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Influence of Phytohormones on Growth, Yield and Quality of tomato (*Solanum lycopersicon* L.) in irrigated ecosystems of Punjab, India

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ABSTRACT

The present study was conducted at the research farm and Horticulture lab of Sant Baba Bhag Singh University, Punjab during the year 2020 and 2021. The experiment was conducted in a randomized block design comprising of 9 treatments (T_0 - Control, T_1 - GA_3 @ 20 ppm, T_2 - GA_3 @ 30 ppm, T_3 - GA_3 @ 40 ppm, T_4 - NAA @ 15 ppm, T_5 - NAA @ 20 ppm, T_6 - NAA @ 25 ppm, T_7 - GA_3 @ 30 ppm + NAA @ 20 ppm, T_8 - GA_3 @ 40 ppm + NAA @ 25 ppm) with three replications. Findings of the present study revealed that treatment T_8 - GA_3 @ 40 ppm + NAA @ 25 ppm resulted in highest number of leaves per plant (56), plant height (82.46 cm), number of flowers per plant (44.8), number of fruits (22.9), fruit diameter (5.83 cm), fruit weight (50.27 g), TSS (5.32 ^{o}Brix), fruit yield per plot (20.68 kg/plot) and fruit yield per hectare (344.69 q/ha). Hence, it is successfully established that the application of GA_3 + NAA can be helpful in enhancing the yield and quality parameters of tomato crop thereby, improving the socio-economic status of the tomato growers.

Key words: *Solanum lycopersicon, Phyto-hormones, Socio-economic status and Punjab*

Introduction

Tomato (*Solanum lycopersicon*) is a self-pollinated crop and belongs to the family Solanaceae, genus Solanum, kingdom Plantae, order Solanales, section lycopersicon with chromosome number 2n = 24. The cultivated tomato originated in Peruvian and Mexican region. Area and production of tomato in India is 852 thousand ha and 21003 MT, respectively (Horticulture Statistics Division, 2020-2021). Tomato is an excellent source of many nutrients and secondary metabolites; mineral matter, organic acids, phenolic (Elbadrawy *et al.,* 2016). The well ripe tomato (per 100 g of edible portion) contains energy (23 calories), calcium (1.0 g), magnesium (7.0 mg), vitamin A (1000 IU), ascorbic acid (22 mg), thiamin (0.09 mg), and niacin (0.8 mg) (Uddain *et al.,* 2009). It also contains high amount of lycopene (60-64%), phytoene (10-12%), neurosporene (7-9%), carotenes (10-15%) (Singh *et al.,* 2021).

Plant growth regulators are enormously used in horticulture to amplify the growth and development of plant and to increase yield. They play an important role in flowering, fruit setting, ripening, senescence and physio chemical properties of fruit during storage. The foliar spray of Plant Growth Regulators has also been observed to improve the yield quality of tomato (Choudhury *et al.,* 2013). Gibberellic acid (GA_3) is widely used in vegetable crops for improving fruit set. Spray of GA_3 at full-blossom stage can

offset the harmful effect of frost (Kazemi Mohsen 2014). Moreover, naphthalene acetic acid (NAA) helps in stimulate cell division, cell elongation, water uptake and cell differentiation which may initiate the development of plant organs. Foliar spray of NAA helps to increase total number of fruit per cluster, check abortion of young embryo and fruit drop in tomato (Ujjwal *et al.,* 2018). Thus in this context, studies were undertaken to assess the impact of foliar spray of GA_3 and NAA on growth and yield attributes of tomato.

