



THE EFFECT OF SPRAYING WITH DIFFERENT CONCENTRATIONS OF KELPMAX SEAWEED EXTRACT ON THE GROWTH AND CHEMICAL COMPOSITION OF THE YIELD OF TWO BARLEY VARIETIES (*HORDEUM VULGARE L.*)

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Abstract. This study was conducted to determine the effect of foliar spraying with different concentrations of the Kelpmax seaweed extract on the growth and chemical composition of two barley varieties (*Hordeum vulgare L.*), namely Al-Jazira 1 and Rayhan, under greenhouse conditions. The plants were sprayed with three concentrations of the extract (0.0, 2.5, and 5) mL L⁻¹ at three growth stages. The results showed that spraying with the Kelpmax seaweed extract had significant effects on a number of growth traits and the chemical composition of the yield. The 5 mL/L concentration significantly increased plant height, leaf area, and chlorophyll concentrations (a and b), as well as the concentrations of carbohydrates, protein, and the minerals calcium, magnesium, sodium, and potassium in the grains compared to the control treatment. In contrast, the 2.5 mL/L concentration did not show a significant effect on plant height compared to the control treatment. No significant differences were observed between the 2.5 and 5 mL/L concentrations in terms of protein and sodium concentrations. The results also showed significant differences between the two varieties: the Rayhan variety outperformed the Al-Jazira 1 variety in plant height and the concentrations of chlorophyll, carbohydrates, protein, and sodium, while the Al-Jazira 1 variety significantly outperformed the Rayhan variety in leaf area and potassium concentration. The results also indicate that the use of Kelpmax extract, particularly at a concentration of 5 mL/L, contributes to improving the growth, physiological status, and chemical composition of barley grains, with the response varying depending on the variety.

Keywords: Kelpmax, Seaweed Extract, Foliar Application, Barley (*Hordeum Vulgare L.*), Grain Chemical Composition

Introduction

Seaweeds are among the most important natural resources that have garnered increasing attention in the agricultural sector, particularly in the production of bioextracts used to stimulate plant growth and improve plant productivity. They are a group of marine plants found in various aquatic environments; they are attached to substrates on the seafloor, particularly in shallow coastal areas, and can also be found in deeper marine environments, as well as in river estuaries, stagnant waters, and on various rocky and coral surfaces. Seaweeds have been known and used since ancient times in various fields; they have served as food for humans and animal feed, have been utilized in numerous industries, and have become an important source of many compounds and bioactive substances that influence plant growth and development

[1]. Seaweeds differ from higher plants in terms of structure and anatomy; they do not possess distinct true plant organs, such as roots, stems, and leaves, and they lack the specialized vascular tissues and distinct reproductive organs characteristic of higher plants. Despite their simple structure, seaweeds possess a wide range of bioactive compounds, organic substances, minerals, and growth-promoting compounds, making their extracts promising materials in the field of sustainable agriculture and for improving crop growth and productivity. Seaweed extracts are considered promising natural agricultural inputs that have garnered increasing attention in recent years due to their plant-growth-promoting properties and ability to enhance crop productivity. These materials are extracted using methods designed to preserve, as much as possible, the bioactive compounds and distinctive natural properties of marine tissues, thereby contributing to the production of extracts rich in the active compounds found in seaweed [2]. These extracts are characterized by their content of a variety of macronutrients, including phosphorus, potassium, magnesium, and calcium, as well as micronutrients such as iron, zinc, copper, and manganese, making them an important natural source of many elements essential for plant growth and development [3]. The importance of seaweed extracts is not limited to providing nutrients to plants; it extends to include multiple physiological and biological effects, as studies have indicated their ability to stimulate a number of processes related to growth and development, including increased vegetative growth, improved nutrient uptake, enhanced bud formation, and increased photosynthetic efficiency, as well as their effect on root and shoot growth and vegetative reproduction. These extracts can also help improve the root-to-shoot ratio, thereby enhancing the plant's ability to explore a larger volume of soil and increasing the efficiency of water and nutrient uptake from its various layers [3]. With the increasing use of chemical fertilizers to compensate for nutrient deficiencies and achieve high levels of production, growing concerns have emerged regarding the negative effects of their overuse, particularly those related to soil degradation, nutrient imbalance, and environmental impacts. Consequently, many recent studies have focused on identifying natural alternatives or agricultural inputs that can be used in conjunction with conventional fertilizers, most notably seaweed extracts, which not only contain nutrients but also include organic compounds and substances with effects similar to plant growth regulators, thereby playing an important role in improving plant growth and development [4]. Studies have indicated that seaweed and its extracts contain a number of bioactive compounds, including plant growth regulators such as cytokinins, indole-3-butyric acid (IBA), indole-3-acetic acid (IAA), gibberellins (GA₇ and GA), as well as alginic acid, a range of macro- and micronutrients, and other bioactive compounds. Together, these components play an important role in regulating many of the plant's physiological processes, which positively affects its growth, development, and certain productive traits [5, 6]. Other studies have also indicated the presence of bioactive compounds in seaweed extracts that can contribute to improving plant response and stimulating plant growth, which has heightened interest in them as natural sources of growth-

