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FLUORIDE-INDUCED ABNORMALITIES AND MODULATIONS IN GROWTH PARAMETERS OF *SOLANUM MELONGENA* L. (BRINJAL, BENGUN, AUBERGINE, EGGPLANT)

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ABSTRACT: Fluoride is a naturally accruing element which harms our environment. Accumulation of excess fluoride in the environment poses a serious threat to plants. It causes various changes in the biophysiological processes of plants. The present study was conducted to determine the effect of NaF on *Solanum melongena* L. (brinjal, bengun, aubergine, eggplant). *S. melongena* belongs to the family Solanaceae and is an important edible plant. It was grown during the crop season (August-October, 2017) in pots. Different concentrations of NaF, i.e., 100, 200, 300, 400, 500, and 600 ppm, were applied, along with a control, as a soil drench and foliar spray twice a week. The parameters examined to determine the effect of the stress of NaF on the plant growth were the shoot and root length and the number and the area of the leaves. There was a dose-related reduction in growth with the NaF treatment. In general, the soil drench affected growth more than the foliar spray. The results show that *Solanum melongena* L. is a salt sensitive crop.

Keywords: Fluoride stress; Growth; Pakistan; Sensitive; *Solanum melongena* L.

INTRODUCTION

Salinity is one of the major abiotic stresses and results in massive crop losses every year. Increased salination of arable land is expected to have devastating global effects, and in 2003 it was estimated that it would result in a 30% loss of agricultural land by the year 2028 and up to 50% by the 2050.[1] Soil salinity imposes serious threats to plant growth, agricultural production, and soil fertility, particularly in arid and semiarid areas.[2] About one-third of cultivated land is salt affected throughout the globe which makes salinity a major limiting factor of the production of food and fodder.[2] The most devastating stress factor is soil salinity which limits the growth and metabolism of plants.[3]

Fluorine which is the 13[th] most abundant element in the earth's crust and because it is the most electronegative of all the elements and has a strong tendency to acquire a negative charge, it forms fluoride ions in solutions and mineral complexes with a number of cations rather than existing as an elemental diatomic gas, which occurs only in rare circumstances. Fluorine is one of the most phytotoxic environmental pollutants and can persist for a long time in soil, air, and water. It has negative effects on all ecosystem levels.[4,5] The average abundance of fluorine in the earth's crust is 0.06–0.09% (0.32 g/kg).[6,7] It is added to the environment from different anthropogenic sources including the industrial use of both fluorine and fluorides. Fluorine is used in the aluminium, glass fibre, and steel industries and in non-stick utensils.[8] High salt concentrations of fluoride in soil is an important stress factor for plants. Salt stress or salinity depresses plant growth.[9] Fluoride moves into the transpiration stream via the roots or stomata and then accumulates in the leaf

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margins.[8] Fluoride from the atmosphere is deposited on plants in gaseous or particulate form and enters through the cuticle or stomata.[10] Fluoride compounds typically cause necrosis of the tips and margins of the leaves which is usually called tip burn. Necrosis and chlorosis are visible toxic symptoms of fluoride in plants.[11]

Solanum melongena L., commonly known as brinjal, bengun, eggplant, and aubergine, is a popular crop of tropical and sub-tropical regions belonging to the Solanaceae family. The crop is not tolerant to cold and frost. Brinjal has been a part of diet of Indus valley people since Harappa civilization.[12] It is a rich source of antioxidants, particularly flavonoids and phenolics.[13] It had been used as food, as medicine, and for ornamental purpose in Ancient/Indian, Arabic, and European civilizations.[14] Most of the cultivars of *Solanum melongena* L. are affected by salinity stress owing to their inability to control or regulate the uptake and accumulation of sodium in the leaves.[15]

The aim of the present study was to determine the effect of different concentrations of sodium fluoride (NaF) (0 [control], 100, 200, 300, 400, 500, and 600 ppm), applied for 90 days as a root drench and as a foliar spray, on *Solanum melongena* L. (brinjal, bengun, aubergine, eggplant).

