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FOLIAR APPLICATION OF CHITOSAN IMPROVED MORPHO-PHYSIOLOGICAL ATTRIBUTES AND YIELD IN SUMMER TOMATO (*Solanum lycopersicum*)

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Chitosan acts as an elicitor in many plant species. It not only activates the immune system of plants, but also increases the crop yields. A study was planned to investigate the effect of foliar application of chitosan on morphological, growth and reproductive characters and its consequence on fruit yield of summer tomato. The experiment comprised five levels of chitosan concentrations *viz*., 0 (control), 25, 50, 75 and 100 mg L^{-1}. The chitosan was sprayed two times, 25 and 35 days after transplanting. Foliar application of chitosan at early growth stages increased plant height, number of branches and leaf area $plant^{-1}$ and nitrate reductase activity in leaves, resulting increased total dry mass $plant^{-1}$ and absolute growth rate. Reproductive parameters (number of effective flower clusters and flowers $plant^{-1}$, and reproductive efficiency) also increased in chitosan applied plants and thereby increased the prime yield component, number of fruits $plant^{-1}$ of summer tomato. The higher fruit yield was recorded in 50 and 75 mg L^{-1} of chitosan in summer tomato with being the highest in 75 mg L^{-1} (35.61 t ha^{-1}). Therefore, foliar application of chitosan at 75 mg L^{-1} may be used at early growth stage for getting maximum fruit yield of summer tomato under sub-tropical condition.
Keywords: Chitosan, foliar spray, plant growth, fruit yield, summer tomato.

INTRODUCTION

Tomato (*Solanum lycopersicum*) is considered to be a day neutral plant but it is not productive under high temperature (>30°C) due to thermo-sensitiveness for flowering (Mondal *et al*., 2011). The crop performs better under an average monthly temperature of 20-25°C. But commercially, it may grow at temperature ranging from 15-27°C (Haque *et al*., 1999). Plant could set fruit abundantly when the night temperature is between 15°C and 20°C and the day temperature at about 22-25°C (Kalloo, 1985). In Bangladesh, congenial atmosphere remains for tomato production during November to March. So, tomato is widely grown in Bangladesh usually in winter season (November-March). High temperature during day and night above 32°C and 21°C, respectively was recorded as limiting factor to fruit set due to impaired complex physiological processes in the pistil which results on floral or fruit abscission (Picken, 1984) during summer season. Both day and night temperatures in Bangladesh are very high, which is the major environmental challenges for tomato cultivation in summer season (Mondal *et al*., 2011). Therefore, it is very essential to find out the suitable varieties/genotypes that are tolerant to high temperature. In this regard, the scientists of different research Institutes in Bangladesh are successful in developing tomato genotypes those are suitable for summer season and has been cultivated commercially for few years in Bangladesh. However, the yield performance of summer tomato varieties is very poor. So, it is urgent to increase tomato yield by proper management and cultural practices. Plant growth regulators are one of the most important factors for increasing higher yield. Application of hormone has good management effect on growth and yield of tomato. On the other hand, flower and fruit abortion are common phenomenon in tomato (Imam *et al*., 2010). A large proportion of tomato reproductive structures abscise before reaching maturity, which is the primary cause of lower yield in summer season (Mondal *et al*., 2011). Fruit yield of tomato can be increased through reducing reproductive abscission. Hormones regulate abscission process and application of synthetic hormones may reduce abscission of flowers and increase yield of fruit crops (Imam *et al*., 2010; Mondal *et al*., 2012; Mondal *et al*., 2013). Chitosan is a natural biopolymer derived from chitin, a polysaccharide found in exoskeleton of crustaceans, insects as well as cell wall of fungi and some algae (Boonlertnirum *et al*., 2010). It is low toxic and inexpensive compound that is biodegradable and environmentally friendly with various applications in agriculture. Chitosan has been widely used in agricultural applications mainly for stimulation of plant immunity, to protect plants and food products against microorganisms (bacteria and fungi) (Hadwiger *et al*., 2002;