promoting compounds [7]. Barley (*Hordeum vulgare L.*) is one of the most important cereal crops in the grass family (Poaceae) and is also considered one of the oldest crops known to humankind; archaeological evidence indicates that it has been cultivated for thousands of years, reflecting its historical, nutritional, and economic importance [8, 9]. Barley is of great importance in many regions of the world, as it is used for human and animal consumption, as well as in a number of food industries, which necessitates a focus on improving its productivity and increasing the efficiency of resource utilization in various agricultural environments.

In this context, experimental studies have shown that seaweed extracts can be used to improve certain stages of barley growth. Möller & Smith [10], noted that soaking barley seeds for 24 hours in a solution of seaweed extracts prepared from the kelp (*Ascophyllum nodosum*) (ANS) and (*Laminaria hyperborea*) (LHS), followed by re-drying and sowing, resulted in a statistically significant increase in germination rates, as well as a reduction in microbial effects—particularly bacterial and fungal—on the seedlings. These results confirm the potential for using marine extracts as natural bio-regulators that can contribute to improving certain physiological processes related to growth and germination. Many Arab countries, including Iraq, face challenges related to achieving self-sufficiency in grain crops due to limited production compared to growing consumer demand. Therefore, increasing the productivity of these crops requires the adoption of modern scientific methods in agricultural production management and the search for safe and sustainable technologies and inputs that can help boost growth and production efficiency and improve the utilization of available resources. Seaweed extracts stand out as one such natural input due to their content of nutrients, bioactive compounds, and plant growth regulators that can positively influence the physiological and productive processes of plants. Given the importance of the barley crop and the need to identify natural and effective means to improve its growth and productivity, this study was conducted to determine the effect of foliar spraying with the natural seaweed extract (Kelpmax) on barley growth and yield components, and to determine the extent of the plants' response to different spray rates, thereby contributing to the provision of scientific information that can be utilized in the development of agricultural management techniques and the improvement of this crop's productivity under local environmental conditions.

Methods

Grain Preparation

Grains of two barley varieties cultivated in Iraq were obtained from the Seed Inspection and Certification Department in Nineveh Governorate. The first variety was Jazira 1 and the second was Rayhan; both belong to the six barley varieties (*Hordeum vulgare L.*). These two varieties were selected based on previous studies.

Soil Sample Collection and Analysis of Physical and Chemical Properties

Soil samples were selected from agricultural fields located in the Al-Rashidiyah area of Nineveh Governorate; the samples were collected from a depth of 0–30 cm in the topsoil layer. The samples were air-dried, then finely ground and passed through a sieve with a mesh size of 2 mm, in preparation for the necessary physical and chemical analyses. Laboratory analyses were conducted at the laboratories of the Department of Soil Science and Water Resources, College of Agriculture and Forestry, University of Mosul. Soil texture was determined according to the method described by Blake & Hartge [11]. Soil pH was measured according to the

method described by Black [12], and soil organic matter was determined using the method described by Jackson [13]. The electrical conductivity (EC) of the soil aqueous extract was measured according to the standard methods reported by Richards [14]. The concentrations of certain nutrients and dissolved ions in the soil extract were determined; potassium (K^+) and sodium (Na^+) were measured using a flame photometer, while the concentrations of calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl^-) were determined according to the analytical methods described by Black [12]. The chemical and physical measurements resulting from these analyses were also used to characterize the basic properties of the soil used in the study, as shown in Table (1).

