

Effect of foliar applied kinetin and indole acetic acid on maize plants grown under saline conditions

Cengiz KAYA^{1,*}, Atilla Levent TUNA², Abdulkadir Mustafa OKANT³

¹Harran University, Agriculture Faculty, Soil Science and Plant Nutrition Department, Şanlıurfa - TURKEY

²Muğla University, Biology Department, Muğla - TURKEY

³Harran University, Agriculture Faculty, Field Crops Department, Şanlıurfa - TURKEY

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Abstract: This study examined the effects of kinetin (KIN) and indoleacetic acid (IAA) sprayed on the leaves of salinity-stressed maize (*Zea mays* L. cv., DK 647 F1) plants grown in field conditions. Salt stress was created by adding 100 mM NaCl to the irrigation water through a drip irrigation system during the irrigation schedule. Kinetin (KIN), indole acetic acid (IAA), and their combinations were sprayed foliarly. Salt stress (S) reduced the total dry matter, grain yield, chlorophyll content, and relative water content (RWC), but increased electrolyte leakage and proline accumulation in the maize plants. Foliar applications of both KIN and IAA treatments overcame to variable extents the adverse effects of NaCl stress on the earlier mentioned physiological parameters. However, the combination of KIN plus IAA did not improve salinity tolerance in maize plants. Salt stress increased Na⁺ concentration, and reduced those of Ca²⁺ and K⁺ in the leaves of maize plants. Foliar application of both KIN and IAA significantly reduced Na⁺ concentration and increased those of Ca²⁺ and K⁺. Foliar application of KIN and IAA, especially at 2 mM, counteracted some of the salt induced adverse effects by enhancing essential inorganic nutrients as well as by maintaining membrane permeability.

Key words: Corn, inorganic nutrients, proline, salinity, *Zea mays*

Yapraktan uygulanan kinetin ve indol asetik asitin tuzlu koşullarda yetişen mısır bitkisi üzerine etkisi

Özet: Bu çalışma, tarla koşullarında yetişen tuz stresindeki mısırın yapraklarına püskürtülen kinetin ve indol asetik asitin etkilerini test etmeyi amaçlamıştır. Tuzluluk stresi, damla sulama sistemiyle verilen sulama suyuna sulama programı boyunca 100 mM NaCl ekleyerek yaratılmıştır. Kinetin (KIN), indol asetik asit (IAA) ve diğer kombinasyonlar yapraktan püskürtülmüştür. Tuz stresi (S) mısırın toplam kuru ağırlığını, klorofil içeriğini, oransal su içeriğini (RWC) azaltmıştır, fakat elektrolit sızıntıyı, ve prolin birikimini artırmıştır. Hem yaprağa uygulanan KIN ve hem de IAA uygulamaları daha önce bahsedilen fizyolojik parametreler üzerindeki tuzun olumsuz etkilerini belirli düzeyde gidermişlerdir. Ancak, KIN artı IAA kombinasyonu mısır bitkisinde tuza toleransı geliştirmemiştir. Tuz stresi mısır bitkisinin yapraklarında Na⁺ konsantrasyonunu artırmış ve Ca²⁺ ve K⁺ ninkini ise azaltmıştır. Hem KIN ve hem de IAA yaprak uygulamaları Na konsantrasyonunu önemli düzeyde düşürmüş ve Ca²⁺ ve K⁺ nın konsantrasyonlarını ise yükseltmiştir. Özellikle 2 mM KIN ve IAA yaprak uygulamaları zorunlu inorganik besin elementlerinin alımını artırarak ve hücre zarı geçirgenliğini düzenleyerek tuzun zararlı etkilerini azaltmışlardır.

Anahtar sözcükler: Mısır, inorganik besinler, prolin, tuzluluk, *Zea mays*

* E-mail: c_kaya70@yahoo.com

Introduction

Maize is a major source of food for millions of people around the world. In addition, it is widely used for fodder production and non-food industries (e.g. biofuel production). Cultivation of hybrid maize originated in North America about 100 years ago (Troyer 1999). Maize is a salt-sensitive crop plant (Maas 1986), although intra-specific variability for salt resistance has been reported (Maas et al. 1983; Fortmeier and Schubert 1995).

