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Research Article

Mitigating Salinity Stress in *Zea mays* L. through Combined Foliar Applications of Amino Acids and Marine Algal Extracts

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ABSTRACT

The present study assessed the effects of foliar-applied amino acids and seaweed extracts, along with spray frequency, on maize growth and yield to evaluate their potential in enhancing productivity under field conditions. The results revealed that foliar nutrient treatments significantly improved plant height, leaf area, chlorophyll content, and dry matter accumulation. Among the treatments, seaweed extract + amino acids at 100%, consistently produced the highest values, with increases of 11.97% in plant height, 16.36% in leaf area, 27.01% in chlorophyll content, and 29.90% in dry weight compared to the control. Yield components were also markedly enhanced, as this treatment increased ear length by 61.44%, grains per ear by 47.03%, and 100-grain weight by 20.96%. Consequently, grain yield reached 6.04 t ha⁻¹, representing a 70.04% increase over the control (3.56 t ha⁻¹). Spray frequency significantly influenced most parameters, with two sprays (S2) outperforming a single spray (S1). S2 increased plant height, chlorophyll content, grains per ear, 100-grain weight, and grain yield by 5.90%, 6.70%, 12.29%, 5.47%, and 5.47%, respectively. Although most interaction effects were statistically non-significant, combinations such as T5 × S2 showed the highest numerical improvements across traits. The observed enhancements can be attributed to improved nutrient availability, hormonal regulation, and increased photosynthetic efficiency resulting from amino acids and seaweed extracts. In conclusion, foliar application of combined amino acids and seaweed extracts, particularly at higher concentrations and with repeated spraying, is an effective strategy to improve maize growth and yield.

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Introduction

Meeting farmers' needs under current conditions characterized by harsh environmental stresses and water scarcity has become a major challenge for the future of agriculture in Iraq, particularly in the production of major economic crops that play a key role in maintaining regional food security. Among these crops, yellow corn is one of the most important. Iraq produces approximately 5

million tons annually from both spring and autumn seasons (Ministry of Planning, 2024). However, national yellow corn production in underutilized lands remains a target for horizontal and vertical agricultural expansion through improving productivity and crop development. Environmental stress conditions can be listed among the most significant factors which impact the distribution and growth of yellow corn because they affect

physiological and biological processes like photosynthesis, respiration, nutrient and water absorption. One of the most serious abiotic stresses to crops in most countries, including Iraq is salinity. Yellow corn is considered to be moderately saline tolerant, although, higher salinity in the soil causes reduction in yield and productivity. To reduce this kind of stress, there is a growing necessity of adopting the agricultural practices and technologies, such as using the foliar nutrients, such as amino acids and seaweed extracts. These are some of the main inputs that contribute to productivity growth and quality of crops (Yakhin et al., 2017; Abdullahi et al., 2021). Amino acids are very significant in a variety of biological activities since they are fundamental constituents of proteins. Their significance is observed in all plants growth phases, as they increase the capacity of cells to absorb water and soil nutrients, the vegetative growth, osmotic pressure regulation, antioxidant activity activation, and cell membrane stability. All of these effects mitigate the effect of abiotic stress (Pasala et al., 2022; Sun et al., 2024), which is in line with the results of Chfat et al. (2023). Instead, extracts of seaweeds contain essential and various nutrients, and plant growth regulators, minerals, and other compounds with beneficial impacts on plant life. They increase the tolerance in plants by increasing the metabolic pathways that are involved in the production of antioxidant molecules in plant cells, which result in stress resistance. This is manifested by enhanced growth, quality, and yield (Pei et al., 2024) concurring with the results of Hassan et al. (2025). Thus, the purpose of this research was to identify the most suitable ratio of amino acids and seaweed extracts and assess the influence of the frequency of spraying on the growth and productivity of yellow corn in saline soils.

Materials and Methods

To study the effects of foliar application of amino acids and seaweed extracts and the frequency of spray on the growth and productivity of yellow corn under salinity soil condition, a field trial was conducted in the experimental fields of the Department of Field Crops, College of Agriculture, University of Diyala in the fall of 2024.

A split-plot, two factorial, randomized complete block design (RCBD) with three replicas was used for the study. The factors used in the experiment were:

First factor (main plots) was the spraying frequency.

S1 = Spraying once and S2 = Spraying twice

Second factor (subplots) was the foliar treatments (five levels) as follow:

T1 = Control (spraying using distilled water only),

T2 = Spray of seaweed extract @ 2 g/L,

T3 = Spraying amino acids @ 2 g/L,

T4 = 50% spraying of seaweed extract + amino acids,

T5 = Spraying seaweed extract + amino acids at 100%

Agricultural practices

The experimental field was prepared following all the standard practices such as plowing, leveling and soil preparation as per the recommended guidelines of the Ministry of Agriculture (2011).

The soil of the experimental unit was analyzed prior to the start of the trial for various chemical and physical properties and is given in Table 1.

Table 1. Physical and chemical properties of the soil used in the experiment for the 2025 growing season.