Table 1. Physical and Chemical Properties of the Study Soils

T	Characteristics	Unit	Value
First	Physical Properties		
1	Sand	%	333.
2	Gravel	%	31.5
3	Clay	%	35.2
4	Breeding texture	_____	Clay loam
Second	Chemical Properties		
5	Organic Matter	%	1.70
6	Electrical Conductivity (EC)	dSm ⁻¹	1.25
7	Soil pH	_____	7.45
		—	
Third	Mineral Elements and Ions		
8	Sodium Na^+	mg kg ⁻¹	68
9	Potassium K^+	mg kg ⁻¹	121
10	Calcium Ca^{+2}	mg kg ⁻¹	280
11	Magnesium Mg^{+2}	mg kg ⁻¹	140
12	Chloride Cl^-	mg kg ⁻¹	80

Note: The values in the table represent the results of physical and chemical analyses of the soil sample used in the experiment, taken from a depth of 0–30 cm.

Estimation of Field Capacity

The field capacity of the soil used in the experiment was determined using the saturation method, employing small, bottom-perforated containers of known weight. A filter paper moistened with water was placed at the bottom of each container; the container was then weighed along with the filter paper, and 100 g of air-dried soil was added. Next, the base of the container was placed in a vessel containing water, allowing the water to gradually rise through the holes in the base by capillary action, and the soil was left for a sufficient period until it reached a state of water saturation. Once the soil was fully saturated, the container was removed from the vessel and left for an appropriate period until free water ceased to drain and the last drop of excess water had drained away; the container was then weighed along with the saturated soil. The amount of water retained in the soil—which represents field capacity—was calculated using the following equations:

$$\text{Soil water weight (g)} = \text{Wet soil weight (g)} - \text{Dry soil weight (g)}$$

$$\text{Weight-based moisture content (\%)} = \frac{\text{Soil water weight (g)}}{\text{Dry soil weight (g)}} \times 100$$

The field capacity of the soil used in the experiment was 25% of the dry soil weight.

Cultivation and Irrigation

Barley seeds were sown on December 5, 2024, in plastic pots 23 cm in diameter and 20 cm high, each containing 5 kg of soil, at a rate of 15 seeds per pot, ensuring that the seeds were distributed evenly within each pot. The pots were placed randomly under greenhouse conditions, in accordance with the experimental design adopted in the study. The pots were watered with tap water to maintain soil moisture at 75% of field capacity; the amount of water needed to maintain this level was determined, and the daily water addition was adjusted using a scale to ensure that soil moisture content remained constant throughout the experiment. Ten days after planting, thinning was performed, leaving five uniformly developed seedlings in each pot. Leaf area and chlorophyll a and b concentrations were measured 75 days after planting, while the remaining traits under study were measured after the plants had fully matured and harvesting had been completed. Harvesting took place on May 6, 2025, and plants from each experimental unit were collected individually to conduct measurements related to growth traits, yield, and yield components according to the approved measurement methods for each trait.

Treatments Used

The vegetative stages of the Al-Jazira 1 and Rayhan barley varieties in the greenhouse experiment were sprayed three times with Kelpmax seaweed extract at two concentrations: 2.5 and 5 mL/L. Kelpmax is a commercial extract prepared from the brown seaweed *Ecklonia maxima* and was obtained from the College of Agriculture at the University of Mosul. Spraying was performed using a 3-liter hand sprayer. The first application was made after seed germination and when the plants reached the 2–3-leaf stage (), while the second application was made at the onset of tillering (branching). The third application was carried out at the spike emergence stage, in accordance with the growth stages established for cereal crops according to Large's scale [15]. To ensure the accuracy of the treatments and prevent the transferred extract from spreading to adjacent plots, temporary wooden dividers were placed between the plots during the spraying process. The sprayer was also thoroughly rinsed with water after completing the spraying of each plot to avoid cross-contamination between plots and mixing of concentrations. The plants were sprayed from various directions in a uniform manner to ensure that the entire vegetative mass was covered by the sprayed material and to achieve the best possible distribution of the extract across the plant parts.

