RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
55 (5) 1654-1665, 2023
http://doi.org/10.54910/sabrao2023.55.5.18
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

UTILIZATION OF GIBBERELLIC ACID (GA3) AND MEPIQUAT CHLORIDE (M.C) AS GROWTH REGULATORS ON MAIZE TO ALLEVIATE SALINITY STRESS

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SUMMARY

Maize (*Zea mays* L.) is a vital grain crop cultivated globally, which ranks third after wheat and rice. Its consumption in Egypt is primarily for human food, livestock and poultry feed, and raw materials for industrial products, such as, oil and starch. The main environmental factors that limit crop productivity worldwide include salinity, drought, and nutrient imbalance. Plant Growth regulators (PGR), such as, gibberellic acid (GA3) and mepiquat chloride (M.C), reduce the dramatic impacts of salinity and drought on crop growth and yield. This experiment sought to verify the influence of foliar spray application of GA3 and M.C as growth regulators on the growth metrics, chemical components, and maize harvest cultivated in calcareous soil under salinity during the summer of 2021 and 2022, respectively. The following treatments comprised foliar applications of 50 ppm GA3, 100 ppm GA3, 100 ppm M.C, and 250 ppm M.C, applied three times every season. It is clear from the results that foliar application of gibberellic (GA3) and mepiquat chloride (M.C) enhanced growth metrics, biochemical parameters, nutritional content, yield and its components, and oil percentage. After treatment with 100 ppm GA3 and 250 ppm M.C foliar spray, the yield and its constituents and oil percentage achieved the highest shares, with substantial differences between the two treatments. Compared with the control, treatments with 100 ppm GA3 and 250 ppm M.C increased grain yield by 33% and 29.9%, respectively. The study concluded that the most effective therapy for improving maize growth, development, and output under salt stress was 100 ppm GA3 and 250 ppm M.C foliar application during the growth stages. Administering GA3 and M.C mitigated successfully the damage caused by salt stress. Under salinity, gibberellic acid and mepiquat chloride addition increased the growth of maize, chlorophyll content, soluble protein, proline, and the concentration of K^+ ions while decreasing the oxidative stress and the accumulation of Na^+ ions.

Keywords: maize, gibberellic acid (GA3), mepiquat chloride (M.C), salinity, biochemical parameters, yield, and oil content

Citation: El-Nwehy SS, Afify RRM (2023). Utilization of gibberellic acid (GA3) and mepiquat chloride (M.C) as growth regulators on maize to alleviate salinity stress. *SABRAO J. Breed. Genet.* 55(5): 1654-1665. http://doi.org/10.54910/sabrao2023.55.5.18.

Key findings: Administration of GA3 and M.C mitigated successfully the damage caused by salt stress. Under salinity stress, gibberellic acid (100 ppm) and mepiquat chloride (250 ppm) addition increased maize growth, chlorophyll content, soluble proteins, proline, and the concentration of K^+ ions while decreasing the oxidative stress and the accumulation of Na^+ ions.

Communicating Editor: Dr. Khundej Suriharn

Manuscript received: June 19, 2023; Accepted: August 11, 2023.

INTRODUCTION

Maize (*Zea mays* L.) is an essential grain crop grown worldwide, with maize ranking third behind wheat and rice in terms of grains for food and forage for both humans and animals in Egypt. Given that it contains carbohydrates, protein, oil, fiber, sugar, and ash, it has a high nutritional value for people and animals alike. It also supplies raw materials for various industrial uses (Jiang *et al.*, 2017). Under field conditions, maize crops are vulnerable to diverse abiotic stresses, i.e., soil salinity, dryness, temperature, and light, which can significantly decrease total production (Bishnu *et al.,* 2021).

Soil salinity is one of the highly critical biotic stressors that restrict the growth of crops and their production. It considerably affects approximately 6% of the world's arable land (Ajay, 2021). Soil salinity adversely affects field crop growth, development, and yield, lowering seed emergence and germination rates (Saade *et al.,* 2016). Beyond that, increasing salt concentration in the soil affected stomata closing, chlorophyll, and the amount of the photosynthesis process (Deinlein *et al.,* 2014).