MATERIALS AND METHODS

Seeds of a certified variety of brinjal (*Solanum melongena* L.) were acquired from the Mehar Seed Store, Ellah Abad. All the seeds were examined to separate the unhealthy seeds from the healthy ones. The refined seeds were stored in paper bags for further use in the experimental work. The experiment was conducted in the Botanical Garden, Quaid-e-Azam Campus, University of the Punjab, Lahore, Pakistan. This experimental site is situated to the south of Lahore (74º 21’ 00” E, 31º 35’ 00” N). The experiment lasted from August-October, 2017. In order to save the experimental plants from outside attack by animals, the plants were placed in a wire house. Loamy and sandy soils were mixed in a ratio of 3:1 along with farmyard and leaf manure to prepare soil best suited for the experimental work. The pots were arranged and labeled in a randomized complete block design (RCBD) manner under natural environmental conditions. Seven treatments were planned for the respective crops and each treatment had six replicates. Seeds of brinjal were soaked for about 12 hours before sowing. Initially, three seeds were sown per pot. Seeds germinated within five days and after complete germination, the number of seedlings was reduced to a single seedling in each pot by simple manual thinning of the seedlings. The local agricultural practices were used to manage the plants grown at the experimental site throughout the course of the growth and development of the brinjal crop. Two methods of treatment were followed to apply the sodium fluoride on the brinjal plants. One of the treatment methods was soil drench and other one was foliar spray. The required concentrations of sodium fluoride solution were prepared by mixing sodium fluoride in measured amounts along with distilled water. The solutions of sodium fluoride were diluted to different concentrations (100, 200, 300, 400, 500, and 600 ppm) to examine the effects of different sodium fluoride concentrations on the brinjal cultivar. The control plants were watered with tap water. The treatments were carried out twice a week during the experiment till its maturity. Two harvests, at 50 and 90 days after sowing (DAS), were taken. The complete plants were removed carefully along with their roots. The plants were thoroughly washed with tap water to remove the soil sticking to the roots of the plants. The plants were carried to the laboratory wrapped in polythene bags for the measurement of shoot length (cm), root length (cm), number of leaves, and leaf area (cm^2). After the data from the pot experiment were collected, the statistical analysis (mean, standard error, and Duncan's multiple range test [DMR]) were done with the software package COSTAT (ver. 3.03) based on the methods described by Steel and Torrie.[16]

RESULTS

Shoot and root length: Seven different NaF concentrations were applied during the experiment in the form of a soil drench and a foliar spray. At 50 DAS, the plants which were treated with NaF using the soil drench method of application showed a regular trend of shoot length reduction as the concentration of NaF increased (Figure 1A). The maximum shoot length reduction, observed with the highest NaF, i.e., 600 ppm concentration, was 71.98%. When the NaF was used as a soil drench, the percentage reductions for the other concentrations of NaF (100, 200, 300, 400, and 500 ppm) were 17%, 18.94%, 21.6%, 39.14%, and 50.14%, respectively (Figure 2A).

The plants treated with NaF using the foliar spray method of application did not show as much reduction in shoot length as occurred with the plants treated with the soil drench application (Figure 1B). However, the trend of shoot length reduction in the foliar spray method was same as that with the soil drench method and showed the maximum shoot length reduction at highest NaF concentration (600 ppm). The percentage reductions for the concentrations of 100, 200, 300, 400, 500, and 600 ppm were 23.37%, 29.75%, 34.42%, 44.4%, 53.38%, and 57.36%, respectively (Figure 2B).

At 90 DAS, similar trends were recorded in the results for shoot length in the plants treated with different NaF concentrations. The maximum percentage shoot length reductions were noted in the case of the 600 ppm-treated plants. Plants treated with soil drench at 600 ppm showed a 71.74% reduction compared to a reduction of 5.42% in the plants treated with 100 ppm. The plants treated with a foliar spray of 600 ppm showed a reduction of 65.4% compared the reduction of 19.9% in the plants treated with a foliar spray 100 ppm (Figure 2B).

