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Improving the growth, yield, and quality of heirloom tomato (*Solanum lycopersicum*) using plant support, graded organic and inorganic fertilizers

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ABSTRACT

Adilabad district is endowed with rich agro-biodiversity, and several heirloom cultivars of vegetables, such as Kashi tomato, are still cultivation to a limited extent. Compared to modern hybrids, realizing the full potential of the Kashi heirloom tomato cultivar requires a thorough understanding of its specific needs, particularly regarding plant support and nutrient management, as it is more susceptible to fruit rot and physiological disorders such as cat face, blossom end rot, sun scald, and radial cracking. A field experiment was conducted using different plant support systems, graded levels of organic manures along with recommended doses of fertilisers to improve fruit yield and quality. The study demonstrated that keeping heirloom tomato plants off the ground through staking or trellising enhances fruit yield and quality. The trellis plant support system, with the application of 25% Nitrogen (N) through Farm Yard Manure (FYM) + 75% of the recommended dose of chemical fertilizers (RDF), resulted in a significantly higher fruit yield of 7.15 kg per plant and reduced the non-marketable fruit yield to 0.25 kg per plant furthermore, fruit quality improved with the application of 50% N through FYM + 50% RDF, showing enhanced fruit size and total soluble solids.

Key words: Kashi tomato, nutrient management, staking, trellising, fruit yield.

INTRODUCTION

The Adilabad district in Telangana is a significant agro-biodiversity hotspot, particularly for horticultural crops such as field beans, brinjal, tomato, cucurbits, and various fruits like citrus, jamun, and ber. While the diversity of field crops in the region is well-documented (Pandravada *et al.,* 15), increased consumer demand for heritage and quality has shifted attention toward heirloom tomatoes. Heirloom tomatoes are open-pollinated varieties, preserved through seed-saving traditions. Locally known as Kashi or "half kilogram" tomato, this cultivar is distinguished by its large fruit size (>300 g), indeterminate growth, extended cropping period (6–8 months), and high lycopene content (Ahamad *et al.,* 1; Lang and Nair, 12). Though prized for flavor and nutritional value, it has poor shelf-life and is cultivated mainly in the cool season to avoid summer flower drop. Consumer preference for diverse, locally grown produce has revived interest in heirloom cultivation. However, these tomatoes present several challenges: they lack pest and disease resistance, require more labor and inputs, and their delicate, irregular fruit limits large-scale harvest and shipping. Indeterminate growth necessitates staking to prevent lodging and sunscald, adding to management complexity (Treadwell *et al.,* 20).

Staking is an essential agronomic practice for indeterminate tomatoes, as it provides structural support, enhances yield, and improves fruit quality. By keeping fruits off the ground, staking reduces the incidence of diseases such as fruit rot and minimizes pest infestations. It also results in cleaner, firmer, and larger tomatoes, optimizes field space, facilitates harvesting, and improves the efficiency of pesticide and fungicide applications (Chaudhari *et al*., 8). A well-designed staking system must be durable enough to withstand environmental conditions throughout the growing season. Elevating the plants and fruit clusters prevents soil contact, reducing losses due to fruit rot and sunburn caused by inadequate foliage coverage. Since tomato plants extract substantial nutrients from the soil, balanced fertilization is crucial for sustained productivity. With rising chemical fertilizer costs and increasing environmental concerns, integrating organic and inorganic nutrient sources is necessary. Farmyard manure (FYM) has traditionally served as an important organic nitrogen source, contributing to soil health and fertility (Ronga *et al.,* 18). Physiological

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disorders such as blossom end rot (caused by calcium deficiency, high soil moisture, and elevated temperatures), radial cracking (due to irregular irrigation), sunscald, yellow and green shoulders (linked to intense sunlight and nutrient imbalance), and zippering (caused by low temperatures and slow fruit development) are common in tomatoes. Red acidic and non-calcareous soils are particularly prone to blossom end rot and fruit cracking disorders. A balanced application of organic (FYM) and inorganic fertilizers can help mitigate these issues, reducing the occurrence of corky fruit texture and cracking (Haleema *et al.,* 10).

