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Reproductive Behavior of Tomato Plant under Saline Condition with Exogenous Application of Calcium

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Abstract: The effect of salinity and mitigation of saline toxicity with calcium on reproductive response of tomato plants grown under pot conditions was studied with five salinity levels (0, 2, 4, 6 and 8 dS m^{-1}) and three Ca^{2+} levels (0, 5 and 10 mM). Irrigation with salinized water alone resulted in a significant suppression in flower and fruit production, flower dropping pattern, fruit length, fruit diameter and yield. Applying the salinized plants with calcium improved tomato fruit production to some extent in regards to salinity impact. Under the studied salinity level there was a decrease in flower production rate with significant reduction in tomato fruit yield where Ca successfully reduce the reduction rate of yield. Therefore, this experiment suggests that Ca^{2+} can effectively mitigate the deleterious effect of Na^+ stress in tomato cultivation.

Key words: *Lycopersicon esculentum* · Flower dropping · Flower and fruit number · Fruit size · Yield

INTRODUCTION

Salinity is one of the most crucial abiotic factors affecting global agricultural land area and the problem is increasing at a rate of 10% annually [1, 2]. Salinity hinders the crop growth through alteration of morphological, physiological and biochemical changes and thus reduces the productivity of crops. The response of plants to excess salinity is complex and involves morphological and developmental changes as well as physiological and biochemical processes [3, 4].

It has been reported that salinity reduced the number of flowers $cluster^{-1}$ of tomato [5] and fruit yield through decreasing the number of fruits and flowers $plant^{-1}$ [6, 7]. Fruit production reduced due to salinity which was also reported by [8, 9] separately. While excessive salt exposure reduces tomato fruit size, total yield and photosynthesis and increases blossom end rot [10]. Jaleel *et al*. [11] reported that tomato growth in saline conditions leads to change the combination and the concentration of plant shoot elements.

One possible approach to reducing the effect of NaCl stress on plant productivity is through the addition of calcium (Ca^{2+}) supplements to irrigation in the case of salt stress [12]. Ca^{2+} is a signaling molecule and second messenger who plays a significant role in recognition and response mechanism to abiotic stresses in plants [13]. Supplementation of Ca^{2+} alleviates growth inhibition by salt in glycophytic plants [14]. Ca^{2+} sustains K^+ transport and K^+/Na^+ selectivity in Na^+ challenged plants. The interaction of Na^+ and Ca^{2+} on plant growth and ion relations is well established [15]. Ca^{2+} restricts the entry of Na^+ into the plant cells under sodium stress [16]. Ca^{2+} also increases average fruit weight and size of strawberry fruits with no significant affect on titratable acidity [17, 18]. Sholi [19] showed that in saline soils, use of high amount of Ca^{2+} leads to increase the plant tolerance against salinity. In this circumstance the present study was therefore undertaken to investigate the reproductive response of tomato plant in saline condition with supplementation of Ca^{2+} to reduce the salt stress.

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MATERIALS AND METHODS

The experiment was conducted in pots under venyl house at Horticulture farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. The soil of the experimental area belongs to the Modhupur Tract under AEZ No. 28. The experiment was laid out in Randomized Complete Block Design (RCBD) with fifteen treatment combinations and four replications on tomato variety called BARI Tomato-5. Thirty-day-old seedlings were used to salinity treatment at different levels *viz.,* 0, 2, 4, 6, 8 dS m^{-1} which were maintained by adding 0, 12, 27, 48 and 58 g of sodium chloride (NaCl) respectively combined with three levels of Ca^{2+} in the form of $CaSO_4.0.5H_2O$ *viz.,* 0, 5, 10 mM irrigation water in three splits at 30, 50 and 70 DAT where each pot contained 10 kg soil. Ca^{2+} was also applied with irrigation water at same time. Number of flower cluster $plant^{-1}$, number of flowers $cluster^{-1}$, number of flowers $plant^{-1}$, number of fruits $cluster^{-1}$, number of fruits $plant^{-1}$, number of dropped flower $plant^{-1}$, fruit length (cm), fruit diameter (cm) and fruit yield (t ha^{-1}) were recorded.

