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Influence of seed priming and foliar application of GA3 on fruit morphology and biochemical composition of tomato in Gangetic Alluvial Zone

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ABSTRACT

Among the vegetable crops, tomato is one of the most important for the human diet. It is also important to get quality fruit and more nutritious materials. With the above consideration, the present investigation was carried out with the BCT-25 genotype of tomato seeds treated with different priming treatments with the objective to enhance the different qualities of fruits. The seed was primed with different priming materials like Moringa leaf extract (T1) for eighteen hours; 1% NaCl (T2) for thirty-six hours; 10% Polyethylene glycol (PEG) (T3) for twelve hours; 100 ppm GA3 (T4), 5% KNO3 (T5) (under dark condition) and 1000 ppm Thiourea (T6) for twenty-four hours; distilled water (T7) for twelve hours; 2% KH2PO4 (T8) and 93 ppm NAA (T9) (at 4°C) for six hours. The field research work was conducted at C Block, Incheck Farm, BCKV, Kalyani, and Nadia during the Rabi seasons of 2019-20 and 2020-21. Seedlings were transplanted in the separate main plot 21 days after sowing with three replications following Strip Plot Design, where each block or replication was divided into 10 horizontal and 2 vertical strips based on the types of priming materials and foliar application with GA3 and without GA3. Five plants were randomly tagged after exogenous application of GA3 and fruits turning mature red color were harvested from those plants in the laboratory, the harvested fruits were taken for estimation of different quality parameters. Foliar application of GA3 on tomato plants produced larger fruits (fruit diameter 5.71 cm in the first and 5.44 cm second year; fruit perimeter13.94 cm in the first and 12.55 cm in the second year) and increased value of biochemical composition as compared to without GA3. Significant differences in fruit diameter, fruit perimeter, and biochemical composition were also observed in GA3-treated tomatoes. Seed priming improved the morphological and biochemical composition of tomatoes. Among different priming treatments, seed priming with moringa leaf extract indicated the highest perimeter and diameter of the fruit. Various fruit quality parameters like total soluble solids were found highest after seed priming with moringa leaf extract followed by KH2PO4 and distilled water; maximum total phenol content (25.41 mg 100 g-1 in 1st year and 25.17 mg 100 g-1 in 2nd year) of fruit was noted for priming with moringa leaf extract followed by GA3 and KH2PO4; highest total sugar percentage (3.52% in 2019-2020 and 3.58% in 2020-2021) and lycopene content (3.78 mg 100 g-1 in the first year and 4.01 mg 100 g-1 in second year) of tomato fruit were exhibited in KH2PO4 followed by moringa leaf extract and distilled water. Whereas, ascorbic acid and β-carotene content were observed maximum after seed priming with both moringa leaf extract and KH2PO4. Soluble protein (9.98 mg g-1 in 2019-2020 and 9.76 mg g-1 in 2020-2021) and total carbohydrate content (41.93 mg g-1 in 1st year and 41.42 mg g-1 in 2nd year) of fruit were observed maximum after KH2PO4 priming, followed by moringa leaf extract and distilled water. From this experiment, it can be concluded that moringa leaf extract and KH2PO4 play the best performance than other priming materials as they induced most of the quality parameters.

Keywords- *Priming; tomato; fruit morphology; biochemical components.*

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INTRODUCTION

Tomato is one of the most valuable and popular vegetables in the world. Fruit size, shape, taste, color, and skin firmness differ according to the cultivars of the crop. Tomato fruit is rich in organic acids, sugars, dietary fiber, pectic substances, proteins, fats, minerals (potassium, phosphorus, sulfur, magnesium, calcium, iron, copper, and sodium), vitamins (B1, B2, B3, PP, C, provitamin A, I, and H), and carotenoids, viz. lycopene, β-carotene, etc., possessing antioxidant activities. The nutritional value, color, and flavor of tomatoes as well as their processed products depend mainly on lycopene, β-carotene, ascorbic acid, and sugar content, and their ratios present in the fruits. The consumption of tomato products helps in the prevention of chronic diseases, such as cancer and cardiovascular disease, thus tomato products are considered functional foods and show that lycopene and β-carotene act as antioxidants [21]; [22]; [61]. Seed priming prior to sowing is a promising technique. Soaking seeds in different value-added solutions enhance the yield, and quality potential and controls diseases of high-value crops [13]. Priming stimulates the activity of enzymes such as amylases, proteases, and lipases that break down macromolecules for the growth and development of the embryo. Earlier, priming with distilled water (hydropriming) and moringa leaf extract has been used in improving the vigor and nutritional quality of moringa plants under normal and stress conditions [46] ; [53], but hardly any study has been yet reported describing the improvement in biochemical quality and antioxidant system of tomato under salinity as well as normal situation induced by seed priming techniques. Exogenous application of plant growth regulators (PGRs) and micronutrients is one of the strategies, which is practiced to increase yield, improve crop quality, and regulate the uptake and accumulation of mineral nutrients in plants [6]; [10]; [12]; [43]. Gibberellins played important role in increasing yield in many kinnow mandarins [44]; in marigold [50]; in sweet orange [52].

Hence, the research work was conducted to investigate the effect of seed priming and foliar application of GA3 on various fruit quality parameters both morphological and biochemical components of the tomato genotype, i.e., BCT-25.