Plant growth regulators (PGR) have so far named "magic compounds," which have the potential to dramatically improve agricultural output while reducing and avoiding many of the limitations imposed by heredity and environmental challenges (Mazhar *et al*., 2021; Almukhtar, 2022; Atta *et al*., 2022). Applications of plant growth regulators in agriculture include promoting growth, flowering, and stress management (Shagufta *et al.,* 2019).

Gibberellic acid is a growth regulator that has an important effect on plant development and productivity (Sevgi *et al.,* 2021). As it increases the content of pigment and decreases roots and shoot contents of the Na^+ ion, gibberellic acid (GA3) treatment can aid to promote plant growth and development under salt stress (Iqbal and Ashraf, 2013). Gibberellic acid promotes root, shoot, and leaf growth by modifying cell division and elongation processes (Abdel-Hamid, 2014). Applying GA3 to maize resulted in a significant increase in the total chlorophyll content under salinity. With the increased photosynthetic activities, GA3 application boosted wheat dry matter production and plant growth under salt stress (Kashif *et al.,* 2021).

Mepiquat chloride (M.C), classified as a plant growth regulator known as 1,1-dimethylpiperidinum Chloride, methodically operates after plant leaves' absorption when sprayed on a crop. Its function was to limit the gibberellic acid effect, which reduces the longitudinal expansion of some crops, such as, cotton and maize, to increase productivity. Additionally, it has demonstrated efficacy in determinate crops and has increased output (Prakhar *et al.,* 2021). The mepiquat chloride's use worldwide is due to controlling excessive vegetative growth in plants and canopy development. It alters the order of nutrient uptake and translocation, reserve remobilization, and assimilation (De Almeida and Rosolem, 2012).

It slows gibberellic acid formation by inhibiting the conversion of geranyl diphosphate from being converted to ent-kaurene, resulting in decreased cell division and expansion (Raut *et al.,* 2019). With the mepiquat chloride (MC) application, the plant height, the number of nodes on the main stem, leaf expansion, internodal distance, and efficient use of light decreased (Niu *et al.,* 2016). The M.C increases the rate of CO_2 exchange in the leaf, as well as, stomatal conductance, transpiration, chlorophyll content, and fixation of CO_2. It also boosts the assimilation and uptake of nutrients into the reproductive parts by increasing the growth of the lateral roots (Sawan, 2013). Plants treated with M.C absorb more N than untreated plants (Yang *et al.,* 2014). The latest study sought to determine the impact of foliar application of GA3 and M.C as growth regulators on growth metrics, chemical components, and yield of maize cultivated in a calcareous soil under salinity.

MATERIALS AND METHODS

Field experiments ensued at the farm of El-Nubaria Agricultural Research Station, Behaira Governorate, Agriculture Research Center (ARC), Ministry of Agriculture and Land Reclamation (MALR), Egypt. During the summer of 2021 and 2022, foliar application of GA3 and M.C as growth regulators affected the growth metrics, chemical components, and yield of maize cultivated in calcareous soil under salinity. The geographical features of the farm are 30° 90′ N, 29° 96′ E, with an altitude of 25m above sea level. Analysis of soil samples (0–30 cm depth) was according to the method described by Page *et al.* (1982). The soil texture was sandy loam and had the following characteristics: pH-8.3, organic matter-0.67%, $CaCO_3$-32%, EC-4.11 dS/m, K, Ca, Na, Mg, Fe, Mn, Zn, and Cu (380, 360, 360, 162.2, 6.92, 3.52, 1.14, and 2.64 ppm respectively), as an average of two successive seasons.

Experimental design and treatments

The experimental design was a randomized complete block design arrangement with three replications. The total number of experimental plots was 15 plots (the plot was 10.5 m^2). In this field experiment, there were four lines in each parcel of the plantation, and rows were 3.5 m long with 0.75 m row spacing and a plant-to-plant spacing of 0.20 m, and planting depth for seeds was 5–6 cm. The treatments were as follows: control, 50 ppm GA3, 100 ppm GA3, 100 ppm M.C, and 250 ppm M.C of gibberellic (GA3) and mepiquat chloride (M.C) foliar applications. Application of treatments was after 25 days from sowing, two times per season, with a one-month interval during maize growth stages.

