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EFFECT OF EXOGENOUS APPLICATION OF CITRIC ACID ON GROWTH OF MAIZE (*ZEA MAYS* L.) UNDER SODIUM FLUORIDE STRESS

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ABSTRACT: Fluoride toxicity is a leading cause of environmental pollution and is particularly considered as a phytotoxic element for cereal crops. Accumulation of high amount of fluoride in the soil alters the metabolism of plants and reduces their growth. Therefore, an experiment was conducted to understand the effects of sodium fluoride (NaF) on the plant growth and the amelioration of its toxic effects by the application of citric acid on the two cultivars of maize, Pak Afgoi (salt tolerant) and Pearl (salt sensitive). NaF in a concentration of 100ppm and 200ppm was applied to one week old seedlings. Citric acid (100 mgL^{-1} and 150 mgL^{-1}) was applied as a foliar spray after two weeks of application of NaF salinity stress. The data regarding shoot length, shoot, root fresh and dry weight, chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, ions and ash contents were collected after fifteen days of citric acid application. Our results showed that citric acid 150 mgL^{-1}had a positive effect on the growth of maize plants and had reduced the toxic effects of sodium fluoride.

Keywords: Citric acid, Growth parameters, Maize, Mineral nutrients, Pak Afgoi, Pearl.

INTRODUCTION

Water reservoir shortages, environmental pollution and enhanced salt levels in water and soil were observed in the country and around the world by the start of 21stcentury. Rapid population growth and reduction of arable land are two major dangers to the sustainability of agriculture [1]. There are different environmental pressures such as extreme temperature, soil salinity; drought and floods have an effect on cultivation and production of crops. Among these, salinity of soils is one of the most devastating environmental factors, leading to a substantial reduction in arable land, crop productivity and quality [2, 3]. Salinity is a serious environmental restriction for agriculture in arid and semi-arid areas of the world [4]. There are more than 800 million hectares of sodicity (434 million hectares) or salinity (397 million hectares) impacted in the globe [5].Various researchers have noted that the magnitude of sodium ion elimination at root level depends on the fluctuation in salt tolerance or vacuolization ability [6].

Fluorine (F) is one of the most common elements found on Earth. Anthropogenic activities have dramatically increased the amount of fluoride in air, water and soil. Irrigation of vegetables and crops contaminated by fluoride would be harmful for human health. Plants can absorb fluoride from contaminated soil via roots and can also absorb fluoride from the atmosphere [7]. Fluoride exposure affects major enzymes such as chloroplast ATPase, ribulose 1,5 bisphosphate carboxylase/ oxygenase, and sucrose synthetase [8, 9].The contamination of soil through fluoride reduces the nutritive value of crops and thus reduces the yield. In maize plant, it also affects the amino acid content [32].

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Anions organic acids have at least one group of (COOH or COO^-) carboxylase, from fatty acids to secondary metabolites [10]. Plants that release huge quantities of organic anions appear to have comparatively elevated concentrations of Fe, Zn, Mn and Cu [11]. By exogenously applying citric acid under stress conditions, plants improved stress tolerance by improving antioxidant enzyme activity. A significant level of citric acid under stressful conditions enhances stress tolerance in plants by increasing the activity of antioxidant enzymes [12].

Zea mays L. (maize) is a very important crop that becomes the source of food for people and source of fodder for animals throughout the world. The main countries around the world that produce maize include the United States, France, Mexico, Nigeria and Hungary. In Pakistan, corn is cultivated in different areas of the country for the market. But the productivity of this crop has been decreased over the years due to environmental changes [13].

MATERIALS AND METHODS

A research experiment was carried out to evaluate the morphological, physiological and biochemical response of maize to citric acid under sodium fluoride (NaF) stress. Two maize cultivars; Pak Afgoi for salt tolerant while Pearl was selected as sensitive one. Seeds of both maize cultivars were obtained from Maize and Millets Research Institute, Yousafwala, Sahiwal, Pakistan. Ten seeds of each variety were sown in plastic pots (30 cm diameter) containing 8 Kg well mixed clay loam soil. Maize seeds were surface sterilized with 5% sodium hypochlorite for 10 minutes and then washed with water

After one week of seed germination, plants were exposed to salt stress (NaF). Salinity treatments were given at 100 ppm and 200 ppm with NaF on soil saturation percentage basis. The two solutions of NaF (100 ppm and 200 ppm) were applied on plants in three stages to acclimatize salt stressed plants. Foliar spray of citric acid (100 ppm and 150 ppm) was applied after 15 days of salt stress application.

After fifteen days of foliar spray, morphological, physiological and biochemical attributes were collected.

1. Growth Attributes

a) Shoot Length and Leaf Area

Shoot length was measured from each treatment. Using flexible inch tape, shoot length was measured from base to the end of the leaf tip and leaf area was measured according to the formula presented by [14] with a correction factor of 0.75 for the length and width of the leaf.

b) Leaf area equation

Leaf Area (LA) = (L × W) 0.75

W= Width of leaf (cm)

L= Length of leaf (cm)

c) Fresh and Dry Shoot Weight

From each treatment, new plants were collected from pots and tap water used to wash and remove the dust particles and measure the fresh shoot weight on electrical

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weight balance and for dry weight, fresh shoots under room temperature were dried for two weeks in shade. They weighed these dried shoots again and measured their dry masses.

d) Fresh and Dry Root Weight

Fresh roots were taken from pots and tap water was used to clean the tangled mud from the roots and noticed the fresh root weight using electrical balance. Weighted fresh roots were dehydrated in shade under room temperature and then placed the samples in oven at 45ºC and measured root dry weight with electrical balance.

2. PHYSIOLOGICAL ATTRIBUTES

a) Chlorophyll Contents

Chlorophyll and carotenoids assessment was determined by the [15] modification of [16] Arnon's technique (1949). Aqueous acetone solution 80 % in 4 ml, a weighted quantity (0.1 g) of fresh leaf was ground. This homogenized solution was filtered and the green supernatant was then obtained. Visible UV spectrophotometer (AA 6300, SHAMIDZO. Japan) was used to record optical density measurements. For quantitative determination of chlorophyll, from the prepared solution optical density was noted at 480 nm, 510 nm, 663 nm and 645 nm wavelengths and calculated the values of Chl. a, Chl. b, total Chl. and carotenoids with the following formula:

Chl.a = [12.7(OD663) - 2.69(OD645)] × V / 1000ÞW

Chl.b = [22.9(OD645) - 4.68(OD663)] × V / 1000ÞW

V = Volume of the extract (ml)

W= Weight of the fresh leaf tissue (g)

b)Minerals estimation

Plant materials were digested according to the methods of [17]. The dry plant materials (1g) were taken in digested test tubes containing 4 ml of concentrated sulfuric acid and incubated overnight. Two to three drops of hydrogen peroxide (H_2O_2) were added in digested tubes after the intervals of thirty minutes during the digested process. Hydrogen peroxide was added after cooling the samples. Repeated this method until the colorless solution was acquired and the solution was filtered. Using distilled water (dH_2O), the final volume of solution was made up to 50 ml. Atomic absorption spectrophotometer (AA 6300, SHAMIDZO, Japan) was used for estimation of minerals concentration.