Salinity is one of the major environmental factors limiting plant growth and productivity (Allakhverdiev et al. 2000; Ashraf et al. 2008). High salt concentration, in particular Na^+ which deposits in the soil, can alter the basic texture of the soil, thereby causing decreased soil porosity, and consequently leading to reduced soil aeration and water conductance.

Currently, there are no economically viable technological means to facilitate crop production under abiotic stress conditions. However, development of crop plants tolerant to environmental stress is considered a promising approach, which may help satisfy growing food demand of the developing and under-developed countries. Crop stress tolerance can be improved by a number of means including selection and breeding, genetic modifications, and use of osmoprotectants and growth regulating substances (Parida and Das 2005). Soil salinity alters root and shoot hormone relations, e.g. it decreases cytokinins and gibberellins and increases abscisic acid contents (Zhang and Zhang 1994).

Plant growth regulators are being widely used to counteract the deleterious effects of adverse environmental stresses on plants. Kinetin is one of the cytokinins known to significantly improve the growth of crop plants grown under salinity (Salama and Awadalla 1987), soil waterlogging (Gadallah 1995a), and soil acidity (Gadallah 1994). Indole acetic acid (IAA) is also known to play a significant role in plant tolerance to salt stress. However, little information appears to be available on the relationship between salinity tolerance and auxin or cytokinins levels in plants. The variations in IAA content under stress conditions appeared to be similar to those of abscisic acid (Ribaut and Pilet 1991), and increased levels of

IAA have been correlated with reduced growth (Ribaut and Pilet 1994). Considerable efforts are required to study the alleviating effect of some PGRs like kinetin and indole acetic acid to achieve improved stress resistance in native crop plants. Reports mentioned above deal with the effects of kinetin or IAA on plants at a young stage. Therefore, the data on the field response of maize plants to saline irrigation are rather scarce, in terms of either plant yield or physiology of adaptation. In this respect, the objectives of this study were (1) to evaluate growth and water relations of field-grown maize irrigated with saline water, (2) to define its physiological response, (3) to specifically compare plant performance under salt stress, (4) to examine the combined effects of foliar applications of KIN and IAA and salinity on grain yield, key growth parameters, and nutritional status in maize plants, and (5) to study the antagonistic or synergetic effects of KIN and IAA in combination on maize plant grown under salt stress conditions.

Materials and methods

Plant culture and treatments

This investigation was based on 2 individual experiments each using the same cultivar of maize (*Zea mays* L. cv., DK 647 F1: DEKALP). The experiment was conducted on a clay loam soil classified as İkişice soil series (Vertic Calcicorthid Aridisol) from the end of June to the end of October 2006 at the Agricultural Research Station of the University of Harran, Şanlıurfa. Water content at field capacity, water content at the permanent wilting point, dry bulk density, pH, organic matter content, and electrical conductivity (EC) of the top 0.3 m of soil were 30.8, 24.4%, 1.38 g cm^{-3} , 7.1, 1.2%, and 1.10 dS m^{-1} , respectively. Soil pH was measured using a digital pH meter and electrical conductivity (ECe) (Mettler S 47 K model, Switzerland) was determined using an EC-meter. Water quality at the site was good enough for irrigation ($\text{EC} = 0.52 \text{ dS m}^{-1}$, and pH 7.2). Soil EC content was monitored once a week throughout the crop growing seasons to keep the EC of the soil constant.

The seeds of maize were sown in plots, each of 6.0 m × 2.8 m size. Ninety-six plants per treatment

replicate (or plot) were spaced 0.25 m apart within rows and 0.70 m apart between rows. Each treatment was replicated 3 times in a randomized split-block design. Salinity treatments were main plots and application of KIN and IAA were subplots.