Farmer perceptions indicate that vertical staking may sometimes lead to a decline in tomato yield, particularly in heirloom varieties where fruit cracking, blossom end rot and fruit rot are predominant. However, these issues can be minimized through the combined application of FYM and fertilizers, along with the adoption of proper agronomic practices. Staking plays a crucial role in preventing direct fruit-to-soil contact, thereby reducing fruit rot disease and improving fruit shape and colour. By implementing these strategies, farmers can enhance the productivity and marketability of heirloom tomatoes while maintaining sustainable cultivation practices. Considering the facts above, the study was undertaken to evaluate the effect of staking and graded organic and inorganic fertilizers on the growth, production, and quality of Heirloom tomatoes.

MATERIALS AND METHODS

The field study was conducted at the Horticultural Research Station, Adilabad, during the 2024 - 2025 Rabi season. It is in the Northern Telangana Agro-climatic Zone (Latitude 19.64°, Longitude N 78.53° and Altitude: 303 m above Mean Sea Level). The average annual temperature is 30.08 °C, the annual rainfall is 1157.6 mm, and July is the wettest month.

The experiment was carried out using a randomized block design with a factorial concept that was replicated thrice. Factor A: Staking methods: 3 (S_1: No staking, S_2: Vertical staking, S_3: Trellises system) and Factor B: Fertilization: 3 (F_1: Recommended doses of fertilizers and manures RDF, F_2: 25% N through FYM+ 75% RDF and F_3: 50% N through FYM+ 50 % RDF). The growth and fruit quality attributes of the Kashi tomato are presented in Table 1.

Heirloom tomato seeds were sown in protrays containing vermicompost and cocopeat in a 3:1 ratio. The seedlings were transplanted four weeks after germination, when they reached a height of 15 cm and had approximately 5 to 6 leaves. The seedlings were transplanted at a spacing of 45 cm × 45 cm. After the establishment of plants in the main field, staking was implemented. Vertical staking was implemented using bamboo sticks, and in the trellis system, wires were stretched from one end to the other and back at different heights with GI wires. Once the plants grew to about 25 cm in height, the tomato stems were loosely tied to the wires using coir ropes for support (Wubetie, and Wubetu, 21).

The recommended dose of fertilizers (RDF) per acre for tomato cultivation includes 8 -10 tonnes of farmyard manure (FYM), 87 kg of urea, 150 kg of Single super phosphate and 40 kg of muriate of potash. The required amount of nitrogen was applied in the form of calcium ammonium nitrate (CAN) at 154 kg per acre. The quantity of nitrogen applied through

Table 1: Growth and fruit quality attributes of heirloom tomato cv Kashi tomato.

Growth characters	Trait details
Plant growth habit	Indeterminate
Plant height	151 cm
Primary branches	6-7
Secondary branches	11-12
Average no of fruit per plant	26
Fruit shape	Round slightly C-shaped
Fruit weight (g)	325
Fruit diameter (mm)	75.12
No of locules	8
Fruit firmness	Soft
Reproductive phase (DAP)	55
Colour of immature fruit (Recorded before maturity)	Greenish-white
Presence of green shoulders	Present (fruit shoulders - upper part of the fruit, around calyx - are green while pistillar area of the fruit is red)
Total soluble solids (°Brix)	6.2
Titrable acidity (%)	0.96
TSS: Acid ratio	6.45
Total sugars (%)	3.5
Reducing sugars (%)	3.1
Lycopene content	2520 µg/100 g
Total protein content	10.78%
Total carbohydrate content	3.58%
Pulp-to-seed ratio	79.66
Plant fresh weight (kg)	1.17
Plant dry weight (g)	311

25% FYM and 50% FYM was 2.5 tonnes and 5 tonnes per acre, respectively. The quantity of 50% and 75% recommended dose of fertilizer applied is 77 kg and 115.5 kg per acre, respectively. Different doses of farm yard manure and nitrogen in the form of calcium ammonium nitrate were applied in split doses at the time of land preparation and after transplanting. Full doses of phosphorus and potassium were added at the time of planting. (Haleema *et al.,* 10).

