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Effects of Plant Growth Regulators on Morphophysiology and Yield of Tomato

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is a major vegetable crop of Bangladesh and globally valued for its nutritional and economic importance. However, its yield potential is often limited by sub-optimal growth and physiological performance. Plant growth regulators (PGRs) such as gibberellic acid (GA_3), salicylic acid (SA), and methyl jasmonate (MeJA) play vital roles in regulating plant morphophysiology, flowering, fruit development, and yield. A field experiment was conducted during 2022–2023 at the research farm of Sher-e-Bangla Agricultural University, Dhaka, to investigate the effects of GA_3, SA, and MeJA, either alone or in combination, on tomato growth and yield. The experiment was laid out in a randomized complete block design with seven treatments and four replications. Results revealed that 20 ppm GA_3 significantly increased plant height (82.64 cm), whereas GA_3 combined with MeJA(20 ppm GA_3 + 10 ppm MeJA) improved leaf number (54.59 leaves plant $^{-1}$), SPAD value (54.09), flower clusters plant $^{-1}$ (10.78), fruit diameter (16.03 cm), single fruit weight (52.87 g), number of fruits plant^{-1} (37.41), fruit weight plant^{-1} (kg) (2.91 kg), fruit weight plot^{-1} (17.77 kg) and the highest fruit yield ha^{-1} (70.86 t) while GA_3 combined with SA, MeJA combined SA or control produced the lowest yield (58.95 t ha^{-1}). These findings suggest that the combined application of GA_3 and MeJA is more effective than individual application or control, and may be recommended as a promising strategy to enhance tomato productivity under the edaphic and agro-climatic conditions of Bangladesh at Sher-e-Bangla Agricultural University (SAU).

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Introduction

Tomato (*Solanum lycopersicum L.*) is a fruit vegetable that belongs to the family Solanaceae. It is a self-pollinated vegetable and the most popular and widely grown vegetable in the world, ranking second after potato (Prasad et al., 2013). Tomatoes have a significant role in human nutrition. It is a rich source of minerals and vitamins, including ascorbic acid and carotene, which are antioxidants that promote good health (Wilcox et al., 2003). Tomatoes can make people healthier and decrease the risk of conditions such as cancer, osteoporosis and cardiovascular disease. People who eat tomatoes regularly have a reduced risk of contracting cancer diseases such as lung, prostate, stomach, cervical, breast, oral, colorectal, esophageal, pancreatic, and many other types of cancer (Bhowmik et al., 2012). The red pigment of tomato contains lycopene, a newly discovered bioflavonoid that acts as an anticancer agent (Bhowmik et al., 2012). Therefore, it is of great importance to human health. The lower yield of tomato in Bangladesh, however, is not an incidence of the low yielding potentiality of this crop but of the fact that the lower yield may be attributed to a number of reasons viz. unavailability of quality seeds of improved varieties, fertilizer management, disease infestation and improper moisture management and lack of knowledge about the use of plant growth regulators (PGRs) in tomato to improve fruit yield To overcome low yield potentiality of tomato, plant growth regulators may be considered as a yield promoting substances. Plant growth regulators (PGRs) are natural or synthetic chemicals that are sprayed or otherwise applied to a seed or plant in order to alter its characteristics. Sometimes it is referred to as plant hormones. Plant growth regulators function as chemical messengers for intercellular communication (Pramanik and Mohapatra, 2017). In tomato, growth regulators like GA_3 play a pivotal role in germination, root development, branching, flower initiation, fruiting, lycopene development, synchronization and early maturation, parthenocarpic fruit development, ripening, TSS, acidity, seed production etcetera (Pramanik et al., 2017). Salicylic acid (SA) is an endogenous plant growth regulator of phenolic nature that enhances plant resistance to pathogens and other stresses (Rao et al., 2000).

In addition to providing resistance to plant diseases, SA has also been found to induce tolerance to than some abiotic stresses such as drought (Hayat et al., 2008), heat (Larkindale and Huang, 2004), salinity (Shakirova et al., 2003), chilling (Taşgin et al., 2003), heavy metal (Metwally et al., 2003; Choudhury and Panda, 2004) and UV radiation (Rao and Davis, 1999). Moreover, SA plays role in the regulation of some physiological processes such as seed germination, fruit yield, glycolysis, flowering in the morphogenic plants, nutrient uptake and transport, photosynthetic rate, stomatal conductance and transpiration (Hayat et al., 2010). Jasmonic acid (JA) is an another plant growth regulators that play an important role in plant development and physiological processes such as seed germination, root growth, flowering, ripening, senescence, photosynthesis, the formation of gum and bulb, defense response against pathogens and insect attack, plant response to wound and abiotic stresses (Maciejewska et al., 2004; Choi et al., 2005; Kim et al., 2009; Warabieda et al., 2010). In addition, MeJA induces or increases the biosynthesis of many secondary metabolites that play important roles in plant adaptation to particular adverse environments (Choi et al., 2005). Ester of JA is MeJA, which has been used in agriculture to achieve a desirable crop yield. Considering the above facts, this study was undertaken to investigate the effects of plant growth regulators on the morphophysiology and yield of tomato.