Statistical Analysis: All the data collected on different parameters were statistically analyzed following the analysis of variance (ANOVA) technique using MSTAT-C [20] programme and the mean differences were adjudged by least significant difference (LSD) test at 5% level of significance [21].

RESULTS AND DISCUSSION

Number of Flower Clusters $Plant^{-1}$: There was difference in number of flower clusters $plant^{-1}$ of tomato at different levels of salinity (Table 1). The highest number of flower clusters $plant^{-1}$ (14.58) was found in control plants and the lowest (13.08) was recorded from 2 dS m^{-1} salinity treated plants. Significant variation was observed for number of flower clusters $plant^{-1}$ of tomato for different levels of calcium (Table 1). The highest flower clusters $plant^{-1}$ (15.10) was found in 10 mM Ca^{2+} treated plants and without Ca treated plants showed the lowest result (12.05). Number of flower clusters $plant^{-1}$ varied significantly due to interaction of salinity and calcium levels (Table 2). The highest number of flower clusters $plant^{-1}$ (17.75) was found from 8 dS m^{-1} salinity treated plant combined with 10 mM of Ca^{2+}, while the lowest number (10.25) was obtained from 8 dS m^{-1} salinity with no Ca^{2+}.

Number of Flowers $Cluster^{-1}$: Number of flowers $cluster^{-1}$ of tomato showed variation for different salinity levels (Table 1). The highest number of flowers $cluster^{-1}$ (5.392) was observed from control treatment and the lowest number (4.670) was found from 8 dS m^{-1}. Feleafel and Mirdad [5] also found that salt treatment decreased the number of flowers $cluster^{-1}$ of tomato compared to without salt. Different levels of calcium varied significantly for number of flowers $cluster^{-1}$ of tomato (Table 1). The highest number of flowers $cluster^{-1}$ (5.192) was found from without Ca treatment and the lowest number was (4.687) recorded from 10 mM Ca^{2+}. Interaction effect of salinity and calcium showed significant differences for number of flowers $cluster^{-1}$ (Table 2). The highest number of flowers $cluster^{-1}$ (5.905) was recorded from no salinity with 5 mM concentrated Ca^{2+}. On the other hand, the lowest number (4.273) was obtained from 6 dS m^{-1} salinity with no Ca^{2+} treatment.

Table 1: Effect of salinity and calcium levels on number of flower clusters $plant^{-1}$, flowers $cluster^{-1}$, dropped flower $plant^{-1}$, flower $plant^{-1}$ of tomato.

Treatments	No. of flower clusters $plant^{-1}$	No. of flowers $cluster^{-1}$	No. of dropped flower $plant^{-1}$	No. of flowers $plant^{-1}$
Salinity level (dS m^{-1})				
0 dS m^{-1} Na	14.58 a	5.392 a	30.08 d	74.25 a
2 dS m^{-1} Na	13.08 c	4.949 b	26.33 e	64.08 c
4 dS m^{-1} Na	13.33 bc	4.911 b	33.25 c	65.75 b
6 dS m^{-1} Na	13.67 b	4.753 b	35.50 b	65.17 b
8 dS m^{-1} Na	13.75 b	4.670 b	37.08 a	61.50 d
$LSD_{(0.05)}$	0.49	0.44	1.01	0.91
Level of significance	**	**	**	**
Calcium level (mM)				
0 mMCa	12.05 c	5.129 a	26.55 c	59.85 c
5 mMCa	13.90 b	4.988 ab	34.85 b	68.00 b
10 mMCa	15.10 a	4.687 b	35.95 a	70.60 a
$LSD_{(0.05)}$	0.38	0.34	0.79	0.71
Level of significance	**	**	**	**
CV (%)	4.30%	10.73%	3.79%	1.68%

**: significant at $p \leq 0.01$, *: significant at $p \leq 0.05$

Values followed by the same letters do not differ at 5% level of significance.