Data on the plant growth, fruit yield, and quality parameters were collected at the time of harvest. Five randomly selected plants from each treatment were used to measure plant height (cm), number of primary branches, days to 50% flowering, fruit yield per plant (kg), single fruit weight (g) and total soluble solids (°Brix) (Ahamad *et al.,* 2). The harvested fruits were counted per plant to determine the number of fruits per plant. The total fruit yield per plant was counted and weighed. Total fruit yield includes both marketable and non-marketable fruits. Marketable fruits were those of good quality, exhibiting firmness and free from blemishes. Only mature, ripe, unspoiled, and appropriately sized heirloom tomatoes (without blemishes) were harvested. Non- marketable fruits were sorted into: 1. Sunscald, deformed, unevenly ripened, or with whitish areas on the exposed surface. 2. Diseased fruits, eaten by birds or rabbits, or over-ripe (Wubetie, and Wubetu, 21).

Marketable and non-marketable fruits per plant were counted and weighed to determine the marketable fruit yield per plant. Fruit length was measured using a meter rule (cm), while fruit diameter (cm) was recorded using vernier callipers. Tomato juice was squeezed from firm-ripe mature heirloom tomatoes, and then total soluble solids were determined using a hand refractometer consisting of a 0-30% range, with values corrected at 20ºC at room temperature (Ahamad *et al.,* 3). Observations for plant height (cm), number of primary branches, days to 50% flowering, number of fruits per plant, yield per plant (kg), fruit length (cm), fruit diameter (mm) and total soluble solids (°Brix) were recorded and presented in the Tables 2, 3a and 3b. The experimental design used in the study was a Randomized Block design (RBD) with the factorial concept consisting of three replications. Analysis of variance (ANOVA) was performed using the PAST 4.03 statistical software (Hammer and Harper DA, 2001) and the data was recorded if the effects of the treatments were significant ($p < 0.05$).

RESULTS AND DISCUSSION

The results of various parameters, such as plant height (cm), number of primary branches, days to

Table 2: Analysis of variance (ANOVA) of *P-* values on the effect of staking and fertilization on growth, fruit yield and quality of heirloom tomato.

Factor	Plant height (cm)	Number of primary branches	Days to 50% flowering	Number of fruits/ plants	Single fruit weight (g)	Total fruit yield/ plant (Kg)	Marketable fruit yield/ plant (Kg)	Non-marketable fruit yield/plant (Kg)	Fruit length (cm)	Fruit diameter (cm)	Total soluble solids (ºBrix)
Staking (S)	<0.00	<0.000	<0	<0.000	<0.000	<0.00	<0.000	<0.001	<0.000	<0.000	<0.007
Fertilization (F)	<0.00	<0.000	<0	<0.000	<0.000	<0.00	<0.000	0.325	<0.000	<0.000	<0.011
S×F	<0.00	<0.002	<0	<0.041	0.536	0.06	<0.000	0.217	0.738	0.974	0.359

Table 3a: Effect of staking on growth, fruit yield, and quality of heirloom tomato.

Factor	Plant height (cm)	Number of primary branches	Days to 50% flowering	Number of fruits / plant	Single fruit weight (g)	Total fruit yield /plant (kg)	Marketable fruit yield / plant (kg)	Non-marketable fruit yield/ plant (kg)	Fruit length (cm)	Fruit diameter (cm)	Total soluble solids (ºBrix)
Staking (S)											
S_1	132.95	8.85	51.44	17.00	171.44	2.92	2.41	0.57	4.76	7.38	5.95
S_2	145.55	10.47	49.72	23.88	203.11	4.85	4.47	0.38	5.30	7.67	6.21
S_3	155.87	11.88	51.71	28.55	237.77	6.80	6.52	0.28	5.76	7.95	5.63
Fertilization (F)											
F_1	139.38	8.70	51.38	21.22	192.77	4.21	3.80	0.41	5.78	7.48	5.65
F_2	148.88	10.75	50.83	25.55	205.88	5.39	5.02	0.36	6.20	7.68	5.96
F_3	146.11	11.76	50.65	22.66	213.66	4.98	4.58	0.46	6.57	7.84	6.19
S.E(m)±	0.42	0.08	0.06	0.38	1.89	0.12	0.11	0.04	0.08	0.02	0.11
CD (*P*=0.05)	1.26	0.24	0.2	1.13	5.63	0.36	0.31	0.13	0.23	0.06	0.33
CV	0.87	2.33	0.39	4.92	2.78	7.49	7.12	31.34	3.82	0.73	5.57

Table 3b: Interaction effect of staking and fertilization on growth, fruit yield, and quality of heirloom tomato.