Characteristic	Description
Sand	26.1%
Clay	43.5%
Silt	30.4%
Soil reaction(PH)	7.2
Electrical conductivity (EC)	8.2 ds m-1
Available nitrogen	7 Mg.kg ⁻¹
Availablephosphorus	14.3
Available potassium	90
Calcium carbonate	167.9 g.kg ⁻¹
Organic matter	5.9
Soil texture class	Clay loam

Experimental operations and measurements

The experiment was carried out by directly planting yellow corn in rows with spacing of 25 cm between hills and 75 cm between rows on July 29, 2024. Irrigation and fertilization were applied to the experimental units as per the recommendations of the Ministry of Agriculture (2011). Weeds from the experimental units were removed manually, when required (at ETL). Harvesting was done when plants attained full maturity.

Parameters studied

Following vegetative growth and yield characteristics were observed after the termination of the experiment:

Plant height (cm)

Plant height was determined as the minimum height of the stem to the lowest node of the tassel of five randomly selected plants per unit of the experiment.

Leaf area (cm²)

Five plants were used to calculate the area of the leaf below the main ear by the following equation outlined by El-Sahookie and Wassom (1985):

Leaf area per plant = (length of the leaf below the main ear)² × 0.75

Chlorophyll content (SPAD)

In order to determine chlorophyll content, 5 randomly selected plants from each unit of the experiment at tasseling stage were measured with the help of a SPAD meter.

Dry plant weight per plant (g plant⁻¹)

For determination of dry weight of plants, 5 plants were randomly harvested, cut into small fragments and dried under laboratory conditions, by continuously turning the samples until they reached a constant weight.

Ear length (cm plant⁻¹)

Ear length of five randomly selected plants in each experimental unit was recorded at harvest.

Number of grains per ear (grain ear⁻¹)

To determine the number of grains per ear, the number of rows per ear and grains per row of the samples of five randomly harvested plants per experimental unit were counted.

100-grain weight (g)

Each sample of a five randomly harvested plants per experimental unit was used to determine the weight of 100 grains.

Total grain production (ton ha⁻¹)

The average grain weight per plant (five sampled plants/experimental unit) was used to determine total grain yield by multiplying by total number of plants.

Statistical analysis

All the data were subjected to statistical analysis using the Genstat software following randomized complete block design with a split-plot arrangement. Comparisons of means were performed by using the Least Significant Difference (LSD) test at 0.05% of probability level.

Results and Discussion**Plant height**

Table 2 shows that there were significant differences in the average foliar plant height among foliar nutrient treatments and frequency of foliar spraying. The results revealed that the use of nutrients as foliar fertilizer increased plant height. T3, T4 and T5 showed considerable improvements over control treatment (T1), showing 3.99%, 7.75% and 11.97% enhancements

respectively, clearly outperforming T1 which was not significantly different from T2. The use of amino acids led to a significant change in vegetative growth characteristics such as plant height. This can be attributed to the fact that they help in the regulation of osmotic pressure and osmosis that helps in increasing the capacity of the plant cells to absorb water in the growth medium.

This in turn enhances the growth of plants, cell elongation, stomatal opening and closing, and photosynthesis. The amino acids also provide a source of nitrogen required to synthesize protein and hence provide more energy to the plant (Slabbert and Krueger, 2014). These findings are in line with those of Ahmed et al. (2025) and Chfat and Oleiwi (2023), who found an enhancement of plant height in yellow corn after the application amino acids.

This might also be due to the synergistic effect of amino acids and seaweed extracts which contain high amounts of essential nutrients especially nitrogen. Nitrogen serves as a key element in forming chlorophyll and making photosynthesis more efficient by increasing leaf area, and subsequently producing more carbohydrates and proteins. Also, seaweed extracts have plant growth regulators that affect cell division and elongation, resulting in increased internode growth and, subsequently, greater plant height (Hassanin, 2020). These results are congruent with those reported by Al-Yasari and Al-Ghazal et al. (2023), Fatima (2024), and Hassan et al. (2025), who observed an increase in the height of maize plants after the application of seaweed extracts.

As far as spraying frequency is concerned, two sprays (S2) gave the highest average plant height of 158.00 cm while the single spray (S1) gave plant height of 149.20 cm showing an increase of 5.90%. This increase in plant height might be ascribed to an improved metabolism in the plant as a result of the frequent supply of nutrients resulting in high growth rates and plant height.

Similarly, the interaction between foliar nutrient treatments and spraying frequency did not have significant effect on the height of the plants. Nonetheless, the combination T5 × S2 had the maximum mean plant height of 169.00 cm while the lowest mean plant height of 143.33 cm was recorded in T1 × S1, resulting in an increase of 17.91%. These results also show that plant heights were increased with the combination of T3, T4, and T5 under S2 by 5.37%, 8.72%, and 13.42% respectively as compared to T1 under S2.

Table 2. Effect of foliar nutrient spraying, spraying frequency, and their interaction on average plant height (cm) of *Z. mays*.