Materials and Methods

The experiment was conducted during two consecutive seasons of 2020-2021 at research farm of Sant Baba Bhag Singh University, Khiala, Jalandhar. The area is located in the North-East part of the Punjab altitude of 31.42° N and longitude of 75.78° E and at an altitude of 254 meter above the sea-level. It is located in the fertile plains and on the intensively irrigated plain between the Beas and Sutlej rivers. Transplanting was done in October 2020 for first season and in May 2021 for second season at a spacing of 80 cm x 45 cm. The seedlings of Abhilash variety or hybrid of tomato was obtained from Centre of Excellence for Vegetables, Kartarpur, Jalandhar. The experiment was conducted in Randomized Block Design comprising of 9 treatments with 3 replications. Nine treatments were : T_0 - Control, T_1- GA_3 @ 20 ppm, T_2 - GA_3 @ 30 ppm, T_3 - GA_3 @ 40 ppm, T_4 - NAA @ 15 ppm, T_5 - NAA @ 20 ppm, T_6 - NAA @ 25 ppm, T_7 - GA_3 @ 30 ppm + NAA @ 20 ppm, T_8 - GA_3 @ 40 ppm + NAA @ 25 ppm. The foliar spray of GA_3 and NAA was done at 25, 45 and 65 days after transplanting, respectively during morning hours with the help of hand sprayer. Recommended cultural practices of growing Tomato were followed and recommended dose of fertilizers were applied i.e., N: P: K @ 55:155:45 kg/acre. Light irrigation was given immediately after transplanting. In each plot under three replication of every treatment, five plants were randomly selected and tagged for recording plant height (cm), no. of leaves, no. of branches, no. of leaves, no. of flowers per plant, no. of fruits per plant, fruit diameter (cm), yield per plot (kg) and yield per hectare (q/ha) during two seasons, respectively. Economics of tomato was also calculated on the basis of cost of cultivation, gross return (Rs/ha) and net return (Rs/ha). The data of two seasons was statistically analyzed in OPSTAT analysis tool for randomized block design. The critical difference was calculated at 5% level of significance for comparing treatment means.

Results and Discussion

Growth attributes

The findings of the study presented in Table 1 indicated that plant height was significantly influenced by different levels of GA_3 and NAA during both the years of study. During both the years maximum plant height (82.46 cm and 90.11 cm) was recorded in the treatment T_8 (GA_3 @ 40 ppm + NAA @ 25 ppm) whereas, minimum plant height (52.12 cm and 57.41 cm) was recorded in T_{0-} (control). Similarly, in mean analysis maximum plant height (86.28 cm) was recorded in T_8 and minimum plant height (54.77 cm) was recorded in $T_{0.}$ These findings are in close agreement with the results of Tomar *et al.* (2016) which reported that combined use of GA_3+NAA has significant effect on the growth of tomato plant.

Table 1. Effect of GA_3 and NAA on growth attributes of tomato

Treatments	Plant Height (cm)			No. of leaves			No. of branches		
	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean
Control	52.12	57.41	54.77	40.6	44.7	42.65	9.7	10.1	9.9
GA_3 @ 20 ppm	62.77	66.74	64.75	47.6	52.1	49.85	10.6	11.1	10.8
GA_3 @ 30 ppm	66.39	70.26	68.33	49.7	56.8	53.25	12.4	13.0	12.7
GA_3 @ 40 ppm	72.46	75.36	73.91	50.9	60.7	55.8	13.3	13.9	13.6
NAA @ 15 ppm	59.59	64.96	62.28	46.8	50.3	48.55	13.6	14.2	13.9
NAA @ 20 ppm	61.05	68.88	64.97	47.7	54.8	51.25	10.6	11.1	10.8
NAA @ 25 ppm	63.72	71.04	67.38	49	59.4	54.2	11.6	12.1	11.8
GA_3 @ 30 ppm + NAA @ 20 ppm	76.41	81.31	78.86	53.7	62.3	58	14.6	15.3	14.9
GA_3 @ 40 ppm + NAA @ 25 ppm	82.46	90.11	86.28	56	66.3	61.15	16.6	17.4	17.0
CD (5%)	1.88	2.54	2.86	0.93	1.45	1.56	0.36	0.72	0.21