The maize cultivar Giza 310 acquisition came from the Maize Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt. The maize cultivar sowing continued on June 1, with harvesting occurring on September 3, in two growing seasons. The N fertilizer application was at the recommended level of 286 kg N/ha as ammonium sulfate (20.5% N), P fertilizer 70 kg P_2O_5/ha as superphosphate (15.5% P_2O_5), and K fertilizer 100 kg K/ha as potassium sulfate (48% K_2O) following the recommendations of the Ministry of Agriculture and Land Reclamation, Egypt. All other farming practices (i.e., fertilizers, irrigation, weeds, disease control, etc.) followed the standard procedures recommended by the Agricultural Research Center for maize crops. The average monthly meteorological data collected during the growing seasons of 2021 and 2022 are available in Table 1.

Soil samples taken during two growing seasons, 2021 and 2022, were in June, July, and August from eight different sites at the experimental site in a randomized manner to determine salinity, as shown in Table 2.

Growth, yield, and yield components

Taking three plant samples from each plot underwent plant height (m), fresh and dry weights of plant (kg), ear weight/plant (g), length of ear/plant (cm), diameter of the ear/plant (cm), and the number of rows/ear measurements as a mean value for two seasons. Removing the grains and cleaning within 1 m^2 at the center of the plot helped determine the grain yield (ton/ha). The grain yield and weight of grains/plant (g) acquired a dry-weight basis recording. The random sampling of replicated samples had 100 grains counted and weighed.

Analysis

Chlorophyll content measurement in fresh leaves used a chlorophyll meter Spad 502 at 9 AM, according to Wood *et al.* (1992), with the results expressed as the chlorophyll index. Leaf-free proline content determination was according to the method described by Bates *et al.* (1973). Nutrient content in leaves and grains had the harvest samples from leaves and grains determined nutrients by Cottenee's method (Cottenee *et al.,* 1982). Carbohydrate % identification in the grain of maize used aqueous solutions according to DuBois *et al.* (1956). The seed oil percentage estimation was according to A.O.A.C. (1990). The oil content calculation was follows:

$$\text{Oil content (\%)} = \frac{(\text{Weight of the flask} - \text{Oil}) - (\text{Weight of empty flask})}{\text{Weight of sample}} \times 100$$

Statistical analysis

Performing statistical analysis helped compare the means of data from the two seasons using the least significant differences ($LSD_{0.05}$) test (Snedecor and Cochran, 1990). After running the statistical analysis separately for the two experimental years, the homogeneity of error determination was according to Hartley's test (Winer *et al*., 1971); it was homogeneous, presenting the data in a combined analysis for the two years.

RESULTS

Effects of weather on the growth of maize

The meteorological data in Table 1 show that weather conditions varied significantly between the two seasons. The average maximum and minimum temperatures ranged from 34.06 °C to 20.08 °C during the experiment. The relative humidity was 48.6%, and the wind speed was 4.43 m/sec from May to September. Having favorable weather conditions and adequate irrigation water caused fewer insect pests and disease incidence, improving crop production throughout the two growing seasons.

Effects of salinity stress on maize

The mean of EC in June and July were 4.93 and 4.40 ds/m, respectively, in the two growing seasons during seed sowing and seedling growth stage (Table 2). These stages of growth are sensitive to salt stress, and high salt concentrations affect maize growth, biochemical processes, nutrient absorption and content, yield attributes, yield, and oil content. These results appear in the data of the control treatment in Tables 3-6. Salt stress decreased the growth of leaves, fresh and dry biomass, and the length of the roots and shoots of maize.

Effects of growth regulators on maize growth and yield traits

Various doses of foliar application of growth regulators (gibberellic acid, GA3; mepiquat chloride, M.C) increased maize growth and yield attributes compared with the control (Table 3). Regarding growth parameters, such as, plant height and fresh weight, the results indicated that the increase was more due to the GA3 foliar application than the M.C foliar application treatment. This effect refers to the mepiquat chloride as a growth regulator, decreasing cell elongation in contrast with GA3, which increases the growth of production parts, biochemical processes, and yield. Among the different foliar treatments of gibberellic acid, foliar application of 100 ppm GA3 resulted in the highest significant values of plant height and fresh weight (2.7 m and 1.77 kg, respectively). Meanwhile, the lowest values emerged in the control affected by salinity (the mean of EC in June and July were 4.93 and 4.40 ds/m, as shown in Table 2).