Foliar nutrients	Repeat spraying		Average
	S1	S2	
T1 = Distilled water only	143.33	149.00	146.17
T2 = Spray of seaweed at a concentration of 2g/L	144.33	153.00	148.67
T3 = Spray of amino acids at a concentration of 2 g/L	147.00	157.00	152.00
T4 = Spray of seaweed + 50% amino acids	153.00	162.00	157.50
T5 = Spray of seaweed + 100% amino acids	158.33	169.00	163.67
Average	149.20	158.00	-

LSD (0.05) for foliar treatments = 3.30; LSD (0.05) for spray frequency = 2.09; Interaction effect = non-significant (NS).

Leaf area (cm²)

The results presented in Table 3 revealed that there were significant differences in the average leaf area values due to spraying of foliar nutrients. Treatment T5 (seaweed extract + amino acids at 100%) gave the maximum mean leaf area of 5971 cm² showing an increase of 16.36% relative to the control treatment T1 (distilled water alone) which resulted in the minimum mean leaf area of 5131 cm². This might be due to the availability of key nutrients in the extracts of seaweeds, especially zinc, which is important in the synthesis of the amino acid tryptophan, a precursor for the synthesis of auxin (indole-3-acetic acid), which is a major phytohormone responsible for cell division and expansion. This results in increased vegetative growth and leaf area. Moreover, copper and boron found in the seaweed extracts are also important in the electron

transport and sugar translocation which promotes photosynthesis and other growth processes, eventually leading to increased plant growth.

Furthermore, foliar spraying at various growth stages impacts a lot on increasing the leaf area by interfering with the leaf length and width, particularly in the early growth stages (4, 8 and 12 leaves). This enhances the rate of overall plant growth and retards leaf senescence, thus, enhancing photosynthesis and leaf area (Choulot et al., 2022; Raja and Vidya, 2023). These results agree with those of Chfat and Oleiwi (2023), who found a rise in leaf area after amino acid application. The findings also revealed that the foliar nutrient treatments and spraying frequency had a substantial interaction on the leaf area. The combination of T5 × S2 showed the highest mean value of 6000 cm²). On the other hand, the combination of T1 × S1 gave the lowest mean value of 5096 cm².

Table 3. Effect of foliar nutrient spraying, spraying frequency, and their interaction on mean leaf area (cm²) of *Z. mays*.

Foliar nutrients	Repeat spraying		Average
	S1	S2	
T1 = Distilled water only	5167	5096	5131
T2 = Spray of seaweed at a concentration of 2g/L	5234	5181	5208
T3 = Spray of amino acids at a concentration of 2 g/L	5274	5602	5438
T4 = Spray of seaweed + 50% amino acids	5814	5905	5859
T5 = Spray of seaweed + 100% amino acids	5942	6000	5971
Average	5486	5557	

LSD (0.05) for foliar treatments = 45.6; LSD (0.05) for spray frequency = 72.1; LSD (0.05) for interaction between foliar treatments and spray frequency = 102.0.

Chlorophyll content (SPAD)

The application of foliar nutrients and spraying frequency significantly affected mean chlorophyll contents in the leaves of yellow corn as shown by the results presented in

Table 4. Chlorophyll contents were significantly increased by the application of foliar contents, with T5, T4 and T3 outperformed significantly T1 (control treatment) resulting in 27.01%, 14.97%, and 9.49% increases

respectively. On the other hand, there was no significant difference between T1 and T2.

Amino acids promote growth in crops in a number of ways. They boost the metabolic rate of the plant, increase chlorophyll level, enhance the uptake of light energy and promote the production of carbohydrates and proteins. They are also important in the process of translocation of nitrogen between roots, leaves, and reproductive organs and are precursors in the synthesis of chlorophyll biosynthesis. Moreover, amino acids promote cellular osmotic balance, antioxidant activity, and preserve cell membrane integrity (Ramaih et al., 2003). These results are aligned with those of Ahmed et al. (2025), Chfat and Oleiwi (2023) and Shahid et al. (2023) who observed a higher chlorophyll content in yellow corn with the application of amino acids. This better performance of treatments with seaweed extract might be due to the abundance of essential nutrients and plant growth regulators, the levels of which rise with the concentration of the extract. Nitrogen is a basic component of chlorophyll and takes part in the formation of the porphyrin ring structure. Photosynthetic components are linked to approximately 70% of leaf nitrogen that

promotes an increase in leaf greenness, meristematic activity, and cell division. This is attributed to the effective use of photosynthates, which is translocated to the growing tissues, and transformed into nucleic acids and proteins, thus stimulating vegetative growth (Taiz and Zeiger, 2006). In addition, the presence of plant hormones, especially cytokinins, in seaweed extracts is important in slowing down the senescence process in leaves by decreasing degradation of chlorophyll, proteins and RNA. Moreover, other compounds, like betaines, are used to stabilize chlorophyll and inhibit its degradation, which raises its total content (Layek et al., 2016). These findings agree with the results of Omar et al. (2014) who also reported the increased chlorophyll content in yellow corn after the application of seaweed extract. The chlorophyll content was also influenced greatly by the frequency of spraying. The greatest mean value (52.07 SPAD) was obtained when there were two sprays (S2), and the lowest mean value was obtained (48.80 SPAD) when there was one spray (S1). The experiment however, did not indicate any statistical significance between foliar nutrient treatments and frequency of spraying in relation to chlorophyll content.