During the first year significantly maximum number of leaves per plant (56) was produced by the application of GA_3 @ 40 ppm + NAA @ 25 ppm (T_8) in comparison to treatment T_0 which reported minimum number of leaves per plant (40.6). Similarly, during the second year significantly maximum number of leaves per plant (66.3) was produced in $T_8$and the minimum was observed in T_0 number of leaves per plant (44.7). Similar results were also observed by Gurjar *et al.* (2018) and Sattigeri *et al.* (2014) in tomato. Further, the findings predict that with increasing levels of GA_3 and NAA number of branches per plant has also increased significantly. It was observed that the plants treated GA_3 @ 30 ppm + NAA @ 25 ppm (T_8) reported maximum number of branches (16.67 and 17.0) per plant followed byGA_3 @ 30 ppm + NAA @ 20 ppm (T_7) (14.6 and 15.3), respectively. Whereas, the minimum number of branches (9.7 and 10.1) per plant was observed in the controlled plot (T_0). These findings of the study are in line with the findings of Singh *et al.* (2021) which reported higher number of branches per tomato plant with the application of GA_3 in combination with NAA.

Flowering and Fruiting

The data pertaining to the number of days of fruit initiation has been presented in Table 2. It was observed that with the increasing levels of GA_3 and NAA the number of days required for fruit initiation during both the years reduced significantly. It was observed that Treatment T_8 (GA_3 @ 40 ppm + NAA @ 25 ppm) took minimum number of days (60.6) to initiate fruit setting while, the plants treated with water spray (Control T_0) were reported to have the maximum number of days (70.7) required for fruit setting during the first year of growth. Furthermore, during the second year treatment T_8 was found to be most superior and reported the minimum number of days required for fruit initiation, i.e. 52.8 days followed by T_7 54.6 days. However, under water spray treatment (T_0) tomato took 65.3 days for fruit initiation. The finding of the study are in close confirmation with the findings of Ujjwal *et al.* (2018) in tomato and Moniruzzaman *et al.* (2014) in brinjal. The application of varying concentrations of GA_3 and NAA resulted in a significant difference in the quantity of flowers per plant in tomato. Higher concentrations of GA_3 and NAA were found to be effective in increasing the number of flowers per plant. The result demonstrated that during the first season of growth treatment T_8, i.e. GA_3 @ 40 ppm + NAA @ 25 ppm, produced the maximum number of flowers (44.8) whereas, the minimum numbers of flowers (33.7) during the first year of growth was reported from treatment T_0(control). Similarly, during second year of growth treatment T_8, i.e. GA_3 @ 40 ppm + NAA @ 25 ppm reported the highest number of flowers per plant (54.5) whereas, the control treatment (T_0) reported the minimum number of flowers (39.7). Similar, results were also reported by Verma *et al.* (2014). Further, the application of varying amounts of GA-$_3$ and NAA also resulted in significant fluctuations in the quantity of fruits produced by tomato plants. It was observed that treatment T_8 (GA_3 @ 40 ppm + NAA @ 25 ppm) produced maximum number of fruits (22.9 and 34.4) during both years of the study, whereas, T_0 (Control) resulted in minimum quantity of fruits (10.4 and 19.4) during both the seasons.

The findings of the current study revealed that in both single and combined applications, GA_3 and

Table 2. Effect of GA_3 and NAA on number of days to fruit initiation, no. of flowers per plant and no. of fruits per plant

Treatments	No. of days to fruit initiation			No. of flowers per plant			No. of fruits per plant		
	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean
Control	70.7	65.3	68.0	33.7	39.7	36.7	10.4	19.4	14.9
GA_3 @ 20 ppm	66.6	61.1	63.85	37.9	42.5	40.2	15.4	25.6	20.5
GA_3 @ 30 ppm	64.9	59.3	62.1	39.8	47.1	43.45	17.1	28.8	22.95
GA_3 @ 40 ppm	63.6	56.4	60	40.9	49.6	45.25	18.1	29.6	23.85
NAA @ 15 ppm	65.6	60.5	63.65	39.2	44.7	41.95	16.6	26.1	21.35
NAA @ 20 ppm	62.6	57.3	59.95	36.9	46.6	41.75	14.6	24.3	19.47
NAA @ 25 ppm	63.6	55.4	59.5	41.9	50.5	46.2	18.8	27.8	23.3
GA_3 @ 30 ppm + NAA @ 20 ppm	61.5	54.6	58.05	43.2	52.5	47.85	20.5	30.5	25.5
GA_3 @ 40 ppm + NAA @ 25 ppm	60.6	52.8	56.7	44.8	54.5	49.65	22.9	34.4	28.65
CD (5%)	0.69	1.14	1.21	2.15	2.89	3.26	3.03	4.42	4.844