The yield attributes (length, weight, diameter of the ear per plant, and number of rows per ear) of maize had significant influences from different doses of growth regulators, appearing in Table 3. Higher values of ear weight per plant (298 g), ear length per plant (22.6 cm), ear diameter per plant (6 cm), and number of rows per ear (14) were visible with 100 ppm GA3, which was statistically followed by 250 ppm M.C, 50 ppm GA3, and 100 ppm M.C, respectively. The

Table 1. Average monthly meteorological data of solar radiation, wind speed, temperature, and relative humidity during both growing seasons.

Month	Solar radiation (mJ/m²)	Wind speed (m/sec)	TMAX (°C)	TMIN (°C)	Relative humidity (%)
May	27.66	4.62	31.5	16.59	42.56
June	29.74	4.69	36.56	20.43	41.67
July	29.55	4.35	34.62	21.45	51.84
August	27.42	4.19	34.68	21.28	53.96
September	23.64	4.30	32.96	20.66	52.94
Average	27.602	4.43	34.064	20.082	48.594

Source: Central Laboratory for Agricultural Climate, Agricultural Research Center, Ministry of Agriculture and Land Reclamation, Egypt.

Table 2. The E.C. values (ds/m) in June, July, and August at the different sites for the two growing seasons.

Month	Sits E.C. (ds/m)								Mean E.C. (ds/m)
	1	2	3	4	5	6	7	8	
June	4.76	5.02	5.13	4.96	4.96	5.05	4.67	4.88	4.93
July	4.45	4.49	4.53	4.57	3.90	4.30	4.44	4.50	4.40
August	3.40	3.47	3.32	3.50	3.25	3.53	3.88	4.00	3.54

Table 3. Effect of gibberellic (GA3) and mepiquat chloride (M.C) foliar application on plant growth and yield traits of maize grown in saline calcareous soil.

Treatments	Plant height (m)	Fresh weight of plant (kg)	Dry weight of plant (kg)	Weight of ear/plant (g)	Length of ear/plant (cm)	Diameter of ear/plant (cm)	No. Of rows/ear
Control	2.10 B	0.71 E	0.186 E	219 E	18.3 C	4.6 C	11.3 D
50 ppm GA3	2.30 B	1.05 C	0.287 C	262 C	20.3 B	5.3 B	13.0 B
100 ppm GA3	2.70 A	1.77 A	0.371 A	298 A	22.6 A	6.0 A	14.0 A
100 ppm M.C	2.30 B	0.97 D	0.265 D	254 D	19.6 BC	5.0 BC	12.0 C
250 ppm M.C	2.58 A	1.12 B	0.322 B	287 B	21.0 B	5.6 AB	13.6 AB

Combined analysis of two successive seasons.

Table 4. Effect of gibberellic (GA3) and mepiquat chloride (M.C) foliar application on biochemical parameters, yield, and its components of maize grown in saline calcareous soil.

Treatments	Chlorophyll index	Proline µg/g	Protein %	Carbohydrates %	Weight of 100 grains (g)	Yield	
						Grain (t/ha)	Oil %
Control	35.9 E	21.86 E	5.063 B	58.79 D	32 C	9.65 E	3.05 E
50 ppm GA3	40.4 C	53.60 C	5.625 A	87.83 BC	39 B	11.59 C	4.20 C
100 ppm GA3	49.5 A	122.74 A	5.813 A	88.44 A	45 A	12.86 A	6.72 A
100 ppm M.C	38.8 D	37.83 D	5.563 A	87.36 C	34 C	11.06 D	3.80 D
250 ppm M.C	44.0 B	100.03 B	5.688 A	87.98 AB	42 AB	12.53 B	4.52 B

Combined analysis of two successive seasons.

Table 5. Effect of gibberellic (GA3) and mepiquat chloride (M.C) foliar application on leaf nutrients content of maize grown in saline calcareous soil.

Treatments	N	K	Ca	Na	Mg	K/Na	Fe	Mn	Zn	Cu
	%						ppm			
Control	1.4 D	1.7 D	0.50 C	2.5 A	0.30 4E	0.68	110 D	31 C	22 D	21 D
50 ppm GA3	1.8 B	1.9 BC	0.55 BC	2.3 AB	0.338 C	0.83	131 B	39 B	27 C	27 BC
100 ppm GA3	2.1 A	2.2 A	0.63 A	2.1 B	0.374 A	1.05	136 A	44 A	39 A	32 A
100 ppm M.C	1.6 C	1.8 CD	0.51 C	2.4 AB	0.324 D	0.75	124 C	37 B	25 CD	23 CD
250 ppm M.C	2.0 A	2.0 B	0.59 AB	2.2 AB	0.357 B	0.91	134 AB	40 AB	33 B	28 AB

Combined analysis of two successive seasons.