Table 4. Effect of foliar nutrient spraying, spraying frequency, and their interaction on chlorophyll content (SPAD) in *Z. mays*.

Foliar nutrients	Repeat spraying		Average
	S1	S2	
T1 = Distilled water only	5167	5096	5131
T2 = Spray of seaweed at a concentration of 2g/L	5234	5181	5208
T3 = Spray of amino acids at a concentration of 2 g/L	5274	5602	5438
T4 = Spray of seaweed + 50% amino acids	5814	5905	5859
T5 = Spray of seaweed + 100% amino acids	5942	6000	5971
Average	5486	5557	

LSD (0.05) for foliar treatments = 2.58, LSD (0.05) for spray frequency = 1.63, and LSD (0.05) for interaction = not significant (NS).

Dry plant weight per plant (g plant⁻¹)

The data in Table 5 showed that the application of foliar nutrients, the frequency of spraying, and their interaction greatly influenced the plant dry plant weight. T5, T4, and T3 treatments showed a great increase in dry weight as compared to the control treatment resulting in 29.90%, 17.47%, and 8.07% increases respectively. T5 (seaweed extract + amino acids at 100%), had the highest mean dry weight of 292.50 g per plant and T2 (seaweed extract @ 2 g L⁻¹), had the lowest mean value

of 219.67 g per plant and was not significantly different from the control.

The increase in the dry matter weight has been observed to be due to an improvement in the vegetative growth parameters, such as the height of the plants (Table 2), the leaf area (Table 3) and chlorophyll content (Table 4). These improvements are probably owed to the effects of amino acids and seaweed extracts in promoting cell division and cell growth, thus boosting vegetative biomass. Amino acids can be used to achieve balanced

plant development, increase nutrient use efficiency, tolerance to biotic and abiotic stresses, and root development. Moreover, they increase the amount of chlorophyll, the ability to absorb light energy, and the production of carbohydrates and proteins and partly fulfill the nitrogen needs of the plant and alleviating ammonia toxicity (Ramaih et al., 2003).

Furthermore, the amino acids provide carbon and energy and also participate in the synthesis of fundamental compounds like amines, purines, pyrimidines, alkaloids, vitamins, enzymes, and terpenoids, all of which have positive effects on plant growth and stress tolerance. They can also act as enzyme cofactors, control endogenous phytohormones, and stimulate physiological activities, including photosynthesis, mRNA transcription, and sugars and protein synthesis (Amin et al., 2011). These results are in line with previous studies carried out by Ragheb (2016), Shahid et al. (2023), and Ahmed et al. (2025), who reported greater accumulation of dry matter in yellow corn after the application of amino acid.

The enhanced growth resulting from the treatments with seaweed extracts could also be explained by their ability to provide the necessary nutrients, especially nitrogen and

phosphorus, which stimulate vegetative growth. This, further, leads to better root growth, enhanced nutrient and water absorption from the soil, and more carbohydrates and protein synthesis and their retention in plant tissues, which further improves the dry matter weight (Choulot et al., 2022). These findings are similar to those of Hassan et al. (2025), Fatima (2024) and Al-Yasari and Al-Ghazal et al. (2023) who found that yellow corn had greater dry weight after the application of seaweed extracts.

Dry matter weight was also significantly influenced by spraying frequency. Two sprays (S2) gave the highest mean value of 252.87 g per plant. On the other hand, single spray (S1) gave the lowest mean value of 245.20 g per plant.

Similarly, the interaction between spraying frequency and foliar nutrient application was also found to be significant. The maximum dry matter weight of 295.00 g per plant was observed in the combination of T5 × S2, whereas the minimum weight of 213.67 g per plant was recorded in the combination of T2 × S1. Moreover, with S2, T3, T4 and T5 treatments enhanced the weight of dry matter by 11.96%, 17.57% and 30.72% respectively as compared to T1 with the same spraying frequency. T5 × S2 treatment resulted in 31.30% increase relative to T1 × S1.

Table 5. Effect of foliar nutrient spraying, spraying frequency, and their interaction on dry weight (g plant⁻¹) of *Z. mays*.

Foliar nutrients	Repeat spraying		Average
	S1	S2	
T1 = Distilled water only	224.67	225.67	225.17
T2 = Spray of seaweed at a concentration of 2g/L	213.67	225.67	219.67
T3 = Spray of amino acids at a concentration of 2 g/L	234.00	252.67	243.33
T4 = Spray of seaweed + 50% amino acids	263.67	265.33	264.50
T5 = Spray of seaweed + 100% amino acids	290.00	295.00	292.50
Average	245.20	252.87	

LSD (0.05) value for foliar treatment = 4.56, Spray frequency = 2.88, and Interaction effect = 6.45.

Ear length

As shown in Table 6, foliar nutrient treatment and the frequency of spraying had a significant influence on the mean ear length, but not on their interaction. T3, T4 and T5 treatments, showed a significant improvement in ear length showing 13.53%, 29.16% and 61.44% increases respectively as compared to the control treatment (T1). There was no significant difference between the control treatment (T1) and T2.