Table 2: Combined effect of salinity and calcium levels on number of flower clusters plant^{-1}, flowers cluster^{-1}, dropped flower plant^{-1}, flower plant^{-1} of tomato

Salinity (dS m^{-1}) × Calcium level (mM)	No. of flower clusters plant^{-1}	No. of flowers cluster^{-1}	No. of dropped flower plant^{-1}	No. of flowers plant^{-1}
0 Na×0 Ca	13.25 d-f	5.472 ab	21.25 i	73.50 c
0 Na×5 Ca	15.75 b	5.905 a	38.75 c	77.50 b
0 Na×10 Ca	14.75 c	4.798 b-e	30.25 fg	71.75 d
2 Na×0 Ca	12.50 f	5.117 b-d	29.00 g	63.50 g
2 Na×5 Ca	13.25 d-f	4.972 b-e	28.50 g	64.25 g
2 Na×10 Ca	13.50 de	4.757 b-e	21.50 i	64.50 g
4 Na×0 Ca	13.75 de	5.023 b-e	33.75 e	66.50 f
4 Na×5 Ca	13.25 d-f	4.532 c-e	30.25 fg	64.00 g
4 Na×10 Ca	13.00 ef	5.177 a-d	35.75 d	66.75 f
6 Na×0 Ca	10.50 g	4.797 b-e	24.75 h	49.75 i
6 Na×5 Ca	14.00 cd	5.188 a-c	44.75 b	76.25 b
6 Na×10 Ca	16.50 b	4.273 e	37.00 cd	69.50 e
8 Na×0 Ca	10.25 g	5.238 a-c	24.00 h	46.00 j
8 Na×5 Ca	13.25 d-f	4.342 e	32.00 ef	58.00 h
8 Na×10 Ca	17.75 a	4.430 de	55.25 a	80.50 a
$LSD_{(0.05)}$	0.84	0.76	1.76	1.59
Level of significance	**	*	**	**
CV (%)	4.30%	10.73%	3.79%	1.68%

**: significant at $p \leq 0.01$, *: significant at $p \leq 0.05$

Values followed by the same letters do not differ at 5% level of significance.

Table 3: Effect of salinity and calcium levels on number of fruits cluster^{-1}, fruits plant^{-1}, fruit length, fruit diameter and yield of tomato

Treatments	No. of fruits cluster^{-1}	No. of fruits plant^{-1}	Fruit length (cm)	Fruit diameter (cm)	Yield (t ha^{-1})
Salinity level (dS m^{-1})					
0 dS m^{-1} Na	3.668 a	44.17 a	3.32 a	3.09 a	34.44 a
2 dS m^{-1} Na	3.665 a	37.75 b	3.18 b	3.01 b	25.07 b
4 dS m^{-1} Na	3.495 a	32.50 c	3.15 b	2.87 c	21.02 c
6 dS m^{-1} Na	3.704 a	29.67 d	3.15 b	2.94 b	18.99 d
8 dS m^{-1} Na	3.123 b	24.42 e	2.93 c	2.70 d	14.85 e
$LSD_{(0.05)}$	0.25	0.85	0.05	0.07	1.01
Level of significance	**	**	**	**	**
Calcium level (mM)					
0 mMCa	3.563	33.30 b	3.10 b	2.93 ab	21.39 b
5 mMCa	3.572	33.15 b	3.23 a	2.96 a	25.35 a
10 mMCa	3.458	34.65 a	3.12 b	2.88 b	21.88 b
$LSD_{(0.05)}$	0.19	0.66	0.04	0.05	0.78
Level of significance	NS	**	**	**	**
CV (%)	8.46%	3.06%	2.10%	2.96%	5.33%

**: significant at $p \leq 0.01$, *: significant at $p \leq 0.05$, NS: non-significant

Values followed by the same letters do not differ at 5% level of significance.

