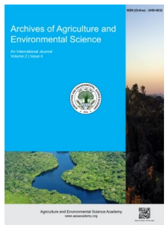
Archives of Agriculture and Environmental Science 4(3): 261-267 (2019)
https://doi.org/10.26832/24566632.2019.040301

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: www.aesacademy.org



ORIGINAL RESEARCH ARTICLE

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Effects of different application methods of chitosan on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.)

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ARTICLE HISTORY

Received: 11 June 2019
Revised received: 20 July 2019
Accepted: 23 August 2019

Keywords

Chitosan
Foliar application
Tomato (*Lycopersicon esculentum*)
Treatment combinations
Yield and quality

ABSTRACT

A pot experiment was conducted to study the effect of different application methods of chitosan on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.). The experiment was laid out in completely randomized design (CRD) with four replications and twelve treatments combinations *viz*., T_0= Control, T_1= Soil application of chitosan (SAC) @80 ppm, T_2= SAC @120 ppm, T_3= Foliar spraying of chitosan (FSC) @60 ppm, T_4= FSC @80 ppm, T_5= FSC @100 ppm, T_6= Combination of T_1 and T_3, T_7= Combination of T_1 and T_4, T_8= Combination of T_1 and T_5, T_9= Combination of T_2 and T_3, T_{10}= Combination of T_2 and T_4, and T_{11}= Combination of T_2 and T_5. The study results revealed that there were significant variations among the treatments on number of leaves, number of flower clusters, flowering duration, fruit length and yield of tomato. The highest yield of tomato was obtained from the treatment T_6, while the lowest was obtained from control treatment. Vitamin-C and lycopene content of tomato fruits varied from 2.19-4.09 and 2.38-3.58 mg $100g^{-1}$ sample, respectively. Among the major minerals, the highest amounts of Ca, Mg, Na, K, S and P were obtained from T_7 (0.69%), T_3 (0.58%), T_8 (0.38%), T_1 (0.62%), T_4 (0.15%) and T_6 (0.33%) treatments, respectively. Study results inferred that the treatment T_4 was more effective concerning most of the growth and biochemical parameters of tomato Finally, the study concluded that foliar application of chitosan alone or in combination with soil has significant effect on growth, yield and biochemical characters of tomato.

Citation of this article: Parvin, M.A., Zakir, H.M., Sultana, N., Kafi, A. and Seal H.P. (2019). Effects of different application methods of chitosan on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.). *Archives of Agriculture and Environmental Science*, 4(3): 261-267, https://dx.doi.org/10.26832/24566632.2019.040301

INTRODUCTION

Chitosan is a natural biopolymer which stimulates growth and increases yield of plants as well as induces the immune system of plants (Pongprayoon *et al*., 2013; Sultana *et al*., 2019). It can be extracted from the marine crustacean like prawn, shrimps, crab or from the exoskeletons of most insects. They are inherent to have specific properties of being environmentally friendly and easily degradable (Boonlertnirun *et al*., 2008). Moreover, chitosan not only activates the cells, but also improves its disease and insect resistant ability at field and storage (Doares *et al*., 1995; Bittelli, *et al*., 2001; Sultana *et al*., 2019). Application of chitosan in agriculture, even without chemical fertilizer, can increase the microbial population by large numbers, and transforms organic nutrient into inorganic nutrient, which is easily absorbed by the plant roots (Bolto *et al*., 2004). Moreover, plants treated with chitosan may be less prone to environmental stress such as drought, salinity and temperature (Lizarraga-Pauli *et al*., 2011; Jabeen and Ahmad 2013; Pongprayoon *et al*., 2013).

Nowadays, consumers demand for more natural, safe food, with high quality and a prolonged shelf life, and without any chemical preservatives (Gol *et al*., 2013). Worldwide chitosan is treated not only as a promising and economic source for efficient and versatile crop protection material, but also as an environmental friendly, biocompatible and biodegradable polymer with various applications (Geisberger *et al*., 2013; Zhang *et al*., 2012). Thus chitosan has a wide scope of use in different field of agriculture viz. crop production and protection, storage, nutritional quality etc. In the meantime, chitosan has been extensively used as a bioactive fungicide (Dutta *et al*., 2009; Miao *et al*., 2014; Gabriela *et al*., 2016), bactericides (No *et al*., 2002) and as edible coatings at preharvest and postharvest stage to preserve the quality of many fruits and vegetables (Meng *et al*., 2008; Huang *et al*., 2012; Sultana *et al*., 2019). But there are scanty of research on effect of chitosan on growth and nutritional qualities of crops and vegetables.