The increase in ear length might be ascribed to the fact that seaweed extracts provide all the essential nutrients and plant growth regulators, which become more

efficient with increases in concentrations. These extracts include cytokinins which slow down the process of chlorophyll degradation, hence increasing chlorophyll content (Table 4), and beneficially affecting growth and yield characteristics. They are also involved in the process of translocation of photosynthates from leaves, which act as source tissues, and sink organs (ears), thus improving the development of ears (Layek et al., 2016). In addition, plant growth regulators increase the leaf expansion and results in elevated leaf area (Table 3) and photosynthetic efficiency. This leads to increased production of assimilates and their translocation to

growing ears (Yazdani et al., 2009). Provision of macro- and micronutrients, growth regulators, and vitamins at crucial stages of growth i.e. ear initiation, rapid ear elongation, dry matter accumulation, etc. also increases assimilate partitioning from the point of source to the sink, which in turn leads to better ear development.

The interaction between foliar nutrient treatments and

spraying frequency was found to be insignificant. It was also found that treatments T3, T4 and T5 under S2 resulted in an increase in the ear length giving 23.79%, 38.07% and 73.79% increases respectively compared to the control treatment (T1) with the same spraying frequency. Moreover, T5 × S2 caused an increase of 95.21% compared to T1 × S1.

Table 6. Effect of foliar nutrient spraying, spraying frequency, and their interaction on ear length (cm) of *Z. mays*.

Foliar nutrients	Repeat spraying		Average
	S1	S2	
T1 = Distilled water only	14.00	18	16.00
T2 = Spray of seaweed at a concentration of 2g/L	14.00	18.33	16.17
T3 = Spray of amino acids at a concentration of 2 g/L	17.33	19.00	18.17
T4 = Spray of seaweed + 50% amino acids	19.33	22.00	20.67
T5 = Spray of seaweed + 100% amino acids	24.33	27.33	25.83
Average	17.80	20.93	

LSD (0.05) for foliar treatment = 1.88, LSD (0.05) for spray frequency = 1.18, LSD (0.05) for Interaction effect = Non-significant (N.S.).

Grains per ear

As a result of the foliar nutrient treatments and frequency of sprays, the findings in Table 7 show a significant impact on the average number of grains per ear. The highest value was obtained in treatment T5 (707 grains per ear), which is 47.03 percent higher than the control (T1) that obtained the lowest mean (480 grains per ear).

The effectiveness of treatments with seaweed extracts and amino acids can be ascribed to the fact that they provide necessary nutrients and natural growth regulators during the major stages of development. This improvement was noticed in height and area of the plants (Tables 2 and 3) which augmented the capacity to photosynthesize and transportation of assimilates to the sink organs. The increased photosynthetic efficiency minimizes the floret abortion by lowering the competition among developing florets to obtain assimilates, which boosts grain set. The number of grains largely depends on the effectiveness of pollination and fertilization, and then the ability of fertilized ovules to develop successfully which is highly affected by the general vigor and biological activity of the plant, the availability of assimilates.

Seaweed extracts are especially useful because they are highly rich in both macro and micronutrients and in plant growth regulators like cytokinins, indole-3-acetic

acid (IAA) and gibberellins. These nutrients enhance nutrient absorption, vegetative growth and dry matter. Besides, they enhance increased effective pollination and fertilization through decreasing ovary abortion. During the reproductive stages, proper nutrient supply and nitrogen in particular, stimulate ear development since the amount of rows per ear and grains per row are determined at this stage which eventually boosts the grains yield (Choulot et al., 2022). These outcomes are in line with those of Hassan et al. (2025) and Fatima and Al-Yasari (2024), who found more number rows per ear after the application of seaweed extracts.

Moreover, the treatments increase the nitrogen content in the leaves that controls the phytohormonal balance and auxin activity related to apical dominance. Cytokinins are very important in controlling assimilate partitioning by inhibiting the transport of auxin from the older grains to the younger ones, hence enhancing grain filling and growth. Similar kinds of findings were made by Pal et al. (2015) and Layek et al. (2016), who reported that the number of grains per row increased with the use of biofertilizers and seaweed-based foliar sprays.

In terms of spray frequency, treatment S2 had the maximum average number of grains per ear (627 grains) showing an increase of 12.29% over S1 (558 grains/ear). There was no significant interaction of nutrient treatments and spray frequency regarding this parameter.

Table 7. Effect of foliar nutrient spraying, spraying frequency, and their interaction on number of grains per ear (grain ear⁻¹) in *Z. mays*.

Foliar nutrients	Repeat spraying		Average
	S1	S2	
T1 = Distilled water only	439	522	480
T2 = Spray of seaweed at a concentration of 2g/L	507	593	550
T3 = Spray of amino acids at a concentration of 2 g/L	569	602	585
T4 = Spray of seaweed + 50% amino acids	620	660	640
T5 = Spray of seaweed + 100% amino acids	656	757	707
Average	558	627	

LSD (0.05) for foliar treatments = 66.6, LSD (0.05) for spray frequency = 42.1, and LSD (0.05) for interaction = N.S. (not significant).