NAA had a significant impact on the percentage of fruit set during both the years (Table 3). The increased number of fruits per plant in treatment T_8 is owing to higher number of flowers per plant. Further, as a fact, that GA_3 and NAA aids in the plant's reproductive growth which in turn trigger fruit setting and therebyresults in higher fruit set percentage. The results in the present study revealed that during both the years the fruit set percentage was significantly higher (63.12% and 50.18%) in treatment T_8, i.e. GA_3 @ 40 ppm + NAA @ 25 ppm. However, the proportion of fruit set was significantly lower (30.95%) in the treatment T_0 (control). Similar results were also reported by Singh *et al.* (2021) and Rahman *et al.* (2015) which predicted that foliar application of GA_3 + NAA resulted in increased fruit set percentage in tomato. Similarly, GA_3 and NAA have also been observed to have a substantial impact on the growth of fruit diameter during both the years. The results revealed that the treatment T_8 (GA_3 @ 40 ppm + NAA @ 25 ppm) reported a maximum fruit diameter of 5.83 cm and 6.9 cm during both the years. However, the smallest fruit diameter (2.33 cm and 3.33 cm) was recorded under the T_1 treatment (control) during both the seasons. This may be due to the fact that bio-regulators, in particular gibberellins, are known to affect both cell division and cell enlargement, hence, the increase in fruit diameter can be accompanied due to the stimulatory effect of GA_3. These results are in close agreement with the findings of Gupta and Patel (2020) who reported that foliar application of GA_3 and NAA increased fruit diameter in case of tomato. The mean data on fruit diameter presented in Table 3 revealed that the maximum fruit weight of 50.27 g and 55.27 g, respectively was reported under treatment T_8 i.e. GA_3 @ 40 ppm + NAA @ 25 ppm during both the years of study. Similarly, for the pooled analysis, maximum fruit weight (52.77 g) was recorded under treatment T_8. This may be due to the application of GA_3 and NAA growth regulators can stimulate the fruit development and hence resulted in increased fruit weight. Furthermore, minimum fruit weight of 25.34 g and 28.26 g was reported under treatment T_0 (water spray). The results are in close concurrence with the findings of Gurjar *et al.,* (2018) which revealed that foliar spray of GA_3 and NAA helps increasing the fruit weight in tomato.

Yield and Quality Attributes

The yield per hectare of tomato was significantly influenced by the different levels of GA_3 and NAA in comparison to control (Table 4). The findings of the study presented that during both the years, maximum fruit yield per hectare (344.6 q/ha and 486.4 q/ha) was recorded in treatment T_8 (GA_3 @ 40 ppm + NAA @ 25 ppm). While the treatment T_0 (control) recorded the lowest yield per hectare (110.4 q/ha). Also as per the pooled analysis treatment T_8 had recorded the maximum yield per hectare (415.6 q/ha). Hence, the results are in close concurrence with the findings of Ujjwal *et al.*(2018) and Mukati *et al.* (2019) in tomato. Further, in the data pertaining to the fruit TSS, GA_3 and NAA were found to have no effect or minimum effect of fruit TSS during both the years of the study. It was observed that the quality of solids dissolved in the tomato's liquid portion regarded as fruit total soluble solids (TSS), were found to be maximum (5.32 ^{o}Brix) in treatment T_8 (GA_3 @ 40 ppm + NAA @ 25 ppm) during first year while the treatment T_0 (control) reported the lowest TSS (3.58^{o}Brix) content in first year. Pooled data showed that maximum TSS (5.83) was recorded from fruits harvested under treatment T_8 whereas, minimum