Interaction effect	Plant height (cm)	Number of primary branches	Days to 50% flowering	Number of fruits /plants	Single fruit weight (g)	Total fruit yield/ plant (kg)	Marketable fruit yield/ plant (Kg)	Non-marketable fruit yield/ plant (Kg)	Fruit length (cm)	Fruit diameter (cm)	Total soluble solids (ºBrix)
S_1F_1	125.53	7.26	51.43	15.00	158.33	2.37	1.90	0.47	4.76	7.20	5.67
S_1F_2	135.33	8.90	51.66	19.00	175.00	3.32	2.80	0.52	5.30	7.40	6.00
S_1F_3	138.00	10.40	51.23	17.00	181.00	3.07	2.53	0.72	5.76	7.56	6.20
S_2F_1	142.33	9.03	50.14	23.00	195.00	4.48	4.09	0.38	6.00	7.50	6.16
S_2F_2	148.00	10.80	49.49	26.66	204.33	5.45	5.11	0.34	6.40	7.70	6.10
S_2F_3	146.33	11.60	49.52	22.00	210.00	4.62	4.20	0.42	6.73	7.83	6.36
S_3F_1	150.30	9.80	52.58	25.66	225.00	5.78	5.40	0.37	6.60	7.76	5.11
S_3F_2	163.33	12.56	51.34	31.00	238.33	7.39	7.15	0.23	6.90	7.96	5.79
S_3F_3	154.00	13.30	51.21	29.00	250.00	7.25	7.00	0.25	7.23	8.13	6.00
S.E(m)±	0.73	0.14	0.11	0.66	3.28	0.21	0.18	0.07	0.14	0.03	0.19
CD (*P*=0.05)	2.18	0.42	0.34	1.95	NS	NS	0.54	NS	NS	NS	NS
CV	0.87	2.33	0.39	4.92	2.78	7.49	7.12	31.34	3.82	0.73	5.57

Values followed by different letters in a column are significantly different by Tukey's HSD test at $p \leq 0.05$.

onset of flowering, number of fruits per plant, yield per plant (Kg), marketable fruit yield per plant (Kg), non-marketable fruit yield per plant (Kg), single fruit weight (g), fruit length (cm), fruit diameter (cm) and total soluble solids (ºBrix) of heirloom tomatoes, are discussed as follows. The positive benefits of staking and fertilization had highly significant effects (*P* < 0.001) on most growth, yield, and quality traits of heirloom tomatoes, including plant height, branches, flowering time, fruit number, fruit weight, total and marketable yield, fruit size, and TSS. The non-marketable yield was significantly influenced by staking (*P* < 0.001) but not by fertilization (*P* = 0.325). The interaction (S × F) was significant for plant height, branches, fruit number, and total and marketable yield, showing their combined impact on productivity. However, fruit weight, non-marketable yield, fruit size, and TSS were mainly influenced by individual factors. Overall, staking and fertilization independently improve growth and yield, while their combination further enhances productivity.

Plant height was significantly higher in the trellis system (155.87 cm) followed by vertical staking (145.55 cm), while the shortest plants were recorded as un-staked plants (132.95 cm). A similar trend was observed in the number of primary branches, where the Trellis system had the highest (11.88), followed by vertical staking (10.47), and the lowest in un-staked plants (8.85). The differences in both parameters were statistically significant, indicating the beneficial impact of staking or trellis on plant structure and vigour. This could be due to improved plant support, promoting vertical growth and better light interception (Rashid *et al.,* 17). Staking has caused the plant to grow upright, increasing its height and other relevant characteristics. In a trellis system, profuse branching with wide plant spread might increase in number of primary branches. The results of tomatoes are in agreement with the growth characteristics of staked tomato plants (Wubetie, and Wubetu, 21).

