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Effects of growth regulators and micronutrients on the growth, yield and quality of Tomato (*Solanum lycopersicum* L.) cv. Kashi Aman

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Abstract
The field experiment was conducted during the *rabi* season 2024-25 at Department of Vegetable Science Kalyanpur of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, (U.P.). Eleven different treatments *viz*., borax @ 0.2% (T_1), zinc sulphate @ 0.5%(T_2), micronutrient mixture @ 0.5% (T_3), NAA 50 ppm (T_4),NAA 50 ppm + borax @ 0.2% (T_5), NAA 50 ppm + zinc sulphate@ 0.5%(T_6),NAA 50 ppm + micronutrient mixture @ 0.5%, (T_7), GA 50 ppm (T_8), GA 50 ppm + borax @ 0.2%(T_9), GA 50 ppm + zinc sulphate @ 0.5% (T_{10}) and GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) were tested against control (T_{12}) in RBD design replicated thrice. Tomato variety 'Kashi Aman' was used in the experiment. The results of the experiment revealed that application of GA 50 ppm couple with micronutrient mixture @ 0.5% (T_{11}) recorded significantly highest plant height (79.39 and 85.23 cm at 60 and 90 DAT, respectively), number of branches per plant (13.21),fruit equatorial diameter (5.96 cm), fruit polar diameter (5.68 cm), average fruit weight (112.42 gm at 4th picking), number of fruits per plant (36.70), yield/plant (2.45 kg), yield/plot (72.16 kg), yield/ha (556.80 q), TSS (5.87 °Brix), ascorbic acid (20.48 mg/100g) along with net return (Rs. 4,09,440/ha) and benefit: cost ratio (4.47). On the basis of results, it is concluded that the foliar application of GA 50 ppm couple with micronutrient mixture @ 0.5% significantly enhances the yield, quality and net returns. Hence, it may be recommended for commercial cultivation of Tomato cv. Kashi Aman under Kanpur conditions to maximize productivity and profitability.

Keywords: Growth regulators, foliar application, micronutrients and tomato.

Introduction
Tomato (*Solanum lycopersicum* L.) is the second most important vegetable crop after potato in the world. It is a dicotyledonous annual herb with diploid chromosome number 2n = 24 and belongs to the family Solanaceae. Tomato is also known as “Poor man’s Orange and Wolf Apple” (Dhall and Singh, 2013) [4]. It is grown on every continent and global production reached approximately 192 million tonnes in 2023, with China (68.2 Mt), India (21.32 Mt), Turkey (13.0 Mt), the United States (6.3 Mt) and Italy (4.2 Mt) leading the way. In India specifically, output rose from 20.43 million tonnes in 2022-23 to 21.32 million tonnes in 2023-24, as per the press information bureau (PIB, 2024). Tomato fruits are generally globular to oval in shape and are consumed fresh or processed into products such as soup, juice, ketchup, puree, paste and powder (NIFTEM-T, 2020). In Tomato, every 100 grams of fruit pulp contains approximately 91.18 g of water, 17.71 g of protein, 4.96 g of fat, 5.96 g of carbohydrates, 8.75 g of mineral matter (ash), 105 mg of calcium, 301 mg of phosphorus, 4.55 mg of iron, 614 IU of vitamin A (as carotenoids), 0.66 mg of thiamine, 9.68 mg of niacin, 0.48 mg of riboflavin and 36.16 mg of ascorbic acid (Ali *et al*., 2020) [1].
Growth regulators are natural and artificial compounds that both stimulate and regulate the plant's physiological functions. The auxins and gibberellins are the most widely utilized growth regulators. It is promoting floral bud development, internodal elongation and the reduction of pre-harvest fruit drops. Naphthalene acetic acid (NAA) is necessary for cell growth, improving respiration, apical bud formation, phototropism and flower-bud initiation. When NAA is applied during flowering, reduced pre-harvest fruit drop and increased fruits per plant are commonly observed. NAA also improves fruit set, fruit size and overall yield (Singh *et al*., 2018) [16].

Gibberellic acid (GA_3) is likewise a crucial growth-stimulating agent that promotes cell division and elongation. It regulates stem elongation, protein synthesis and seed germination and exogenous GA_3 applications can accelerate development, improve fruit maturation and influence tomato yield and quality (Verma *et al*., 2014) [18]. Additionally, GA_3 has been reported to increase leaf area, lycopene content, fruit cluster number, internode elongation and branch number in tomato (Masroor *et al*., 2006) [9].