The brinjal plants treated with different NaF concentrations showed marked reductions in the root length. The maximum root length at 50 DAS was observed in the control plants (12.76 cm with soil drench and 12 cm with foliar spray). The minimum root length was observed in the plants treated with NaF-600 ppm (7.06 cm with soil drench and 7.66 cm with foliar spray). A dose-related reduction in root length was seen in the plants with root length with NaF-100 root length > NaF-200 root length > NaF-300 root length > NaF-400 root length > NaF-500 root length >NaF-600 root length (Figure 2A).

At 90 DAS, the results showed the same trend of reduction in root length with increased NaF concentrations. With both treatment methods there was a marked reduction in root length. The control plants showed the maximum root length (11.7 cm for soil drench and 19.83 cm for foliar spray). The plants treated with NaF-600 ppm showed marked reductions in root length (4.5 cm for soil drench and 7 cm for foliar spray). The maximum percentage reductions were observed with NaF-600 ppm

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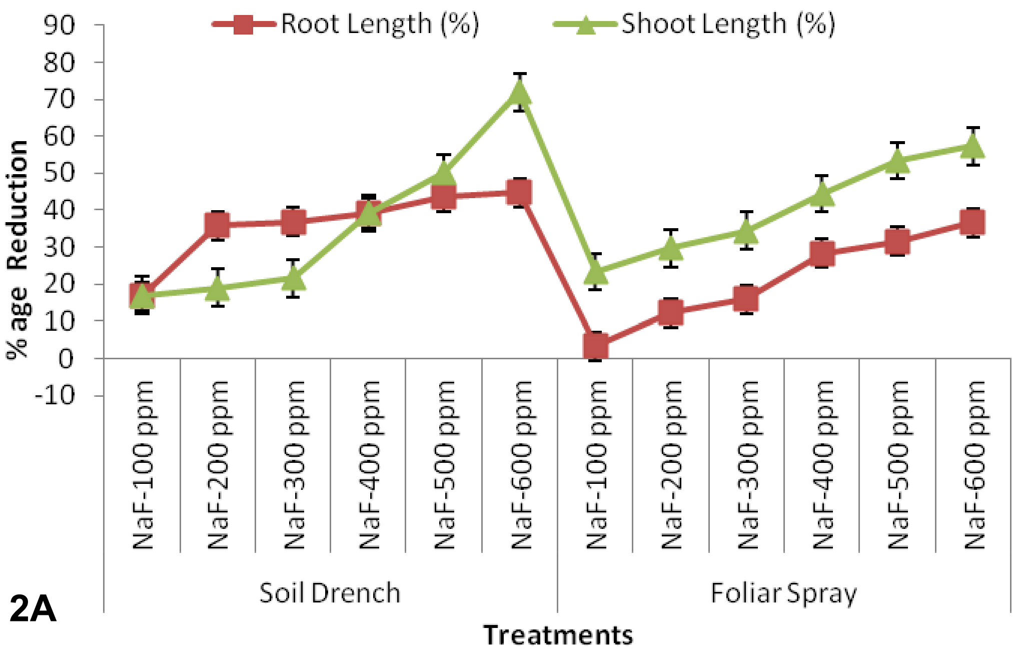
(at 50 DAS: 44.67% for soil drench and 36.66% for foliar spray; at 90 DAS: 61.54% for soil drench and 64.69% for foliar spray) (Figure 2B).