All plants were drip irrigated from 1000 to 1700 hours at $4 \text{ L h}^{-1} \text{ m}^{-1}$ for 2 weeks to promote root establishment prior to salinity stress. Irrigation scheduling was controlled using tensiometers installed at 30 and 45 cm soil depths and centered between 2 plants in the row. The tensiometer readings never fell below -30 kPa at 30 cm and -20 kPa at 45 cm. The evaporation data were obtained from a Class A pan evaporimeter sited near the experimental field and were collected on a daily basis. There was no rainfall during the experimental period. A pan coefficient of 1 was used for the entire growing season to include a leaching fraction in the total volume of water applied at each irrigation event. The operating pressure of the drip irrigation system was maintained constant during the experiment at 100 kPa . Trickle irrigation was scheduled daily at 100% of Epan maintained soil moisture near field capacity (FC). A single-drip irrigation tube with 4.0 L h^{-1} and 0.5 m emitter spacing was placed on the soil surface for each row.

Saline treatments were initiated 20 days after sowing (20 July). The total amount of water applied from the beginning of the salt treatments until harvest was 240 mm in total (distributed in 8 irrigations). Harvesting began 120 days after sowing (October 28).

Before the start of the treatments, plants were grown for 1 week in order to improve root development. The different treatments used were as follows: (1) control (C): irrigation water alone, (2) salt stress (S): 100 mM NaCl, (3) S + KIN1: 100 mM NaCl and 1 mM KIN, (4) S + KIN2: 100 mM NaCl and 2 mM KIN, (5) S + IAA1: 100 mM NaCl and 1 mM IAA, (6) S + IAA2: 100 mM NaCl and 2 mM IAA (7) S + KIN1 and IAA1: 100 mM NaCl and 1 mM KIN plus 1 mM IAA and (8) S + KIN2 + IAA2: 100 mM NaCl, and 2 mM KIN plus 2 mM IAA. Salinity stress was created by adding NaCl to irrigation water. Plants were sprayed with KIN (Sigma) or IAA (Sigma) solution (150 to 500 mL plot^{-1} depending on plant age and growth) mixed with 0.1% Tween-20 ($\text{C}_{58}\text{H}_{114}\text{O}_{26}$ a surfactant and spreading agent) once a week from day

10 after germination up to the maturity stage. The control plants were sprayed with an equal amount of water containing only Tween-20 solution. The solutions of KIN and IAA were prepared by first dissolving them in absolute ethanol, and then adding deionized water to the required volume.

All treatments received the same amounts of total N (200 kg ha^{-1}), P_2O_5 (100 kg ha^{-1}), and K_2O (240 kg ha^{-1}) fertilizers based on soil test results. All of the phosphorus as a triple super-phosphate and potassium as a potassium sulfate were applied prior to sowing and mixed into the soil. The N as urea was added at weekly intervals through the drip irrigation system starting after sowing and continuing until the first week of September. Hand weeding was carried out 3 times during the growing season.

One of 4 rows was used to determine the physiological parameters mentioned below at the beginning of the grain filling stage and the other 3 rows were grown to maturity to determine grain yield.

Grain yield determination

At harvest, 24 plants from 3 rows (8 plants from each row, of each experimental plot) were harvested for determination of grain yield. All maize cobs of harvested plants were removed from the stalks, threshed, and weighed to obtain the grain weight. The grain moisture content at threshing was about 13%.

Leaf relative water content and electrolyte leakage

Leaf relative water content (RWC) was estimated based on the methods of Yamasaki and Dillenburg (1999). The electrolyte leakage (EL) was expressed following Dionisio-Sese and Tobita (1998).

Chlorophyll and proline determination

One plant per replicate was used for chlorophyll and proline determination. A leaf sample was taken from the youngest fully expanded leaf. Chlorophyll concentrations were calculated using the equation proposed by Strain and Svec (1966).

Proline was determined according to the method described by Bates et al. (1973).

Dry Weight determination and nutrient analysis

Shoots of 3 randomly selected plants per replicate were separated and dried in a forced air oven for 2

days at 70 °C to determine dry weights. Chemical analyses were carried out on a dry weight basis. The dried samples were ground to powder using a pestle and mortar and stored in polyethylene bottles. Ground samples were ashed at 550 °C for 6 h. The white ash was taken up in 5 mL of 2 M hot HCl, filtered into a 50 mL volumetric flask, and made up to 50 mL with distilled water. Sodium (Na), Ca, K, and P were determined in these sample solutions and analyzed using an ICP (Chapman and Pratt 1982).