Tomato (*Lycopersicon esculentum* Mill.) is widely grown not only in Bangladesh but also in many countries of the world for its taste and nutritional status. The estimated annual production of tomato in Bangladesh was 385 thousand metric tons in 2017-2018 fiscal year (BBS, 2019), which is not enough to meet up local demand for the country. The most logical way to increase the total production at the national level from our limited land resources is to increase yield per unit area. Application of plant growth promoter (PGP) seems to be one of the important practices in view of convenience, cost and labor efficiency. Recently, there has been global realization of the important role of PGP in agriculture for better growth and yield of crops and vegetables. Developed countries like Japan, China, Poland, South Korea etc. have long been using PGPs to increase crop yield. But use of synthetic PGPs are not good for the consumers, and recently peoples would like to avoid those products. On the contrary, chitosan is fully natural and safe for human consumption, which stimulates vital processes of plants through physiological and biochemical processes, and to changes on the molecular level related to expression of genes (Hadwiger, 2013; Nguyen Van *et al*., 2013). Considering the fact stated above, the present research work was undertaken to study the effect of different application methods of chitosan on growth, yield and quality attributes of tomato (*Lycopersicon esculentum* Mill.) as well as to recommend an application method of chitosan for tomato production in Bangladesh.

MATERIALS AND METHODS

Experimental design

The experiment was laid out in a completely randomized design (CRD) with 4 replications. Thus, the total numbers of pots were 48 (12×4) used for the experiment. The treatments were randomly distributed to the net house of the Department of Agricultural Chemistry of BAU, during the period of November 2016 to March 2017. The place of a pot was changed with others time to time to reduce environmental heterogeneity. The pots were prepared 15 days prior to transplant of the tomato seedlings. The collected soil was air dried first and then sun dried. Then soils were ground and subsequently sieved by using a 2 mm stainless steel sieve. All kinds of weeds, stubbles and residues of crop and weeds were removed from the soil. After then 8.0 kg powered soil was poured in each plastic bucket and kept undisturbed up to transplant of the tomato seedlings.

Treatments for the experiment

There were 12 treatments for the experiment. Both soil and foliar application of chitosan was incorporated in the experiment. The treatment combinations for the experiment was as follows- T_0= Control, T_1= Soil application of chitosan (SAC) @80 ppm, T_2= SAC @120 ppm, T_3= Foliar spraying of chitosan (FSC) @60 ppm, T_4= FSC @80 ppm, T_5= FSC @100 ppm, T_6= Combination of T_1 and T_3, T_7= Combination of T_1 and T_4, T_8= Combination of T_1 and T_5, T_9= Combination of T_2 and T_3, T_{10}= Combination of T_2 and T_4, and T_{11}= Combination of T_2 and T_5.

Cultivation practices

The experiment was conducted with the seedlings of tomato (*Lycopersicon esculentum*) var. *Ruma-VF*. The seedlings were collected from the Horticulture Center, Kewatkhali, Mymensingh, Bangladesh and transplanted on November 12, 2016. Intercultural operations viz. weeding, irrigation, disease and pest management were done using traditional methods as and when necessary. Fertilizers applied in the pot as recommended for high yield goal and medium soil fertility status as described in Fertilizer Recommendation Guide (FRG, 2012). The recommended dose of nitrogen, phosphorus and potassium were 60, 19 and 38 kg ha^{-1} and fertilizer source were urea, TSP and MoP, respectively. Among the fertilizers, only TSP was applied to the individual pots during final preparation according to the recommendation. Urea and MoP were applied in two equal installments: first split was applied at 15 days after transplanting of seedlings and second split of urea and Mop were applied at 35 days after transplanting of seedlings. No manure was used in the experiment.