Materials and methods

The test crop was BARI tomato-15, a high-producing tomato (*Solanum lycopersicum Mill.*) variety produced by the Bangladesh Agricultural Research Institute (BARI), Gazipur. Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur, Bangladesh, provided the seeds. This cultivar is resistant to the Yellow Leaf Curl Virus. It is a winter cultivar with a good yield. The experiment was conducted at experimental field of Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during July, 2022 to May, 2023. The experiment used Randomized Complete Block Design (RCBD), with four replications and total 28 plots. This was a one factorial experiment with treatments T_1, T_2, T_3, T_4, T_5, T_6 and T_7 where used different concentration of GA_3, SA and MeJA. Urea, Triple superphosphate (TSP), and Muriate of potash (MoP) were used to supply N, P, and K, respectively. Cowdung that has rotted is also used according to Krishi Projukti Hat Boi (2016). Different plant growth regulators (GA_3, SA, and MeJA) were applied at 15-day intervals and at 20, 35, and 50 days following transplantation, depending on the treatments. After seedling establishment, various intercultural operations were carried out to improve tomato growth and development. Fruits were picked every 5 days from maturity until ripening. The crop's ripeness was evaluated by the fruits' red coloration. Ten plants were randomly selected from each unit plot to measure crop parameters, and yield was calculated on a per-plot basis. During the study, the following parameters were recorded: plant height (cm), number of leaves plant^{-1}, SPAD value, number of flower cluster plant^{-1}, number of flowers cluster^{-1}, number of fruits cluster^{-1}, fruit length (cm), fruit diameter (cm), single fruit weight (g), number of fruits plant^{-1}, fruit weight plant^{-1} (g), fruit yield plot^{-1} (kg), fruit yield (t ha^{-1}). The data obtained for different characters were statistically analyzed to observe the significant difference among the treatment by using the Statistix-10 computer package program. The mean values of all the characters were calculated and analysis of variance was performed. The significance of the difference among the treatment means was estimated using the Least Significant Difference Test (LSD) at the 5% level of probability (Gomez and Gomez, 1984).

Results and discussion

Plant height

Except at 25 DAT, plant height of tomato differed greatly due to several growth regulators (Table 1). The treatment T_2 (20 ppm GA_3) produced the maximum plant height (31.48 cm) at 25 DAT, while the control treatment (T_1) produced the lowest plant height (26.59 cm).T_2 (20 ppm GA_3) produced the tallest plant (67.56 cm) at 45 DAT, which was substantially different from all other treatments, while T_1 (Control) produced the smallest plant (45.30 cm). At 65 DAT, T_2 (20 ppm GA_3) produced the maximum plant height (82.64 cm), while T_1 (Control) produced the lowest plant height (73.30 cm), which was statistically equivalent to T_6 (20 ppm GA_3 + 10 ppm MeJA). GA_3 outperformed the solitary application of SA or MeJA in tomato lengthening. To raise tomato plant height, GA_3 activity is also somewhat reduced by SA or MeJA. Jakhar et al. (2018), Rahman et al. (2015b), and Sattigeri et al. (2014) found similar plant height results. These findings imply that GA_3, SA, and MeJA improved tomato plant height.

Table 1. Plant height of tomato as influenced by plant growth regulators

Treatment	Plant height (cm)		
	25 DAT	45 DAT	65 DAT
T_1	26.59	45.30 e	73.30 c
T_2	31.50	67.56 a	82.64 a
T_3	29.56	52.55 b	75.65 b
T_4	30.32	51.90 bc	75.69 b
T_5	29.96	49.44 d	75.64 b
T_6	27.56	50.27 cd	74.26 bc
T_7	30.54	51.68 bc	75.97 b
$LSD_{0.05}$	NS	1.78	2.09
Significant level	NS	*	*
CV (%)	9.07	6.83	8.31