The experiment was performed twice under the same environmental conditions (2 parallel experiments were carried out in the same year). Statistical analysis (ANOVA) indicated that there were no significant differences in measurements between the 2 runs. The data presented here are the averages of the 2 experiments. One-way analysis of variance was performed on all data and the LSD was calculated at $P \leq 0.01$ for comparing mean values.

Results

Saline irrigation water reduced dry matter by 22%, grain yield by 21%, and weight of 1000 seeds by 8% in comparison with control plants (Table 1). However, foliar application of KIN or IAA increased both plant dry matter and grain yield under salinity and only foliar application of KIN increased seed weight. The values for these treatments were still lower than those of the control plants. There are no significant

differences between both KIN and IAA doses in dry matter, grain yield, and relative water content except for IAA₂, which produced significantly higher grain yield compared to IAA₁. Foliar application of KIN and IAA in combination did not increase dry matter, weight of 1000 seeds, or grain yield. Even these treatments decreased these parameters compared to the control plants.

Non-salt-stressed control (C) maize plants showed a relative water content (RWC) below 100%. Leaf RWC declined significantly with salinity stress (S) treatment compared to C treatment (Table 1). Foliar application of KIN or IAA improved RWC in salt-stressed maize plants. However, the combination of KIN and IAA did not alter RWC.

Salinity stress reduced chlorophyll content of the leaves of the maize plants compared to the control plants (Table 2). The foliar application of KIN or IAA to the salinized plants resulted in significant increases in chlorophyll content in maize plants, but the values in these treatments were still lower than those of the control plants (Table 2). There were significant differences between both KIN and IAA doses; 2 mM KIN or IAA produced higher chlorophyll concentrations compared to 1 mM KIN or IAA, but no significant differences were detected between the 2 substances. Foliar applications of KIN and IAA in combination reduced chlorophyll contents of the salt-stressed plants.

Table 1. Shoot dry matter, grain yield, leaf relative water content (RWC), and some yield components in maize plants grown in high salinity and sprayed with or without kinetin or indole acetic acid individually or in combination.

Treatments	Yield cob (g cob ⁻¹)	Grain yield (kg ha ⁻¹)	Weight of 1000 seeds (g)	Shoot DW (g plant ⁻¹)	RWC (%)
C	138 a	9884a	350 a	380a	75.2 a
S	118 c	7850d	324 c	296c	48.2 d
S + KIN 1	122 b	8453 bc	336 b	327 bc	66.7 b
S + KIN2	126 b	8690 b	342 b	342 b	68.9 b
S+I AA1	117 c	8212 c	322 c	308c	63.9 c
S + IAA2	120 bc	8570 b	328 c	317 bc	67.9 b
S + KIN 1 +IAA1	107 d	7304 e	305 d	272 d	46.7 d
S + KIN 2 +IAA2	102 e	7022 f	301 d	256 e	46.9 d

Values followed by different letters in the same column are significantly different at $P \leq 0.01$. C: Control; S: 100 mM NaCl; KIN 1 and KIN 2: 1 and 2 mM Kinetin, respectively; IAA1 and IAA2: 1 and 2 mM IAA, respectively.

Table 2. Chlorophyll a and b (mg kg^{-1} FW), electrolyte leakage (%) and proline (mmol g^{-1} FW) content in maize plants grown in high salinity and sprayed with or without kinetin or indole acetic acid individually or in combination.

Treatments	Chl. a	Chl. b	Electrolyte leakage	Proline
C	1158 a*	985 a	16.54 e	2.07 e
S	956 e	768 e	26.45 b	3.98 a
S + KIN 1	1005 d	805 d	22.47 cd	3.05 c
S + KIN2	1054 c	856 c	21.09 cd	2.97 c
S+I AA1	1003 d	796 d	23.49 c	2.56 d
S + IAA2	1105 b	895 b	20.67 d	2.45 d
S + KIN 1 +IAA1	893 f	743 f	28.65 ab	3.06 c
S + KIN 2 +IAA2	856 g	705 g	30.87 a	3.45 b

Values followed by different letters in the same column are significantly different at $P \leq 0.01$. C: Control; S: 100 mM NaCl; KIN 1 and KIN 2: 1 and 2 mM kinetin, respectively; IAA1 and IAA2: 1 and 2 mM IAA, respectively.