Purified chitosan @ 80 and 120 ppm were applied to the soils as mentioned in the treatments during final pot preparation. As the measured amount of chitosan was very small, first the volume was increased by mixing with few grams of soils of the respective pot and then this soil (chitosan+soil) was thoroughly mixed with the whole soil of the respective pot to maintain homogeneity. There were 4 types of spray solutions of chitosan viz. control (0 ppm), 60 ppm, 80 ppm and 100 ppm used for foliar application to tomato plants. The pH of the solution was adjusted to 5.0 with 0.1 M NaOH solution. 25 mL glacial acetic acid solution (diluted to 1.0 L with distilled water and pH adjusted to 5.0 with 0.1 M NaOH solution) without chitosan was used as control. Solutions of chitosan were applied 6 times at an interval of 15 days, which starts from 25 days after transplanting (DAT). The spray was done by a hand sprayer at afternoon and required total volume of solution was 400 mL for each pot.

Chemical analyses of tomato (*L. esculentum*) fruits

One fully matured light yellow tomato fruit sample from each pot was collected for the determination of total titratable acidity and vitamin-C. Total titratable acidity was estimated by the visual titration method by neutralizing the acid with 0.1M NaOH using 2 drops of phenolphthalein as an indicator. On the other hand, vitamin-C content in tomato fruit was estimated based on the reduction of 2,6-dichlorophenol indophenol dye as outlined by Sadasivam and Manickam (1996). Lycopene is responsible for the red colour of tomato. For the determination of lycopene content, a fully ripened tomato fruit sample was collected from each pot. The carotenoids in the sample are extracted in acetone and then taken up in petroleum ether following the method described by Sadasivam and Manickam (1996).

To determine different mineral elements (Ca, Mg, P, K, Na and S), another tomato fruit sample collected from each pot was cut into small pieces using a sharp stainless steel knife and dried in an electric oven at 50°C temperature for about 72 hrs. Then the samples were ground by a grinding mill and used to prepare tomato fruit extract by wet oxidation method using di-acid mixture as described by Singh *et al.* (1999). Among the nutrient elements, Ca and Mg were determined by titrimetrically, P and S were measured by spectrophotometrically, and Na and K were estimated by flame photometrically as mentioned by Singh *et al.* (1999).

Data collection and statistical analysis

Data on plant height and number of leaves were recorded at 30, 40, 50, 60, 70 and 80 days after transplanting (DAT). Number of flower clusters was counted from each plant at 80 DAT. Fruit length, fruit diameter, number of fruits plant^{-1}, single fruit weight and yield plant^{-1}, were recorded at harvest, and then the average data were used in this study. Obtained data were analysed statistically and the mean differences of the treatments were adjusted by least significant difference (LSD) test with the help of computer package M-STAT.

RESULTS AND DISCUSSION

Effect of chitosan application on morphological characters of tomato (*L. esculentum*)

Effect of different application methods and concentrations of chitosan on plant height of tomato (*L. esculentum*) at different DAT are presented in Figure 1 and there were no significant variations among the treatments at different DAT. But it is evident from Figure 1 that the highest plant height was recorded by the application of T_4 treatment (foliar application of chitosan @ 80 ppm) at all DAT. Results revealed that plant height was greater in chitosan applied tomato (*L. esculentum*) plants than control plants. The longest plant was obtained in T_4treatment (74.00 cm) followed by T_9 and T_{10} at 80 DAT. Control plant produced the shortest plant height (62.75 cm) at 80 DAT. Similar result was also reported by El-Tantawy (2009) who reported that plant height in tomato (*L. esculentum*) increased with the application of chitosan. Sultana *et al.* (2017) reported that foliar spraying of oligo-chitosan with different concentrations (60 and 100 ppm) has positive effect on plant height of tomato at different days after sowing. Mondal *et al.* (2016) also reported that foliar application of chitosan (25, 50, 75 and 100 ppm) at early growth stages increased plant height of summer tomato (*L. esculentum*). Chitosan has been reported as a high potential biomolecule had molecular signals that served as plant growth promoters (Gornik *et al.* 2008). Recently some researchers reported that the stimulating effect of chitosan on plant growth may be attributed to an increase in key enzymes activities of nitrogen metabolism (nitrate reductase, glutamine synthetase and protease) and improved the transportation of nitrogen in the functional leaves which enhanced plant growth and development (Khan *et al.*, 2002; Gornik *et al.*, 2008).