* = Significant at 5% level** = Significant at 1% level

Number of leaves plant^{-1}

As plant height, the number of leaves plant^{-1} at 25 DAT was not substantially influenced by different growth regulators; however, a significant influence on the number of leaves plant^{-1} affected by different growth regulators was recorded at both 45 and 65 DAT (Table 2). At 25 DAT, the treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) produced the most leaves plant^{-1} (11.01), while T_3 (100 ppm SA) produced the fewest (10.18). At 45 DAT, the treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) had the highest number of leaves plant^{-1} (19.01), which was significantly different from all other treatments, but the treatment T_1 (Control) had the lowest number of leaves plant^{-1} (16.59), which was statistically identical to the treatment T_3 (100 ppm SA). At 65 DAT, the largest number of leaves plant^{-1} (54.59) was obtained from T_6 (20 ppm GA_3 + 10 ppm MeJA), followed by T_4 (10 ppm MeJA), while the lowest number of leaves plant^{-1} (47.01) was obtained from T_3 (100 ppm SA), followed by T_1 (Control).These findings contradict the plant height to the identical treatment (Table 1). The T_6 treatment had the most leaves per plant, while the T2 treatment had the tallest plants. These findings indicate that using GA_3 alone did not yield the maximum number of leaves or the highest plant height in this experiment. The current study's findings on the number of leaves plant^{-1} were similar to those of Jakhar et al. (2018), Sattigeri et al. (2014), and Kazemi (2013).

SPAD value

In this study, I examined tomato leaf SPAD as an indication of chlorophyll content. SPAD value at 25 DAT was not significantly changed by different growth regulators, however at 45 and 60 DAT, considerable influence on SPAD value was documented (Table 3). At 25 DAT, the treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) had the greatest SPAD value (50.75), while T_1 (Control) had the lowest (50.02). At 45 DAT, the treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) had the highest SPAD value (55.73), which was statistically identical with the treatment T_7 (100 ppm SA + 10 ppm MeJA) and statistically similar with the treatments T_2 (20 ppm GA_3) and T_5 (20 ppm GA_3 + 100 ppm SA). The T1 (Control) treatment had the lowest SPAD value (45.02) at 45 DAT, which was substantially lower than all other treatments, followed by T_5 (20 ppm GA_3 + 100 ppm SA). At 60 DAT, the treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) had the highest SPAD value (54.09), which was statistically identical to the treatment T_7 (100 ppm SA + 10 ppm MeJA), which had the lowest SPAD value (45.84). As a result, our findings indicate that SPAD levels increase in the presence of plant growth regulators, such as GA_3, SA, and MeJA.

Table 2. Number of leaves plant^{-1} of the tomato as influenced by plant growth regulators

Treatment	Number of leaves plant $^{-1}$		
	25 DAT	45 DAT	65 DAT
T_1	10.43	16.59 c	48.43 e
T_2	10.43	18.09 b	52.84 bc
T_3	10.17	16.85 c	47.01 f
T_4	10.84	17.18 bc	53.43 b
T_5	10.68	18.01 b	52.34 cd
T_6	11.01	19.01 a	54.59 a
T_7	10.26	17.18 bc	51.68 d
$LSD_{0.05}$	1.58	0.88	0.90
Significant level	NS	*	*
CV (%)	10.65	10.21	6.60

* = Significant at 5% level** = Significant at 1% level

Table 3. SPAD value of tomato as influenced by plant growth regulators

Treatment	SPAD value		
	25 DAT	45 DAT	60 DAT
T_1	50.02	45.02 d	45.84 d
T_2	50.37	54.18 ab	50.39 c
T_3	50.18	53.09 b	52.54 b
T_4	50.42	51.07 c	52.86 b
T_5	50.38	54.12 ab	52.43 b
T_6	50.75	55.73 a	54.09 a
T_7	50.44	55.05 a	54.04 a
$LSD_{0.05}$	1.54	1.67	1.12
Significant level	NS	*	*
CV (%)	6.21	6.50	5.39

* = Significant at 5% level** = Significant at 1% level

Number of flower clusters plant^{-1}

The number of flower clusters produced by plant-1 varied significantly across growth regulator treatments (Table 4). When growth regulators were used, the number of flower clusters per plant-1 increased compared to the control. The treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) demonstrated the highest number of flower cluster plant^{-1} (10.78), which was statistically identical with the treatments T_2 (20 ppm GA_3) and T_5 (20 ppm GA_3 + 100 ppm SA), whereas the control treatment (T_1) demonstrated the lowest number of flower cluster plant^{-1} (7.76). These findings are nearly comparable with the morphological parameters of tomato plant height and leaf number per plant (Tables 1 and 2). Jones et al. (2014), Choudhury et al. (2013), and Rezende and Ayub (2010) found similar results. As a result, our findings imply that using plant growth regulators increases the number of flower clusters per plant through altering morphological characteristics.