MATERIALS AND METHODS

The field trial was conducted in the new alluvial zone at C Block, Incheck Farm, BCKV, Kalyani, Nadia, West Bengal following strip plot design with three replications during 2019-20 and 2020-21 for Tomato genotype, BCT-25. Pre-sowing seed priming was made with Moringa leaf extract (T1) (1ml of fresh leaf extract diluted with 30 ml of distilled water) for 18 hours; 1% NaCl (T2) for 36 hours; 10% Polyethylene glycol (PEG) (T3) for 12 hours; 100 ppm GA3 (T4), 5% KNO3 (T5) (under dark condition) and 1000 ppm Thiourea (T6) for 24 hours; distilled water (T7) for 12 hours; 2% KH2PO4 (T8) and 93 ppm NAA (T9) (at 4°C) for 6 hours. Dry seeds were considered as the control (T0). Foliar application of 100 ppm Gibberellic acid (G1) was done 25 days after transplanting of the crop in one set of the priming treatments, i.e., ten horizontal plots of one vertical strip and another set, i.e., the plots of another vertical strip of the same block remained unsprayed (G0) for easy understanding of the influence of foliar spray with GA3 [51]. Five plants were randomly tagged after exogenous application of GA3 and fruits turning mature red color were harvested from those plants. In the laboratory, the harvested fruits were taken for estimation of different quality parameters, like fruit perimeter (cm), fruit diameter (cm), total soluble solids (0Brix) (with the help of hand refractometer), total sugar (%) (by anthrone method as per Dubois et al., 1956 [17], ascorbic acid (mg 100 g-1 fresh weight) [5], lycopene (mg.100 g-1 fresh weight) (by the spectrophotometric method as per Davis, [15], β-carotene (mg 100 g-1 fresh weight) (by the spectrophotometric method as per Davis, [15], total phenol (mg 100 g-1 fresh weight) (spectrophotometrically by Singleton et al.[58], soluble protein (mg 100 g-1 fresh weight) [38] and total carbohydrate content (mg 100 g-1 fresh weight) (by Anthrone's method) of fruits.

RESULTS AND DISCUSSION

Table 1. Influence of different priming materials in combination with or without GA3 on fruit perimeter (cm):

2019-2020											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	11.10	13.87	11.73	11.70	12.91	11.58	11.55	13.37	13.55	11.54	12.29
G_1	12.61	15.76	13.80	13.45	14.74	12.92	12.75	15.28	15.40	12.71	13.94
Mean T	11.86	14.81	12.77	12.58	13.82	12.25	12.15	14.32	14.48	12.12	
Effect	T	G	T at same level of G				G at same level of T				
SEm (±)	0.092	0.014	0.119				0.102				
LSD (0.05)	0.274	0.086	0.354				0.309				
2020-2021											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	10.17	12.62	10.46	10.25	11.44	10.24	10.23	12.06	12.10	10.19	10.98

G_1	11.09	14.27	12.48	12.11	13.24	11.63	11.44	13.94	14.16	11.12	12.55
Mean T	10.63	13.45	11.47	11.18	12.34	10.93	10.83	13.00	13.13	10.66	
Effect	**T**	**G**	**T at same level of G**				**G at same level of T**				
SEm (±)	**0.072**	**0.040**	**0.109**				**0.117**				
LSD (0.05)	**0.214**	**0.242**	**0.324**				**0.389**				

Note: G = With GA_3 and without GA_3 treatment, **G_0 =** Without GA_3, **G_1 =** With GA_3, **T =** Priming treatment, **T_0 =** Control, **T_1 =** Moringa leaf extract, **T_2 =** 1% NaCl, **T_3 =** 10% Polyethylene glycol (PEG), **T_4 =** 100 ppm GA_3, **T_5 =** 5% KNO_3, **T_6 =** 1000 ppm Thiourea, **T_7 =** Distilled water, **T_8 =** 2% KH_2PO_4, **T_9 =** 93 ppm NAA

1. Fruit perimeter (cm):

Significant influence of GA3 and without GA3 could be noticed for enhancing fruit perimeter in both years; higher value was observed for G1, i.e., after application of GA3 (13.94 cm in the first and 12.55 cm in the second year) (Table 1), when the average was made over priming. This was in conformity with [34]; [54]; [56] in tomatoes resulted in enhanced fruit size with respect to length and girth. The mean effect of priming treatments was found to significantly influence the trait, when the average was taken over with GA3 and without GA3; if ranking is done for these priming treatments with regards to fruit perimeter, it could be represented as T1 > T8 ≥ T7 > T4 > T2 ≥ T3 > T5 ≥ T6 ≥ T9 ≥ T0 in 2019-2020 and T1 > T8 ≥ T7 > T4 > T2 > T3 > T5 ≥ T6 ≥ T9 ≥ T0 in 2020-2021 (Table); slight variation in performance of priming treatments may be due to a change in climatic condition over the years. A similar type of influence was recorded in Pepper [24]. The general trend of influence of with and without GA3 on individual priming followed a similar pattern in both years. While clarifying the performance of priming materials, T1 was noted to produce maximum fruit perimeter for both with and without foliar application of GA3 during both years, the trait varied significantly. A similar type of effect was noted in mung bean resulting in increased pod length after foliar application of GA3 [40].