The number of days to flowering showed minimal variation among treatments, ranging from 49.72 to 51.71 days, with no significant differences observed. However, staking significantly influenced fruit production. The trellis system produced the highest number of fruits per plant (28.55), followed by vertical staking with bamboo sticks/wooden pegs (23.88), while the lowest was recorded in control/ no staking (17.00). Similarly, single fruit weight was significantly higher in the Trellis system (237.77 g) compared to vertical staking (203.11 g) and control/ no staking (171.44 g), highlighting the role of staking in enhancing fruit development. Increased production of food material likely enhanced flowering, fruit set, and fruit count per plant. These results are consistent with the findings of Singh and Asrey (19) and Wubetie, and Wubetu (21) in tomatoes.

Total fruit yield per plant was highest in the trellis system with GI wires + coir rope (6.80 kg), significantly outperforming vertical staking with bamboo sticks/wooden pegs (4.85 kg) and control/ no staking (2.92 kg). Marketable yield followed the same pattern, with the highest yield observed in the trellis system (6.52 kg), followed by vertical staking (4.47 kg), and the lowest in control/no staking (2.41 kg). The non-marketable yield was significantly reduced in the Trellis system (0.28 kg), compared to vertical staking (0.38 kg) and control/no staking (0.57 kg), indicating that staking minimizes fruit defects and enhances marketability. Staked plants receive direct sunlight, enhancing photosynthesis and food production, which improves yield attributes and overall yield. Staking increases fruit yield, reduces nonmarketable fruit, and enhances fruit quality (Wubetie, and Wubetu, 21).

Fruit length and diameter were also significantly influenced by staking. The longest fruits (5.76 cm) and largest diameter (7.95 cm) were recorded in the trellis system with GI wires + coir rope, followed by vertical staking with bamboo sticks/wooden pegs (5.30 cm, 7.67 cm), while control/no staking produced the shortest (4.76 cm) and smallest (7.38 cm) fruits. The differences were statistically significant, suggesting that staking contributes to better fruit development. Total soluble solids (TSS) ranged from 5.63 to 6.21 °Brix, with no significant differences among treatments, indicating that staking does not have a major impact on fruit sweetness (Ahamad *et al.,* 4).

The study demonstrated the significant impact of different fertilizer treatments on heirloom tomato growth, yield and fruit quality. Plant height and number of primary branches were significantly higher in 25% N through FYM + 75% doses of recommended fertilizers (148.88 cm, 10.75 branches) and 50% N through FYM + 50% RDF (146.11 cm, 11.76 branches) compared to Control / Recommended doses of fertilizers and manures (139.38 cm, 8.70 branches). These differences were statistically significant, highlighting the positive influence of FYM in enhancing vegetative growth. The presence of growth-promoting substances like hormones and humates, produced by microorganisms through organic manuring, likely contributed to increased flowering and flower production (Arancon *et al.,* 7). These are in line with conformity of Mamun *et al.*, 14; and Rashid *et al.*, 17).

Fruit length and diameter were significantly enhanced by FYM. The longest and widest fruits were recorded in 50% N through FYM + 50% RDF (6.57 cm, 7.84 cm), followed by 25% N through FYM + 75% RDF (6.20 cm, 7.68 cm). The lowest values were in control or recommended doses of fertilizers and manures (5.78 cm, 7.48 cm). Fruit number and single fruit weight were significantly improved with FYM application. The highest values were recorded in 25% N through FYM + 75% RDF (25.55 fruits, 205.88 g/fruit), followed by 50% N through FYM + 50% RDF (22.66 fruits, 213.66 g/fruit), while the lowest were observed in Control / RDF (21.22 fruits, 192.77 g/fruit). Total and marketable fruit yield per plant showed highly significant differences. 25% N through FYM + 75% RDF recorded the highest yield (5.39 kg total, 5.02 kg marketable), followed by 50% N through FYM + 50% doses of RDF (4.98 kg total, 4.58 kg marketable).

The lowest yield was in control / recommended doses of fertilizers and manures (4.21 kg total, 3.80 kg marketable). Higher photosynthetic activity and fruit accumulation may result from an increased number of flowers, which likely developed into fruits due to the sufficient availability of essential nutrients during growth and development (Laxmi *et al*., 13). The yield increase per hectare could be attributed to nutrient availability, which enhanced flower and fruit traits such as number of fruits, fruit size (fruit length and diameter) and fruit weight (Rashid *et al*. 17).