Number of flowers cluster^{-1}

The number of blooms cluster^{-1} varied significantly as a result of several growth regulators (Table 4). When growth regulators were used, the number of floral cluster^{-1} increased when compared to the control. T_5 (20 ppm GA_3 + 100 ppm SA) had the largest number of flower cluster^{-1} (7.79), which was statistically identical with T_6 (20 ppm GA_3 + 10 ppm MeJA) and statistically similar with T_7 (100 ppm SA + 10 ppm MeJA). The control treatment (T_1) had the fewest flower cluster^{-1} (6.56) followed by T_3 (100 ppm SA) and T_4 (10 ppm MeJA). These findings are also consistent with the number of flower clusters per plant in this study's different treatments (Table 4). Jones et al. (2014), Rezende and Ayub (2010), Afsana et al. (2017), and Kowalska and Smolen (2013) discovered similar results. As a result of these findings, GA_3, in combination with SA or MeJA, increases the number of tomato flowers.

Number of fruits cluster^{-1}

The number of flower clusters per plant has a substantial influence on the number of fruits cluster^{-1} altered by various growth regulators (Table 4). The treatment T_5 (20 ppm GA_3 + 100 ppm SA) had the highest number of fruits cluster^{-1} (5.55), which was statistically identical to the treatment T_6 (20 ppm GA_3 + 10 ppm MeJA), while T_3 (100 ppm SA), T_4 (10 ppm MeJA), and T_1 (Control) had the lowest number of fruits cluster^{-1} (4.32). As a result, it suggests that tomato fruits are more abundant in the presence of plant growth regulators than in their absence. Rezende and Ayub (2010) and Afsana et al. (2017) found similar results, which validated the current findings.

Fruit length

Fruit length varied widely across treatments with different growth regulators (Table 4). The treatment T_2 (20 ppm GA_3) produced the longest fruit (8.91 cm), which was significantly different from all other treatments, followed by T_6 (20 ppm GA_3 + 10 ppm MeJA), while the treatment T_1 (Control) produced the shortest fruit (8.64 cm), which was statistically identical with the treatment T_3 (100 ppm SA) and statistically similar with the treatment T_5 (20 ppm GA_3 + 100 ppm SA). It suggests that using plant growth regulators increases tomato fruit length compared to the control condition. Jakhar et al. (2018) and Desai et al. (2012) found similar results, lending credence to the current study.

Fruit diameter

Significant variation in fruit diameter was observed across different growth regulators (Table 4). The treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) produced the largest fruit diameter (16.03 cm), which was substantially larger than that of all other treatments, followed by T_5 (20 ppm GA_3 + 100 ppm SA). The T1 (Control) treatment had the smallest fruit diameter (12.71 cm), followed by T_2 (20 ppm GA_3). Jakhar et al. (2018) and Sattigeri et al. (2014) reported findings similar to those of the current study.

Table 4. Yield contributing parameters of tomato as influenced by plant growth regulators

Treatment	Yield contributing parameters				
	Number of flowers clusters plant^{-1}	Number of flowers Cluster^{-1}	Number of fruits Cluster^{-1}	Fruit length(cm)	Fruit diameter (cm)
T_1	7.76 e	6.56 d	4.83 c	8.64 d	12.71 e
T_2	10.51 a	7.41 b	5.24 b	9.92 a	14.53 d
T_3	9.84 b	7.07 c	4.32 d	8.70 d	15.23 c
T_4	8.77 d	6.88 c	4.65 c	9.13 c	15.25 c
T_5	10.50 a	7.79 a	5.55 a	8.90 cd	15.69 b
T_6	10.78 a	7.75 a	5.52 a	9.58 b	16.03 a
T_7	9.18 c	7.48 ab	5.17 b	9.04 c	15.54 bc
$LSD_{0.05}$	0.41	0.30	0.23	0.28	0.31
Significant level	*	**	*	*	*
CV (%)	6.33	11.40	7.77	8.16	8.29

* = Significant at 5% level, ** = Significant at 1% level

Single fruit weight (g)

The weight of a single fruit varied significantly across growth regulators (Table 5). The treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) had the highest single-fruit weight (52.87 g), which was not statistically different from treatment T_2 (20 ppm GA_3). The T1 (Control) treatment had the smallest single-fruit weight (50.91 g), which was not statistically different from that of T_7 (100 ppm SA + 10 ppm MeJA). The current study's findings on single fruit weight were similar to those of Choudhury et al. (2013) and Ayub and Rezende (2010). These findings are also consistent with the studies morphological and yield contributing characteristics.