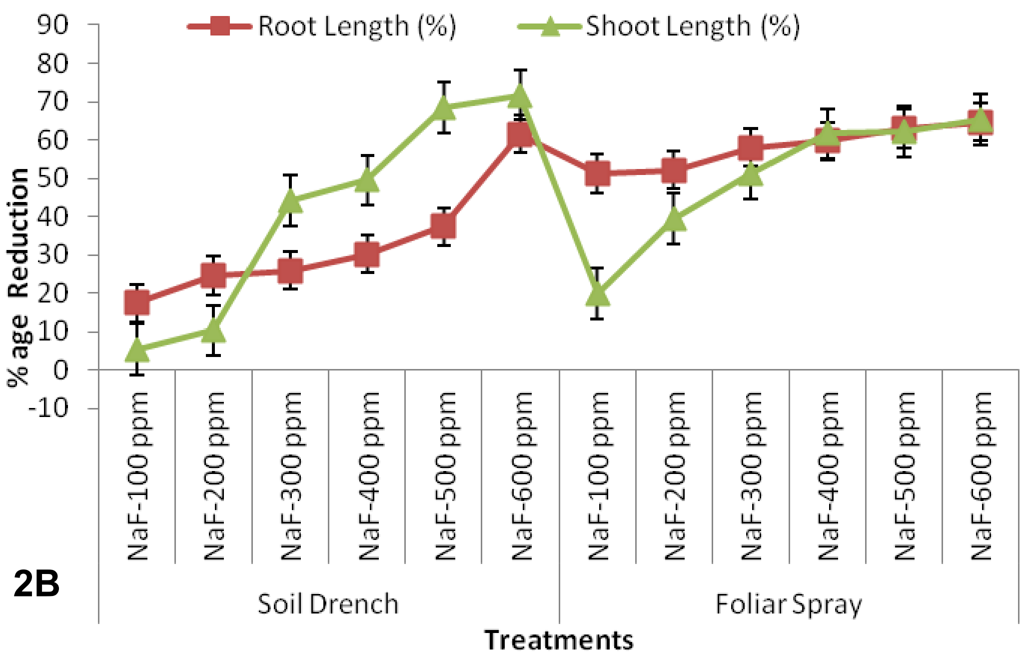
Control | Soil drench NaF 100 ppm | Soil drench NaF 200 ppm | Soil drench NaF 300 ppm | Soil drench NaF 400 ppm | Soil drench NaF 500 ppm | Soil drench NaF 600 ppm

Control | Foliar spray NaF 100 ppm | Foliar spray NaF 200 ppm | Foliar spray NaF 300 ppm | Foliar spray NaF 400 ppm | Foliar spray NaF 500 ppm | Foliar spray NaF 600 ppm

Figures 1A and 1B. Photographs of *Solanum melongena* L. (brinjal) grown under different concentrations of sodium fluoride used as a soil drench (1A) and as a foliar spray (1B) at 50 days after sowing (DAS) during growth season 2017.