TSS, an indicator of fruit quality, were significantly highest in 50% N through FYM + 50% RDF (6.19 °Brix), followed by 25% N through FYM + 75% RDF (5.96 °Brix), while control (5.65 °Brix) recorded the lowest. These findings align with an increase in tomato fruit weight (Ghorbani *et al.*, 9). Similarly, staked tomato plants showed increased yields per plant and overall output, according to Alam *et al*. (5) and Jafar *et al.* (11).

The interaction of staking and fertilization significantly influenced various growth and yield traits of heirloom tomatoes. Plant height and number of primary branches were significantly higher in the trellises system with 25% N through FYM + 75% RDF (163.33 cm, 12.56 branches) and 50% N through FYM + 50% RDF (154.00 cm, 13.30 branches). The shortest plants and lowest branching were observed in the control (125.53 cm, 7.26 branches), indicating that trellising and organic fertilization enhance plant growth. The application of organic fertilizer or inorganic fertilizer alone cannot produce better yield, but the combined effect helps to improve growth and yield attributes. These results conform with Rashid *et al.* (17) in tomato.

Days to commencement of flowering showed minimal variation across treatments, suggesting that staking and fertilization had little impact on the commencement of the reproductive phase. Number of fruits per plant was highest in trellises system with 25% N through FYM + 75% RDF (31.00) and 50% N through FYM + 50% RDF (29.00), while the lowest was in control/ no staking with control (15.00). This indicates that trellising combined with organic fertilization promotes fruit set. More number of fruits per plant, single fruit weight, and total yield were significantly higher in the staked plants (Ali and Moniruzzaman, 6).

Fruit size (length and diameter) was highest in the trellises system with 50% N through FYM + 50% RDF (7.23 cm, 8.13 cm), while the smallest fruits were observed in control/ no staking with control (4.76 cm, 7.20 cm), suggesting that staking and organic amendments contribute to fruit size. Higher rates of photosynthesis in staked plants result in more food materials being stored, which in turn promotes the increase in the fruit size of the tomatoes (Wubetie, and Wubetu 21; Ali and Moniruzzaman, 6).

Total and marketable fruit yield per plant showed no significant interaction effects, but the highest marketable yield was in the trellises system with 25% N through FYM + 75% RDF (7.15 kg) and 50% N through FYM + 50% RDF (7.00 kg), while the lowest was in the control plants (1.90 kg). Non-marketable yield was not significantly affected by interaction, indicating that losses were primarily influenced by individual staking or fertilization effects. Staking can be beneficial to ensure clean, undamaged fruits that are kept off the ground, reducing fruit rot caused due to soil moisture conditions, radial cracking, increasing marketable production, and minimizing non-marketable fruits (Jafar *et al.,* 11; Prativa, and Bhattarai, 16).

TSS did not show a significant interaction effect, with values ranging from 5.11 °Brix (trellises system with control/ recommended doses of fertilizers & manures) to 6.36 °Brix (vertical staking with bamboo sticks with 50% N through FYM + 50% RDF, indicating that fertilization plays a role in fruit quality. The results were similar to the findings of Rashid *et al*. (17); Alam *et al.* (5).

Staking using the trellis system with GI wires and coir ropes promotes profuse branching, leading to increased fruit set and yield, along with improved fruit quality. The integration of this method with combined nutrient management specifically through the partial substitution of inorganic fertilizers with FYM (e.g., 25–50% N from FYM with the remainder from RDF) proved most effective. This combined approach ensures balanced nutrition by enhancing soil structure and microbial activity through organic inputs, while providing readily available nutrients from inorganic sources. As a result, it supports healthier plant growth, optimizes photosynthesis, reduces physiological disorders, and maximizes both total and marketable fruit yield, offering a sustainable and productive farming strategy.

AUTHOR'S CONTRIBUTION

Conceptualization, data gathering, analysis (SPG, VM); Designing experiments (SIA); Data interpretation, manuscript preparation (SPG, AC).

DECLARATION

The authors declare no conflict of interest.

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