ChunYan *et al.*, 2003; Devlieghere *et al*., 2004; Patkowska *et al*., 2006; No *et al*., 2007). Also, many efforts were done to study the effect of chitosan on plant growth, development and productivity. A positive effect of chitosan was observed on the growth of roots, shoots and leaves of various plant species. Foliar application of chitosan increased growth and yield in sweet pepper and radish (Ghoname *et al.*, 2010; Farouk *et al.*, 2011). Similar results were also observed in grapevine and strawberry (Gornik *et al*., 2008; Abdel-Mawgoud *et al*., 2010). Recently, Sheikha and Al-Malki (2011) indicate that application of different concentrations of chitosan enhanced bean shoot and root length, fresh and dry weights of shoots, root and leaf area. In addition, foliar applications with chitosan resulted in higher vegetative growth and improvement in fruit quality of cucumber (Farouk *et al.*, 2008). For other cultivated plants, Bittelli *et al.* (2001) reported that foliar application of chitosan decreased transpiration in pepper plants, and reduced water use by 26-43% while maintaining biomass production and yield. Similar result was also reported by Farouk and Amany (2012) in cowpea by foliar application of chitosan under water stress. However, to the best of our knowledge, there has also been no previous report regarding the effects of foliar application of chitosan on growth, reproductive characters and its consequence on yield in summer tomato. Therefore, the present research work was undertaken to study the effect of chitosan on morph-physiological features, yield attributes and yield in summer tomato under sub-tropical (24°75´N and 90°50´E) conditions.

MATERIALS AND METHODS

Two experiments were carried out at the farm of Bangladesh Institute of Nuclear Agriculture, Mymensingh (24°75´N and 90°50´E), Bangladesh during the two successive seasons (March-June) of 2011 and 2012. Five concentrations of chitosan *viz.*, 0, 50, 75, 100, and 125 mg L^{-1} were applied two times at vegetative, 25 days after transplanting (DAT), and at flowering start phase, 35 DAT. The chitosan was sprayed by a hand sprayer at afternoon. Foliar applications were carried out until run off the solution. The recently released summer tomato variety, BINAtomato-6 was used as test crop. The soil of the experimental area is sandy loam. The unit plot size was 5 m × 4 m. The row to row and plant to plant distances was 50 cm. The experiment was laid out in a randomized complete block design with three replicates. The fertilizers such as urea, triple superphosphate (TSP), muriate of potash (MP), gypsum and cowdung were applied at the rate of 280, 160, 140, 40 and 10000 kg ha^{-1}, respectively. Total amount of TSP, gypsum and cowdung were applied as basal dose during soil preparation. Half of MP was applied as basal dose during final land preparation and rest of half was applied at 45 DAT (flowering and fruiting stages). Half of urea was applied as top dress at 21 DAT and rest half was applied at 45 DAT. Irrigation, weeding, pruning, stalking, pesticides spray and other intercultural operations were done as and when required for normal plant growth and development.

To study growth characteristics, a total of two harvests were made in 2011. The second rows of each plot were used for sampling. The first and second crop sampling was done at 40 and 60 DAT. From each sampling, five plants were randomly selected from each plot and uprooted for collecting necessary parameters. The plants were separated into roots, stems, leaves and fruits, and the corresponding dry weight were recorded after oven drying at 80±2°C for 72 hours. The leaf area was measured by automatic leaf area meter (Model: LICOR 3000, USA) at 80 DAT, just before starting of harvesting fruits. The growth analysis like absolute growth rate (AGR) and relative growth rate was carried out following the formula of Hunt (1978). All biochemical parameters were recorded at 50-60 DAT, the fruiting stage. Reducing sugar was determined following the method of Badruddin (2005). Nitrate reductase (NR) activity was determined by following the method of Stewart and Orebamjo (1979).

Other morphological, reproductive and yield attributes were recorded during tomato harvest. Per cent fruit set to flowers was calculated as follows: % fruit set = (Number of fruits $plant^{-1}$ ÷ Number of flowers $plant^{-1}$) × 100. Harvesting was done at different dates depending on fruit ripening. The collected data were analyzed statistically using the computer package programme, MSTAT-C and the mean differences were adjudged by Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