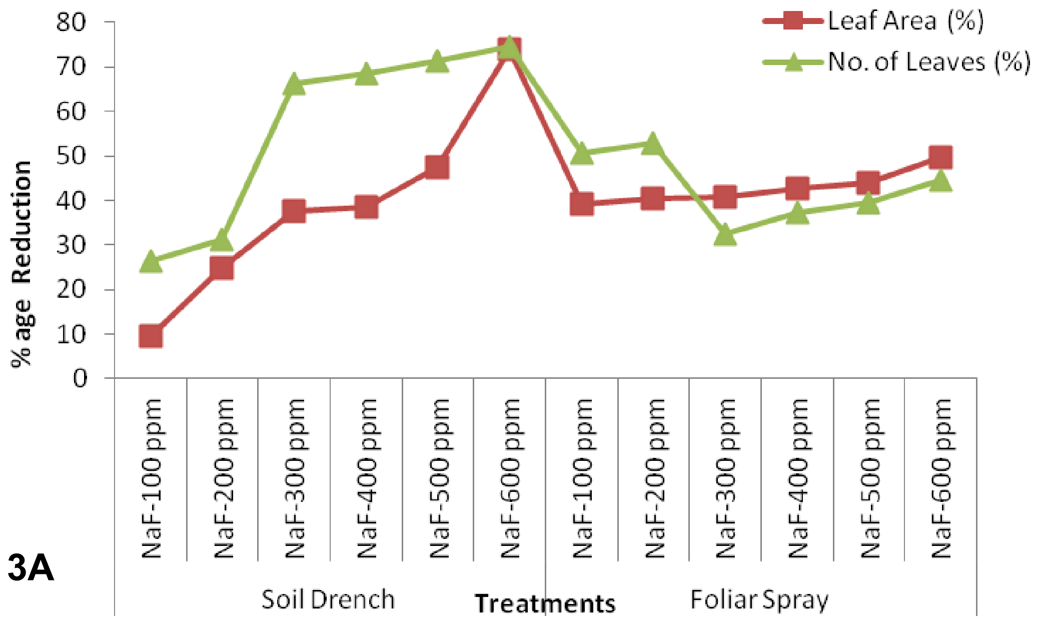
2A



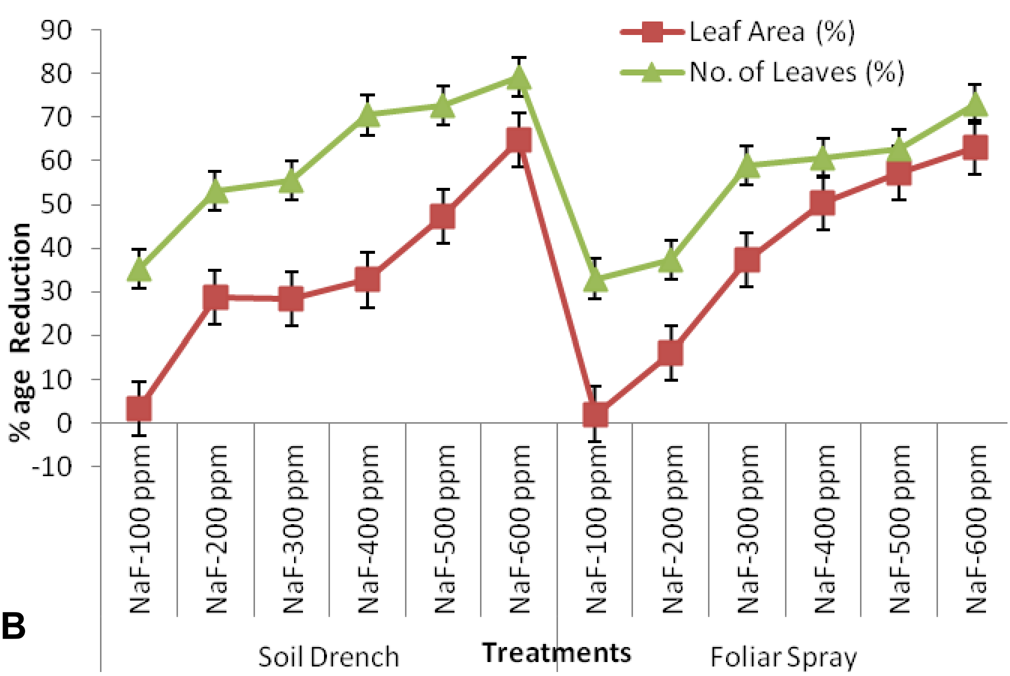
2B

Figures 2A and 2B. The percentage reduction in the root and shoot length in *Solanum melongena* L. (brinjal) harvested at 50 DAS (2A) and 90 DAS (2B) under different treatments of sodium fluoride used as a soil drench and as a foliar spray.

Number of leaves: The number of leaves was recorded at 50 DAS and 90 DAS for the control and the treated plants (Figures 3A and 3B).



3A



3B

Figures 3A and 3B. The percentage reduction in the leaf number and leaf area in *Solanum melongena* L. (brinjal) harvested at 50 DAS (3A) and 90 DAS (3B) under different treatments of sodium fluoride used as a soil drench and as a foliar spray.

At 50 DAS, the mean percentage reduction in the number of leaves in the plants treated with NaF at concentrations of 100 ppm and 200 ppm as a soil drench were 26.27 and 31.33%, respectively, and for the treatments with NaF used as a foliar spray the percentage reductions were 50.79 and 52.85%, respectively (Table 1).

