted in the study: Two-stem training, four stem training and No-stem training.

Results and Discussions

Data on the phenological parameters of tomato (cv. Solan Lalima) under the effect of training systems are presented in Table 1. Stem training exhibited significant variations in plant height, with two stemmed plants were tallest, and the shortest plants were from untrained plots. Continuous pruning of emerging axillary shoots might have shifted the partitioning of photo assimilates towards apical tissues instead of multiple stems, leading to higher cell multiplication and shoot elongation (Osorio *et al.* 2014). Mngoma *et al.* (2022) stated that training of tomato plants plays a critical role in growth by exposing them to brighter light for improved photosynthetic activity. Results revealed no significant differences for days to 50% flowering. This aligns with the findings of Alam *et al.* (2016), Ohta and Makino (2019), who observed that flowering dates remain unaffected by the various training and pruning methods in tomatoes. The number of flowers as well as fruits per cluster was significantly influenced by the stem training system. The number of flowers per cluster is positively correlated with seed yield components. More number of flower clusters^{-1} was found from two stemmed plants and the lowest with no stem training practices. Stem training is known to improve solar interception within canopy, due to which photosynthetic activity is magnified and assimilates available for flower setting. These results corroborate with the findings of Mbonihankuye *et al*. (2013) and Ansari *et al.* (2017). Maximum fruit count per cluster was observed in T1, while minimum in T3. Methela *et al.* (2019) and Krishna *et al*. (2020) reported that tomato plants trained onto a two-stem system gave the highest average number of fruits per cluster due to better growth, higher number of flowers per cluster with better pollination, essential for fruit and seed production. Plants retained with two-stems (T1) gave higher percent fruit set, meanwhile, plants where all the shoots retained gave lowest value. Ohta *et al*. (2022) proposed that the translocation of photosynthates required for flower bud differentiation and fruit maturation in the double-shoots tomato plants was concentrated compared to the untrained ones. Maximum value of days to reach red ripe maturity stage was observed in untrained plants, whereas, plants trained to two-stems recorded minimum days. Mngoma *et al*. (2022) hypothesized exposure of the fruit to high light intensity as the reason for early harvest along with faster synthesis of lycopene (Kumar 2020).

Data on the yield contributing parameters of tomato (cv. Solan Lalima) under the effect of training systems are presented in Table 2. Four stem training (T_2) recorded maximum fruit numbers per plant and minimum was in T_3 i.e. no stem training. Olayinka *et al.* (2023) concludes that stem training and pruning can optimise fruit count, meanwhile, in untrained plants, excessive vegetative growth with poor aeration leads to floral abortion. Retention of varying numbers of shoots significantly affects the average fruit weight of tomato. Fruits harvested from two-stem trained have the highest weight and lowest from untrained plants (T3). Findings are supported with the earlier conclusions drawn by Shilpa *et al.* (2021), and Waheed *et al.* (2022) in tomato. In double stemmed plants, the relative assimilation partitioning to leaves and fruits is shifted in favour of the fruits (Kleinhenz *et al.* 2006). Untrained plants produce numerous lateral shoots, leading to increased metabolite division with restricted availability of metabolites for individual fruit (Aryala and Basnetb 2023). Total fruit yield per plant was maximum in a two-stem training system and minimum in T3 and similar findings were ascertained by Shukla *et al*. (2011) in bell pepper and Tafoya *et al*. (2019) in cucumber. The positive influence of the training system could be attributed to an increased interception of photosynthetically active radiation (PAR) that maximized carbon assimilation, as compared to untrained plants. Highest mean number of seeds per fruit was exhibited by plants trained to two-stem (T1), while the lowest from untrained plants (T3). Lal *et al*. (2016) demonstrated that limiting vegetative growth of bell-pepper through training systems increases seed count by better partitioning of dry matter during fruit maturation.

From the data in Table 3, it was found that the highest seed yield was obtained from plants trained to two-shoots (T2), while untrained plants (T3) yielded the lowest. Canopy management through two-stem training in tomato resulted in more fruit number per plant with seed sufficiency, this eventually might have elevated seed yield. These results concurred with the reports of Ansari *et al.* (2017) and Kumar (2020).