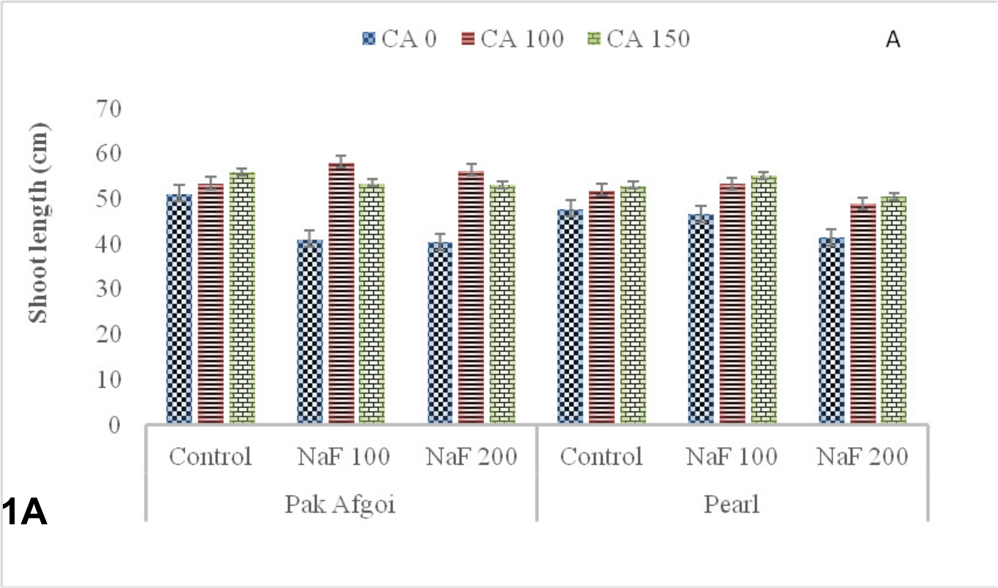
3. Proximate composition

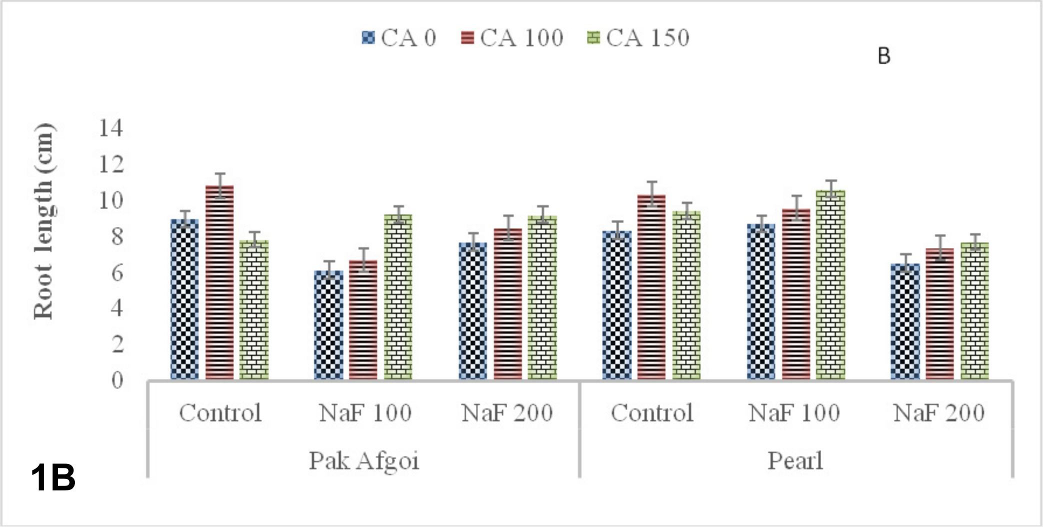
The proximate composition of maize plant like moisture, crude protein, crude fat, crude fiber and ash was determined by following the standard procedures outline in the Association of Official Analytical Chemist (AOAC, 2006).

RESULTS

GROWTH ATTRIBUTES

Shoot length: The maximum of shoot length was observed in Pak Afgoi as compared to Pearl by foliar application of 100 mgL^{-1} citric acid under 100 mgL^{-1}NaF stress (Fig. 1A). Exogenously applied 100 mgL^{-1}citric acid was more effective to mitigate the salt stress and enhanced the shoot length in both cultivars of maize. Same results were observed in root length by the application of citric acid under sodium fluoride stress (Fig 1B) (Table 1).





Figures 1A and 1B. Effect of foliar spray of citric acid on shoot (1A) and root length (1B) (cm) of maize under different levels of sodium fluoride stress.

Table 1. Analysis of variance of growth attributes of maize (*Zea mays* L.) grown under various stress levels of sodium fluoride by the application of citric acid foliar spray

Source	df	Shoot length	Root length	Fresh Shoot wt	Dry shoot wt	Fresh root wt
Variety	1	0.47^{NS}	0.03^{NS}	0.17^{NS}	1.60^{NS}	1.23^{NS}
NaF	2	1.19*	2.11^{NS}	6.04*	4.61*	6.92**
Variety*NaF	2	0.01^{NS}	6.32*	0.17^{NS}	0.87^{NS}	0.75^{NS}
Citric Acid	2	3.48*	0.41^{NS}	27.16**	3.97*	11.09**
Variety* Citric Acid	2	0.64^{NS}	0.83^{NS}	3.31*	1.38^{NS}	2.60
NaF*Citric Acid	4	0.46^{NS}	2.75*	2.43^{NS}	2.78*	5.44**
Variety*NaF*Citric Acid	4	1.31*	0.28^{NS}	3.97**	1.66^{NS}	1.57^{NS}
Error	24					
Total	53					

NS: not significant; *: $p \leq 0.05$; **: $p \leq 0.01$

Shoot fresh weight: Application of NaF stress decreased the fresh shoot weight (Fig.2A). Fresh shoot weight of plants showed best response by the action of foliar application of citric acid. The maximum value was observed by the exogenously applied 100 mgL^{-1}citric acid in Pak Afgoi.

Root fresh weight: The decrease in fresh root weight was observed in Pak Afgoi under stress condition. Citric acid performed a better role to mitigate the toxic effect of salt stress. The highest fresh root weight was noted in Pak Afgoi as compared to Pearl. Overall, citric acid enhanced the fresh root weight in both saline and non-saline conditions. Better response was observed in Pak. Afgoi as compare to Pearl cultivar (Fig. 2B).

Shoot dry weight: The toxic effects of sodium fluoride decreased the dry shoot weight. Maximum dry shoot weight was observed in Pak Afgoi by the foliar spray of 100 mgL^{-1} citric acid as compared to Pearl. Under non-stress condition, 150 mgL^{-1} citric acid also showed better response in both maize cultivars. (Fig. 3A).

Root dry weight: The minimum dry root weight was recorded in Pearl by the application of 200 mgL^{-1} under NaF stress. Application of citric acid increased the dry root weight. Higher value of dry root mass was observed in Pak Afgoi Foliar spray of 100 mg L^{-1} citric acid showed better response under stress condition in both cultivars. Overall, citric acid was useful to ameliorate the toxic effects of sodium fluoride stress (Fig. 3B).

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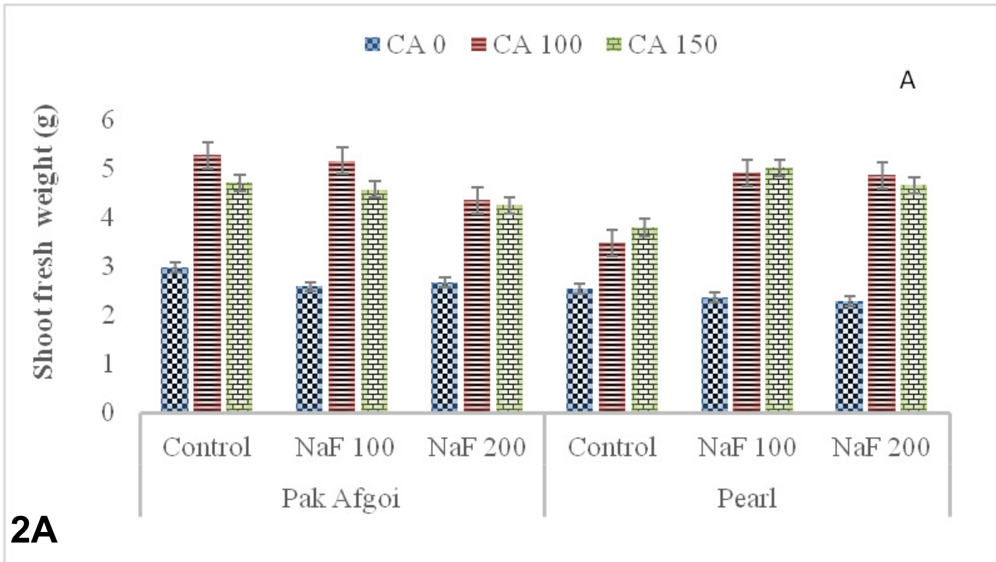

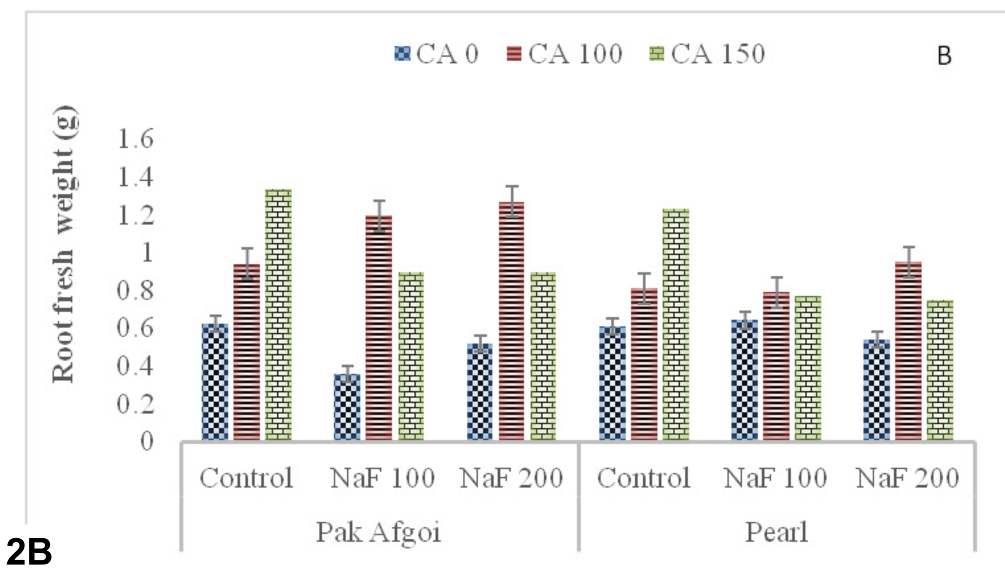

Figures 2A and 2B. Effect of foliar spray of citric acid on shoot (2A) and root (2B) fresh weight (g) of maize under different levels of sodium fluoride stress.