Table 2. Influence of different priming materials in combination with or without GA3 on fruit diameter (cm):

2019-2020											
	T_0	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**Mean G**
G_0	3.56	5.38	4.62	4.58	4.70	4.56	3.85	4.76	4.99	3.70	4.47
G_1	4.96	6.95	5.75	5.50	5.80	5.32	5.07	6.15	6.55	5.06	5.71
Mean T	4.26	6.16	5.19	5.04	5.25	4.94	4.46	5.46	5.77	4.38	
	T	**G**	**T at same level of G**				**G at same level of T**				
SEm (±)	**0.047**	**0.016**	**0.061**				**0.054**				
LSD (0.05)	**0.136**	**0.102**	**0.180**				**0.181**				
2020-2021											
	T_0	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**Mean G**
G_0	3.24	5.15	4.39	4.34	4.41	4.24	3.55	4.52	4.66	3.37	4.19
G_1	4.73	6.68	5.44	5.26	5.50	5.03	4.76	5.91	6.30	4.74	5.44
Mean T	3.99	5.91	4.91	4.80	4.96	4.63	4.16	5.21	5.48	4.06	
	T	**G**	**T at same level of G**				**G at same level of T**				
SEm (±)	**0.065**	**0.039**	**0.092**				**0.097**				
LSD (0.05)	**0.191**	**0.239**	**0.274**				**0.337**				

Note: G = With GA3 and without GA3 treatment, G0 = Without GA3, G1 = With GA3, T = Priming treatment, T0 = Control, T1 = Moringa leaf extract, T2 = 1% NaCl, T3 = 10% Polyethylene glycol (PEG), T4 = 100 ppm GA3, T5 = 5% KNO3, T6 = 1000 ppm Thiourea, T7 = Distilled water, T8 = 2% KH2PO4, T9 = 93 ppm NAA

2. Fruit diameter (cm)

During both years, significant variation was observed for fruit diameter due to foliar application of GA3; G1 resulted in the production of fruits with larger diameter (5.71 cm and 5.44 cm in the first and second year respectively) than G0, when average over priming was done (Table 2). A similar type of influence with respect to an increase in fruit length and diameter in tomatoes [26]. Priming treatments significantly influenced the fruit diameter, when the average was made over foliar treatment of GA3; T1 (6.16 cm in the first and 5.91 cm in the second year) produced the largest fruit diameter, similar to the expression reported for fruit perimeter in both the years and if further ranking is made among the priming treatments for this parameter, it could be displayed as: T1 > T8 > T7 > T4 ≥ T2 > T3 ≥ T5 > T6 ≥ T9 ≥ T0 for the first year and T1 > T8 > T7 > T4 ≥ T2 ≥ T3 > T5 > T6 ≥ T9 ≥ T0 (Table 2) for a second year with a minute change in priming performance, which may be due to climatic condition prevailed during the crop growth period. T1 was identified as the best priming agent, which produced the largest fruit diameter either GA3 application was done or not, in both years. The general trend of influence of with and without GA3 on individual priming followed a similar pattern over two years. Fruit diameter of bottle gourd was increased after seed priming with borax followed by GA3 spraying [4].

Table 3. Influence of different priming materials in combination with or without GA3 on total soluble solids (0Brix):

2019-2020											
	T_0	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**Mean G**
G_0	5.70	6.87	6.63	6.33	6.67	6.40	6.47	6.70	6.77	5.97	6.45
G_1	6.07	7.07	6.77	6.47	6.77	6.63	6.63	6.90	6.80	6.33	6.64
Mean T	5.88	6.97	6.70	6.40	6.72	6.52	6.55	6.80	6.78	6.15	
	T	**G**	**T at same level of G**				**G at same level of T**				
SEm (±)	**0.092**	**0.037**	**0.128**				**0.124**				
LSD (0.05)	**0.274**	**NS**	**NS**				**NS**				
2020-2021											
	T_0	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**Mean G**
G_0	5.90	6.73	6.53	6.27	6.73	6.30	6.33	6.67	6.70	6.40	6.46
G_1	6.03	6.97	6.63	6.33	6.83	6.47	6.57	6.80	6.85	6.47	6.60
Mean T	5.97	6.85	6.58	6.30	6.78	6.38	6.45	6.73	6.78	6.43	
	T	**G**	**T at same level of G**				**G at same level of T**				
SEm (±)	**0.062**	**0.029**	**0.082**				**0.077**				
LSD (0.05)	**0.182**	**NS**	**NS**				**NS**				

Note: G = With GA3 and without GA3 treatment, G0 = Without GA3, G1 = With GA3, T = Priming treatment, T0 = Control, T1 = Moringa leaf extract, T2 = 1% NaCl, T3 = 10% Polyethylene glycol (PEG), T4 = 100 ppm GA3, T5 = 5% KNO3, T6 = 1000 ppm Thiourea, T7 = Distilled water, T8 = 2% KH2PO4, T9 = 93 ppm NAA