Table 3. Effect of GA_3 and NAA on fruit set percentage (%), fruit diameter (cm) and average fruit weight (g) of tomato

Treatments	Fruit set percentage (%)			Fruit diameter (cm)			Average fruit weight (g)		
	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean
Control	30.95	48.87	39.86	2.33	3.33	2.83	25.34	28.26	26.79
GA_3 @ 20 ppm	40.36	60.24	50.31	3.47	4.77	4.12	39.55	42.55	41.05
GA_3 @ 30 ppm	42.18	61.15	51.66	4.02	5.35	4.69	43.76	45.36	44.56
GA_3 @ 40 ppm	44.06	59.68	51.86	4.36	5.86	5.11	46.74	48.14	47.44
NAA @ 15 ppm	43.09	58.39	50.75	2.67	4.4	3.54	35.09	39.23	37.16
NAA @ 20 ppm	39.2	52.14	45.68	3.67	4.73	4.2	35.16	38.69	36.93
NAA @ 25 ppm	43.97	55.05	49.52	3.81	3.87	3.84	38.73	40.73	39.73
GA_3 @ 30 ppm + NAA @ 20 ppm	47.69	58.09	52.86	5.06	6.01	5.34	48.13	51.13	49.63
GA_3 @ 40 ppm + NAA @ 25 ppm	50.18	63.12	56.64	5.83	6.9	6.37	50.27	55.27	52.77
CD (5%)	2.76	3.70	4.17	0.62	0.97	1.04	3.548	4.463	5.156

TSS (3.75) was recorded under T_0(control). The results are in close agreement with findings of Naz *et al.,* (2020) and Gupta *et al.,* (2018). Similarly, the analysis of data related to the titrable acidity revealed that acidity percentage was significantly affected by various treatments of GA_3 and NAA. The lowest percentage of acidity (0.24% and 0.26%) was recorded by treatment T_8 (GA_3 @ 40 ppm + NAA @ 25 ppm) during both the years. The maximum percentage of acidity (0.44% and 0.40%) was recorded with the treatment T_0 (control). The results are in close concurrence with the discoveries of Gupta *et al.* (2018) who reported that application of NAA and GA_3 gave minimum titrable acidity.

Economic Analysis

Input cost for land preparation, seedling cost, fertilizer and manure cost, labor cost, irrigation cost, intercultural operation cost, treatment cost, harvesting and packaging cost of tomato were recorded for unit plot for both the seasons individually and converted into cost per hectare. Prices for tomatoes were evaluated using market rates. In the current research work, economic analysis was done to determine the gross and net return as well as the benefit : cost ratio.

The gross and net returns per hectare from tomato are presented in Table 5 revealed that the highest gross income per hectare of Rs. 485472/- was recorded in the treatment T_8 (GA_3@ 40 ppm + NAA @ 25 ppm) during the second year of growth. However, during the first year the highest gross income per hectare of Rs. 462354/- was recorded in the treatment T_8. Whereas, the lowest gross income per hectare of Rs. 233015/- was recorded in treatment T_0 (control) during the first year and Rs. 244666/- during the second year. Hence, the highest net returns per hectare of Rs. 351696/- was recorded in the treatment T_8 during the second year and Rs. 328579/- during the first year. On the other hand, the lowest net returns per hectare of Rs. 104690/- and Rs. 116341 was recorded in treatment T_0 (control) during both the years of study.