100-grain weight (g)

Table 8 indicates that foliar nutrient treatments as well as spray frequency showed a significant impact on 100-grain weight but their interaction was non-significant. The 100-grain weight increased significantly to 13.00, 13.53, 14.60, and 14.60 g respectively in T2, T3, T4, and T5 treatments showing 7.71%, 12.14%, 20.96%, and 20.96% increases over the control treatment (T1), which gave the lowest value of 12.07 g.

The improvements observed could be credited to improved nutrient supply especially nitrogen which is very critical in the regulation of plant hormonal balance and the activity of auxin in the development of ears. Cytokinins help in better distribution of assimilates as it limits the movement of auxin between the grains hence,

promote grain filling and increase grain weight. These results are in line with the findings of Hassan et al. (2025), Fatima and Al-Yasari (2024), Gatea and Hussein (2023), and Al-Ghazal et al. (2023), who noted an increase in the weight of the grain of maize after foliar application of seaweed extracts.

In addition, Lakshmi and Sundaramoorthy (2010) observed that the extracts of seaweed contain abundant amounts of potassium, minerals and trace elements, which get absorbed by plants and thus lead to better grain filling and yield factors. The frequency of spraying also played an important role with treatment S2 showing the maximum 100-grain weight of 13.92 g, which was 5.47% increase compared to S1 (13.20 g). This parameter did not show any significant interaction between the two factors.

Table 8. Effect of foliar nutrient spraying, spray frequency, and their interaction on 100-grain weight (g) of *Z. mays*.

Foliar nutrients	Repeat spraying		Average
	S1	S2	
T1 = Distilled water only	11.47	12.67	12.07
T2 = Spray of seaweed at a concentration of 2g/L	12.13	13.87	13.00
T3 = Spray of amino acids at a concentration of 2 g/L	13.20	13.87	13.53
T4 = Spray of seaweed + 50% amino acids	14.40	14.80	14.60
T5 = Spray of seaweed + 100% amino acids	14.80	14.40	14.60
Average	13.20	13.92	

LSD (0.05) for foliar treatment = 0.74, LSD (0.05) for spray frequency = 0.46, and LSD (0.05) for interaction = Not significant (N.S.).

Total grain production (ton ha⁻¹)

The results presented in Table 9 revealed that both nutrient spraying and spray frequency showed significant effects on average grain yield, while their interaction was statistically non-significant.

Spray treatments T2, T3, T4, and T5 significantly

enhanced average grain yield to 3.89, 4.34, 5.55, and 6.04 t ha⁻¹, respectively showing 9.56%, 22.08%, 56.12%, and 70.04% increases as compared to control treatment (T1), which gave the minimum yield of 3.56 t ha⁻¹.

The increase in grain yield can be ascribed to improvements in main vegetative growth criteria, such as

plant height, leaf area, chlorophyll content index, plant dry weight, and growth rate, as well as yield parameters such as the number of rows per ear and grains per row (Tables 2, 3, 4, 8, and 9). These improvements led to an increase in the number of grains per plant, eventually resulting in higher overall grain yield. Foliar application of amino acids significantly improved maize growth parameters, such as plant height (Table 2), chlorophyll content (Table 4), and leaf area (Table 3), which, in turn, improved yield components including ear length, number of grains per ear, and 100-grain weight, thereby contributing to increased grain yield.

Seaweed extracts, rich in plant growth regulators and essential micronutrients, serve as effective biofertilizers. They increase crop productivity by improving plant metabolic processes, due to the presence of trace elements and plant hormones such as auxins, gibberellins, and cytokinins (Pal et al., 2015; Lotze and Hoffman, 2016).

These findings are in agreement with those of Gatea and Hussein (2023), Al-Ghazal et al. (2023), Fatima and Al-Yasari (2024) and Hassan et al. (2025), who observed significant increases in grain yield after the application of seaweed extracts in maize. Likewise, Baddour et al. (2017) found that application of amino acid significantly enhanced most of the growth and yield parameters of maize.

Spray frequency also significantly affected grain yield. Treatment S2 resulted in the highest average yield of 4.83 t ha^{-1} showing an increase of 5.47% over S1 which produced an average yield of 4.53 t ha^{-1} .

Although the interaction between nutrient spraying and spray frequency was not statistically significant, combined treatments showed notable numerical improvements. Specifically, the combinations $T3 \times S2$, $T4 \times S2$, and $T5 \times S2$ enhanced grain yields by 20.06%, 56.16%, and 67.34%, respectively, as compared to $T1 \times S2$. Furthermore, the increase in yield for $T5 \times S2$ reached 79.08% as compared to $T1 \times S1$.

Table 9. Effect of foliar nutrient spraying, spray frequency, and their interaction on grain yield (t/ha) of *Z. mays*.

Foliar nutrients	Repeat spraying		Average
	S1	S2	
T1 = Distilled water only	3.49	3.62	3.56
T2 = Spray of seaweed at a concentration of 2g/L	3.66	4.13	3.89
T3 = Spray of amino acids at a concentration of 2 g/L	4.19	4.49	4.34
T4 = Spray of seaweed + 50% amino acids	5.45	5.65	5.55
T5 = Spray of seaweed + 100% amino acids	5.84	6.25	6.04
Average	4.53	4.83	

LSD (0.05) for foliar = 0.55; Spray frequency = 0.35; Interaction effect = non-significant (N.S.).