Table 6. Effect of gibberellic (GA3) and mepiquat chloride (M.C) foliar application on nutrient content in grains of maize grown in saline calcareous soil.

Treatments	N	K	Ca	Na	Mg	K/Na	Fe	Zn	Cu
	%						ppm		
Control	0.81 B	0.25 D	0.13 B	0.38 A	0.037 D	0.66	40 C	39 C	56 D
50 ppm GA3	0.90 A	0.29 C	0.15 AB	0.33 AB	0.043 BC	0.88	46 ABC	51 B	63 BC
100 ppm GA3	0.93 A	0.35 A	0.17 A	0.29 B	0.052 A	1.21	53 A	59 A	68 A
100 ppm M.C	0.89 A	0.28 C	0.14 AB	0.35 AB	0.042 C	0.80	42 BC	49 B	60 CD
250 ppm M.C	0.91 A	0.31 B	0.16 AB	0.31 B	0.047 B	1.00	48 AB	58 A	66 AB

Combined analysis of two successive seasons.

relative increases in ear weight per plant, ear length per plant, ear diameter per plant, and number of rows per ear were 36%, 23.5%, 30%, and 24%, respectively, compared with the control.

Effects of growth regulators on biochemical parameters

The results in Table 4 show the effect of salinity on biochemical parameters, such as, chlorophyll, proline, protein, and carbohydrates, in the control treatments versus the foliar application of different growth regulators. Applying different doses of GA3 and M.C as growth regulators helped enhance all biochemical parameters. The highest values of biochemical parameters emerged with foliar application of 100 GA3 and 250 ppm M.C. The values of chlorophyll was 49.5 and 44, proline was 122.74 and 100.03 μg/g, and carbohydrates were 88.44% and 87.98%, respectively.

Effects of growth regulators on grain yield and oil content

Foliar aapplication of different doses of growth regulators, GA3 and M.C, caused an increase in maize grain yield and oil content, as shown in Table 4. The crop yield depends on the accumulation of photo-assimilates (which increased due to GA3 and M.C foliar application) throughout the growing stage and how their sharing among the plant's desired storage organs surfaced. Among the different doses of GA3 and M.C, the highest significant grain yield (12.86 and 12.53 t/ha) and oil percent (6.72% and 4.52%) were evident under 100 ppm GA3 and 250 ppm M.C treatments, respectively, followed by 50 ppm GA3 and 100 ppm M.C treatments. The highest relative increases over control were (33% and 29.9%) in grain yield and (120% and 48%) in oil percent, respectively.

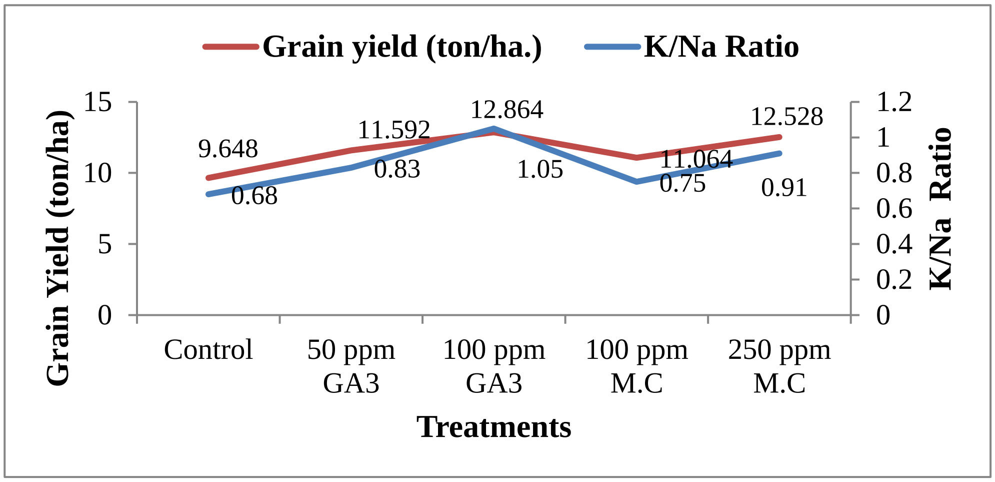

Figure 1. Effect of gibberellic (GA3) and mepiquat chloride (M.C) foliar application on K/Na ratio and grain yield of maize grown in saline calcareous soil.