3. Total soluble solids

The total soluble solid (TSS) is a refractometric index that indicates the proportion of dissolved solids in a solution. Though the foliar application of GA3 did not significantly influence the total soluble solids of the fruit, when the average was considered over the treatments; G1 slightly increased the total soluble solids content than non-applied plants, denoted as G0. Total soluble solids of tomatoes are mainly influenced by the rate of assimilate exportation from leaves, the rate of importation by fruit, and the fruit carbon metabolism. An increase in the total soluble solid of tomato fruit after foliar application of GA3 [20]. In both years, the maximum amount of TSS was recorded in treatment T1 (6.97 0Brix and 6.85 0Brix) (Table 3), followed by T7 and T8 in the first year, whereas in the second year they interchanged their position, though in the first year T1, T7, T8, T4, T2 and in second year T1, T8, T4, T7 were statistically similar, and it was minimum for T0 (5.88 0Brix in first and 5.97 0Brix in second year), while the mean was calculated over with and without application of GA3. The highest α-amylase activity and total soluble sugars for seed priming with moringa leaf extract and magnetized water in peas [45]. Moringa leaves are rich in sugar and starch content and the leaves extract has high levels of cytokinins. Cytokinins promote carbohydrate metabolism and create new source-sink relationships leading to an increase in fruit soluble solids content [18]. Pre-sowing seed priming in combination with the application of GA3 and without GA3 application showed a non-significant influence on the genotype for the total soluble solid (TSS) value of the fruit during both years. There was no significant influence of GA3 spray on individual priming material over unsprayed plants.

Table 4. Influence of different priming materials in combination with or without GA3 on total sugar (%)

2019-2020											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	2.31 (9.66)	2.64 (10.21)	2.39 (9.79)	2.53 (10.03)	3.34 (11.30)	2.33 (9.68)	2.51 (9.99)	3.34 (11.31)	3.46 (11.48)	2.43 (9.86)	2.73 (10.33)
G_1	2.34 (9.69)	2.78 (10.44)	2.46 (9.90)	2.64 (10.21)	3.49 (11.53)	2.36 (9.74)	2.63 (10.19)	3.38 (11.36)	3.58 (11.65)	2.51 (10.00)	2.82 (10.47)
Mean T	2.33 (9.67)	2.71 (10.33)	2.42 (9.85)	2.59 (10.12)	3.42 (11.41)	2.34 (9.71)	2.57 (10.09)	3.36 (11.33)	3.52 (11.57)	2.47 (9.93)	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.013	0.010	0.018				0.020				
LSD (0.05)	0.037	0.063	0.049				0.072				
2020-2021											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	2.27 (9.58)	2.59 (10.12)	2.32 (9.67)	2.59 (10.12)	3.29 (11.23)	2.29 (9.62)	2.45 (9.89)	3.31 (11.26)	3.51 (11.55)	2.47 (9.93)	2.71 (10.30)
G_1	2.30 (9.64)	2.73 (10.35)	2.41 (9.82)	2.66 (10.24)	3.43 (11.43)	2.33 (9.69)	2.57 (10.10)	3.34 (11.30)	3.64 (11.75)	2.55 (10.06)	2.80 (10.44)
Mean T	2.29 (9.61)	2.66 (10.24)	2.36 (9.74)	2.62 (10.18)	3.36 (11.33)	2.31 (9.65)	2.51 (9.99)	3.32 (11.28)	3.58 (11.65)	2.51 (9.99)	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.018	-	0.022				0.017				
LSD (0.05)	0.055	0.013	0.070				0.059				

Note: G = With GA3 and without GA3 treatment, G0 = Without GA3, G1 = With GA3, T = Priming treatment, T0 = Control, T1 = Moringa leaf extract, T2 = 1% NaCl, T3 = 10% Polyethylene glycol (PEG), T4 = 100 ppm GA3, T5 = 5% KNO3, T6 = 1000 ppm Thiourea, T7 = Distilled water, T8 = 2% KH2PO4, T9 = 93 ppm NAA

4. Total sugar (%)

Similar trends were observed for the total sugar content of the fruit regarding the influence of GA3 as well as seed priming in both years. Application of GA3 (G1) significantly increased the total sugar content of fruit than the fruits obtained from plants, where there was no application of GA3 (G0) in two consecutive years. A similar type of influence for the application of GA3 in aonla [57]. This increase in total sugar content with GA3 might be due to the influence of gibberellins in the activation of the amylase enzyme which is responsible for the conversion of starch into sugars. Among the seed priming treatments, T8 (3.52% in 2019-2020 and 3.58% in 2020-2021) recorded the highest total sugar content (Table 4), followed by T4 and T7 in both years, when the average was made over with and without application of GA3, though T4 and T7 were statistically at par with each other during the second year, while it was lowest for T0 and T5 with statistically non-significant values. Foliar spraying of phosphorus and potassium was noted to affect the total sugar content of guava in a better way compared to the control [37]; [45]. T8 was found to be noted as the best-performing priming material on with and without GA3 basis. A similar type of influence of GA3 was observed on individual priming treatment.