Number of Dropped Flowers Plant^{-1}: Influence of different levels of salinity on number of dropped flowers plant^{-1} of tomato varied significantly (Table 3). The highest number of dropped flowers plant^{-1} (37.08) was recorded from 8 dS m^{-1} and the lowest number (26.33) was found from 2 dS m^{-1} treated plants. Results revealed that, salinity increased the number of dropped flowers with increased levels of salinity resulted the lower number of fruits plant^{-1} as well as yield. Statistically significant variation was found for number of dropped flowers plant^{-1} of tomato due to application of different levels of calcium (Table 3). The highest number of dropped flowers plant^{-1} (35.95) was found from 10 mM concentrated Ca^{2+} treated plants and the lowest value (26.55) was observed from without Ca^{2+} treatment. The results obtained from this experiment showed that the highest flower dropping was happened with 10 mM Ca^{2+} application where this concentration of calcium is also responsible for highest number of flower plant^{-1} and thus produced highest fruit yield plant^{-1}. Interaction effect of salinity and calcium showed significant differences in case of number of dropped flowers plant^{-1} (Table 4). The highest number of dropped flowers plant^{-1} (55.25) was recorded from 8 dS m^{-1} salinity with 10 mM of Ca^{2+} and the lowest (21.25) was observed from control treatment.

Table 4: Effect of salinity and calcium levels on number of fruits cluster^{-1}, fruits plant^{-1}, fruit length, fruit diameter and yield of tomato

Salinity (dS m^{-1}) × Calcium level (mM)	No. of Fruits cluster^{-1}	No. of fruits plant^{-1}	Fruit length (cm)	Fruit diameter (cm)	Yield (t ha^{-1})
0 Na×0 Ca	4.07 a	52.25 a	3.200 b-d	2.950 cd	35.74 b
0 Na×5 Ca	3.51 c-e	38.75 d	3.575 a	3.300 a	37.50 a
0 Na×10 Ca	3.43 c-e	41.50 c	3.175 cd	3.025 bc	30.07 c
2 Na×0 Ca	3.40 c-e	34.50 ef	3.125 de	2.900 de	20.92 f
2 Na×5 Ca	3.82 a-c	35.75 e	3.275 b	3.050 bc	27.01 d
2 Na×10 Ca	3.78 a-c	43.00 b	3.150 c-e	3.075 b	27.29 d
4 Na×0 Ca	3.45 c-e	32.75 gh	3.125 de	2.850 d-f	19.53 fg
4 Na×5 Ca	3.60 b-d	33.75 fg	3.150 c-e	2.900 de	23.92 e
4 Na×10 Ca	3.44 c-e	31.00 i	3.175 cd	2.850 d-f	19.62 fg
6 Na×0 Ca	3.95 ab	25.00 j	3.075 e	3.125 b	17.59 h
6 Na×5 Ca	3.65 a-d	31.50 hi	3.225 bc	2.950 cd	20.11 f
6 Na×10 Ca	3.51 c-e	32.50 gh	3.150 c-e	2.750 fg	19.25 f-h
8 Na×0 Ca	2.96 f	22.00 k	2.950 f	2.800 e-g	13.16 i
8 Na×5 Ca	3.28 d-f	26.00 j	2.900 f	2.600 h	18.20 gh
8 Na×10 Ca	3.14 ef	25.25 j	2.925 f	2.700 gh	13.19 i
$LSD_{(0.05)}$	0.43	1.47	0.09	0.12	1.74
Level of significance	*	**	**	**	**
CV (%)	8.46%	3.06%	2.10%	2.96%	5.33%

**: significant at $p \leq 0.01$, *: significant at $p \leq 0.05$

Values followed by the same letters do not differ at 5% level of significance.

Number of Flowers Plant^{-1}: Number of flowers plant^{-1} of tomato showed differences with different levels of salinity (Table 1). The highest number of flowers plant^{-1} (74.25) was observed from without salt, whereas the lowest (61.50) was recorded from 8 dS m^{-1} salinity level. Results showed that, number of flowers plant^{-1} gradually reduced with the increased levels of salinity through dropping of flowers and also consistent with flowers cluster^{-1}. Significant variation was recorded for the number of flowers plant^{-1} of tomato for different doses of calcium (Table 1). The maximum number of flowers plant^{-1} (70.60) was found from 10 mM Ca^{2+} level and the lowest (59.85) was obtained from without Ca^{2+}. It was found that, application of calcium increased the number of flowers plant^{-1}. Interaction effect of salinity level with calcium showed significant variation in terms of number of flowers plant^{-1} (Table 2). The highest number of flowers plant^{-1} (80.50) was observed in 8 dSm^{-1} with 10 mM level of Ca^{2+} and the lowest (46.00) was recorded from 8 dS m^{-1} salinity combined with no Ca^{2+}. Calcium chloride also reported to increased productivity of many plants [22] which also confirmed increased in number of trusses and flowers.