Effects of growth regulators on nutrient content

Leaf nutrient contents

As illustrated in Table 5, foliar application of different doses of growth regulators considerably impacted the macro- and micronutrients in maize plant leaves. The maximum increase in N% appeared with the foliar 100 ppm GA3 and 250 ppm M.C treatments. The treatment applications provided greatest values for Mg, K/Na, K, Ca, and Zn. Relative to the control, there are significant distinctions between the two treatments. The same treatments revealed that the leaves of maize plants had the lowest Na concentration, reflected in the highest K/Na ratio (1.05 and 0.91), respectively (Figure 1). Meantime, Fe, Mn, and Cu had the highest increase with 100 ppm GA3 and 250 ppm M.C treatments. There were no significant differences between the two treatments compared with the control.

Grains nutrient content

Foliar application of GA3 and M.C significantly affected nutrients in maize grains (Table 6). The findings for grain N content showed the highest increase with foliar 100 ppm GA3 and 250 ppm M.C treatments without substantial differences between the two treatments. Potassium (K) and Mg content showed the utmost significant increase with foliar treatments of 100 ppm GA3 and 250 ppm M.C, respectively, showing notable discrepancies between the two treatments. The same treatments had the lowest Na content in the maize grains, reflected in the maximum K/Na ratio (1.21 and 1.00). Likewise, Ca, Fe, Zn, and Cu had the highest increase with 100 ppm GA3 and 250 ppm M.C treatments, respectively, with no significant differences between the two treatments compared with the control.

Rank correlation coefficients

The data in Table 7 show that the N% in leaves, proline, chlorophyll, grain yield, and oil% of maize revealed a maximum and positive association with the other characteristics and yield components investigated. The correlation coefficients (r) between grain yield and all examined traits were positive and significant ($P < 0.05$). A favorable and substantial ($P < 0.05$) association between grain yield and nutrient content was also evident. Furthermore, a promising and sizable (P 0.05) association appeared between grain yield and nitrogen,

Table 7. Rank correlation coefficient between N %, Na %, Chlorophyll, Proline, Grain yield (t/ha), and Oil % with other studied traits for maize (Combined analysis of two successive summer, 2021 and 2022).

Studied Traits	N% leaves	Na% leaves	ChlorophyII index	Proline (µg/g)	Grain Yield (t/ha)	Oil%
Na (%) leaves	-0.852					
ChlorophyII index	0.917	-0.799				
Proline (µg/g)	0.936	-0.807	0.979			
Grain Yield (t/ha)	0.955	-0.802	0.930	0.942		
Oil (%)	0.847	-0.781	0.973	0.910	0.855	
K (%) leaves	0.960	-0.813	0.947	0.926	0.892	0.922
Ca (%) leaves	0.917	-0.773	0.930	0.940	0.884	0.894
Mg (%) leaves	0.959	-0.820	0.977	0.979	0.981	0.923
Fe (ppm) leaves	0.939	-0.749	0.841	0.842	0.962	0.767
Mn (ppm) leaves	0.888	-0.644	0.910	0.871	0.942	0.873
Zn (ppm) leaves	0.881	-0.742	0.979	0.974	0.914	0.931
Cu (ppm) leaves	0.933	-0.720	0.924	0.906	0.902	0.879
N (%) grains	0.872	-0.792	0.798	0.773	0.908	0.768
Na (%) grains	-0.943	0.800	-0.830	-0.835	-0.859	-0.781
K (%) grains	0.904	-0.813	0.922	0.891	0.876	0.917
Ca (%) grains	0.682	-0.636	0.812	0.809	0.808	0.777
Mg(%) grains	0.882	-0.724	0.957	0.938	0.931	0.931
Fe (ppm) grains	0.898	-0.675	0.913	0.894	0.868	0.877
Zn (ppm) grains	0.938	-0.789	0.892	0.912	0.980	0.817
Cu (ppm) grains	0.851	-0.600	0.897	0.903	0.936	0.818
Protein (%) grains	0.872	-0.792	0.798	0.773	0.908	0.768
Plant height (m)	0.786	-0.592	0.831	0.833	0.816	0.779
Fresh weight (kg)	0.838	-0.745	0.967	0.896	0.850	0.994
Dry weight (kg)	0.944	-0.804	0.959	0.940	0.987	0.915
Diameter of ear (cm)	0.874	-0.712	0.920	0.911	0.917	0.858
100 grain Wt. (gm)	0.887	-0.688	0.936	0.945	0.934	0.870
Carbohydrates (%)	0.735	-0.600	0.642	0.617	0.841	0.592