Electrolyte leakage (EL) was determined to assess membrane damage caused by salt stress. In NaCl-stressed plants, EL levels were higher than in the control plants (Table 2). However, the foliar application of KIN or IAA to salinity-stressed plants caused a significant reduction in EL in leaves compared with the NaCl-stressed ones, but the values in these treatments were still much higher than those in the control plants (Table 2). However, foliar application of KIN plus IAA in combination did not maintain membrane permeability of the salt-stressed plants and even in these treatments membrane permeability was further impaired.

Proline content in NaCl-stressed plants was higher

than that in the control plants. However, foliar application of KIN or IAA to salinity-stressed plants reduced the levels of proline (Table 2). Foliar application of KIN and IAA in combination did not alter proline content of the salt-stressed plants.

Salinity significantly increased Na^+ concentration and reduced those of K^+ and Ca^{+2} in the leaves of maize plants. Stressed maize plants accumulated significantly less Na^+ and more K^+ and Ca^{+2} upon application of KIN and IAA (Table 3). Sodium:potassium (Na:K) ratio in the leaves was significantly increased after the exposure of plants to NaCl stress, but foliar application of KIN and IAA to the salinized plants decreased the Na:K ratio.

Table 3. Sodium, potassium, and calcium (g kg^{-1} DW) concentration, and Na:K ratio in the leaves of maize plants grown in high salinity and sprayed with or without kinetin or indole acetic acid individually or in combination.

Treatments	Na	K	Ca	Na:K
C	0.9 e*	15.1 a	7.0ab	0.059 f
S	7.4 a	10.4 e	4.2 d	0.711 a
S + KIN 1	6.9 b	11.6 d	7.1 ab	0.594 b
S + KIN2	5.8 d	11.9 d	7.3 a	0.487 c
S+I AA1	5.6 d	12.6 c	7.4 a	0.444 d
S + IAA2	5.7 d	13.5 b	6.2 c	0.422 de
S + KIN 1 +IAA1	5.9 d	13.8 b	6.7 b	0.427 d
S + KIN 2 +IAA2	6.3 c	15.4 a	7.5 a	0.409 e

Values followed by different letters in the same column are significantly different at $P \leq 0.01$. C: Control; S: 100 mM NaCl; KIN 1 and KIN 2: 1 and 2 mM kinetin, respectively; IAA1 and IAA2: 1 and 2 mM IAA, respectively.

Discussion

Plant growth, grain yield and relative water content

Reductions in dry matter of salt-stressed maize plants are expected in view of some earlier studies that show that salinity stress results in a marked stunting of plants (Hernandez et al. 1995; Cherian et al. 1999; Takemura et al. 2000). Salt stress also results in a considerable decrease in the fresh and dry weights of plants (Ali-Dinar et al. 1999; Chartzoulakis and Klapaki 2000). Turgor pressure reductions in expanding tissues, reductions in the photosystem activity, and direct effects of accumulated salt on critical metabolic steps in dividing and expanding cells are 3 key physiological mechanisms responsible for the growth inhibition induced by salinity (Newman 1997).

Foliar application of KIN or IAA increased plant dry weights. Higher concentrations of KIN and IAA (2 mM) produced higher total dry matter compared to lower concentrations (1 mM). It has been reported for a number of species that salinity stress can reduce cytokinins such as kinetin export from the root to the shoot (Kuiper et al. 1990). However, an adequate shoot kinetin supply is essential for normal growth and development (Schmülling et al. 1997; Brault and Maldiney 1999). Therefore, the exogenous application of kinetin is likely to diminish the effects of salt stress on the growth and grain yield of maize. These results are in agreement with those of some other studies that have shown kinetin-induced salt tolerance in wheat (Iqbal and Ashraf 2005). Similarly, Das et al. (2002) reported that foliar application of KIN increased chlorophyll content and leaf yield of mulberry. There is also a report that an increase in IAA contents promotes the formation of an attraction signal in the leaf growth zone in response to salt stress (Akhiyarova et al. 2005).