Effect of different application methods and concentrations of chitosan on number of leaves plant^{-1} of tomato (*L. esculentum*) at different DAT are presented in Figure 2. There were significant variations among the treatments at 40, 50 and 80 DAT. It is evident from Figure 2 that the highest number of leaves plant^{-1} of tomato was recorded by the application of T_4 treatment (foliar application of chitosan @ 80 ppm) at 50, 70 and 80 DAT. Results revealed that foliar application of chitosan had significant positive effect to increase number of leaves plant^{-1} of tomato (*L. esculentum*) than soil application of chitosan. The maximum number of leaves plant^{-1} of tomato was obtained in T_4 treatment (36.75) followed by T_5, T_7 and T_{10}treatments at 80 DAT. Treatment T_1produced the minimum number of leaves plant^{-1} of tomato (24.00), which was statistically similar with T_2 and control treatments at 80 DAT. The result obtained from the present study is consistent with the result of El-Tantawy (2009) who stated that leaf number in tomato plants increased with the application of chitosan than control plants.

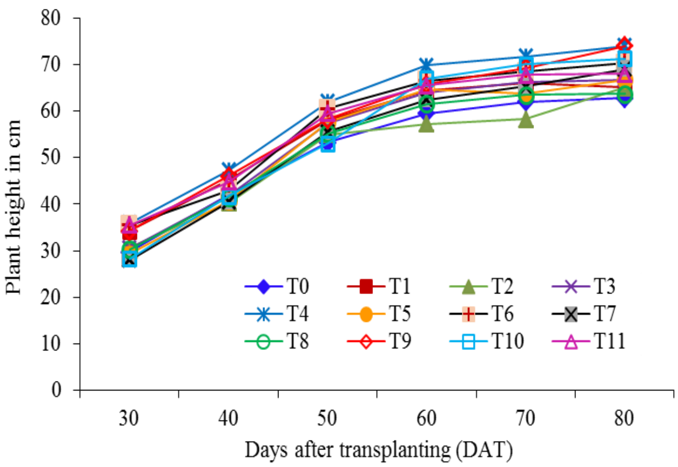

Figure 1. *Effect of different application methods and doses of chitosan on plant height of tomato (L. esculentum) at different days after transplanting (DAT).*

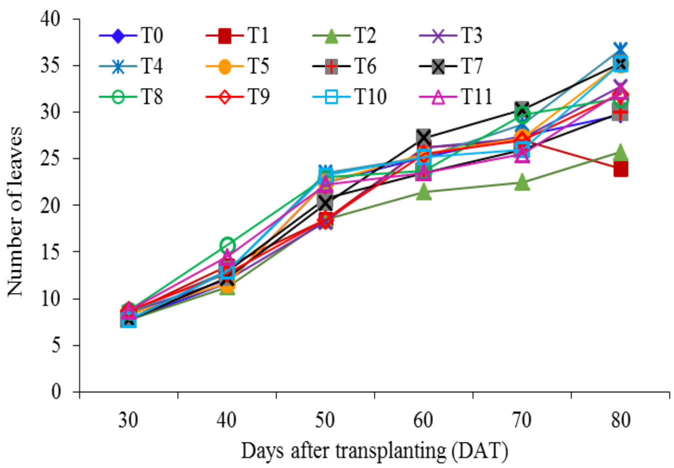

Figure 2. *Effect of different application methods and doses of chitosan on number of leaves of tomato at different days after transplanting (DAT).*

Effect of chitosan application on reproductive characters of tomato (*L. esculentum*)

Different application methods and concentrations of chitosan showed significant effect on number of flower clusters plant^{-1} and flowering duration of tomato (Table 1). The average number of flower clusters plant^{-1} of tomato varied from 9.75-13.75 with a mean value of 12.02 among the treatments. The maximum number of flower clusters plant^{-1} of tomato was recorded in treatments both T_5 and T_7, while the minimum numbers of flower cluster plant^{-1} was obtained from control treatment (Table 1). Results revealed that different application methods of chitosan had significant positive effect to increase number of flower clusters plant^{-1} of tomato. Similar result was also reported by Sultana *et al.* (2017), and they stated that foliar spraying of oligo-chitosan with different concentrations (60 and 100 ppm) has positive effect on number of flower clusters plant^{-1} of tomato at different days after sowing. Mondal *et al.* (2016) also found that the number of effective flower cluster and flowers plant^{-1} were greater in chitosan (25, 50 and 75 ppm) applied to summer tomato (*L. esculentum*) plants than control plants. On the other hand, the average flowering duration of tomato varied from 65.00-81.50 days with a mean value of 72.21 days. The maximum flowering duration of tomato was recorded in treatment T_6, which was statistically at par with the treatments T_3 and T_9, while the minimum duration was obtained from control treatment (Table 1). Results revealed that different application methods of chitosan had significant positive effect to flowering duration of tomato (*L. esculentum*). Mondal *et al.* (2016) also stated that foliar application of chitosan increased reproductive efficiency of summer tomatoes and thereby increased the prime yield component.