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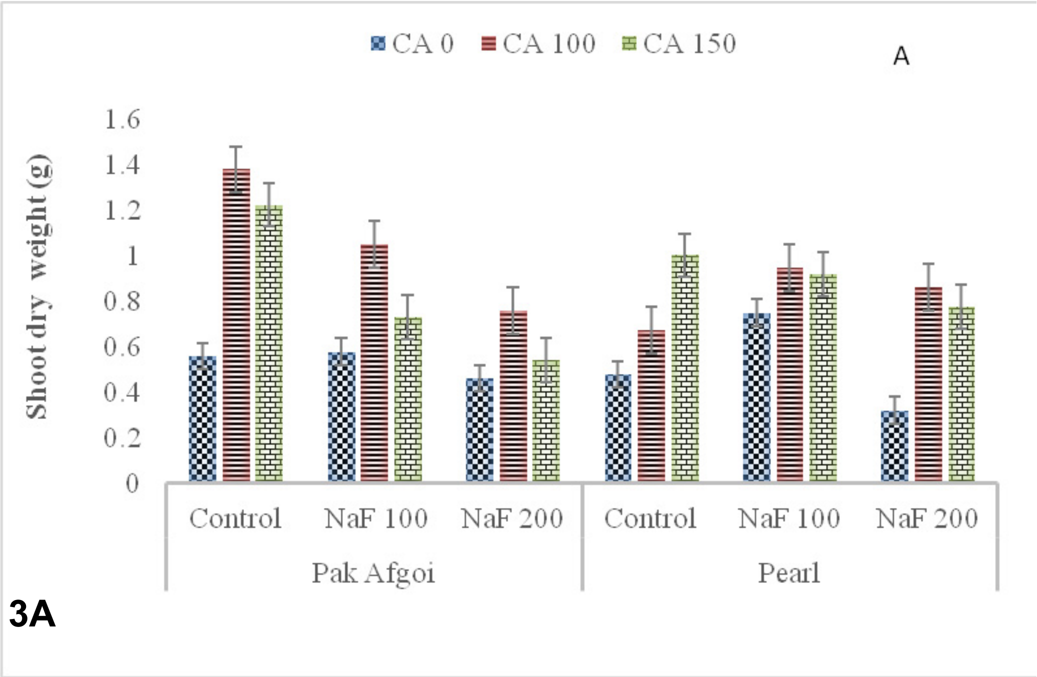
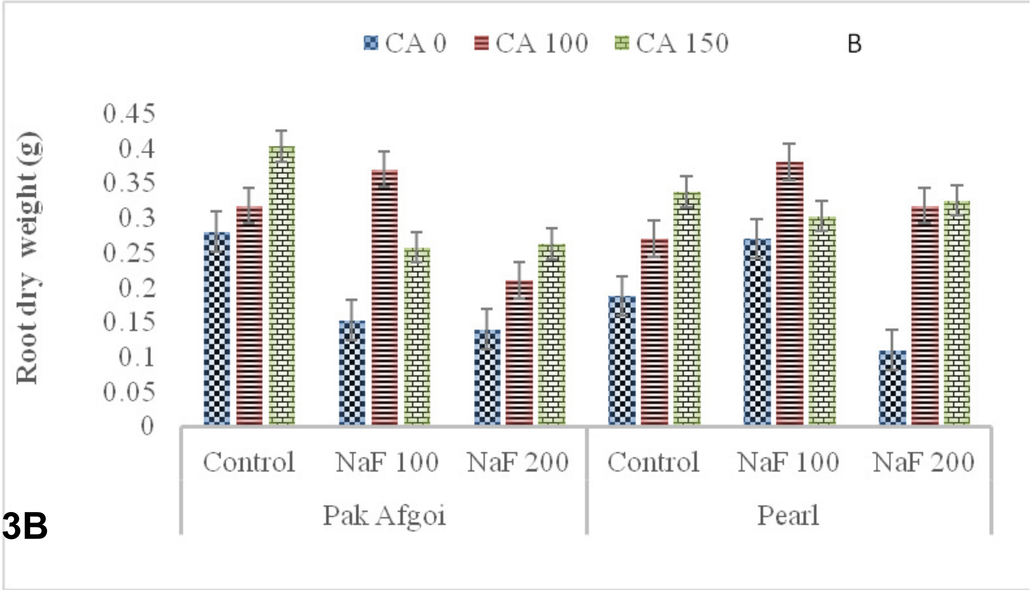
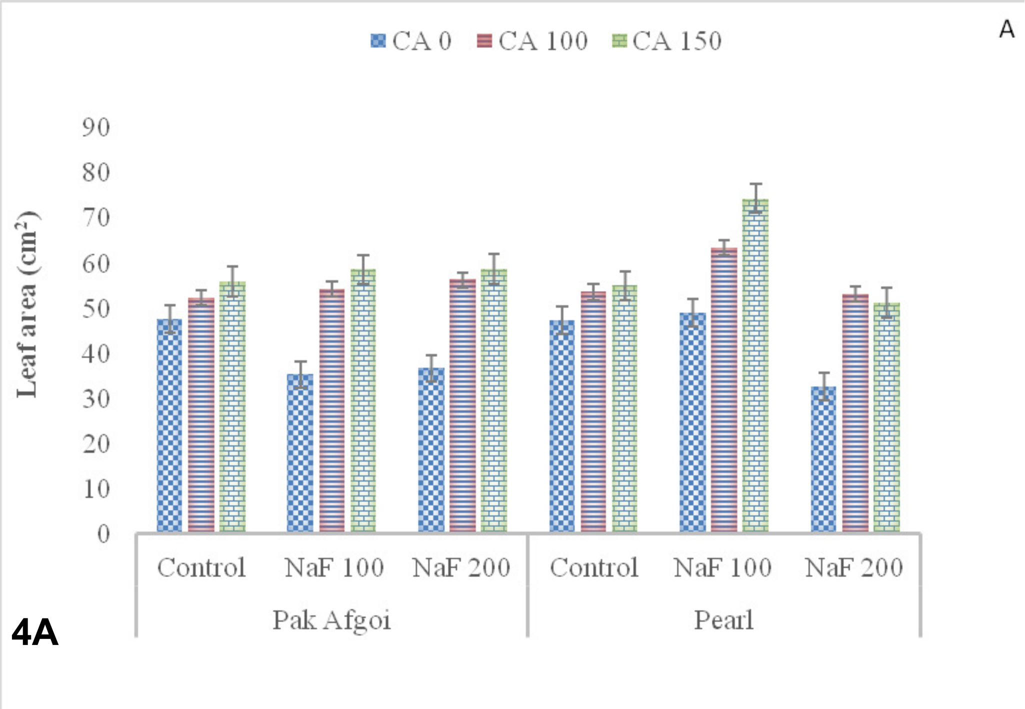
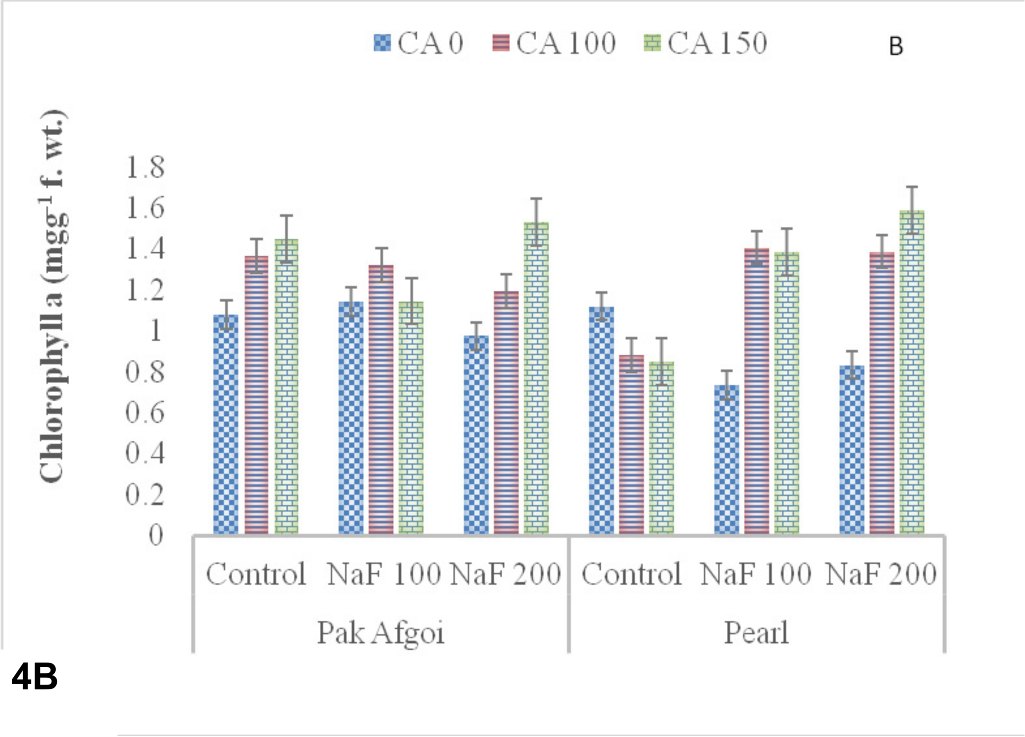