At 90 DAS, the mean percentage reduction in the number of leaves in the plants treated with NaF at concentrations of 100 ppm and 200 ppm as a soil drench were 35.26 and 53.17%, respectively, and for the treatments with NaF used as a foliar spray the percentage reductions were 32.97 and 37.30%, respectively (Table 2).

At 50 DAS, the control plants showed the maximum number of leaves, 33.00 with the soil drench and 64.33 with the foliar spray. At 90 DAS, the number of leaves in the control plants was 57.66 with the soil drench and 61.66 with the foliar spray. The reduction in the number of leaves with the NaF treatment was dose related, least with 100 ppm, and greatest with 600 ppm.

At 50 DAS, for the treatments with 100 and 200 ppm NaF, the percentage reduction in the number of leaves was greater in the plants given NaF as foliar spray compared to those given as a soil drench, while at 90 DAS the reduction was greater in those receiving treatment as a soil drench.

The reduction in the number of leaves with the NaF was increased with increased NaF concentrations and a longer duration of treatment. With both NaF treatments, the number of leaves present at 90 DAS was less than the number present at 50 DAS. The number of leaves present on the plants for both treatment methods at both 50 and 90 DAD was NaF-100>NaF-200>NaF-300>NaF-400>NaF-500>NaF-600.

With the soil drench treatment with 600 ppm NaF, the percentage reduction in the leaf number at 50 and 90 DAS was 50.52 and 79.19%, respectively (Tables 1 and 2). With the foliar spray treatment with 600 ppm NaF, the percentage reduction in the leaf number at 50 and 90 DAS was 71.51 and 72.98%, respectively (Tables 1 and 2). With the foliar spray treatment, at 90 DAS, the percentage reduction in leaf number in the 100 ppm NaF group of 32.97% was less than that in the 600 ppm group of 72.98%.

Leaf area: The leaf area was recorded at 50 DAS and 90 DAS for the control and the NaF-treated plants (Tables 1 and 2). At 50 DAS, the control plants had a leaf area of 302.30 cm^2 with the soil drench treatment and 429.38 cm^2 with the foliar spray treatment. At 50 DAS, the leaf area for the plants treated with NaF at concentrations of 100 and 200 ppm as a soil drench was 273.2 and 227.43 cm^2, respectively, and for those treated as a foliar spray they were 260.86 and 255.81 cm^2, respectively.

With the soil drench treatment with 100 ppm NaF, the percentage reduction in the leaf area at 50 and 90 DAS was 9.63 and 3.37%, respectively (Tables 1 and 2). With the foliar spray treatment with 100 ppm NaF, the percentage reduction in the leaf area at 50 and 90 DAS was 39.25 and 2.06%, respectively (Tables 1 and 2).

With the soil drench treatment with 200 ppm NaF, the percentage reduction in the leaf area at 50 and 90 DAS was 24.77 and 28.60%, respectively (Tables 1 and 2). With the foliar spray treatment with 200 ppm NaF, the percentage reduction in the leaf area at 50 and 90 DAS was 40.42 and 16.06%, respectively (Tables 1 and 2).

With the soil drench treatment with 600 ppm NaF, the percentage reduction in the leaf area at 50 and 90 DAS was 74.06 and 64.85%, respectively (Tables 1 and 2). With the foliar spray treatment with 600 ppm NaF, the percentage reduction in the leaf area at 50 and 90 DAS was 49.67 and 63.07%, respectively (Tables 1 and 2).