Effect of different application methods and levels of chitosan had no significant effect on fruit length and diameter of tomato (*L. esculentum*). The average fruit length of tomato varied from 4.05-4.65 cm with a mean value of 4.40 cm (Table 1). The highest fruit length of tomato was obtained from the treatment T_2 (i.e. soil application of chitosan @ 120 ppm) followed by T_7, T_1 and control. On the other hand, the lowest fruit length of tomato (*L. esculentum*) was obtained from the T_5 treatment. The average fruit diameter of tomato ranged from 3.18-3.75 cm with a mean value of 3.50 cm (Table 1). The highest fruit diameter of tomato was obtained from the treatment T_2 (i.e. soil application of chitosan @ 120 ppm) followed by T_7, T_4, T_{11}, T_1 and control. On the other hand, the lowest fruit diameter of tomato (*L. esculentum*) was obtained from the T_{10} treatment. So, it can be inferred from the present study results that fruit length and diameter of tomato (*L. esculentum*) are not affected by the different application method and concentration of chitosan. Similarly, number of fruits plant^{-1} of tomato (*L. esculentum*) also did not vary significantly by the effect of different application methods and concentration of chitosan (Table 1). The maximum number of fruits plant^{-1} of tomato was obtained from the treatment T_6 (i.e. combination of soil and foliar application of chitosan @ 80 ppm and 60 ppm, respectively) followed by T_7, T_9, T_{10} and T_3. On the other hand, the minimum number of fruits plant^{-1} of tomato was recorded from the control plant followed by T_5, T_1 and T_2 treatments. Present study results revealed that number of fruits plant^{-1} of tomato (*L. esculentum*) increased by the different application method and concentration of chitosan although the results were insignificant. On the contrary, several study reported that foliar spraying of chitosan has positive significant effect on number of fruits plant^{-1} of tomato (Mondal *et al.*, 2016; Sultana *et al.*, 2017).

Different application methods and levels of chitosan had insignificant effect on single fruit weight of tomato (Table 1). Single fruit weight of tomato (*L. esculentum*) varied from 33.35-40.90 g with an average value of 36.08 g among the treatments. The highest single fruit weight of tomato (*L. esculentum*) was obtained from the treatment T_6 (i.e. combination of soil and foliar application of chitosan @ 80 ppm and 60 ppm, respectively) followed by T_7, T_3 and T_1. On the other hand, the lowest single fruit weight of tomato (*L. esculentum*) was recorded from the T_{11} followed by control and T_{10} treatments. This result indicates that fruit size and weight was largely controlled by inherently. However, Sultana *et al.* (2017) reported that the average number of fruits plot^{-1} at different days after sowing (45-90) gradually increased with increasing concentration of chitosan up to 100 ppm. But the effect of different application methods and concentration of chitosan on fruit yield was statistically significant at 5% level of probability. The average fruit yield plant^{-1} of tomato (*L. esculentum*) ranged from 418.48-663.54 g with a mean value of 418.48 g (Table 1). The highest fruit yield of tomato (*L. esculentum*) was obtained from the treatment T_6 (i.e. combination of soil and foliar application of chitosan @ 80 ppm and 60 ppm, respectively) followed by T_7, T_9 and T_3 treatments. On the other hand, the lowest fruit yield of tomato (*L. esculentum*) was obtained from the control treatment. This result is at par with the research works done by Sultana *et al.* (2017) and Mondal *et al.* (2016), they stated that foliar spraying of oligo-chitosan with different concentrations has positive effect on fruit yield of tomato (*L. esculentum*).