Table 5. Influence of different priming materials in combination with or without GA3 on ascorbic acid content (mg 100 g-1 fresh weight):

2019-2020											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	26.35	27.36	26.64	26.62	26.87	26.63	26.75	27.11	27.33	26.51	26.82
G_1	26.44	27.45	26.70	26.70	26.98	26.75	26.80	27.20	27.42	26.58	26.90
Mean T	26.39	27.40	26.67	26.66	26.93	26.69	26.77	27.15	27.38	26.55	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.013	0.015	0.013				0.015				
LSD (0.05)	0.045	NS	0.051				0.095				
2020-2021											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	26.29	27.18	26.40	26.71	26.92	26.42	26.64	27.01	27.28	26.43	26.73
G_1	26.58	27.40	26.75	26.90	27.04	26.76	26.85	27.25	27.42	26.56	26.95
Mean T	26.44	27.29	26.57	26.81	26.98	26.59	26.74	27.13	27.35	26.50	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.062	0.033	0.097				0.105				
LSD (0.05)	0.186	0.199	NS				NS				

Note: G = With GA3 and without GA3 treatment, G0 = Without GA3, G1 = With GA3, T = Priming treatment, T0 = Control, T1 = Moringa leaf extract, T2 = 1% NaCl, T3 = 10% Polyethylene glycol (PEG), T4 = 100 ppm GA3, T5 = 5% KNO3, T6 = 1000 ppm Thiourea, T7 = Distilled water, T8 = 2% KH2PO4, T9 = 93 ppm NAA

5. Ascorbic acid (mg 100 g-1 fresh weight)

Ascorbic acid is one of the most important components in tomatoes as it contains rich source of Vitamin C or ascorbic acid, which acts as an antioxidant. Foliar application of GA3 (G1) showed to significantly influenced the ascorbic acid content of the tomato fruit in a minute range than the without application of GA3 (G0) only in the second year when the average was taken over the seed priming treatments. Among the organic acids found in vegetables, ascorbic acid (Vitamin C) is an important element of nutritional quality, as its consumption has been related to a lower incidence of several chronic diseases including cardiovascular disease and cancer [30]. Application of GA3 increased ascorbic acid content in tomatoes [14]; [47]. Seed priming treatments significantly influenced the trait, when the average was made over with and without GA3; in the first year T1 (27.40 mg 100 g-1 fresh weight), and in the second year T8 (27.35 mg 100 g-1 fresh weight) was found to be the best treatment, though T1 and T8 were statistically at par with each other in both the years and it was lowest for T0 (26.39 and 26.44 mg 100 g-1 fresh weight in two years respectively), though in second year T0, T9, T2, and T5 were statistically non-significant for the trait (Table 5). Foliar spray of moringa leaf extract enhanced the plant length, fresh and dry biomasses, photosynthetic pigments, photosynthetic rate, stomatal conductance, total soluble protein, ascorbic acid content, and phytohormones in rocket plants [1]. Positive relationship between phosphorus and fruit ascorbic acid content [7]. While exhibiting the performance of priming materials, T1 showed the highest ascorbic acid content in fruit both with and without exogenous application of GA3 in the first year, whereas non-significant variation was observed in the second year. Similarly, the trait varied significantly during 2019-2020, when GA3 application was made on individual priming treatment, but it was non-significant in the second year.

Table 6. Influence of different priming materials in combination with or without GA3 on lycopene content (mg 100 g-1 fresh weight) in pulp:

2019-2020											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	3.41	3.70	3.56	3.61	3.64	3.55	3.62	3.71	3.74	3.46	3.60
G_1	3.49	3.77	3.64	3.70	3.74	3.62	3.68	3.79	3.82	3.51	3.68
Mean T	3.45	3.74	3.60	3.65	3.69	3.59	3.65	3.75	3.78	3.48	
	T	G	T at same level of G				G at same level of T				

SEm (±)	0.013	0.006	0.013				0.006				
LSD (0.05)	0.029	0.025	NS				NS				
2020-2021											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	3.54	3.85	3.72	3.73	3.77	3.74	3.76	3.79	3.92	3.63	3.74
G_1	3.78	4.07	3.88	3.88	3.85	3.81	3.83	3.89	4.09	3.74	3.88
Mean T	3.66	3.96	3.80	3.80	3.81	3.78	3.79	3.84	4.01	3.68	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.022	0.006	0.037				0.039				
LSD (0.05)	0.061	0.042	NS				NS				

Note: G = With GA3 and without GA3 treatment, G0 = Without GA3, G1 = With GA3, T = Priming treatment, T0 = Control, T1 = Moringa leaf extract, T2 = 1% NaCl, T3 = 10% Polyethylene glycol (PEG), T4 = 100 ppm GA3, T5 = 5% KNO3, T6 = 1000 ppm Thiourea, T7 = Distilled water, T8 = 2% KH2PO4, T9 = 93 ppm NAA

6. Lycopene content (mg 100 g-1 fresh weight)

At the time of maturity in tomato red color occurs due to the presence of the pigment called, lycopene. Biochemical analysis of tomato pulp revealed variation in lycopene content present in the genotype due to several pre-sowing seed priming treatments (T) as well as foliar application of GA3 (G1) on the plants at later crop growth stage leaving one set of priming without any application of GA3 (G0). Application of GA3 noted significant enhancement in lycopene content over the non-applied ones, average over seed priming treatments during two years. GA3 application enhanced the accumulation of phosphorous in the leaves and stems of tomato plants that were also responsible for the required lycopene content in the fruit [2]. Lycopene content increased of tomato fruit treated with GA3[34]. Among the treatments, T8 (3.78 mg 100 g-1 in the first year and 4.01 mg 100 g-1 in the second year) was reported to be the best priming agent regarding influencing the lycopene content when average over foliar application of GA3 and without GA3 and the minimum was recorded in control, i.e., T0 (3.45 mg 100 g-1 in 2019-2020 and 3.66 mg 100 g-1 in 2020-2021) (Table 6). After T8, T7 (hydro-priming) in the first and T1 (moringa leaf extract) in the second year were found to be effective, though T1 and T7 showed a statistically similar result in the first year. The highest lycopene content was shown in KH2PO4 treatment of storage methods in tomato fruits [29]. Potassium increased the lycopene content of tomato fruits through the synthesis of pigments [9]. The contribution of phosphorus and potassium on lycopene concentration in grape fruit [16]. There was no significant influence on the trait when the evaluation was made for the performance of seed priming treatments on an individual basis with GA3 and without GA3 as well as the influence of GA3 on individual priming agents.