Plants lacking in boron may be stunted because boron is linked to the production of cell walls. It is involved in pollen grain production and germination, flower retention and the transportation of sugar. Reduced boron supply results in lower seed and grain output. Symptoms of a boron deficit first appear at growing points and include stunting, hollow or corky stems and fruits, discoloured foliage and reduced fruit set in tomato (Saha *et al*., 2023 and Chhaba *et al*., 2024) [15, 3]. Zinc is an essential micronutrient that improves auxin synthesis, chlorophyll formation and enzyme activity, thereby benefiting fruit set, flowering and overall plant growth; its use enhances fruit quality, increases yields and corrects zinc deficiency by improving nutrient absorption and metabolic processes (Ravat *et al*., 2024 and Saha *et al*., 2023) [14, 15]. Micronutrient mixtures containing zinc, iron, manganese, copper, boron and molybdenum are essential for balanced tomato growth and development, enhancing photosynthesis, enzyme activity, disease resistance and fruit quality, which leads to increased yield and better nutrient-use efficiency (Yadav *et al*., 2024) [19].

Material and methods

The field experiment was conducted during the Rabi season 2024-25 at Department of Vegetable Science Kalyanpur of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh to evaluate the effects of growth regulators and micronutrients on the growth traits, yield attributes, yield and quality of tomato. The experiment was laid out in a randomized block design (RBD) with three replications. Eleven different treatments *viz*., borax @ 0.2% (T_1), zinc sulphate @ 0.5%(T_2), micronutrient mixture @ 0.5% (T_3), NAA 50 ppm (T_4),NAA 50 ppm + borax @ 0.2% (T_5), NAA 50 ppm + zinc sulphate@ 0.5%(T_6),NAA 50 ppm + micronutrient mixture @ 0.5%, (T_7), GA 50 ppm (T_8), GA 50 ppm + borax @ 0.2%(T_9), GA 50 ppm + zinc sulphate @ 0.5% (T_{10}) and GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) were tested against control (T_{12}). Tomato variety 'Kashi Aman' was used in the experiment. The soil of the experimental field was sandy loam with good fertility and a well-developed drainage system. The seeds were sown on 28th September, 2024 and seedlings were transplanted on 26th October, 2024, with a planting spacing of 60 × 60 cm. The plot size of 3.60 × 3.60 m was maintained and 36 plants were accommodated in each plot. Standard cultural practices were followed uniformly in all plots except treatments. In each plot, the five plants were selected randomly and tagged for the purposes of observations and recorded observations were analysed.

Result and discussion

Plant height (cm) at 60 and 90 DAT

Height of the plant is represented by its growth and vigour. The maximum plant height (79.39 cm) at 60 DAT was recorded in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) followed by GA 50 ppm + borax @ 0.2%(T_9) with 78.32 cm, while the minimum plant height (68.17 cm) was observed in control (T_{12}) (Table 1). Similar trend was also observed at 90 DAT and maximum plant height of 85.23 cm was found in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) and minimum in T_{12} (71.53 cm). These results are in conformity with the findings of Basavarajeswari *et al*., (2008) [2] and Rab and Haq (2012) [13].

Number of branches per plant

Increased number of branches per plant has been associated with higher flowering and fruiting potential. The maximum number of branches (13.21) per plant was obtained in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}), followed by T_9 with 12.62, while the minimum number of branches (9.17) was noted in control (T_{12}) (Table 1). These findings corroborate the results of Rab and Haq (2012) [13].

Days to flower initiation

Minimum days to flower initiation reflect vigorous growth and early reproductive development. The minimum days (20.91 days) to flower initiation was observed in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) followed by T_9 with 22.14 days, whereas the maximum of 28.66 days to flower initiation was recorded in control (T_{12}) (Table 1). It might be due the effect of GA and micronutrient as this accelerated flower induction by improving plant nutrition and hormonal balance. These results corroborate the findings of Hamsaveni *et al*., (2003) [6] and Siwna *et al*., (2019) [17].

Days to 50% flowering

Minimum days to 50% flowering reflect vigorous growth, early flowering and hence potential yield advantage. The minimum days (29.91 days) to 50% flowering were recorded in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) followed by T_9 with 31.24 days, whereas the maximum 36.11 days to 50% flowering was recorded in T_{12} (Table 1). The application of GA and micronutrients likely hastened flowering by improving the plant's metabolic status. These results corroborate the findings of Hamsaveni *et al*., (2003) [6] and Siwna *et al*., (2019) [17].