Effect of chitosan application on biochemical parameters of tomato (*L. esculentum*)

Different application methods and concentrations of chitosan showed highly significant difference on biochemical parameters (vitamin-C, titratable acidity and lycopene) of tomato (*L. esculentum*) fruits (Table 2). Tomato is a good source of vitamin-C and according to Erba *et al.* (2013), the ingestion of 200 g of fresh tomatoes provides about 30% and 36% of the recommended dietary allowances for vitamin-C for men and women, respectively. The average vitamin-C content of tomato fruits ranged from 2.19-4.09 mg 100g^{-1} sample with a mean value of 3.05 mg 100g^{-1} sample (Table 2). The highest vitamin-C content in tomato (*L. esculentum*) fruits was obtained from the treatment T_4 (i.e. foliar application of chitosan @ 80 ppm) followed by T_5 and T_8 treatments. On the other hand, the lowest amount of vitamin-C was recorded from the treatment T_1 followed by T_2 and control. Present study results revealed that foliar application of chitosan alone or in combination with soil application significantly

Table 1. Effect of different application methods and doses of chitosan on yield attributes and yield of tomato (*L. esculentum*).

Treatment	Number of flower cluster	Flowering duration (day)	Fruit length (cm)	Fruit diameter (cm)	Number of fruits plant^{-1}	Single fruit weight (g)	Yield plant^{-1} (g)
T0	9.75c	65.00e	4.58a	3.55	12.00	34.53	418.48b
T1	13.50a	67.25d	4.56a	3.54	12.50	36.71	459.83ab
T2	10.00c	66.25de	4.65a	3.75	12.50	35.00	437.43b
T3	13.25ab	81.25a	4.28ab	3.50	14.50	37.25	548.13ab
T4	12.75abc	72.50b	4.57a	3.58	13.50	35.25	477.37ab
T5	13.75a	71.00bc	4.05b	3.30	12.25	35.57	442.43ab
T6	11.00abc	81.50a	4.44ab	3.54	16.25	40.90	663.54a
T7	13.75a	70.50bc	4.58a	3.63	15.25	38.56	600.80ab
T8	12.50abc	71.00bc	4.46ab	3.44	12.50	35.31	442.63ab
T9	11.50abc	80.25a	4.33ab	3.35	15.25	35.90	549.42ab
T10	10.25bc	69.75c	4.21ab	3.28	15.25	34.64	527.24ab
T11	12.25abc	70.25c	4.17ab	3.55	13.00	33.35	421.39b
CV (%)	2.36	1.01	0.94	1.09	2.71	1.69	3.62
LSD	1.82	1.27	0.28	0.29	2.74	4.70	128.52
Level of Significance	*	**	*	NS	NS	NS	*

* & ** = Significant at 5 and 1% level of probability, respectively; NS= Not significant.

Table 2. Effect of different application methods and doses of chitosan on major biochemical and mineral constituents of tomato (*L. esculentum*).

Treatment	Vitamin-C (mg 100g^{-1} sample)	Total acidity (%)	Lycopene (mg 100 g^{-1} sample)	Major mineral constituents in %					
				Ca	Mg	Na	K	S	P
T0	2.63g	0.27ef	3.44b	0.64b	0.29d	0.34bc	0.535f	0.128j	0.18de
T1	2.19h	0.34de	3.41b	0.58c	0.49b	0.36ab	0.623a	0.142b	0.15ef
T2	2.63g	0.25f	2.54e	0.48d	0.49b	0.36ab	0.574c	0.132g	0.18de
T3	2.92f	0.34de	3.21c	0.32e	0.58a	0.36ab	0.533f	0.132f	0.17de
T4	4.09a	0.41bc	3.17c	0.64b	0.39c	0.36ab	0.568d	0.151a	0.13f
T5	3.65b	0.36d	2.38f	0.48d	0.29d	0.26e	0.364k	0.139d	0.15ef
T6	2.90f	0.35de	3.55a	0.64b	0.39c	0.33bcd	0.520g	0.135e	0.33a
T7	3.40c	0.39bc	3.17c	0.69a	0.39c	0.33bcd	0.589b	0.131h	0.26b
T8	3.60c	0.62a	2.24g	0.48d	0.29d	0.38a	0.553e	0.135e	0.19cd
T9	3.36c	0.46b	3.23c	0.48d	0.29d	0.30d	0.456i	0.129i	0.19cd
T10	3.04e	0.41bc	3.58a	0.48d	0.49b	0.32cd	0.507h	0.140c	0.16def
T11	3.21d	0.37c	2.95d	0.64b	0.29d	0.31cd	0.434j	0.122k	0.22c
CV (%)	2.72	4.37	2.41	3.26	4.33	1.82	2.26	0.93	4.86
LSD	0.044	0.044	0.062	0.014	0.010	0.014	0.010	0.017	0.010
Level of Significance	**	**	**	**	**	**	**	**	**