***Morpho-physiological parameters*:** The effects of different concentrations of chitosan on morpho-physiological characters such as plant height, branch and leaf number $plant^{-1}$, leaf area (LA) and straw weight $plant^{-1}$ were significant (Table 1). Results showed that plant height, LA and straw weight $plant^{-1}$ increased with increasing concentration of chitosan till 75 mg L^{-1} followed by a slide decline; whereas, number of branches and leaves $plant^{-1}$ increased with increase in concentration of chitosan till 100 mg L^{-1} but the increase was not significant after increment of chitosan concentration (Table 1). However, the above morphological parameters increased significantly up to 75 mg L^{-1} of chitosan and thereafter increase or decrease was non-significant over the maximum value. The lowest plant height, number of branches and leaves $plant^{-1}$, LA and straw weight $plant^{-1}$ was recorded in control plants. The LA increased in chitosan applied plants than control plants due to increase in number of branches.

Chitosan has been reported as a high potential bio-molecule that increases plant growth and development (Chibu and Shibayama, 2003; Gornik *et al.*, 2008). Hadwiger *et al.* (2002) reported that chitosan had molecular signals that served as

Table 1. Effect of different concentrations of chitosan and season on morphological characters in summer tomato.

Chitosan (mg L^{-1})	Plant height (cm)	Branches $plant^{-1}$ (No.)	Leaves $plant^{-1}$ (No.)	Leaf area $plant^{-1}$ (cm^2)	Straw weight $plant^{-1}$ (g)
0	69.8 c	4.02 c	46.0 d	1916 b	51.65 d
25	70.7 c	4.25 c	49.1 c	2044 b	55.24 c
50	78.3 b	4.85 b	53.7 b	2216 ab	69.85 b
75	83.1 a	5.55 a	57.0 a	2360 a	77.40 a
100	79.5 ab	5.58 a	57.0 a	2131 ab	68.35 b
F-test	**	**	**	*	**
Season					
2011	70.4 b	4.21 b	46.7 b	1862 b	57.62 b
2012	82.2 a	5.50 a	58.4 a	2404 a	71.38 a
F-test	**	**	**	**	**
CV (%)	4.66	8.92	4.66	10.64	4.52

In a column, either within concentration or season, the figures bearing the same letter (s) do not differ significantly at $P \leq 0.05$ by DMRT; *, ** indicate significant at 5% and 1% level of probability, respectively

Table 2. Effect of different concentrations of chitosan on growth and biochemical parameters in summer tomato.

Chitosan (mg L^{-1})	Growth parameters				Biochemical parameters	
	Total dry mass (g $plant^{-1}$) at		Absolute growth rate(mg $plant^{-1}$ day^{-1})	Relative growth rate (mg g^{-1} day^{-1})	Nitrate reductase (µmol NO_2^- g^{-1} fw)	Total sugar (mg g^{-1} fw)
	40 DAT	60 DAT				
0	17.85 b	29.84 d	600 c	25.71 d	5.36 c	65.25 c
25	18.99 b	35.22 c	812 c	30.90 c	5.68 bc	65.75 bc
50	20.26 ab	43.26 b	1150 b	37.90 b	6.19 a	71.35 a
75	21.98 a	52.60 a	1531 a	43.63 a	6.48 a	71.15 a
100	18.28 b	39.11 bc	1042 b	38.02 b	6.00 ab	70.00 ab
F-test	*	**	**	**	**	*
CV (%)	7.79	6.52	11.16	8.13	6.52	5.08

In a column, figures having the same letter (s) do not differ significantly at $P \leq 0.05$ by DMRT; *, ** indicate significant at 5% and 1% levels of probability, respectively; DAT = Days after transplanting

plant-growth promoters. It is reported that foliar application of chitosan increased plant growth and development in cucumber (Shehata *et al.,* 2012), in strawberry (Abdel-Mawgoud *et al.,* 2010), in sweet pepper (Ghoname *et al.,* 2010), in radish (Farouk *et al.*, 2011), in beans (Sheikha and Al-Malki, 2011) and in munbean (Mondal *et al.*, 2013). The stimulating effect of chitosan on plant growth may be attributed 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) or may be attributed to an increase in the key enzyme activities of nitrogen metabolism (nitrate reductase, glutamine synthetase and protease) and improved the transportation of nitrogen (N) in the functional leaves as well as increased photosynthesis which enhanced plant growth and development (Mondal *et al.*, 2012). In the present experiment, similar phenomenon may be occurred and thereby increased plant height, number of branches and leaves $plant^{-1}$, LA and straw weight $plant^{-1}$ in chitosan applied tomato plants than control plants.