Figures 3A and 3B. Effect of foliar spray of citric acid on shoot (3A) and root (3B) dry weight (g) of maize under different levels of sodium fluoride stress.





Figures 4A and 4B. Effect of foliar spray of citric acid on leaf area (4A) and chlorophyll (4B) of maize under different levels of sodium fluoride stress.

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LEAF AREA

The maximum leaf area was observed in Pearl by the foliar application of 150 mgL^{-1} citric acid under 100 mgL^{-1}NaF stress. Citric acid was more beneficial to ameliorate the salt stress in both maize cultivars. Overall, both varieties showed better response towards the foliar spray of citric acid (Fig. 4A).

CHLOROPHYLL A

Sodium fluoride significantly decreased the chlorophyll contents in both maize cultivars.Maximum contents of chlorophyll were observed in Pak Afgoi as compared to Pearl by the foliar application of 150 mgL^{-1} citric acid (CA 150). In regard to Pearl, 150 mgL^{-1} citric acid was more effective under 200 mgL^{-1} sodium fluoride stress to increase the chlorophyll contents (Fig. 4B).

CHLOROPHYLL B

The highest value of chlorophyll b was observed in Pak Afgoi by the foliar spray of 150 mgL^{-1} citric acid under non-saline conditions. Under saline conditions, 100 mgL^{-1} concentration of citric acid elevated the Chlorophyll b contents. In Pearl 100 mgL^{-1} citric acid was more effective under 100 mgL^{-1} sodium fluoride stress (Fig 5A). Citric acid proved to be useful for mitigating the harmful effects of sodium fluoride.

TOTAL CHLOROPHYLL

Maize cultivar Pearl showed maximum quantity of total chlorophyll by foliar spray of 100 mgL^{-1} citric acid under 100 mgL^{-1}NaF. Citric acid ameliorated the toxic effects of salt stress. Out of these treatments Pak Afgoi showed better performance by the exogenously applied 100 mgL^{-1} citric acid under 100 mgL^{-1}NaF. (Fig. 5B).

CAROTENOIDS

Under non-saline conditions, maximum value of carotenoid concentration was recorded in Pak Afgoi by the application of 150 mgL^{-1}citric acid. In both maize cultivars, highest carotenoid contents was observed in plants which were treated with exogenous application of 100 mgL^{-1} citric acid under 100 mgL^{-1}NaF. Pak Afgoi performed better by the application of citric acid as compared to the Pearl (Fig.6A).

Application of saline growth medium decreased the proximate contents in plants. The toxic effects of stress were decreased by the application of citric acid. Analysis of variance of proximate of maize plants was shown in Table 3.

FIBER

Pak. Afgoi showed highest fiber contents by the application of 100 mgL^{-1} of citric acid under 100 mgL^{-1} of sodium fluoride stress while under non-saline conditions Pearl performed better by the application of citric acid (Fig. 6B).

PROTEIN

The maximum value of protein contents was observed in Pak Afgoi by the foliar application of 150 mgL^{-1}citric acid under non-saline conditions. Same level of citric acid showed better response in Pearl with same citric acid treatment (Fig. 7A).

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FATS

Application of 200 mgL^{-1}citric acid enhanced the fat contents in Pak. Afgoi cultivar under non-saline conditions. The maximum value of fats were recorded in Pearl by the application of 100 mgL^{-1} citric acid under non-saline conditions. Application of 100 mgL^{-1} citric acid as a foliar spray showed significant role under different concentrations of sodium fluoride stress in regard to fat contents (Fig. 7B).

MOISTURE AND ASH

The maximum value of ash and moisture content was observed in Pak. Afgoi by the foliar spray of 150 mgL^{-1} citric acid. Application of 100 mgL^{-1} citric acid was found to be effective in Pearl. Different concentration of citric acid observed to be significant in both maize cultivars in regard to ash and moisture contents. (Fig. 8A and B).

Table 2. Analysis of variance of Chlorophyll and carotenoids in maize (*Zea mays* L.) grown under various stress levels of sodium fluoride and citric acid

Source	Df	Leaf area	Dry root	Chl. a	Chl. b	Total Chl.	Carotenoids
Variety	1	3.33*	0.51^{NS}	2936.52**	96324.9**	443.23*	8088.87**
NaF	2	14.12**	3.57^{NS}	3193.29**	43103.2**	914.94**	5556.99**
Variety*NaF	2	0.11^{NS}	5.65*	51.65**	2343.09**	143.43**	205.21**
Citric Acid	2	2.50*	0.83^{NS}	526.38**	6568.84**	1312.71**	2943.68**
Variety*Citric Acid	2	5.02**	1.07^{NS}	1320.62**	107.98**	288.09**	163.74**
NaF*Citric Acid	4	2.07^{NS}	0.43^{NS}	1326.26**	1255.85**	1371.04**	1360.80**
Variety*NaF*Citric Acid	4	1.10^{NS}	2.04^{NS}	1461.80**	2767.62**	544.09**	423.04**
Error	24						
Total	53						