Foliar application of KIN and IAA in combination did not improve dry matter of salt-stressed plants, and even values in these treatments were lower than those in the salt treatment. Kinetin and IAA in combination could show an antagonistic effect like some nutrients do with one another and may cause a toxic effect on tested parameters. IAA has a regulatory effect on the salinity tolerance of crop plants. However, little information is available in the literature on the

relationship between salinity tolerance and auxin levels in plants. The variations in indole acetic acid (IAA) content under stress conditions appeared to be similar to those of abscisic acid (Ribaut and Pilet 1991), and increased levels of IAA have been correlated with reduced growth (Ribaut and Pilet 1994). Exogenous application of KIN has been found to overcome the adverse effects of salinity stress on the growth of wheat seedlings (Naqvi et al. 1982) and treatment of potato plants with KIN prior to salt stress partially overcame salt-related growth inhibition (Abdullah and Ahmad 1990). However, earlier studies reported that application of KIN to bean plants grown under salt stress exacerbated the adverse effects of salt (Kirkham et al. 1974).

Garg and Singla (2009) reported that salinity reduced RWC in chickpea plants as reported in the present experiment. A decrease in RWC due to salt stress resulted in a loss of turgor, which caused limited water availability for the cell extension process in sugar beet (Katerji et al. 1997).

Foliar application of KIN and IAA elevated RWC in salt-stressed plants. Similarly, it has been reported that kinetin treatment improved the water status of wheat plants grown in high salinity (Gadallah 1999).

Proline, chlorophyll and electrolyte leakage

Proline, one of the important amino acids, is known to occur widely in higher plants and normally accumulates in large quantities in response to environmental stress (Ashraf 1994; Ali et al. 1999; Öztürk and Demir 2002; Hsu et al. 2003; Kavi Kishore et al. 2005). Most plant species exhibit a remarkable increase in their proline content under salt stress (Delauney and Verma 1993). In the present experiment, a similar increase in the leaves of maize seedlings with respect to proline content was found. Supporting findings come from leguminous plants (alfalfa, soybean, and pea) (Tramontano and Jouve 1997) and sugar beet (Ghoulam et al. 2002), where salt stress resulted in a substantial proline accumulation. Likewise, in tomato salt tolerance has been attributed to the degree of accumulation of osmoprotectants in plants, like proline (Santa-Cruz et al. 1998). In support of our observations, a uniform accumulation of proline has recently been shown to be related to increasing external NaCl concentrations in rice roots exposed to NaCl stress (Khan et al. 2002).

In the present experiment, foliar applications of KIN or IAA in combination or individually reduced proline content in the leaves of maize plants in high salinity. The present results, in general, support the earlier findings of Das et al. (2002) in which reduced proline accumulation was observed in NaCl treated plants by foliar spray of KIN. It is obvious from the present results that foliar application of KIN or IAA onto the salt-treated plants lowered the proline accumulation in salinized plants, indicating the partial relief of the inauspicious conditions. In line with the present results, Singh et al. (1994) stated that application of kinetin to salt-stressed mungbean (*Vigna radiata*) resulted in lower proline accumulation.

Foliar application of KIN or IAA improved the chlorophyll level in salinity-stressed plants, but the combination of KIN and IAA as foliar application decreased it further in these plants.

Membrane permeability (MP) was increased in the leaves of maize plants in the salt treatment compared to the non-stressed plants. The increase in MP observed in the present study under salt stress may have been partly due to the reduced chlorophyll concentration (Kaya et al. 2001), because Dhindsa et al. (1981) and Chen et al. (1991) have linked increased electrolyte leakage to reductions in chlorophyll concentration (due to leaf senescence). Our results support this viewpoint because the increase in chlorophyll concentrations in the maize plants brought about by foliar application of KIN or IAA also minimized electrolyte leakage. Although foliar application of KIN or IAA treatments partly reduced this leakage, the values in these treatments were still much higher than those of control plants (Table 2). Such effects could have been due to the effects of kinetin on cell membrane permeability (Williams and Hester 1983). In the present study, membrane protection by kinetin improved the tolerance of maize plants to salinity. Membrane protection by kinetin can improve the tolerance of maize plants to salinity conditions where the extent of membrane damage is commonly used as a measure of tolerance to various stresses in plants (Gadallah 1995a, 1995b) and adjustment to solute transport capabilities across the membranes is of great significance to salinity adaptation (Niu et al. 1995). The subsequent growth reduction could be attributed to altered endogenous

hormonal levels, as hormonal regulation is involved in membrane permeability and water relations (Ilan 1971). There appears to be no previous report on the effect of IAA on membrane permeability of plants grown at high salinity.