***Growth and biochemical parameters*:** The effects of different levels of chitosan application on growth parameters such as total dry mass (TDM) $plant^{-1}$ at 40 and 60 days after transplanting (DAT), absolute growth rate (AGR) and relative growth (RGR), and biochemical parameters such as nitrate reductase (NR) activity and total sugar content in leaves were significant (Table 2). Results revealed that all the growth and biochemical parameters increased with increasing concentration of chitosan till 75 mg L^{-1} followed by a decline. TDM was greater in chitosan applied plants than control plants might be due to increase LA (Table 1). These results indicate that application of chitosan at early growth stages had effect on growth and development in tomato. Ke *et al*. (2011) reported that application of carboxymethyl chitosan increased key enzymes activities of nitrogen metabolism (nitrate reductase, glutamine synthetase and protease) which enhanced plant growth and development, thereby increased

TDM in rice. In the study, NR activity was greater in chitosan applied plants than control plants and resulting increased TDM in chitosan applied plants than control plants in tomato. These results have conformity with El-Tantawy (2009) who reported that plant growth and development enhanced by the application of chitosan in tomato.

***Reproductive parameters*:** The number of effective flower cluster and flowers plant^{-1} were greater in chitosan applied plants than control plants (Table 3). The highest number of effective flower cluster and flowers plant^{-1} was recorded in 75 mg L^{-1} concentration of chitosan followed by 100 mg L^{-1} with same statistical rank. Similarly, the highest number of fruits cluster^{-1} was observed in 75 mg L^{-1} concentration of chitosan followed by 50 mg L^{-1} concentration of chitosan. The lowest number of fruits cluster^{-1} was recorded in 100 mg L^{-1} concentration of chitosan. However, reproductive efficiency (RE) was the highest in 50 mg L^{-1} concentration of chitosan followed by 25 mg L^{-1} and 50 mg L^{-1} concentrations of chitosan. The lowest RE was observed in 100 mg L^{-1} concentration of chitosan. The number of non-effective flower cluster plant^{-1} was higher in control plants than chitosan applied plants (Table 3). The non-effective flower clusters plant^{-1} decreased with increasing concentration of chitosan till 75 mg L^{-1} followed by increased. These results indicate that application of chitosan increased flower production and also increased RE which resulted increase yield attributes and thereby fruit yield. These results are consistent with Mondal *et al*. (2013) who reported that application of chitosan increased flower production and decreased flower abortion in mungbean. The increase in the number of effective flower cluster and flowers plant^{-1} and RE at higher doses of chitosan (50 and 75 mg L^{-1}) reported here might be a result of reduction in the number of non-effective flower clusters plant^{-1} and reduced flower abortion (Table 3). Again, higher RE in chitosan applied plant might be resulting from the translocation of sufficient assimilate to the flowers (Nahar and Ikeda, 2002).

***Yield components and fruit yield*:** There were significant variations in number of fruits plant^{-1} and fruit yield both plant^{-1} and hectare^{-1} due to different levels of foliar application of chitosan on tomato plant but single fruit weight was not significantly influenced by chitosan application (Table 4). The number of fruits plant^{-1} and fruit yield both plant^{-1} and hectare^{-1} increased with increasing concentration of chitosan

Table 3. Effect of different concentrations of chitosan on reproductive characters in summer tomato (year 2011).

Chitosan (mg L^{-1})	Effective flower clusters plant^{-1} (No.)	Non- effective flower clusters plant^{-1} (No.)	Fruits cluster^{-1} (No.)	Flowers plant^{-1} (No.)	Reproductive efficiency (%)
0	3.50 c	15.38 a	2.14 b	30.50 c	29.51 b
25	5.05 b	12.00 b	2.08 b	33.51 bc	31.37 ab
50	5.75 ab	9.88 c	2.39 ab	39.00 ab	35.29 a
75	6.25 a	7.50 d	2.64 a	45.75 a	31.69 ab
100	6.00 ab	10.12 c	1.58 c	44.25 a	26.44 b
F-test	**	**	**	**	*
CV (%)	9.21	8.29	10.29	10.13	9.05

In a column, figures having the same letter (s) do not differ significantly at P ≤0.05 by DMRT; *, ** indicates significant at 5% and 1% levels of probability, respectively

Table 4. Effect of different concentrations of chitosan and season on yield components and fruit yield in summer tomato.