NS: not significant; *: $p \leq 0.05$; **: $p \leq 0.01$

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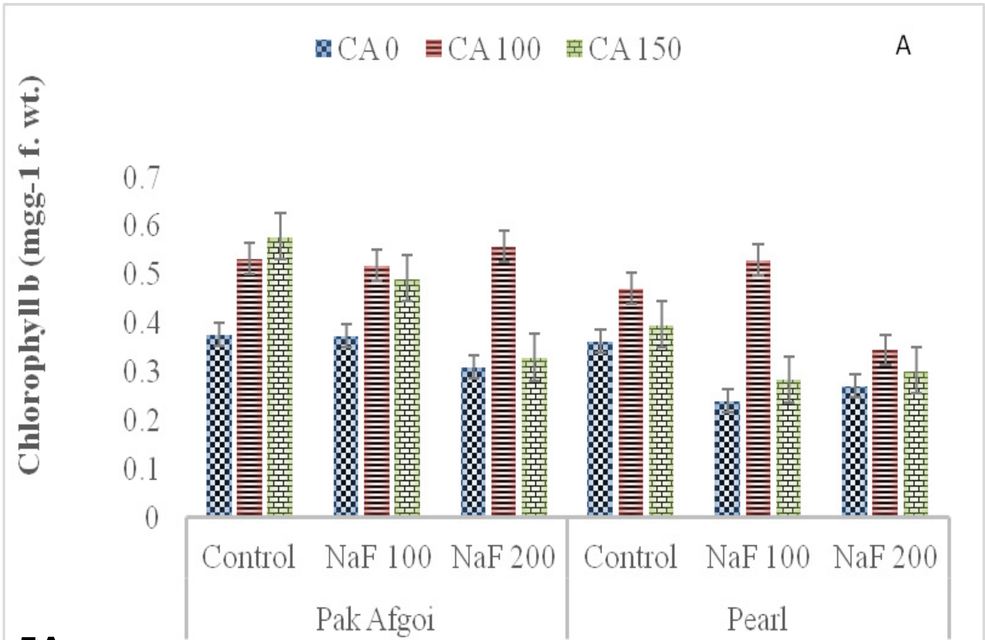
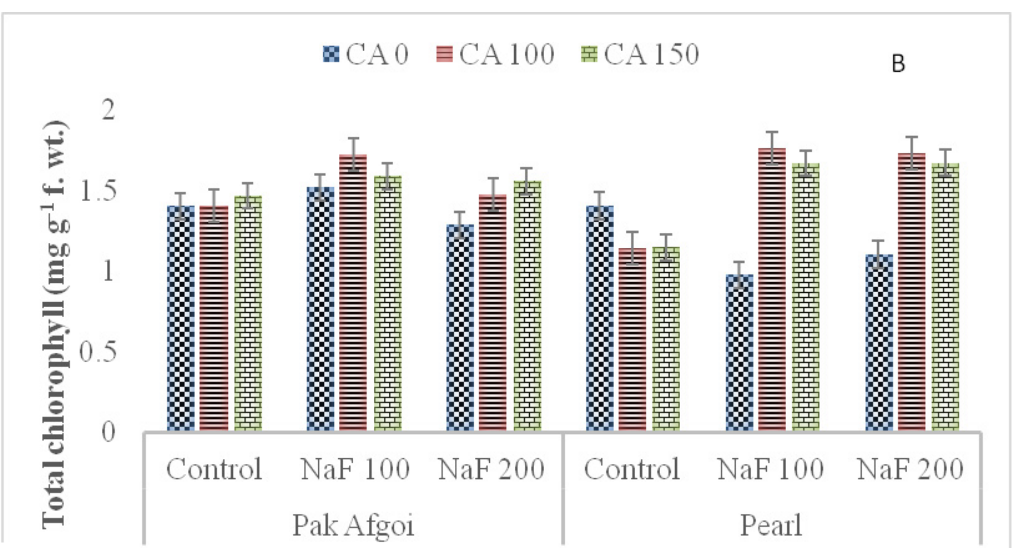


5A



5B

Figures 5A and 5B. Effect of foliar spray of citric acid on chlorophyll a (5A) and total chlorophyll (5B) of maize under different levels of sodium fluoride stress.

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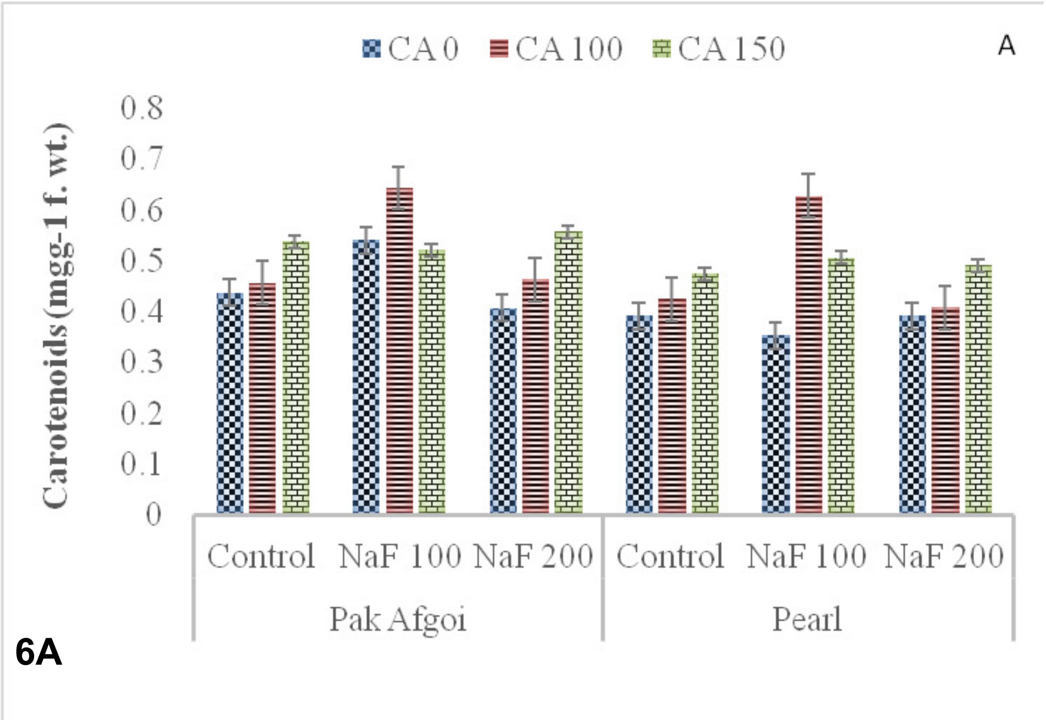

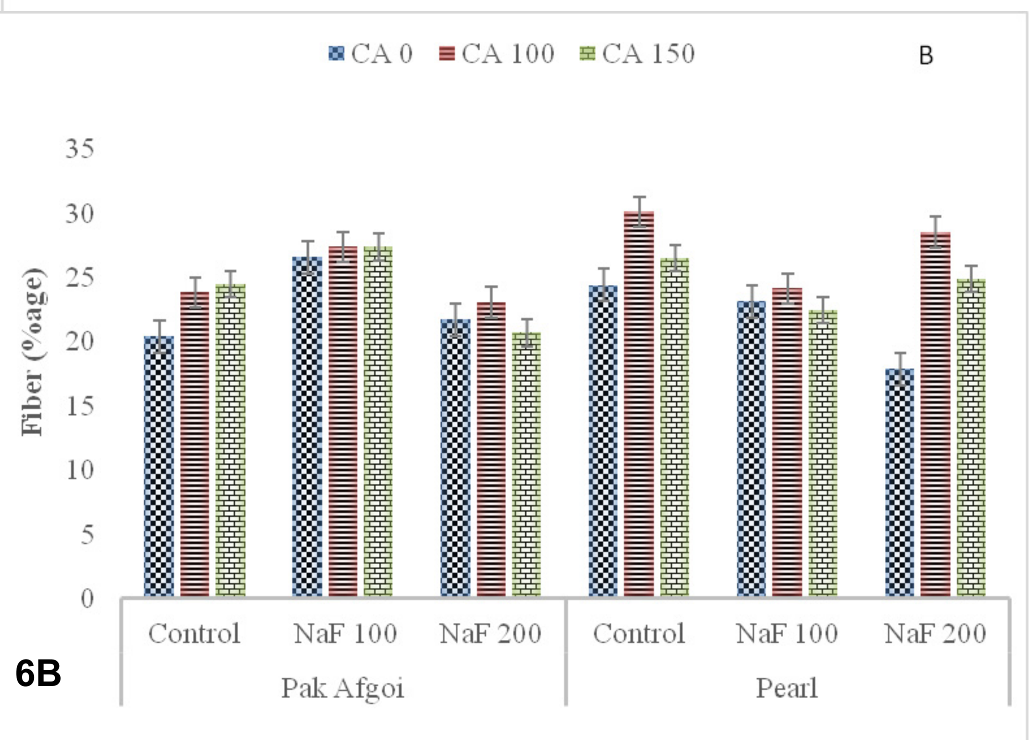

Figures 6A and 6B. Effect of foliar spray of citric acid on carotenoids (6A) and fiber (6B) of maize under different levels of sodium fluoride stress.