Number of Fruits Cluster^{-1}: Variation was recorded for the number of fruits cluster^{-1} of tomato due to different levels of salinity (Table 1). Number of fruits cluster^{-1} gradually decreased with the increasing level of salinity where salinity reduced the flower number. Application of different levels of calcium had non-significant effect on number of fruits cluster^{-1} of tomato (Table 1). The highest number of fruits cluster^{-1} (3.572) was recorded from 5 mM concentrated plant. The lowest value (3.458) was found from 10 mM level of Ca^{2+} treatment. Interaction effect of salinity and calcium differed significantly for number of fruits cluster^{-1} (Table 2). The highest number of fruits cluster^{-1} (4.07) was found from without salt and calcium treatment where the lowest value (2.96) was recorded from 8 dS m^{-1} level of salinity combined with no Ca^{2+} application.

Number of Fruits Plant^{-1}: Number of fruits plant^{-1} of tomato showed differences in response to different levels of salinity (Table 3). The highest number of fruits plant^{-1} (44.17) was recorded from control and the lowest number (24.42) was observed from 8 dS m^{-1}. Salinity reduced the number of fruits plant^{-1} which was also consistent with the number of flowers plant^{-1} and ultimately reduced the fruit yield which was also supported by [6, 7]. According to Sun *et al*. [23], salinity adversely affects reproductive development by inhibiting microosporogenesis and stamen filament elongation, enhancing programmed cell death, ovule abortion and senescence of fertilized embryo. Statistically significant variation was recorded for number of fruits plant^{-1} of tomato due to application of different levels of calcium (Table 3). The highest number of fruits plant^{-1} (34.65) was observed from 10 mM concentrated Ca^{2+} treatment and the lowest value (33.15) from 5 mM of Ca^{2+}. Number of fruits plant^{-1} in tomato plant increased with the increased levels of calcium. Andriolo *et al*. [8] and Siddiq *et al*. [9] were also reported that fruit production reduced due to salinity. Interaction effect of different salinity and calcium levels had significant effect on number of fruits plant^{-1} (Table 4). The highest number of fruits plant^{-1} (52.25) was recorded from control plants and the lowest value (22.00) was obtained from highest salinity level (8 dS m^{-1}) with without Ca^{2+} application.

Fruit Length (cm): Different salinity levels exhibited variation in fruit length of tomato (Table 3). From Table 3, it was evident that, the maximum fruit length (3.32 cm) was found from control treatment, whereas the minimum (2.93 cm) was obtained from 8 dS m^{-1}. It was observed in almost all cases that relative large size fruits were obtained from control plants and gradual small size fruits were obtained from increased salinity levels due to its inhibitory effect on cell expansion. Calcium had significant effect on tomato fruit length (Table 3). The longest fruit (3.23 cm) was produced from 5 mM Ca^{2+} treatment and the shortest (3.10 cm) was produced from without Ca^{2+} application. Ca^{2+} increases average fruit weight and size of strawberry fruits [17, 18]. Interaction effect between different salinity levels and calcium levels in case of fruit length of tomato exhibited significant variation (Table 4). The maximum fruit length (3.575 cm) was found from the treatment combination of no salinity and 5 mM concentrated Ca^{2+} treatment. The minimum fruit length (2.900 cm) was obtained from 8 dS m^{-1} salinity with 5 mM level of Ca^{2+}.