Table 1. Vegetative growth parameters of *Solanmu melongena* L. harvested at 50 days after sowing (DAS) by using foliar spray and soil drench with different sodium fluoride concentrations during the growth season 2017

Method of application	Treatment	Parameter			
		Shoot length (cm)	Root length (cm)	Number of leaves	Leaf area (cm²)
Soil drench	Control	37.63 ± 1.73	12.76 ± 0.12	33.00 ± 2.64	302.30 ± 1.06
	NaF-100 ppm	31.23 ± 0.58	10.63 ± 0.54	24.33 ± 1.77	273.20 ± 1.96
	NaF-200 ppm	30.50 ± 0.4	8.20 ± 0.17	22.66 ± 1.45	227.43 ± 0.92
	NaF-300 ppm	29.50 ± 0.27	8.06 ± 0.26	21.66 ± 1.2	188.96 ± 1.89
	NaF-400 ppm	22.90 ± 0.86	7.76 ± 0.12	20.33 ± 1.45	185.80 ± 3.23
	NaF-500 ppm	18.76 ± 0.79	7.20 ± 0.17	18.33 ± 1.2	157.83 ± 1.15
	NaF-600 ppm	12.70 ± 0.66	7.06 ± 0.34	16.33 ± 1.2	78.43 ± 2.14
Foliar spray	Control	43.46 ± 1.03	12.00 ± 0.06	64.33 ± 1.77	429.38 ± 0.56
	NaF-100 ppm	33.30 ± 0.55	11.60 ± 0.23	31.66 ± 0.88	260.86 ± 0.90
	NaF-200 ppm	30.53 ± 0.33	10.53 ± 0.25	30.33 ± 0.88	255.81 ± 0.46
	NaF-300 ppm	28.50 ± 0.55	10.10 ± 0.12	22.33 ± 0.88	253.83 ± 1.55
	NaF-400 ppm	24.16 ± 0.65	8.66 ± 0.2	20.66 ± 1.2	245.53 ± 1
	NaF-500 ppm	20.26 ± 0.5	8.20 ± 0.15	20.00 ± 1.53	241.10 ± 1.26
	NaF-600 ppm	18.53 ± 0.67	7.66 ± 0.18	18.33 ± 1.2	216.10 ± 0.95

Each treatment mean is sum of three replicates; values are mean ± standard error (SE); within each parameter, values not followed by same letter are significantly different with Duncan’s multiple range test (DMRT).

Table 2. Vegetative growth parameters of *Solanmu melongena* L. harvested at 90 days after sowing (DAS) by using foliar spray and soil drench with different sodium fluoride concentrations during the growth season 2017

Method of application	Treatment	Parameter			
		Shoot length (cm)	Root length (cm)	Number of leaves	Leaf area (cm²)
Soil drench	Control	61.33 ± 2.03	11.70 ± 0.60	57.66 ± 1.2	216.80 ± 1.94
	NaF-100 ppm	58.00 ± 1.53	9.67 ± 0.73	37.33 ± 1.45	209.50 ± 0.27
	NaF-200 ppm	55.00 ± 2.08	8.83 ± 0.60	27.00 ± 1.53	154.80 ± 0.64
	NaF-300 ppm	34.33 ± 2.19	8.67 ± 0.73	25.66 ± 1.85	155.00 ± 1.28
	NaF-400 ppm	31.00 ± 1.89	8.17 ± 1.02	17.00 ± 1.53	145.96 ± 1.40
	NaF-500 ppm	19.33 ± 2.49	7.33 ± 0.88	15.66 ± 1.85	114.08 ± 0.35
	NaF-600 ppm	17.33 ± 2.32	4.50 ± 0.29	12.00 ± 0.58	76.20 ± 0.43
Foliar spray	Control	70.33 ± 0.88	19.83 ± 1.30	61.66 ± 0.88	241.83 ± 9.25
	NaF-100 ppm	56.33 ± 2.33	9.66 ± 0.93	41.33 ± 1.45	236.86 ± 0.89
	NaF-200 ppm	42.67 ± 1.45	9.50 ± 1.04	38.66 ± 0.88	203.00 ± 0.68
	NaF-300 ppm	34.33 ± 2.33	8.33 ± 0.73	25.33 ± 1.45	151.50 ± 0.55
	NaF-400 ppm	27.00 ± 3.22	8.00 ± 1.00	24.33 ± 1.45	120.10 ± 0.49
	NaF-500 ppm	26.67 ± 2.73	7.33 ± 0.6	23.00 ± 1.53	103.40 ± 0.31
	NaF-600 ppm	24.33 ± 2.60	7.00 ± 0.29	16.66 ± 1.2	89.30 ± 1.18

Each treatment mean is sum of three replicates; values are mean ± standard error (SE); within each parameter, values not followed by same letter are significantly different with Duncan's multiple range test (DMRT).