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Table 3. Analysis of variance of proximate in maize (*Zea mays* L.) grown under various stress levels of sodium fluoride and citric acid

Source	DF	Fiber %	Protein %	Fats %	Moisture %	Ash contents
Variety	1	267.36*	29.32*	1222.48**	27393.9**	53.88**
NaF	2	1182.74**	1089.82**	1756.05**	98317.1**	9.69**
Variety*NaF	2	220.87**	23.02**	235.73**	9066.39**	3.59*
Citric Acid	2	2375.28**	16008.6**	1551.71**	283702**	3.57*
Variety*Citric Acid	2	1538.22**	476.23**	445.98**	76983.0**	0.46^{NS}
NaF*Citric Acid	4	746.05**	1226.85**	1189.51**	63324.7**	1.97^{NS}
Variety*NaF*Citric Acid	4	952.64**	294.02**	758.09**	42105.5**	1.97**
Error	24					
Total	53					

NS: not significant; *: p≤0.05; **: p≤0.01

Table 4. Analysis of variance of nutrient estimation (Na^+, K^+, Mg^+, Fe^{2+}, Ca^{2+}) in maize (*Zea mays* L.) grown under various stress levels of sodium fluoride and citric acid

Source	DF	Na^+	K^+	Mg^{2+}	Fe^{2+}	Ca^{2+}
Variety	1	5.29^{NS}	193085**	232890**	154.26**	*67334.8**
NaF	2	1.86^{NS}	3005.70**	1117.29**	56.07**	20117.2**
Variety*NaF	2	2.71^{NS}	4893.02**	1060.66**	17.49**	23603.5**
Citric Acid	2	3.31*	20461.2**	2445.55**	14.23**	3300.08**
Variety*Citric Acid	2	2.63^{NS}	2062.61**	2691.89**	22.38**	3648.49**
NaF*Citric Acid	4	2.60^{NS}	2059.12**	506.67**	14.83**	8481.62**
Variety*NaF*Citric Acid	4	2.49^{NS}	6134.20**	490.44**	15.08**	9524.51**
Error	24					
Total	53					

NS: not significant; *: p≤0.05; **: p≤0.01

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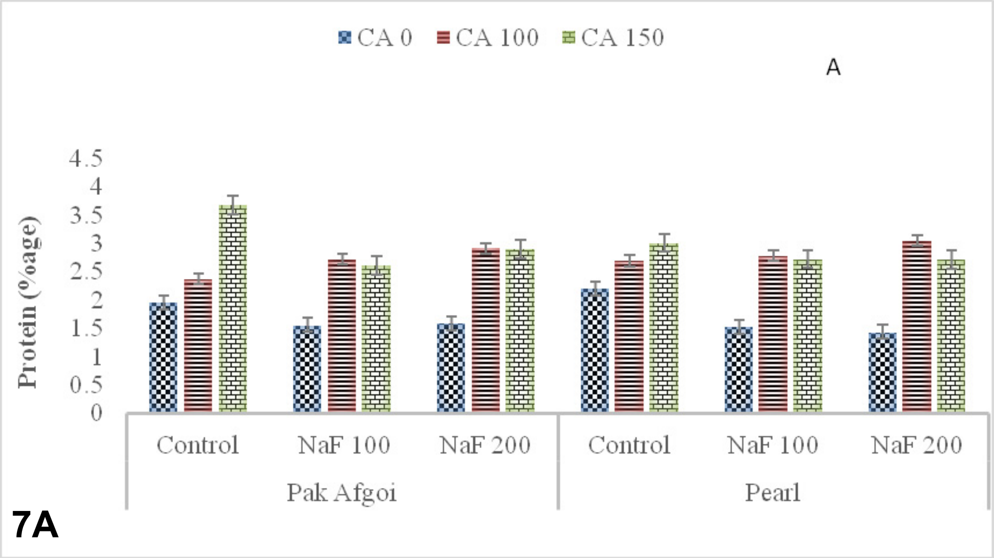

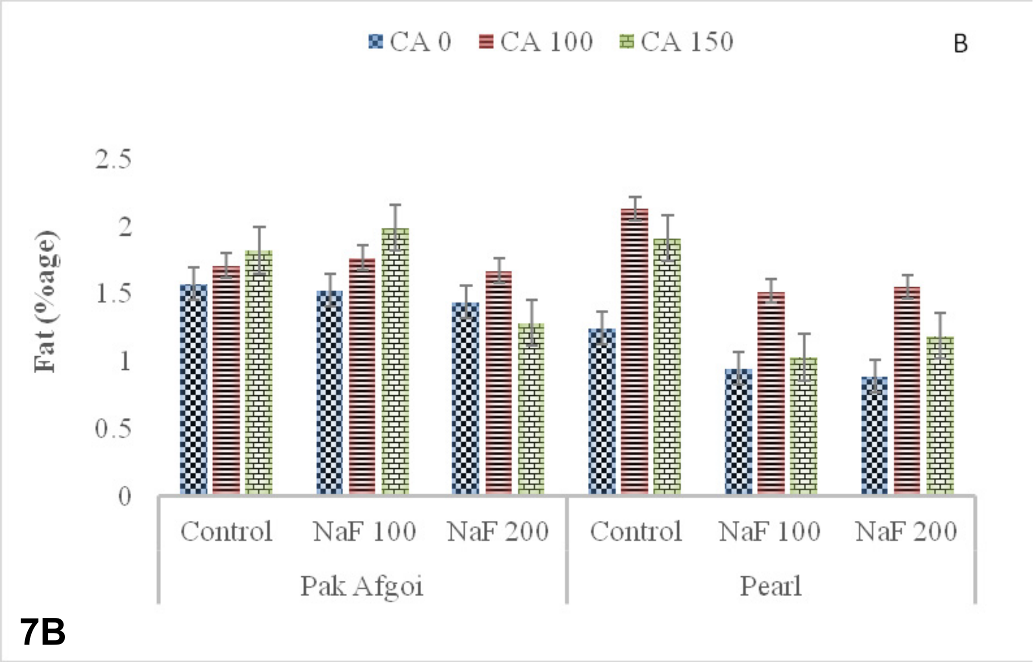

Figures 7A and 7B. Effect of foliar spray of citric acid on protein contents (7A) and fats content (7B) in maize under different levels of sodium fluoride stress.

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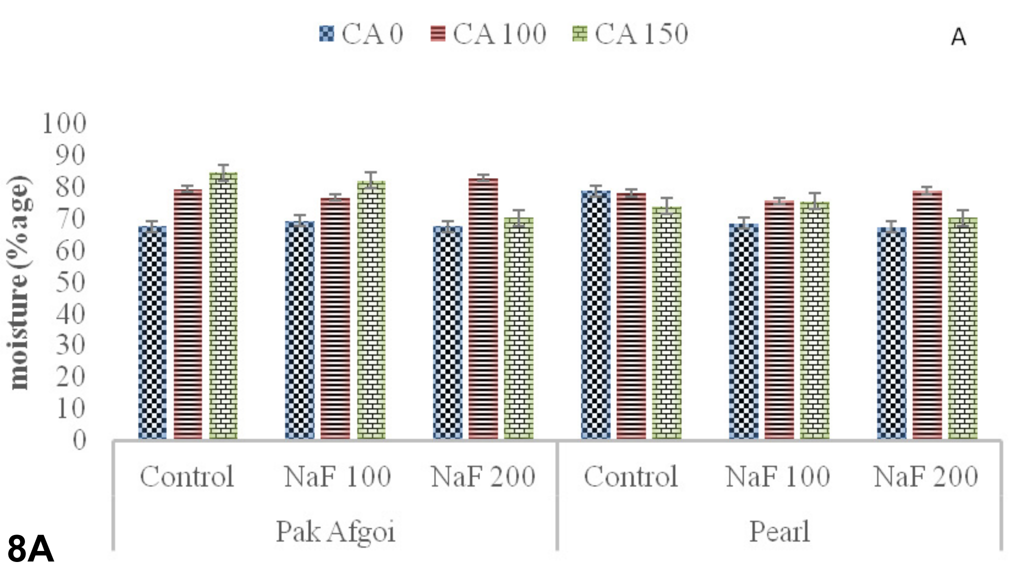
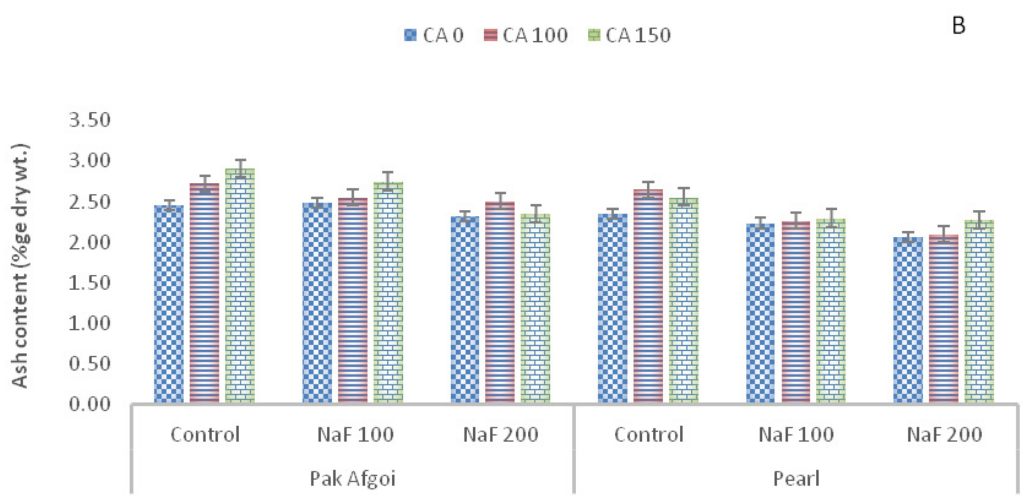


8A



8B

Figure 8A and 8B. Effect of foliar spray of citric acid on moisture contents (8A) and ash contents (8B) in maize under different levels of sodium fluoride stress.