Fruit Diameter (cm): Diameter of individual tomato fruit varied significantly for the different levels of salinity (Table 3). The maximum fruit diameter (3.09 cm) was recorded from control treatment whereas the minimum (2.70 cm) was found in 8 dS m^{-1}. It was observed that, salinity decreased the tomato fruit size. Statistically significant difference was observed for fruit diameter of tomato due to the application of different levels of calcium (Table 3). The highest fruit diameter (2.960 cm) was recorded from 5 mM Ca^{2+} and the lowest diameter (2.880 cm) was observed from 10 mM Ca^{2+}. Salinity and calcium levels significantly affected fruit diameter of tomato (Table 4). The highest fruit diameter (3.300 cm) of tomato was recorded from non-saline condition with 5 mM concentrated treatment combination whereas the lowest (2.600 cm) was found from 8 ds m^{-1} salinity with 5 mM of Ca^{2+} application. It has been reported that excessive salt exposure reduces tomato fruit size [10].

Yield (t ha^{-1}): Variation was recorded for yield due to the different salinity levels (Table 3). The highest yield (34.44 t ha^{-1}) was obtained from without salinity whereas, the lowest (14.85 t ha^{-1}) was found in 8 dS m^{-1}. The result showed the gradual decrease of yield with the increased levels of salinity, which was strongly supported by [23-25]. Tzortzakis [26] reported that, salinity either of soil or of irrigation water causes disturbance in plant growth and nutrient balance and reduces crop yields. At relatively lower salinity levels, the yield reduction observed is caused mainly by a reduction in the average fruit weight; the declining number of fruits explains the main portion of yield reduction at higher levels of salinity. Plants treated with salinity alone, produced low fruit yield [8, 28, 29]. It has been reported that salinity decreases pepper and melon yield [30, 31]. Excessive salt exposure reduces tomato fruit size, total yield and photosynthesis [10]. Application of different calcium levels showed the significant effect on yield of tomato plant (Table 3). The highest yield (25.35 t ha^{-1}) was obtained from 5 mM Ca^{2+} whereas, the lowest (21.39 t ha^{-1}) was found from without Ca^{2+}. These results suggest that the application of calcium increased the tomato fruit yield compared to control but 10mM concentration of calcium gave comparatively lower yield than 5mM. Lolaei *et al*. [25] reported that, application of Ca^{2+} in the nutrient solution increased the fruit yield of tomato. The present work showed that under both non-saline and saline conditions, the exogenous application of Ca^{2+} alone, through the rooting medium, had an ameliorative effect on yield of tomato. Ca^{2+} increase average fruit weight of strawberry fruits [17, 18]. Calcium chloride increases the weight per fruit due to maximum food reserves during the stage when fruit attain size and mass [32]. More yields in term of weight per fruit were obtained by calcium chloride. Due to less number of fruit production [28, 8] more weight attainment in these fruits occurred [18] which therefore, lowering the yield. Combined effect of different salinity levels and calcium levels showed significant differences for tomato yield (Table 4). The highest yield (37.50 t ha^{-1}) was obtained from no salinity with 5 mM Ca^{2+} and the lowest yield (13.16 t ha^{-1}) was observed from 8 dS m^{-1} salinity with without Ca^{2+}.

CONCLUSIONS

Above finding revealed that the yield of tomato was gradually decreased by the increase of salinity levels which was consistence with the reduction rate of flowers and fruits number plant^{-1} and this reduction rate was decreased by exogenous supply of calcium. Number of dropped flower consistently increased with gradual increase of salinity levels where exogenous calcium also increased the total number of dropped flower due to its higher flower production behavior and as make sure its contribution in higher tomato flower production in saline condition. Among the calcium levels, almost 5 mM showed the highest result as compared to others. From these results, it can be concluded that the addition of Ca^{2+} to NaCl-stressed tomato plants have a significant role in alleviating the deleterious impacts of salinity stress on reproductive response and ultimately increase the fruit yield. This work recommends that the application of Ca^{2+} can ameliorate the negative effect of salinity on tomato plants and could offer an economical and simple way to reduce the salinity problem in tomato cultivation under saline condition.

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