proline, and chlorophyll (0.955, 0.942, and 0.993, respectively). In contrast, substantial negative associations occurred between Na% and nitrogen, proline, chlorophyll, K, grain yield, and oil%. The remaining characters correlated positively with each other, indicating that agronomists should consider these factors when choosing growth regulator therapies to increase maize plant output.

DISCUSSION

Having favorable weather conditions (Table 1) and adequate irrigation water caused lesser insect pests and disease incidence, improving crop production throughout the two growing seasons. It confirms that no other external factors (temperature, humidity, and diseases) affected the plants and that the effect is only due to the factors under study.

The application of GA3 and M.C increased the resistance of maize plants to salinity stress. The contemporary investigation showed that salinity stress considerably inhibited maize growth and biomass accumulation, especially during the early growth stages (Table 2). Such salinity levels increased during June, rose to 4.93 ds/m, affected the early growth stage, and decreased to 3.54 ds/m during August compared with the treated plants with growth regulators (GA3 and M.C), as shown in Tables 3-6. Compared with the control, salt stress in maize decreased the growth of leaves, dry and fresh biomass, and root and shoot lengths (Hoque *et al.,* 2015). The higher concentration of Na^+ ions in roots and out of plant cells could cause decreases in plant biomass (Kumar *et al.,* 2020). Higher salt concentrations in the soil impair the ability of the plant roots to absorb water and nutrients. Additionally, a higher concentration of root Na^+ ions may cause osmotic stress, reduce water potential, and upset the plant's nutritional balance. The K^+ influx in the cell, a crucial component necessary for plant growth, has adverse effects from greater Na^+ concentrations inside and outside the plant cell (Singh *et al.,* 2015).

Table 3 indicates the growth of the productive sections of the maize crop under salinity stress greatly improved in the presented study with the application of GA3 and M.C foliar spray,. Results show that the highest considerable improvement in growth metrics, such as, weight of ear/plant (g) was notable with GA3 100 ppm (298 g), followed by M.C 250 ppm (287 g). Several researchers have previously reported the favorable effects of GA3 and M.C foliar sprays in various field crops; an exogenous GA3 and M.C supply may boost endogenous accumulation, allowing plants to develop more efficiently (Iftikhar *et al.,* 2019). As GA3 is regarded as a key hormone in cell division, the improved growth and plant height of GA3-treated maize in the relevant study (Table 3) could be attributable to increased cell and stem elongation (Kashif *et al.,* 2021).

As shown in Table 4, salinity stress dramatically reduced leaf chlorophyll content in this study, as evident in the control treatment (35.9) compared with plants treated with plant growth regulators, especially GA3 100 ppm (49.5) and M.C 250 ppm (44). Chlorophyll is the primary pigment in plant photosynthesis and participates in several physiological processes (Gu *et al.,* 2016). Several previous studies have similarly found that salt stress reduces the activity of photosynthetic pigments (El-Esawi *et al.,* 2018). The formation of proteolytic enzymes at high salt concentrations may be responsible for the decrease in chlorophyll content, which is, in turn, liable for chlorophyll degradation and photosynthesis reduction under salt conditions. The use of GA3 and M.C improved the chlorophyll concentration of salt-stressed maize leaves, with the highest increase occurring when using 100 ppm GA3 and 250 ppm M.C. Higher chlorophyll accumulation in GA3 and M.C treated maize under salt stress may be due to decreased Na^+ accumulation, lower oxidative damage, and an improved antioxidant defense mechanism. These findings are consistent with prior research reporting that the application of GA3 boosted leaf chlorophyll concentration (Zang *et al.,* 2016).