Ion contents

In the present work, salt-stressed maize plants accumulated significantly higher Na^+ and lower K^+ than did the control plants. Higher Na and lower K contents in shoots of carrot under salinity treatment were also reported by Inal et al. (2009). Conversely, foliar application of KIN or IAA to salt-stressed plants caused a reduction in Na^+ concentration and an increase in K^+ concentration when compared to NaCl-stressed plants (Table 3). Modulation of ion fluxes is amongst the earliest cellular events in response to abiotic stresses (Knight and Knight 2001). Salinity tolerance is typically characterized by enhanced exclusion of Na^+ and increased absorption of K^+ to maintain Na^+/K^+ balance in shoots. Due to the impact of K^+ retention by the cell in salinity tolerance, the ameliorating effect of foliar application of KIN or IAA on NaCl-induced K^+ efflux would have significant consequences on the salt tolerance of plants. Where sodium (Na^+) is deleterious for plant growth, K^+ is one of the essential elements and is required by the plant in large quantities. Thus, by decreasing the NaCl induced K^+ efflux, the tolerance of maize to salinized conditions could be improved by the supply of exogenous application of KIN or IAA. This effect is important in salt tolerance where maintenance of high cytoplasmic level of K^+ is essential for survival in saline habitats (Chow et al. 1990). In this study, K^+/Na^+ ratio in the shoots of maize decreased steadily with increasing external salt concentration. He and Cramer (1993) and Gadallah (1996) have also reported similar findings. It is accepted that competition exists between Na^+ and K^+ , leading to a reduced level of internal K^+ at a high external NaCl concentration (Bohra and Dörffling 1993; Botella et al. 1997). The data reported here indicate that this acquired tolerance may be due to mitigation of NaCl-induced K^+ efflux. This is in agreement with the previous findings of He and Cramer (1993) and Gadallah (1996).

For decades, it has been shown that another ion Ca^{2+} has a potential role in providing salt tolerance to

plants. Externally supplied Ca^{2+} reduces the toxic effects of NaCl, presumably by facilitating higher K^+/Na^+ selectivity (Cramer et al. 1987; Lauchli and Schubert 1989; Liu and Zhu 1998). High salinity results in increased cytosolic Ca^{2+} that is transported from the apoplast as well as the intracellular compartments (Knight et al. 1997). This transient increase in cytosolic Ca^{2+} initiates the stress signal transduction, leading to salt adaptation. Sodium-calcium interaction under salinity has been well reviewed in wheat plants (Davenport et al. 1997). It has been reported that sodium ions may compete with calcium ions for membrane-binding sites. Therefore, it has been hypothesized that high calcium levels can protect the cell membrane from the adverse effects of salinity (Bush 1995). Decreases in Ca^{2+} content of leaves have also been reported upon salt accumulation in plants, suggesting enhanced membrane stability and decreased chlorophyll content, respectively (Parida et al. 2004). Foliar application of KIN or IAA increased leaf Ca^{2+} but values remained lower than those of the control plants (Table 3). This could well explain why membrane permeability is impaired in the leaves of salinity-stressed plants where Ca level was lower and foliar application of both KIN and IAA

enhanced Ca levels and restored the membrane integrity in the salt-stressed plants (Tables 2 and 3).

Finally, it can be concluded that foliar application of KIN or IAA increased the ability of maize plants to grow successfully under saline conditions. The effects of KIN and IAA as a foliar application were various with respect to reduction in Na^+ accumulation and increase in membranes stability, some inorganic ions, and K/Na ratio. In view of these results, it is possible to recommend foliar applications of KIN or IAA to attain reasonable grain yield and plant growth of maize under saline conditions. Foliar application of KIN and IAA in combination did not ameliorate the adverse effects of salinity on maize plants. These treatments could be toxic to plants and so further studies are needed to investigate the actual mechanism of this in the future.

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