** = Significant at 1% level of probability.

increase vitamin-C content in tomatoes, but there were some inconsistencies which might be due to stage of maturity of fruits, size as well as environmental factors. This result is similar to the reports published by Abd El-Gawad and Bondok (2015) and Sultana *et al.* (2017). According to Khan *et al.* (2002), the pronounced promotional effect of chitosan on vitamin-C content compared with control could be due to the enhanceable nature of chitosan on photosynthesis process that strongly correlated with the synthesis of sugars, polysaccharides and vitamins. Chitosan served as a plant growth promoters may be due to an increase in the availability and uptake of water and essential nutrients through adjusting cell osmotic pressure and reducing the accumulation of harmful free radicals by increasing antioxidants and enzyme activities (Guan *et al.*, 2009).

The highest amount of total acidity was found at T_8 treatment (0.62%) followed by T_9, T_{10} and T_4 treatments. On the other hand, the lowest amount of total acidity was obtained from the control treatment which was statistically at par with T_1, T_2 and T_3 treatments (Table 2). So, it can be inferred from this study results that combined application of chitosan increased total acidity compared to control and foliar treatments. But Ghoname *et al.* (2010) reported that spraying with chitosan showed positive responses on total acidity content of sweet pepper. On the contrary, Sultana *et al.* (2017) reported that foliar application of chitosan showed reduction in acidity compared to control samples in tomato (*L. esculentum*). Similarly, Meng *et al.* (2008), stated that total acidity of the grape fruit decreased with increase in maturity and was not significantly affected by preharvest chitosan spraying treatment. However, there were some variations in results that might be due to maturity status of fruits, size as well as environmental factors.

Lycopene is one kind of carotenoids responsible for the red colour of tomato (*L. esculentum*). Epidemiological, as well as cell culture and animal studies suggest that lycopene and the consumption of lycopene containing foods may reduce cancer or cardiovascular disease risk (Story *et al.*, 2010). The amount of lycopene obtained from different treatments of tomato fruits are presented in Table 2. The average lycopene content of tomato fruits ranged from 2.38-3.58 mg 100g^{-1} sample with a mean value of 3.07 mg 100g^{-1} sample (Table 2). The highest amount of lycopene in tomato fruits was obtained from the treatment T_{10} (i.e. soil application of chitosan @ 120 ppm + foliar application of chitosan @ 80 ppm), which was statistically at par with T_6 treatment (i.e. soil application of chitosan @ 80 ppm + foliar application of chitosan @ 60 ppm). On the other hand, the lowest amount of lycopene was recorded from the treatment T_5 followed by T_2. Present study results revealed that foliar application of chitosan alone or in combination with soil application significantly increased lycopene content in tomatoes, but there were some inconsistencies in obtained result which might be due to stage of maturity of fruits, size as well as environmental factors. According to Meng *et al.* (2008), the activities of superoxide dismutase decreased by the application of chitosan treatments and postharvest chitosan spraying/coating treatments also changed the activities of polyphenol oxidase, peroxidase and phenylalanine ammonia-lyase. They also stated that total phenolic compounds content in preharvest chitosan spraying treated fruit decreased but then increased at the end of the storage period.

Effect of chitosan application on mineral contents of tomato fruits

The highest amount of Ca was found at T_7 treatment (0.69%) followed by T_4, T_6, T_{11} and control treatments. On the other hand, the lowest amount of Ca was obtained from the T_3 treatment (Table 2). So, it can be inferred from this study results that application of chitosan had positive effect on total Ca content of tomato (*L. esculentum*) fruits. Paul and Shaha (2004) stated that citrus fruits are not considerable to be the good sources of Ca, but some fruits may contain appreciable amount of Ca. However, they obtained 27.0±1.2 mg% Ca in tomato fruits collected from the northern region of Bangladesh. According to Olaniyi *et al.* (2010), the tomato variety *Roma VF* contained 0.376% Ca, which was a bit lower compared to the present study.