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CONCENTRATION OF Na^+

Significant concentration of sodium contents was observed in both varieties of maize plants under sodium fluoride stress. Foliar spray of citric acid mitigated the toxic effects of sodium fluoride in plants (Table 4).

The maximum concentration of sodium was observed in Pak Afgoi under 200 mgL^{-1} sodium fluoride. Foliar spray of citric acid reduced the effect of Na^+ in both maize cultivars. However, citric acid showed better response to reduce the toxic effect of sodium in both maize cultivars (Fig. 9A).

CONCENTRATION OF K^+

The plants which were exposed to sodium fluoride stress have decreased the K^+ concentration (Table 4). Maximum contents of potassium were observed in Pak Afgoi by the exogenously application of 100 mgL^{-1} citric acid. The same concentration of citric acid was more effective in Pearl with 100 mgL^{-1} under sodium fluoride stress. However, citric acid was more effective to mitigate the effect of sodium fluoride in both cultivars of maize (Fig.9B).

CONCENTRATION OF Mg^{2+}

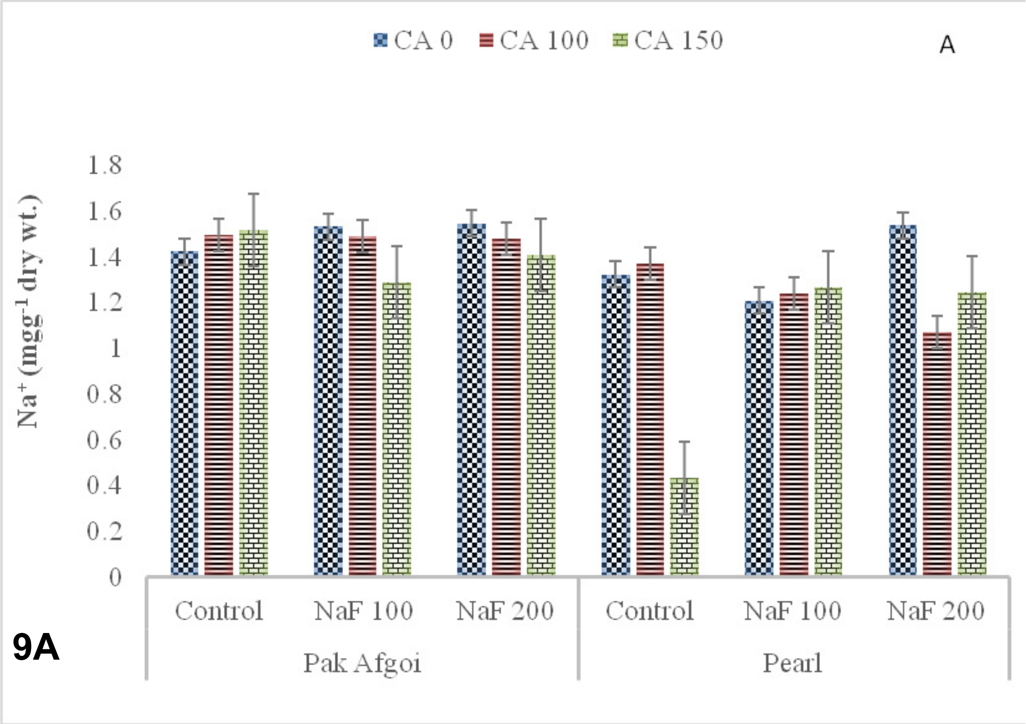
The plant treated with sodium fluoride has decreased the $Mg^{\mathbf{2+}}$. Maximum $Mg^{\mathbf{2+}}$ concentration was observed in Pak, Afgoi by the exogenously applied100 mgL^{-1} citric acid under sodium fluoride stress. Same trend of Mg was also observed in Pak. Afgoi treated with 150 mgL^{-1} citric acid. Overall, 100 mgL^{-1} citric acid have more significant effects on both maize cultivars (Fig.10A).

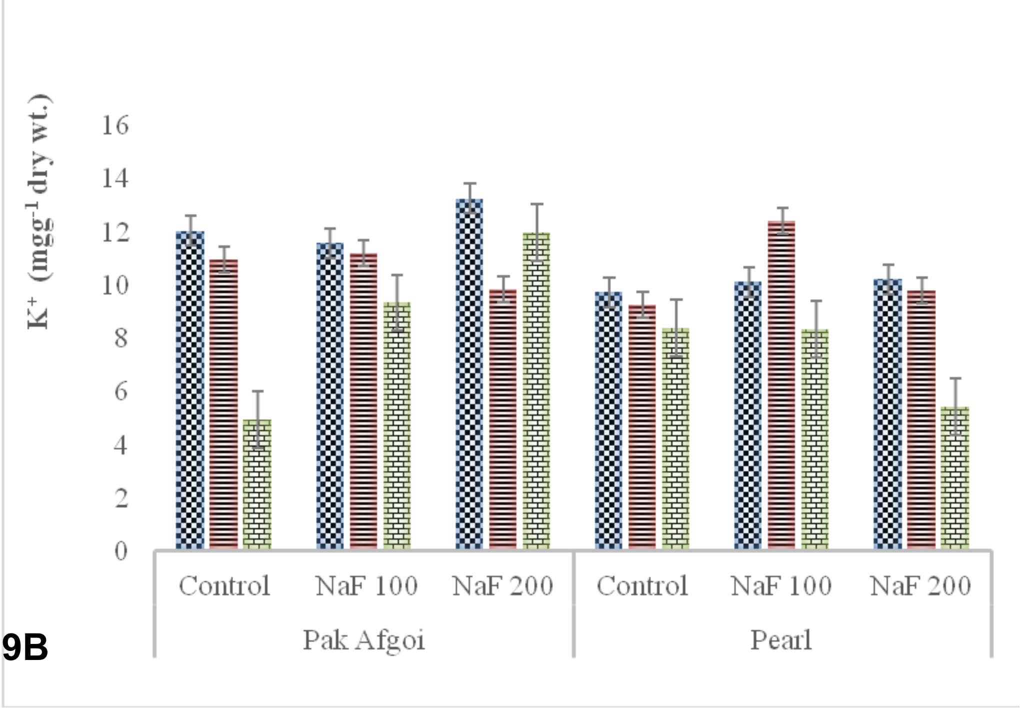
CONCENTRATION OF Fe

Maximum value of Fe was found in Pearl and Pak Afgoi by the foliar application of 150 mgL^{-1} citric acid. Exogenous application of citric acid was found to be beneficial for plants to survive under stressed condition. Overall, both cultivars revealed better results with exogenously applied citric acid in the presence or absence of salinity (Fig. 10B).

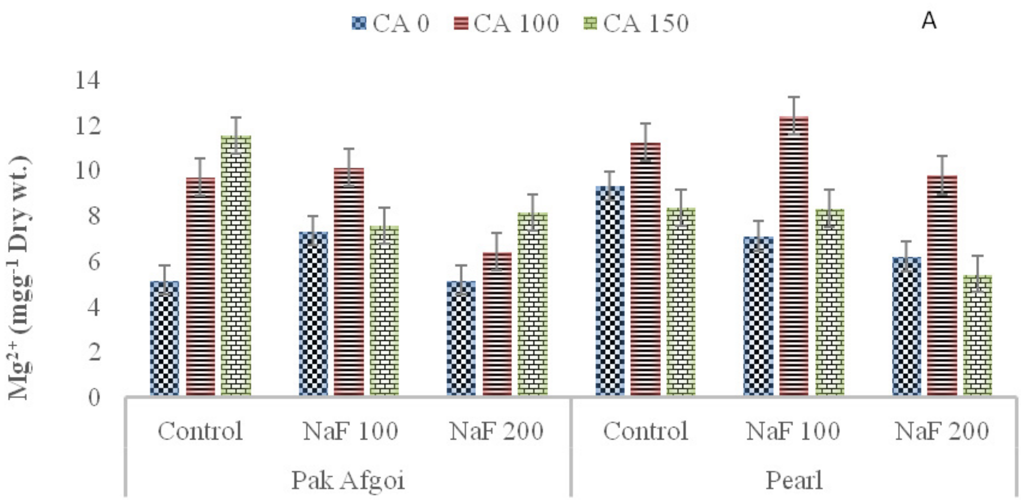
CONCENTRATION OF Ca^{2+}

Maximum value of Ca^{2+} in plants were found by the exogenous application of 150 mgL^{-1} citric acid under sodium fluoride stress. Citric acid showed more positive response towards the concentration of Ca in both cultivars of maize. However, 150 mgL^{-1} of citric acid showed significant increase in Ca^{2+} concentration in both cultivars under saline and non-saline conditions (Fig. 11).