Days to first fruit picking

Early fruiting indicates better plant vigour and yield potential. The minimum of 55.85 days to first fruit picking were recorded in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) followed by T_9 with 56.21 days, while the maximum was in T_{12} (63.11 days) (Table 1). GA and micronutrient application likely promoted earlier fruit maturity by enhancing physiological processes. These findings agree with Siwna *et al*., (2019) [17] and Rab and Haq (2012) [13], who reported earlier fruiting with GA treatment and boron spray.

Fruit equatorial diameter (cm) at 2nd picking

Fruit diameter is indicative of good fruit growth. The maximum fruit equatorial diameter (5.96 cm) was recorded in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) (Table 1) followed by T_9 with 5.64 cm, whereas the minimum diameter was observed in T_{12} (4.71 cm). The increased fruit diameter under treated plants may be due to enhanced cell expansion and assimilate accumulation. These results are in agreement with Hamsaveni *et al*., (2003) [6] and Basavarajeswari *et al*. (2008) [2].

Fruit polar diameter (cm) at 2nd picking

The maximum fruit polar diameter of 5.68 cm was recorded in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) followed by T_9 with 5.56 cm, whereas the minimum was in T_{12} (3.58 cm) (Table 1). The larger polar diameter in treated plants indicates better overall fruit development. These results corroborate the reports of Hamsaveni *et al*., (2003) [6] and Rab and Haq (2012) [13].

Average fruit weight

Weight of fruit is determined by accumulation of photo assimilates and nutrient translocation. The maximum average fruit weight (112.42 g) at 4th picking was recorded in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) followed by T_9 with 108.38 g and the minimum in T_{12} (84.71 g) (Table 1). The higher fruit weight under treated plants may be due to improved assimilate synthesis and translocation. These findings corroborate the reports of Hamsaveni *et al*., (2003) [6] and Rab and Haq (2012) [13].

Number of fruits per plant

A higher number of fruits per plant indicates vigorous growth and better fruit set. The maximum number of fruits per plant (36.70) was obtained in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) followed by T_9 with 35.30, while the minimum (25.10) was in T_{12} (Table 1). The increase in fruit number under treated plants may be due to enhanced flowering and fruit set from the combined effects of GA and micronutrients. These findings are supported by Hamsaveni *et al*., (2003) [6] and Rab and Haq (2012) [13].

Fruit yield

Fruit yield was significantly influenced by the treatments. The maximum fruit yields of per plant (2.45 kg), per plot (72.16 kg) and per hectare (556.80 q) were recorded in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}), followed by T_9 with 2.32 kg/plant, 69.43 kg/plot and 535.80 q/ha (Table 1). The minimum yield of per plant (1.69 kg), per plot (54.87 kg) and per hectare (423.40 q) was found in control treatment. The higher yield under treated plants could be attributed to the combined increase in fruit number and fruit weight. These results conform to the findings of Murlee *et al*., (2006) [10] and Karuppaiah (2005) [7].

Total soluble solids (°Brix)

The maximum TSS (5.87 °Brix) was recorded in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}), followed by T_9 with 5.23 °Brix, whereas the minimum (4.01 °Brix) was in T_{12} (Table 1). The increased TSS under treated plants may be due to enhanced sugar accumulation from more efficient photosynthesis. These results are consistent with Rab and Haq (2012) [13] and Siwna *et al*., (2019) [17], who reported higher TSS with boron and GA treatments.

Ascorbic acid (mg/100g)

The maximum ascorbic acid content (20.48 mg/100g) was recorded in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}), followed by T_9 with 20.31 mg/100g, while the minimum (16.01 mg/100g) was in T_{12} (Table 1). The higher vitamin C content in fruits of treated plants may be attributed to reduced stress and improved metabolic activity. These findings conform to the results of Siwna *et al*., (2019) [17] and Madhav *et al*., (2023) [8].

Table 1: Effect of growth regulators and micronutrients on growth, yield and quality of tomato.