Table 7. Influence of different priming materials in combination with or without GA3 on β-carotene content (mg 100 g-1 fresh weight) in pulp:

2019-2020											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	0.96	1.24	1.07	1.10	1.16	1.09	1.10	1.21	1.21	1.03	1.12
G_1	1.12	1.40	1.22	1.30	1.34	1.24	1.34	1.37	1.38	1.15	1.29
Mean T	1.04	1.32	1.14	1.20	1.25	1.17	1.22	1.29	1.30	1.09	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.013	0.006	0.013				0.006				
LSD (0.05)	0.035	0.034	0.044				0.047				
2020-2021											

	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	1.05	1.40	1.23	1.23	1.33	1.16	1.31	1.35	1.39	1.17	1.26
G_1	1.28	1.72	1.48	1.53	1.58	1.31	1.53	1.56	1.84	1.34	1.52
Mean T	1.16	1.56	1.36	1.38	1.45	1.24	1.42	1.45	1.62	1.26	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.041	0.008	0.058				0.055				
LSD (0.05)	0.121	0.048	NS				NS				

Note: G = With GA3 and without GA3 treatment, G0 = Without GA3, G1 = With GA3, T = Priming treatment, T0 = Control, T1 = Moringa leaf extract, T2 = 1% NaCl, T3 = 10% Polyethylene glycol (PEG), T4 = 100 ppm GA3, T5 = 5% KNO3, T6 = 1000 ppm Thiourea, T7 = Distilled water, T8 = 2% KH2PO4, T9 = 93 ppm NAA

7. β-carotene content (mg 100 g-1 fresh weight)

β-carotene content exhibited an almost similar trend of variation to fruit lycopene. During both years, significant variation was observed for the influence of GA3, when the average was considered over priming agents. A similar type of influence of GA3 on the carotene content of wax apples [35]. An accumulation of lycopene and β-carotene in cara cara orange due to the exogenous application of GA3 and ABA [62]. Average over G (with and without application of GA3), seed priming treatments significantly influenced the trait, maximum β-carotene content was measured for T1 (1.32 mg 100 g-1 fresh weight) during the first year and for T8 (1.49 mg 100 g-1 fresh weight) during the second year, though T1, T8, T7 in first and T1, T8 in second year recorded statistically at per result for this character, whereas, the minimum amount of β-carotene was measured for T0 (1.04 mg 100 g-1 in 1st year and 1.16 mg 100 g-1 in 2nd year) (Table 7). The beneficial effects of supplemental potassium probably resulted from a combination of improved leaf photosynthetic CO2 assimilation, assimilate translocation from leaves to fruits, improved leaf and fruit water relations, increased enzyme activation and substrate availability for ascorbic acid and β-carotene biosynthesis all associated with adequate potassium nutrition [23]; [27]. Fertilization with an increased amount of phosphorus had increased β-carotene production in tomatoes [66]. The increase in phenolics and antioxidants might be due to the fact that moringa leaf extract possessed a wide spectrum of antioxidants (ascorbic acid), phenols, flavonoids, and β-carotene [31]; thus affecting the metabolic process directly or indirectly in such a way that it increased the internal level of phenolics and antioxidants. Similar to the lycopene content of tomato pulp, non-significant variation was noticed for β-carotene also, based on the performance of seed priming treatments on an individual basis with GA3 and without GA3 as well as the influence of GA3 on individual priming agents in the second year, whereas the trait varied significantly in the first year and T1 exhibited maximum fruit β-carotene content in combination with GA3 as well as without GA3 application.

Table 8. Influence of different priming materials in combination with or without GA3 on total phenol content (mg 100 g-1 fresh weight) in pulp:

2019-2020											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	24.66	25.27	24.82	24.82	25.21	24.75	24.81	25.07	25.20	24.74	24.93
G_1	24.89	25.55	25.05	25.01	25.42	24.94	24.90	25.31	25.40	24.91	25.14
Mean T	24.78	25.41	24.94	24.91	25.32	24.85	24.85	25.19	25.30	24.83	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.013	0.008	0.018				0.019				
LSD (0.05)	0.036	0.054	0.048				0.064				
2020-2021											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	24.18	24.93	24.49	24.59	24.78	24.48	24.57	24.74	24.84	24.39	24.60
G_1	24.42	25.40	24.82	24.87	25.13	24.79	24.80	25.04	25.21	24.61	24.91
Mean T	24.30	25.17	24.66	24.73	24.95	24.64	24.68	24.89	25.03	24.50	
	T	G	T at same level of G				G at same level of T				