Conclusion

The study explicitly shows that foliar application of nutrients, especially the combined application of seaweed extract and amino acids, significantly enhanced both growth and yield traits of maize (*Zea mays* L.). Among all treatments, T5 (seaweed extract + 100% amino acids) consistently produced the highest values for plant height, leaf area, chlorophyll content, dry matter accumulation, ear length, grains per ear, 100-grain weight, and overall grain yield. Yield enhancement reached up to 70.04% over the control. Increased spray frequency further improved efficiency, with two sprays (S2) demonstrating better than the single spray across most attributes. Even though interaction effects were mostly non-significant, the combination $T5 \times S2$ revealed the best numerical performance, showing a strong synergistic effect of

nutrient composition and application frequency. Generally, the enhancements can be ascribed to improved biological activities, better nutrient uptake and translocation, improved photosynthetic efficiency, and better assimilate partitioning.

Recommendations

Foliar application of seaweed extract combined with amino acids, particularly at full strength (T5), is recommended for maximizing maize growth and yield. Application should preferably be carried out twice during critical growth stages to guarantee sustained nutrient availability and optimal plant performance. Farmers should adopt integrated foliar nutrition approaches using bio-stimulants such as amino acids and seaweed extracts to increase production in an environmentally sustainable

way. Further research is suggested to assess the economic viability, optimize application timing under different agro-ecological conditions, and evaluate long-term soil and crop health effects.

Author's contributions

Al Waga et al. conceived and designed the study and were primarily responsible for conducting the experiments, data collection, and both laboratory and field investigations. All authors contributed to data analysis and interpretation of the results. They also participated in drafting, reviewing, and critically revising the manuscript to ensure scientific accuracy and intellectual rigor. All authors read and approved the final version of the manuscript prior to submission.

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Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger

SDG 12: Responsible Consumption and Production

SDG 15: Life on Land

Policy Addressed

1. Climate-Smart Agriculture (CSA) Policy

2. Integrated Nutrient Management (INM) Policy

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References

- Abdullahi, U.A., Khandaker, M.M., Alias, N., Shaari, E.M., Alam, M.A., Badaluddin, N.A., Mohd, K.S., 2021. Seaweed effects on plant growth and environmental remediation: A review. *Journal of Phytology* 13, 122-129.
- Ahmad, M.H., Zafar, Z., Bibi, H., Latif, N., Afzal, B., Ali, N., et al., 2025. Effect of exogenously applied amino acids on photosynthetic pigments, metabolites and enzymatic antioxidants in *Zea mays* L. subjected to salt stress. *Scientific Reports* 15, 39025.
- Al-Ghazal, S.A.Y., Aziz, M.M., Al-Juheiehy, W.K.S., 2023. Response of growth and yield of corn (*Zea mays* L.) to biofertilizer and sea-algae extract. *International Journal of Agriculture Statistics Science* 19, 161-165.
- Al-Yasari, M.N.H., Al-Ghazal, S.A.Y., Al-Juheiehy, M.M., Al-Jobouri, S.M., 2023. Influence of foliar application of seaweed extract and amino acids on growth and yield of maize (*Zea mays* L.). *International Journal of Agricultural and Statistical Sciences* 19(1), 225-231.
- Amin, A.A., Fatma, E.A., Gharib, M., El-Awadi, M., Rashad, S.M., 2011. Physiological response of onion plants to foliar application of putrescine and glutamine. *Scientia Horticulturae* 129, 353-360.
- Baddour, A.G., Rashwan, E.M., El-Sharkawy, T.A., 2017. Effect of organic manure, antioxidant and proline on corn (*Zea mays* L.) grown under saline conditions. *Environmental Biodiversity and Soil Security* 1, 203-217.
- Chfat, L.M., Al-Lami, A.H., Al-Inizi, M.A., 2023. Effect of mycorrhizae and organic fertilizers on growth and yield parameters of maize (*Zea mays* L.). *IOP Conference Series: Earth and Environmental Science* 1158(1), 012015.
- Chfat, L.M., Oleiwi, M.S., 2023. Some growth characteristics of maize were affected by inoculation with mycorrhizae and spraying with amino acids. *IOP Conference Series: Earth and Environmental Science* 1262, 082023.
- Choulot, M., Le Guillard, C., Bourgougnon, N., Michalak, I., 2022. Seaweed-based fertilizing products. In: *Algae and Aquatic Macrophytes in Cities*, Elsevier, 271-313.
- El-Sahookie, M.M., Wassom, C.E., 1985. Homeostasis estimation for crop germplasm adaptation. *Journal of Agricultural Research* 4, 1-5.
- Fatima, M.M., Al-Yasari, M.N.H., 2024. Maize response to mineral fertilizers and seaweed extract for growth and yield-related traits. *SABRAO Journal of Breeding and Genetics* 56, 1738-1748.
- Gatea, A., Hussein, H., 2023. Effect of sprays of licorice and seaweed extracts on yield and quality of corn (*Zea mays* L.). *Euphrates Journal of Agricultural Science* 15, 51-60.
- Hassan, W.F., Dina, H.A., Dawood, M.H., 2025. The impact of adding bio-fertilizer and spraying seaweed