The reduction in the leaf area with the NaF was increased with increased NaF concentrations and a longer duration of treatment. With both NaF treatments, the leaf area at 90 DAS was less than the leaf area at 50 DAS. The leaf area on the plants for both treatment methods at both 50 and 90 DAD was NaF-100>NaF-200>NaF-300>NaF-400>NaF-500>NaF-600.

With the foliar spray treatment, at 90 DAS, the percentage reduction in leaf area in the 100 ppm NaF group of 2.09% was less than that in the 600 ppm group of 63.07%.

DISCUSSION

Brinjal (*Solanum melongena* L.) is grown in the plains of Pakistan where salinity is a widespread problem and detrimental to the growth of crops. The present experiment was carried out to examine the effect of sodium fluoride on the growth, and yield characters of brinjal. We found the vegetative growth parameters of *Solanum melongena* L. showed significant dose-related reductions with increased NaF concentrations.

Fluoride gradually accumulates in the foliage of plants and is therefore known as accumulative poison. Fluoride inhibits photosynthesis process and other processes in plants.[8] Necrosis and chlorosis are visible symptoms of fluoride toxicity in plants.[11] Brinjal (*Solanum melongena* L.) belongs to the family of Solanaceae and had been used as food, medicine, and for ornamental purposes in Ancient/Indian and Arabic and European civilizations.

The results of present study showed a progressive reduction in plant growth, measured as the root length, shoot length, number of leaves, and area of leaves, with increasing fluoride concentrations. The reduction with 100 and 200 ppm NaF, were less than those occurring with 500 and 600 ppm NaF. Pant et al. found that 0.001, 0.01, and 0.02 M NaF reduced the root and shoot lengths of seedlings of wheat (*Triticum aestivum*), Bengal gram (*Cicer arietinum* L.), and mustard (*Brassica juncea*) with the shoot growth, in general, being more affected than the root growth at higher concentrations of NaF.[17] With tomato (*Lycopersicon esculentum*), the root length was not decreased by NaF and the shoot length was diminished only with 0.02 M NaF and not at 0.001 and 0.01 M NaF.[17]

We found that, compared to the foliar spray method, the soil drench application method resulted in greater reductions in the number of leaves and leaf area at 90 DAS, with 100, 200, and 600 ppm NaF and at 50 DAS with 600 ppm NaF. However, at 50 DAS with 100 and 200 ppm NaF, the reductions in leaf area and number of leaves were greater with the foliar spray method than with the soil drench method.

Root and shoot length reductions have been reported by various researchers in the previous studies with *Lycopersicum esculentum*,[18] *Salicornia brachiata*,[19] *Brassica rapa*,[20,21] *Brassica juncea*,[17] *Cicer arieninum*,[22] *Oryza sativa*,[23] and *Triticum aestivum*.[24]

Studies on *Gossypium hirsutum*[25] and *Hordeum vulgare*[26] have clearly shown that with higher fluoride concentrations more adverse effects are shown by the plant. Similar effects, involving reductions in plant lengths with increased fluoride concentrations, have also been found with *Prosopis juliflora*,[27] *Cajanuscajan*,[28] *Oryza sativa*,[29] *Abelmoschus esculentus*,[30,31,32] *Pinus rigida,* and *Pinus koraiensis.*[33]

CONCLUSIONS

We found that *Solanum melongena* L. (brinjal, bengun, aubergine, eggplant) is a salt sensitive crop whose growth is adversely affected, in a dose-dependent manner, by the application of NaF at concentrations of 100–600 ppm as a soil drench and as a foliar spray. In general, the soil drench affected growth more than the foliar spray.

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