SEm (±)	0.032	0.006	0.043	0.039	
LSD (0.05)	0.096	0.034	NS	NS	

Note: G = With GA3 and without GA3 treatment, G0 = Without GA3, G1 = With GA3, T = Priming treatment, T0 = Control, T1 = Moringa leaf extract, T2 = 1% NaCl, T3 = 10% Polyethylene glycol (PEG), T4 = 100 ppm GA3, T5 = 5% KNO3, T6 = 1000 ppm Thiourea, T7 = Distilled water, T8 = 2% KH2PO4, T9 = 93 ppm NAA

8. Total phenol content (mg 100 g-1 fresh weight) in pulp

Pre-sowing seed priming indicated significant influence on this trait while considering the average over with and without GA3 application during both the years; T1 (25.41 and 25.17 mg 100 g-1 fresh weight) was noted to be the best-performing priming treatments in both the years and it was followed by T4 and T8 in the first year, but in the second year T4 and T8 interchanged their places with each other with and they were statistically at per during both years, whereas, the lowest value for the phenol content was observed for T0 (24.78 and 24.30 mg 100 g-1 fresh weight) in both the years (Table 8). An increase in a total phenolic compound in wheat after the seeds were primed with moringa leaf extract [65]. The increase in phenolic contents due to seed priming with moringa leaf extract might be attributed to a higher content of vitamin C in moringa leaf extract [11]. Foliar application of GA3 significantly influenced the total phenol content of fruit in the first as well as in the second year with little variation in magnitude over the treatment means. Localized application of the various concentrations of GA3 significantly increased the phenolics content of the Java Apple fruits (Syzygium samarangense) [42]. Seed priming either alone or in combined with foliar application of GA3, T1 indicated the highest amount of total phenol present in the fruit. Total phenolic compounds contents of cv. Cardinals were statistically influenced by foliar spray applications of biostimulant in combination with GA3 applications, which resulted in the highest total phenolic compounds content in grapes [36]. Similar to the β-carotene content of tomato pulp, non-significant variation was noticed for total phenol also in the second year, based on the performance of seed priming treatments on an individual basis with GA3 and without GA3 as well as the influence of GA3 on individual priming agent.

Table 9. Influence of different priming materials in combination with or without GA3 on soluble protein content (mg g-1 fresh weight) of fruit:

2019-2020											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	9.57	9.89	9.73	9.76	9.80	9.73	9.80	9.80	9.91	9.67	9.76
G_1	9.80	9.98	9.81	9.83	9.95	9.79	9.85	9.93	10.06	9.72	9.87
Mean T	9.69	9.93	9.77	9.80	9.88	9.76	9.82	9.87	9.98	9.70	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.022	0.010	0.037				0.040				
LSD (0.05)	0.071	0.059	NS				NS				
2020-2021											
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean G
G_0	9.26	9.60	9.48	9.52	9.62	9.44	9.54	9.58	9.67	9.48	9.52
G_1	9.44	9.77	9.54	9.56	9.74	9.51	9.59	9.64	9.84	9.53	9.62
Mean T	9.35	9.69	9.51	9.54	9.68	9.48	9.57	9.61	9.76	9.50	
	T	G	T at same level of G				G at same level of T				
SEm (±)	0.032	0.025	0.048				0.055				
LSD (0.05)	0.098	NS	NS				NS				

Note: G = With GA3 and without GA3 treatment, G0 = Without GA3, G1 = With GA3, T = Priming treatment, T0 = Control, T1 = Moringa leaf extract, T2 = 1% NaCl, T3 = 10% Polyethylene glycol (PEG), T4 = 100 ppm GA3, T5 = 5% KNO3, T6 = 1000 ppm Thiourea, T7 = Distilled water, T8 = 2% KH2PO4, T9 = 93 ppm NAA

9. Soluble protein content (mg. g-1 fresh weight) of fruit

The soluble protein content of fruit was observed significantly varied for the influence of the foliar application of GA3 during the first year and it was calculated to be increased by 1.13% over the control, but in the second year, there was no significant influence of GA3 (Table 9), when the average was made over seed priming treatments. GA3 stimulates overall protein synthesis [48]. It is established that plant growth regulators acted solely or in part by controlling the transcription of genes [8]; [39] and thus levels of mRNA [64], which would in turn regulate the rate of specific hormone induced proteins. A change in the polypeptide in pea fruits between molecular weight 20 and 60 kilos Dalton with gibberellin treatment [28]. Considering the influence of priming treatments, maximum protein content was recorded for T8, i.e., 9.98 mg g-1 in 2019-2020 and 9.76 mg g-1 in 2020-2021; followed by T1, T7, T4 to perform in a better way for expression of the parameter than the control, though T1, T4, and T7 were statistically at par in first as well as second year; minimum protein content (9.69 mg g-1 in 1st year and 9.35 mg g-1in 2nd year) was measured for T0. Potassium significantly boosted grain protein content in two out of four corn hybrids tested, even though no yield response was measured [32]. The application of potassium resulted in an increase in both sesame seed yield and the amount of seed protein [41]. Protein content in Pisum sativum was increased with the increasing rate of phosphorus application and phosphorus at the rate of 60 kg ha-1 produced maximum protein content [49]. Phosphorus application significantly influenced the protein content in brinjal [25]. But seed priming in combination with foliar applied GA3 recorded non-significant variation for the trait during the first as well as second year. Seed priming treatments on an individual basis with GA3 and without GA3 as well as the influence of GA3 on individual priming agents showed a non-significant impact on the protein content of fruit.