In this study, foliar application of GA3 and M.C lowered Na^+ levels in maize tissue, as shown in Table 5. GA3 100 ppm reduced Na concentration in leaves to 2.1%, and M.C 250 ppm decreased it to 2.2% compared with the control (2.5%), implying that PGR treatments may limit Na^+ translocation from roots to shoots. Fewer Na^+ accumulation in maize tissue may have fewer negative impacts on the functions of the leaf, which may have affected pigments in the research. Table 7 shows substantial negative correlations (r) between Na% and nitrogen, proline, chlorophyll, K, grain yield, and oil%. Applying GA3 and M.C reduced Na^+ content in maize grains and leaves. Furthermore, PGR treatment caused a considerable increase in Ca^{2+}, K^+, and K/Na ratios in several maize sections under salinity stress (Figure 1, Tables 5 and 6). Plant survival under salt stress depended on limiting the concentration of Na^+ while maintaining or increasing the concentrations of Ca^{2+} and K^+. Higher Ca^{2+} concentrations assist plants in sustaining growth in saline soils (Gupta and Huang, 2014). Several studies have demonstrated that using GA3 and M.C under salt stress dramatically reduces Na^+ ions while increasing Ca^{2+} and K^+ ions (Riboldi *et al.,* 2018).

Applying GA3 and M.C as PGR markedly boosted total soluble protein and proline under salt stress in this experiment (Table 4). Proline content increased significantly with foliar application of PGR, especially with GA3 100 ppm and M.C 250 ppm, which helped produce 122.74 and 100.03 μg/g proline, respectively, compared with the control (21.86 μg/g). These findings are consistent with previous research that found that PGR enhanced maize protein and proline contents. The availability of GA3 and M.C is critical for protein production because they increase N absorption from the soil (Saeidi-Sar *et al.,* 2013). Organic solute accumulation, such as, soluble proteins and proline, may aid in plants' osmotic correction and membrane stabilization. Organic solutes are widely known for improving plant tolerance to many stressors, including salt, through sustaining membrane integrity and pressure potential, safeguarding proteins, and scavenging free radicals (Saeidi-Sar *et al.,* 2013; El-Nwehy *et al.,* 2022).

GA3 and M.C application considerably enhanced the number of ears/plant, ear length, number of grains/ear, ear diameter, grain yield, and oil percentage, which are the maize's most vital yield-determining components in the pertinent study (Table 4). Plant growth regulators additionally augment the utilization of reserve food supplies to the growing sink by promoting the activity of hydrolyzing and oxidizing enzymes (Ghodrat *et al.,* 2012). According to Tung *et al.* (2018), the M.C treatment maintained a balance between vegetative and reproductive growth since any alteration to the physiological or metabolic route could affect photo-assimilate translocation and partitioning.

The correlation data (r) in Table 7 shows that there is a positive and significant (P 0.05) association between grain yield and nitrogen, proline, and chlorophyll (0.955, 0.942, and 0.993, respectively). In contrast, there were substantial negative associations between Na% and nitrogen, proline, chlorophyll, K, grain yield, and oil%. The remaining traits correlated positively, indicating that agronomists should regard these factors when choosing growth regulator therapies to increase maize plant output.

Finally, the most effective therapy for improving maize growth, development, and yield under salt stress was the 100 ppm GA3 and 250 ppm M.C foliar applications during the growth stage. Future studies should investigate other growth regulators and antioxidant materials that can minimize the consequences of stress and oxidative damage.

CONCLUSIONS

The administration of GA3 and M.C can successfully mitigate the damage caused by salt stress. Under salinity, adding gibberellic acid or mepiquat chloride increased the growth of maize, soluble protein, chlorophyll, proline, and concentration of K^+ ions while decreasing Na^+ ion buildup and oxidative stress. The most effective therapy for improving maize growth, development, and yield under salt stress was the foliar application of 100 ppm GA3 and 250 ppm M.C during the growth stage. In salt-affected soil, improvements in the K/Na ratio, osmolyte accumulation (proline), antioxidant defense, maintenance of photosynthetic pigments, and ionic homeostasis emerged, promoting superior stress tolerance and maize growth in this treatment. Future studies should check other growth regulators and antioxidant materials that can significantly reduce the consequences of stress and oxidative damage.

ACKNOWLEDGMENTS

As part of the Egypt-German Project "Micronutrients and Other Plant Nutrition Problems" (coordinator, Prof. Dr. M. M. El-Fouly), the National Research Centre (NRC), Fertilization Technology Department, and Plant Nutrition Department conducted this study.

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