The Mg content in tomato (*L. esculentum*) fruits ranged from 0.29 -0.58% with a mean value of 0.39% (Table 2). The highest amount of Mg was obtained from the treatment T_3 (foliar application of chitosan @ 60 ppm), while the lowest amount of Mg was found in control treatment which was statistically similar to T_5, T_8, T_9, and T_{11} treatments. Present study results revealed that foliar application of chitosan had positive effect on total Mg content of tomato fruits. Paul and Shaha (2004) reported 17.0±1.8 mg% Mg in tomato fruits collected from the northern region of Bangladesh. According to Olaniyi *et al.* (2010), the tomato variety *Roma VF* contained 0.222% Mg, which was almost similar to the present study.

Different application methods and level of chitosan showed highly significant effect on Na and K contents of tomato (*L. esculentum*) fruits (Table 2). The highest amount of Na was found at T_8 treatment (0.38%), which was statistically similar to T_1, T_2, T_3 and T_4 treatments. In case of K, the maximum amount was obtained from the treatment T_1 followed by the T_7, T_2 and T_4 treatments. On the other hand, the lowest amount of Na and K was obtained from the T_5 treatment. So, it can be inferred from this study results that both soil and foliar application of chitosan had positive effect on total Na and K content of tomato (*L. esculentum*) fruits. Paul and Shaha (2004) reported 5.5±0.9 mg% Na and 275±2.8 mg% K in tomato fruits collected from the northern region of Bangladesh. According to Olaniyi *et al.* (2010), the tomato variety *Roma VF* contained 0.148% K. But Mukta *et al.* (2015) stated that the K content in tomato fruits varied from 0.76 to 0.90%.

Similar to other mineral nutrients, different application methods and level of chitosan also showed highly significant effect on S and P contents of tomato (*L. esculentum*) fruits (Table 2). The highest amount of S was found at T_4 treatment (0.151%), followed by the treatments T_1 (0.142%), T_{10} (0.140%) and T_5 (0.139%). On the other hand, the lowest amount of S was obtained from the T_{11} treatment followed by control. According to Mukta *et al.* (2015), the content of S in tomato fruits varied from 0.05 to 0.39%, and present study results were within this range. The P content in tomato (*L. esculentum*) fruits ranged from 0.13-0.33% with a mean value of 0.19%. The highest amount of P was obtained from the treatment T_6 followed by the T_7 and T_{11} treatments. On the other hand, the lowest amount of P was found in T_4 treatment. Paul and Shaha (2004) stated that citrus fruits are not good source of P although they reported 28.0±1.8 mg% P in tomato fruits collected from the northern region of Bangladesh. According to Olaniyi *et al.* (2010), the tomato variety *Roma VF* contained 0.445% P, which was comparatively higher than this study. But Kadiri *et al.* (2015) reported 1.02±0.01 mg kg^{-1} P in tomato fruits, which was very much smaller than the present study. However, there were some inconsistencies in major nutrients content which might be due to stage of maturity of fruits, size as well as environmental factors.

Conclusion

Different application methods and levels of chitosan had significant effect on number of leaves, number of flower clusters, flowering duration, fruit length, yield, major biochemical and mineral nutrients of tomato (*L. esculentum*). The highest fruit yield and lycopene content of tomato were obtained from the treatments T_6 (i.e. soil application of chitosan @80 ppm + foliar application of chitosan @60 ppm) and T_{10} (i.e. soil application of chitosan @120 ppm + foliar application of chitosan @80 ppm), respectively. On the other hand, treatment T_4 (i.e. foliar application of chitosan @ 80 ppm) was more effective concerning most of the growth and biochemical parameters of tomato (*L. esculentum*). Thus, it can be summarized from the present study results that foliar application of chitosan alone or in combination with soil application has significant effect on growth, yield and biochemical characters of tomato (*L. esculentum*) fruits, but there were some inconsistencies which might be due to stage of maturity of fruits, size as well as environmental factors. So, before final recommendation of application dose and method of chitosan, further study is needed in different years and agro-ecological zones of Bangladesh.

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