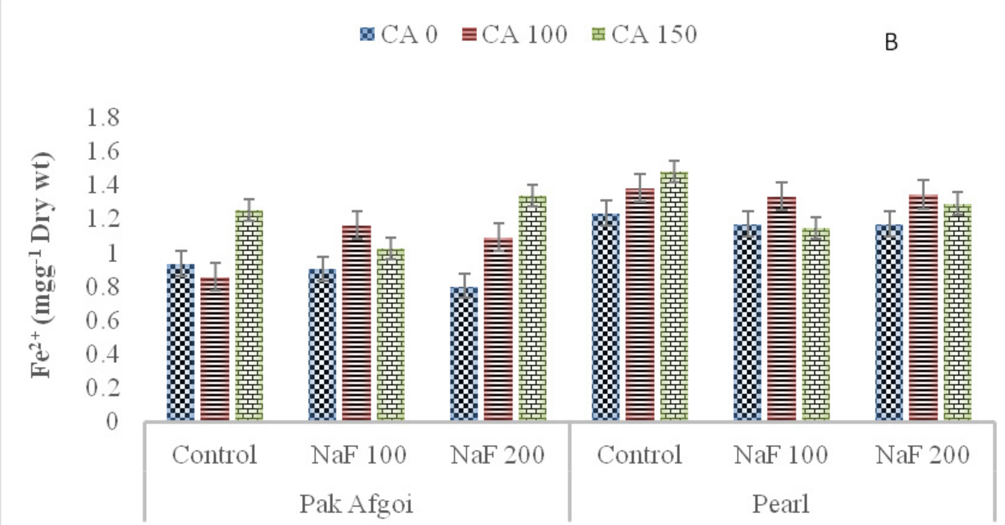




Figures 9A and 9B. Effect of foliar spray of citric acid on Na^+ (9A) and K^+ (9B) contents in maize under different levels of sodium fluoride stress.



10A



10B

Figures 10A and 10B. Effect of foliar spray of citric acid on Mg^{2+} (10A) and Fe^{2+} (10B) contents in maize under different levels of sodium fluoride stress

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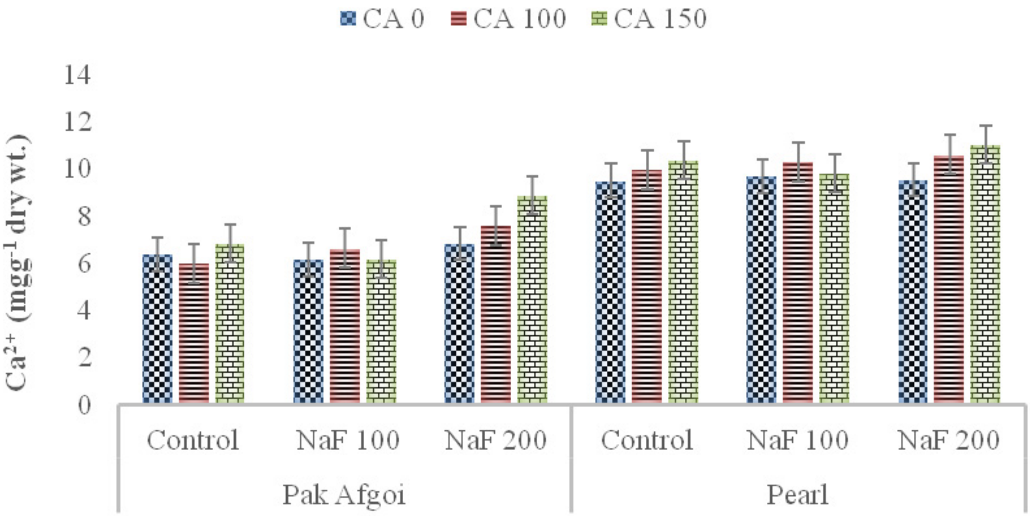

Figures 11. Effect of foliar spray of citric acid on Ca^{2+} contents in maize under different levels of sodium fluoride stress.

DISCUSSION

High deposition of salt in the soil creates areas with lower water potential in the soil, making water and nutrients extremely difficult for crops. High drought stress and salt stress have basic physiology overlap with each other. Salt stress therefore guarantees the dehydration of crops and lead to the physiological drought form [18].

In the current study, the development of the plant shoot was noted to be influenced by salinity. These findings were according to Tuna et al.[19], who indicated that salt stress lessened the development of maize shoots by suppressing the growth of internodes, initiating and expanding leaves and accelerating leaf abscission. Gupta et al.[20] also supported to the present findings that the impact of salinity on corn cultivars ' physiological features were demonstrated. They observed that salinity was responsible for a significant reduction in fresh and dry mass, shoot length, area of leaf and comparative water content in cultivars of maize. Also discovered by them that under the salt pressure situation, the percentage of proline, Na^+ and $Na^+/K^+$are enhanced.

It was discovered during the present study that root development, leaf area and shoot weight were also affected by salinity. The contamination of air by fluoride adversely affects the crop production in *Zea mays.* It also affects the seed germination, growth, total protein content. It also reduces the pigment content in maize plant [31]. According to Champa et al.[21], these findings also stated that the chlorophyll contents, total dry matter and the relative maize water content in the saline environment has been reduced. The decline in fresh shoot mass and dry mass may be due to decreased plant roots osmotic potential and toxicity to ions. According

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to Tuna et al. [19] the application of saline water outcomes in a substantial decreased in shoot height, fresh shoot mass and dry shoot weight, and leaf area in both maize cultivars. The study on the impact of distinct sodium fluoride soil levels on distinct growth parameters in *Raphanus sativus L.* was conducted in 2011- 2013. Different sodium fluoride levels inhibited proportion of seedling germination, flowers number per plant, leaves number, plant height, root length, shoot length, leaf size, proportion of fruit set and proportion of seed set. Growth of crops in soil supplemented with NaF soil indicates maximum decrease in development parameters relative to crops in control. Present findings are also supported by Chandrakar et al.[22]. Applications of SA with HA might be an efficient and cost-effective approach to seedling growth, establishment and plant development in early season areas impacted by soil drought, particularly in semi-arid areas for SC 705 corn hybrid [23].

However, abiotically stressed cells lately revealed a reduced DNA synthesis, Lower DNA safety and enhanced DNase activity against damaged histone protein [24]. The findings indicated that fluoride ion therapy decreased growth (radicular length and accumulation of dry mass), protein content, membrane stability index, genomic template stability, and free radical scavenging, but increased mortality rates for cells, active oxygen species (AOS), protein carbonylation, lipase, malondialdehyde (MDA) and DNA polymorphism. In addition, Fluoride toxicity lifts endogenous proline, glutathione, and ascorbic acid levels and changes the iso-enzyme structures and expressions of genes towards stress-response proteins (catalase, superoxide dismutase, ascorbate peroxidase and glutathione-S-transferase) [25].

The findings of Alim e al.[26] endorsed the significance of stomatal conductance as shown by the distinct adaxial / abaxial leaf sides behaviors. In addition, Ghazijahani et al. [27] recorded a pH decline in the apoplast continuum with associated impacts on Fe and chlorophyll contents or distributions.

By altering free ribonucleotides and RNA, fluoride can also reduce the rate of RNA synthesis. The reduction may also be due to the effect of vacuolar sequestration on transportation of fluoride over longer distances. Plant harm caused by toxins such as fluoride follows their transportation through the plant after first accumulation in vacuoles [28].

All medications have enhanced the proportion of root length. Enhanced amount of citric acid improved the average root length. All citric acid treatments increased the length of the shoot while MA treatments remained unaffected [29]. Being glycophytic, corn development and yield delays as salt content in the soil medium increased considerably[30]. Salt tolerant genotypes have increased K^+ concentrations over Na^+ in maize [31].

CONCLUSIONS

Results clearly displayed the drastic effects of sodium fluoride on morphological and biochemical parameters. Citric acid 150 mgL^{-1} had a positive effect on the growth of maize plants and reduced the toxic effects of sodium fluoride. Salt tolerant maize cultivar, Pak Afgoi performed better under stress.

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