Table 10. Influence of different priming materials in combination with or without GA3 on total carbohydrate content (mg g-1 fresh weight) of fruit:

2019-2020											
	T_0	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**Mean G**
G_0	41.16	41.84	41.32	41.54	41.70	41.33	41.51	41.75	41.87	41.26	41.53
G_1	41.38	41.93	41.43	41.58	41.80	41.39	41.57	41.89	41.98	41.43	41.64
Mean T	41.27	41.89	41.38	41.56	41.75	41.36	41.54	41.82	41.93	41.35	
	T	**G**	**T at same level of G**				**G at same level of T**				
SEm (±)	**0.041**	**0.022**	**0.045**				**0.033**				
LSD (0.05)	**0.118**	**NS**	**0.128**				**0.137**				
2020-2021											
	T_0	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**Mean G**
G_0	40.47	41.17	40.70	40.91	41.05	40.73	40.89	41.16	41.26	40.64	40.90
G_1	40.69	41.35	40.76	40.95	41.25	40.81	40.97	41.33	41.58	40.73	41.04
Mean T	40.58	41.26	40.73	40.93	41.15	40.77	40.93	41.25	41.42	40.69	
	T	**G**	**T at same level of G**				**G at same level of T**				
SEm (±)	**0.047**	**0.022**	**0.065**				**0.064**				
LSD (0.05)	**0.138**	**0.138**	**NS**				**NS**				

Note: G = With GA3 and without GA3 treatment, G0 = Without GA3, G1 = With GA3, T = Priming treatment, T0 = Control, T1 = Moringa leaf extract, T2 = 1% NaCl, T3 = 10% Polyethylene glycol (PEG), T4 = 100 ppm GA3, T5 = 5% KNO3, T6 = 1000 ppm Thiourea, T7 = Distilled water, T8 = 2% KH2PO4, T9 = 93 ppm NAA

10. Total carbohydrate content (mg g-1 fresh weight) of fruit

Carbohydrates also known as carbs are a type of macronutrient found in tomatoes. It was observed that foliar application of GA3 (G1) made a significant variation in total carbohydrate content present in tomato fruit than the control (G0), average over seed priming agents in the second year. Foliar application of GA3 increased the breakdown of starch and higher glucose and fructose levels in the potato tuber [3]. Gibberellins affect the activity of enzymes, some of which may control carbohydrate accumulation within the tubers [55]. Among the seed priming treatments, the highest carbohydrate content was observed for T8 (41.93 mg g-1 in 1st year and 41.42 mg g-1 in 2nd year), followed by T1 and T7 in two years respectively, though T1 and T7 exhibited non-significant difference among themselves in both the years and it was lowest for T0 (41.27 mg g-1 in 1st year and 40.58 mg g-1 in 2nd year), though in first year T0, T9, T5, T2, and T0, T9 in the second year showed a statistically similar result (Table 10). Potassium is required for the efficient transformation of solar energy into chemical energy that could increase carbohydrate content [59]. Potassium deficiency exerts a negative effect on photosynthesis and carbohydrate transport in sugarcane and high rates of potassium are required for maximum economic cane yield [60]. Potassium played the pertinent role for improving photo-assimilate production by maintaining net photosynthesis and sucrose accumulation and translocation by regulating carbohydrate metabolizing enzyme activities [19]; [63]. T8 was observed to be the best-performing priming treatment on an individual basis with GA3 and without GA3 in both years, though the character varied significantly in the first year only. A significant influence of GA3 on each priming treatment was noticed during the first year, whereas, it was non-significant in the second year. Carbohydrates formed by photosynthesis play a vital role in fruit production since they are not only the raw materials for fruit growth but also the major determinants of fruit quality [21]; [33].

CONCLUSION

Exogenous application of GA3 on tomato plants produced larger fruits and enhances biochemical compositions over non-applied plants. Foliar application of GA3 significantly increased fruit diameter, fruit perimeter, and biochemical composition except for ascorbic acid and total carbohydrate in the first year, soluble protein in the second year, and total soluble solids content of fruit in both years. Seed priming improved the morphological and biochemical composition in tomatoes. Seed priming with moringa leaf extract produced the highest perimeter and diameter of fruit than other priming materials. Total soluble solids were found highest after seed priming with moringa leaf extract followed by KH2PO4 and distilled water; maximum total phenol content (25.41 mg 100 g-1 in 1st year and 25.17 mg 100 g-1 in 2nd year) of fruit was noted for priming with moringa leaf extract followed by GA3 and KH2PO4; maximum total sugar percentage (3.52% in 1st year and 3.58% in 2nd year) and lycopene content (3.78 mg 100 g-1 in the first year and 4.01 mg 100 g-1 in second year) of tomato fruit were exhibited in KH2PO4 followed by moringa leaf extract and distilled water. Whereas, ascorbic acid and β-carotene content were observed maximum after seed priming with both moringa leaf extract and KH2PO4. Soluble protein (9.98 mg g-1 in 1st year and 9.76 mg g-1 in 2nd year) and total carbohydrate content (41.93 mg g-1 in 1st year and 41.42 mg g-1 in 2nd year) of fruit were observed maximum after KH2PO4 priming, followed by moringa leaf extract and distilled water. So, moringa leaf extract and KH2PO4 were best than other priming materials as they induced most of the morphological parameters.

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