Fruit weight plant^{-1} (kg)

Fruit weight plot^{-1} varied dramatically as a result of several growth regulators (Table 5). The treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) produced the largest fruit weight plant^{-1} (1.90 kg), which was statistically identical to the treatment T_2 (20 ppm GA_3). The treatment T_1 (Control) produced the smallest fruit weight per plant (2.57 kg), which was not significantly different from that of T_3 (100 ppm SA). Jakhar et al. (2018), Kumar et al. (2018), Kazemi (2013), and Rahimi et al. (2013) reported similar results, supporting the current study. These findings are also consistent with other study characteristics, such as morphology, single-fruit weight (g), and number of fruits per plant. As a result, these findings imply that plant growth regulators boost tomato fruit yield.

Fruit weight plot^{-1}

Fruit weight plot^{-1} was significant when using various growth regulators (Table 5). The treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) produced the highest fruit weight plot^{-1} (17.77 kg), which was statistically identical to the treatment T_2 (20 ppm GA_3). The treatment T_1 (Control) had the lowest fruit weight in plot 1 (12.92 kg), followed by T_3 (100 ppm SA). Similar results were reported by Jakhar et al. (2018), Kumar et al. (2018), Kazemi (2013), and Rahimi et al. (2013), which validated the current study. These findings are also consistent with other study characteristics, such as morphology, single-fruit weight (g), and number of fruits per plant. As a result, these findings imply that plant growth regulators boost tomato fruit yield.

Fruit yield (t ha^{-1})

Fruit yield ha^{-1} (t) was significant with the administration of several plant growth regulators as fruit plant^{-1} (Table 5). The treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) produced the highest fruit yield (70.86 t ha-1), which was not statistically different from that of T_2 (20 ppm GA_3). The treatment T_1 (Control) produced the lowest fruit yield (58.95 t ha-1), followed by treatment T_3 (100 ppm SA). It was also discovered that the maximum fruit production per hectare from treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) was associated with the same treatment's top results for single fruit weight, number of fruits plant^{-1}, fruit weight plant^{-1}, and fruit weight plot^{-1}. The fruit yield ha^{-1} values were comparable to those obtained by Jakhar et al. (2018), Kumar et al. (2018), Kazemi (2013), and Rahimi et al. (2013). These findings are also consistent with criteria from other studies, including morphology, single-fruit weight (g), fruit length (cm), and fruit diameter (cm) (Tables 4 and 5). As a result, these findings imply that plant growth regulators boost tomato fruit yield.

Table 5. Yield parameters of tomato as influenced by plant growth regulators

Treatment	Yield parameters			
	Single fruit weight (g)	Fruit weight plant^{-1} (kg)	Fruit weight plot^{-1} (kg)	Fruit yield t/ha
T_1	50.91 c	2.57 d	14.92 d	58.95 d
T_2	52.80 a	2.84 a	17.30 a	68.86 a
T_3	52.52 ab	2.63 cd	15.43 c	61.11 c
T_4	52.01 b	2.73 b	16.20 b	64.29 b
T_5	52.51 ab	2.74 b	16.45 b	65.33 b
T_6	52.87 a	2.91 a	17.77 a	70.86 a
T_7	51.31 c	2.71 bc	16.13 b	64.01 b
$LSD_{0.05}$	0.55	0.08	0.47	2.10
Significant level	*	**	*	*
CV (%)	8.17	7.29	9.64	10.63

* = Significant at 5% level, ** = Significant at 1% level

Conclusion

Based on the findings, treatment T6 (20 ppm GA3 + 10 ppm MeJA) produced the greatest results across most yield- and yield-contributing parameters. In terms of tomato yield, treatments T_6 (20 ppm GA_3 + 10 ppm MeJA) and T_5 (20 ppm GA_3 + 100 ppm SA) produced statistically identical results, while T_6 (20 ppm GA_3 + 10 ppm MeJA) produced the highest yield. As a result, this treatment T_6 (20 ppm GA_3 + 10 ppm MeJA) can be considered the best of the treatments investigated during the crop period.

Authors Contribution

The study was planned and designed by P.A.B. Data collection and fieldwork were done by P.A.B. and S.R. Statistical analysis was done by M.A.R.O. The manuscript was written and organized by P.A.B., S.R. and A.A. The final text was reviewed, modified, and approved by all authors.

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