S. No.	Plant height (cm)		No. of branches	Days to flower initiation	Days to 50% flowering	Days to first fruit picking	Fruit diameter (cm)		Average fruit weight (g)	No. of fruits/plants	Fruit yield (kg)		Yield (q/ha)	TSS (°Brix)	Ascorbic acid (mg/100g)
	60 DAT	90 DAT					Equatorial	Polar			per plant	per plot			
T_1	71.01	75.19	9.77	26.67	34.67	61.34	5.23	3.94	95.53	30.10	1.99	62.15	479.60	4.31	16.62
T_2	73.34	77.89	9.98	27.46	34.96	60.96	5.14	4.15	92.58	27.99	1.87	59.83	461.70	4.23	16.48
T_3	75.63	80.72	11.24	24.59	33.59	58.89	5.51	4.64	99.71	32.30	2.10	64.60	498.50	4.59	18.54
T_4	72.27	76.63	10.65	26.01	35.01	60.01	5.04	4.05	91.85	27.90	1.85	59.10	457.10	4.19	16.21
T_5	76.39	81.65	11.58	24.35	33.35	58.21	5.57	5.08	100.69	32.15	2.09	65.30	503.90	4.68	18.72
T_6	74.78	79.51	11.14	25.16	34.16	59.38	5.35	4.28	95.43	30.30	1.98	62.52	482.40	4.39	17.24
T_7	77.61	83.22	12.21	23.12	32.12	57.35	5.61	5.15	105.37	34.10	2.24	67.61	521.70	5.02	20.11
T_8	75.15	80.06	11.01	24.56	33.56	58.67	5.42	4.41	97.63	31.20	2.04	63.55	490.40	4.49	18.18
T_9	78.32	84.01	12.62	22.14	31.24	56.21	5.64	5.56	108.38	35.30	2.32	69.43	535.80	5.23	20.31
T_{10}	77.13	82.58	11.89	23.96	32.96	57.91	5.59	5.12	104.13	32.80	2.11	67.06	517.50	4.94	18.76
T_{11}	79.39	85.23	13.21	20.91	29.91	55.85	5.96	5.68	112.42	36.70	2.45	72.16	556.80	5.87	20.48
T_{12}	68.17	71.53	9.17	28.66	36.11	63.11	4.71	3.58	84.71	25.10	1.69	54.87	423.40	4.01	16.01
SE(m)±	2.20	2.39	0.33	0.71	0.98	1.74	0.15	0.13	2.89	0.96	0.06	1.88	14.55	0.13	0.54
CD (5%)	6.46	7.03	0.97	2.09	2.89	5.10	0.46	0.40	8.50	2.84	0.18	5.52	42.70	0.40	1.59
CV	5.94	6.07	5.96	5.83	5.96	5.95	5.99	5.90	5.91	6.24	6.07	5.95	5.95	5.92	6.04

Economics

Economic performance was evaluated in terms of gross return, net return and benefit-cost (B:C) ratio. The highest gross return (Rs. 501120/ha), net return (Rs. 409440/ha) and B:C ratio (4.47) was observed in GA 50 ppm + micronutrient mixture @ 0.5% (T_{11}) (Table 2). It was followed by GA 50 ppm + borax @ 0.2% (T_9) with gross return of Rs. 482220/ha, net return of Rs. 391320/ha and B:C ratio of 4.30. The lowest economic efficiency was noted under control treatment (T_1). The highest profitability under T11 is likely due to synergistic effects on fruit yield and quality, which amplify revenue relative to input costs. Comparable economic gains from combining GA with micronutrients have also been observed. Panjikar *et al*., (2023) [11].

Table 2: Effect of growth regulators and micronutrients on the economics of tomato.

S. No.	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
T_1	88500	431640	343140	3.88
T_2	88975	415530	326555	3.67
T_3	89280	448650	359370	4.03
T_4	89170	411390	322220	3.61
T_5	89550	453510	363960	4.06
T_6	90025	434160	344135	3.82
T_7	90330	469530	379200	4.20
T_8	90520	441360	350840	3.88
T_9	90900	482220	391320	4.30
T_{10}	91375	465750	374375	4.10
T_{11}	91680	501120	409440	4.47
T_{12}	88120	381060	292940	3.32

Conclusion

Based on the study, it can be inferred that the combined application of GA @ 50 ppm and micronutrient mixture @ 0.5% (T_{11}) was found significantly superior over all other treatments in terms of growth traits, yield attributes, yield, quality and economic returns. Hence, it may be recommended for tomato farmers for higher returns from tomato crop under central plain zone of Uttar Pradesh.

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