Chitosan (mg L^{-1})	Fruits plant^{-1} (No.)	Single fruit weight (g)	Fruit yield plant^{-1} (g)	Fruit yield (t ha^{-1})
0	11.72 b	54.7	653 c	24.80 c
25	12.55 b	55.0	704 c	26.75 c
50	15.73 a	56.1	891 ab	33.85 ab
75	16.50 a	56.5	937 a	35.61 a
100	14.80 a	54.5	823 b	30.76 b
F-test	**	NS	**	**
Season				
2011	11.89 b	50.7 b	606 b	23.03 b
2012	16.63 a	60.0 b	997 a	37.68 a
F-test	**	**	**	**
CV (%)	9.92	4.20	9.59	8.75

In a column, either within concentration or season, the figures bearing the same letter (s) do not differ significantly at P ≤ 0.05 by DMRT; ** indicate significant at 1% level of probability; NS = Not significant

Table 5. Interaction effect of season and chitosan concentration on yield components and fruit yield in summer tomato.

Interaction		Fruits plant^{-1} (No.)	Single fruit weight (g)	Fruit yield plant^{-1} (g)	Fruit yield (t ha^{-1})
Season	**Chitosan (mg L^{-1})**				
2011	0	9.00 e	50.11 d	451 d	17.14 d
	25	10.50 de	48.20 d	506 d	19.23 d
	50	13.75 bc	51.40 cd	707 c	26.87 c
	75	14.50 b	54.60 bc	792 bc	30.10 bc
	100	11.70 cd	49.10 d	574 d	21.82 d
2012	0	14.43 b	59.20 a	854 b	32.45 b
	25	14.60 b	61.80 a	902 b	34.28 b
	50	17.72 a	60.70 a	1075 a	40.83 a
	75	18.50 a	58.40 ab	1082 a	41.12 a
	100	17.89 a	59.90 a	1071 a	39.70 a
F-test		*	*	*	*
CV (%)		9.92	4.20	9.59	8.75

In a column, figures having the same letter (s) do not differ significantly at $P \leq 0.05$ by DMRT; * indicates significant at 5% levels of probability

till 75 mg L^{-1} followed by decline. The lowest number of fruits plant^{-1} and fruit yield was recorded in control plants. The yield attributes and fruit yield were greater in 2012 than in 2011. The management practices were almost similar in both experiments. But plant growth and yield performances were greater in 2012 than in 2011 might be due to more congenial environment for summer cultivation in 2012 than in 2011 (weather data not shown). Another factor is that two experiments were conducted at two locations of an experimental farm, distances with each other was about 100 meters. The soil nutritional status of the second experiment (conducted in 2012) was may be better than the first experiment. Therefore, plant growth and yield performances were higher in 2012 than in 2011. Chibu *et al.* (2002) reported that application of chitosan at early growth stages increased plant growth and development thereby increased seed yield in rice and soybean. Similar results were also observed by Mondal *et al.* (2013) in mungbean who reported that foliar application of chitosan at vegetative stages increased pod number and seed yield.

The interaction effect of season and chitosan concentration on yield attributes and fruit yield in summer tomato was significant (Table 5). In both the seasons, fruit yield was greater at 75 mg L^{-1} of chitosan application due to production of high number of effective flower cluster, flowers and fruits plant^{-1} but the magnitude of increment was high in 2011 than in 2012. Again, in 2012, the yield attributes and fruit yield were statistically identical in 50, 75 and 100 mg L^{-1} of chitosan.

In conclusion, foliar application of chitosan at vegetative stage enhance plant growth and development which resulted increased fruit yield in tomato. Among the concentrations, 75 mg L^{-1} had superiority for plant growth, reproductive characters, yield components and yield over 25, 50 and 100 mg L^{-1}. Therefore, application of chitosan @ 75 mg L^{-1} at vegetative and early flowering stages may be recommended for summer tomato cultivation after few more field trials.

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