The B:C ratio was calculated and represented in Table 5 revealed that maximum benefit cost ratio (2.63) was recorded in treatment T_8 (GA_3 @ 40 ppm

Table 4. Effect of GA_3 and NAA on yield and quality attributes of tomato

Treatments	Yield per hectare (q/ha)			TSS (°Brix)			Titrable acidity (%)		
	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean
Control	110.4	173.6	141.9	3.58	3.92	3.75	0.44	0.40	0.42
GA_3 @ 20 ppm	193.6	235.3	214.44	4.09	4.88	4.49	0.39	0.36	0.38
GA_3 @ 30 ppm	222.6	296.0	259.35	4.27	5.1	4.68	0.35	0.32	0.34
GA_3 @ 40 ppm	263.3	346.7	305.02	4.83	5.7	5.27	0.32	0.30	0.31
NAA @ 15 ppm	181.1	204.5	192.87	4.17	4.48	4.33	0.42	0.41	0.42
NAA @ 20 ppm	211.3	258.1	234.69	4.02	4.68	4.35	0.38	0.35	0.37
NAA @ 25 ppm	234.1	310.8	272.4	4.68	5.24	4.96	0.33	0.30	0.32
GA_3 @ 30 ppm + NAA @ 20 ppm	295.2	395.1	345.19	5.03	5.96	5.50	0.30	0.29	0.3
GA_3 @ 40 ppm + NAA @ 25 ppm	344.6	486.4	415.61	5.32	6.34	5.83	0.26	0.24	0.25
CD (5%)	3.14	4.44	4.92	0.26	0.86	0.82	0.09	0.10	0.13

Table 5. Economic analysis of tomato cultivation as influenced by different concentrations of GA_3 and NAA

Treatments	Total Cost (Rs/ha)		Gross Returns (Rs/ha)		Net Returns (Rs/ha)		B:C ratio
	2020	2021	2020	2021	2020	2021	
Control	128325	233015	244666	104690	116341	0.82	0.91
GA_3 @ 20 ppm	130505	316523	332349	186018	201844	1.43	1.55
GA_3 @ 30 ppm	131165	327821	344212	196656	213047	1.50	1.62
GA_3 @ 40 ppm	131825	356142	373949	224317	242124	1.70	1.84
NAA @ 15 ppm	130085	382563	401691	252478	271606	1.94	2.09
NAA @ 20 ppm	130375	410325	430841	279950	300466	2.15	2.30
NAA @ 25 ppm	130675	413654	434337	282979	303661	2.17	2.32
GA_3 @ 30 ppm + NAA @ 20 ppm	132815	423672	444856	290857	312040	2.19	2.35
GA_3 @ 40 ppm + NAA @ 25 ppm	133775	462354	485472	328579	351696	2.46	2.63

+ NAA @ 25 ppm) during the second season and (2.46) during the first year because of their lower cost of input and higher yield, these treatments are more profitable whereas the minimum cost benefit ratio was recorded in treatment T_0 (control) which may be due to lower yield. From an economic standpoint, it is clear that GA_3 @ 40 ppm + NAA @ 25 ppm were more profitable than the other treatments used in the study (Table 5).

Conclusion

Based on the results obtained in this study, it can be inferred that the treatment T_8 - foliar spray of GA_3 @ 40 ppm + NAA @ 25 ppm applied at 25, 45 and 65 days after transplanting was recorded higher values for plant growth, flowering initiation, fruit setting, average fruit weight (g), yield per plot (kg/plot), yield per hectare (q/ha), TSS (°Brix) and titrable acidity (%). Similarly, the economic analysis of present investigation revealed that the treatment T_8 gave the highest net returns per hectare of Rs. 328579/- and the maximum benefit cost ratio (2.46) was recorded in treatment T_8 (GA_3 @ 40 ppm + NAA @ 25 ppm) because of its lower cost of input and higher yield, this treatment is more profitable. Therefore, from an economic standpoint, it can be concluded that treatment T_8 GA_3@ 40 ppm + NAA @ 25 ppm was the most profitable for farmers than the other treatments used in this study. Therefore, the treatment T_8 can be helpful to the farmers in enhancing the yield and quality parameters of tomato crop. Further, it would also be helpful for doubling their income and enhance their socio-economic status.

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