The treatment T1 (Two-stem training) produced the highest seed yield leading to the higher benefit : cost ratio. The results align with Patel *et al*. (2022) and Kottapu *et al*. (2023), who indicated that production of increased yield leads to better net returns and B : C ratio.

Table 1. Effects of stem training systems on phenological parameters of tomato cv. Solan Lalima.

Treatment	Plant height (cm)			Days to 50% flowering			No. of flowers/cluster			No. of fruits/cluster			Fruit set (%)			Days to red ripe stage		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Two-stem (T1)	145.60^{A}	142.87^{A}	144.27^{A}	32.33	37.67	35.00	5.89^{A}	5.83^{A}	5.86^{A}	4.20	3.89	4.05^{A}	62.63^{A}	59.00	60.82^{A}	84.00^{B}	86.00^{B}	85.00^{B}
Four-stem (T2)	136.40^{B}	132.53^{B}	134.47^{B}	33.00	37.33	35.17	5.79^{A}	5.68^{A}	5.73^{B}	3.93	3.56	3.75^{B}	58.16^{A}	56.17	57.16^{A}	85.67^{B}	88.33^{B}	87.00^{B}
Control (T3)	132.33^{B}	129.07^{B}	130.70^{C}	33.67	38.00	35.83	4.92^{B}	4.93^{B}	4.93^{C}	3.59	3.37	3.48^{C}	45.26^{B}	44.67	44.96^{B}	89.67^{A}	93.33^{A}	91.5^{A}
Grand Mean	138.13	134.82	136.48	33.00	37.67	35.33	5.53	5.48	5.51	3.91	3.61	3.76	55.35	53.58	54.31	86.44	89.22	87.83
LSD (P=0.05)	5.67	4.54	2.24	NS	NS	NS	0.45	0.16	0.09	NS	NS	0.24	6.87	NS	4.624	3.89	4.59	2.55

Table 2. Effects of stem training systems on seed yield contributing traits of tomato cv. Solan Lalima.

Treatment	No. of fruits/plant			Average fruit weight (g)			Fruit yield (kg/plant)			Seed count/fruit		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Two-stem (T1)	22.53	22.80^{A}	22.67^{A}	70.37	72.44	71.41^{A}	1.63^{A}	1.66^{A}	1.64^{A}	93.63^{A}	94.10^{A}	93.87^{A}
Four-stem (T2)	23.07	23.13^{A}	23.10^{A}	68.14	69.48	68.81^{B}	1.62^{A}	1.65^{A}	1.64^{A}	88.40^{B}	88.70^{B}	88.55^{B}
Control (T3)	21.20	21.00^{B}	21.10^{B}	65.39	67.93	66.66^{C}	1.33^{B}	1.37^{B}	1.38^{B}	80.17^{C}	83.00^{C}	81.58^{C}
Grand Mean	22.27	22.311	22.29	67.97	69.95	68.96	1.55	1.56	1.55	87.40	88.60	88.00
LSD (P=0.05)	NS	0.68	0.712	NS	NS	1.84	0.09	0.18	0.09	1.98	3.80	4.31

Table 3. Effects of stem training systems on seed yield and economic return in tomato cv. Solan Lalima.

Treatment	Seed yield (g/plant)			Seed Yield (kg/ha)			B:C ratio (Pooled)
	2023	2024	Pooled	2023	2024	Pooled	
Two-stem (T1)	4.39	4.35	4.37^{A}	159.52	158.18	158.85^{A}	2.19
Four-stem (T2)	4.18	4.21	4.19^{B}	152.00	152.97	152.48^{B}	2.05
Control (T3)	4.03	4.09	4.06^{B}	146.42	148.61	147.51^{B}	1.86
Grand Mean	4.20	4.21	4.21	152.65	153.25	152.95	
LSD (P=0.05)	NS	NS	0.15	NS	NS	5.44	

Means having same letter in the column are not significantly different among each other based on DMRT at 5% level of significance.

Canopy management through stem-training and pruning in indeterminate tomato cultivar showed up as a boon for enhancing phenological traits and yield contributing parameters. Aside from these potential benefits, a two-stem training system manifolds the seed yield, enabling the practice to be adopted while undertaking commercial seed production in tomatoes. Most importantly, two-stem training was identified as the most effective option to prioritise monetary returns and profitability.

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