- extract on the growth and yield of *Zea mays*. Kufa Journal for Agricultural Sciences 17, 1-10.
- Hassanin, A.H.M., 2020. Crop Physiology. Faculty of Agriculture, Al-Azhar University, Egypt.
- Lakshmi, S., Sundaramoorthy, P., 2010. Response of *Festuca arundinacea* L. on liquid seaweed fertilizer. International Journal of Current Research 2, 39-42.
- Layek, J., Das, A., Ramkrushna, G.I., Ghosh, A., Panwar, A.S., Krishnappa, R., Ngachan, S.V., 2016. Effect of seaweed sap on germination, growth and productivity of maize (*Zea mays* L.) in North Eastern Himalayas. Indian Journal of Agronomy 61, 354-359.
- Lotze, E., Hoffman, E.W., 2016. Nutrient composition and content of various biological active compounds of three South African-based commercial seaweed biostimulants. Journal of Applied Phycology 28, 1379-1386.
- Ministry of Agriculture. 2011. Guidelines for the cultivation and production of yellow corn, General Authority for Agricultural Extension and Cooperation. Extension Bulletin, Iraq.
- Ministry of Planning. 2024. Statistics and Geographic Information Systems Authority. https://www.cosit.gov.iq/documents/agriculture/agre_plant/full%20reports/% pdf
- Omar, H., Abdullatif, B., Al-Kazan, M., El-Gendy, A., 2014. Various applications of seaweed improve growth and biochemical constituents of *Zea mays* L. and *Helianthus annuus* L. Journal of Plant Nutrition 38, 28-40.
- Pal, A., Dwivedi, S.K., Maurya, P.K., Kanwar, P., 2015. Effect of seaweed saps on growth, yield, nutrient uptake and economic improvement of maize (*Zea mays* L.). Journal of Applied and Natural Science 7, 970-975.
- Pasala, R., Kulasekaran, R., Pandey, B.B., Manikanta, C.H.L.N., Gopika, K., Daniel, P.J., et al., 2022. Recent advances in micronutrient foliar spray for enhancing crop productivity and managing abiotic stress tolerance. Plant Nutrition and Food Security in the Era of Climate Change, 377-398.
- Pasala, R., Kulasekaran, R., Pandey, B.B., Manikanta, C.H.L.N., Gopika, K., Daniel, P.J., Elthury, S., Yadav, P., 2022. Recent advances in micronutrient foliar spray for enhancing crop productivity and managing abiotic stress tolerance. Plant nutrition and food security in the era of climate change, pp. 377-398.
- Pei, B., Zhang, Y., Liu, T., Cao, J., Ji, H., Hu, Z., Wu, X., Wang, F., Lu, Y., Chen, N., Zhou, J., 2024. Effects of seaweed fertilizer application on crops' yield and quality in field conditions in China-A meta-analysis. Plos One, 19(7), e0307517.
- Ragheb, E.E., 2016. Sweet corn as affected by foliar application with amino and humic acids under different fertilizer sources. Egyptian Journal of Horticulture 43, 441-456.
- Raja, B., Vidya, R., 2023. Application of seaweed extracts to mitigate biotic and abiotic stresses in plants. Physiology and Molecular Biology of Plants 29, 641-661.
- Ramaih, S., Guedira, M., Paulsen, G.M., 2003. Relationship of indoleacetic acid and tryptophan dormancy and pre-harvest sprouting of wheat. Functional Plant Biology 30, 939-945.
- Shahid, S., Kausar, A., Zahra, N., Hafeez, M.B., Raza, A., Ashraf, M.Y., 2023. Methionine-induced regulation of secondary metabolites and antioxidants in maize (*Zea mays* L.) subjected to salinity stress. Gesunde Pflanzen 75, 1143-1155.
- Slabbert, M., Krüger, G., 2014. Antioxidant enzyme activity, proline accumulation, leaf area and cell membrane stability in water stressed *Amaranthus* leaves. South African Journal of Botany 95, 123-128.
- Sun, W., Shahrajabian, M.H., Kuang, Y., Wang, N., 2024. Amino acids biostimulants and protein hydrolysates in agricultural sciences. Plants 13, 210.
- Taiz, L., Zeiger, E., 2006. Plant Physiology, 4th ed. Sinauer Associates, Sunderland, Massachusetts.
- Yakhin, O.I., Lubyantov, A.A., Yakhin, I.A., Brown, P.H., 2017. Biostimulants in plant science: a global perspective. Frontiers in Plant Science 7, 2049.
- Yazdani, M., Bahmanyar, M.A., Pirdashti, H., Esmaili, M.A., 2009. Effect of phosphate solubilization microorganisms and plant growth promoting rhizobacteria on yield and yield components of corn (*Zea mays* L.). World Academy of Science, Engineering and Technology 37, 90-92.