Traits Studied

A. Measurement of Plant Height and Leaf Area

Plant height was measured, and the leaf area of the flag leaf was estimated in cm² at the stage specified for measurement within the experiment. To calculate leaf area, measurements of the flag leaf's length and maximum width were taken, and then the mathematical relationship proposed by Kemp [16], was used, according to the following equation:

$$\text{Flag leaf area (cm}^2\text{)} = \text{Leaf length (cm)} \times \text{Maximum leaf width (cm)} \times 0.905$$

This method was adopted to estimate the actual leaf area based on the leaf's linear dimensions and the correction factor provided in Kemp's method [16].

B. Estimation of chlorophyll content in leaves

The chlorophyll a and b content in the leaves was determined spectroscopically using 80% acetone extraction, based on the method of Arnon [17]. The spectral absorption coefficients reported by Mackinney [18], were used. This method is considered one of the most common traditional methods for determining chlorophyll pigments in plant tissues, as it relies on measuring the absorption of the extract at two wavelengths: 645 and 663 nanometers. The

second leaf was taken from the foliage of each plant within the experimental unit; the samples were stored in appropriate bags and transported directly to the laboratory for extraction. Two hundred milligrams of soft leaf tissue were weighed for each sample, then homogenized and ground in a porcelain mortar with 20 mL of 80% acetone until a homogeneous extract was obtained. The supernatant was then separated from the remaining solids using a Hettich EBA 35 centrifuge, and the filtrate was collected for spectral measurements. The light absorption of the extract was measured at 663 and 645 nanometers using a Spectrophotometer/CAM, with 80% acetone serving as the reference solution. The resulting absorbance values were used to calculate the concentrations of chlorophyll a and b according to the following equations:

$$\text{Chlorophyll a (mg g}^{-1} \text{ FW)} = [(12.7 \times A_{663}) - (2.69 \times A_{645})] \times V / (1000 \times W)$$

$$\text{Chlorophyll b (mg g}^{-1} \text{ FW)} = [(22.9 \times A_{645}) - (4.68 \times A_{663})] \times V / (1000 \times W)$$

Where:

A_{663} : is the absorbance value measured at 663 nanometers.

A_{645} : is the absorbance value measured at 645 nanometers.

V the final volume of the pigment extract in 80% acetone, in mL.

W: The weight of the fresh sample of the plant tissue used in the extraction, in grams.

FW: The fresh weight of the plant tissue.

The determination was conducted using three replicates per treatment, such that leaves were collected from plants in each experimental unit, then the samples were processed separately for each replicate, and the resulting values were used in the statistical analysis.

C. Determination of Carbohydrate Content in Grains

The carbohydrate content of barley grains grown under greenhouse conditions was determined using the colorimetric method described by Herbert *et al.* [19]. The plant samples were prepared after drying and then finely ground using a porcelain mortar to obtain a homogeneous powder. The soluble fraction of carbohydrates was extracted by adding 10 mL of distilled water to the ground sample, and the aqueous extract was then separated using a Hettich EBA 35 centrifuge. The quantitative determination of carbohydrates was based on the phenol–sulfuric acid assay, in which a color is produced by the reaction of the degradation products of sugars with the reagent; the intensity of the resulting color is proportional to the amount of carbohydrates present in the extract. The optical absorbance of the resulting extract was measured using a spectrophotometer at a wavelength of 488 nanometers, and the absorbance readings were used to estimate the carbohydrate content in barley grains based on the phenol–sulfuric acid color reaction. The results were expressed on a dry weight basis for the sample, in accordance with the unit of measurement adopted in the analysis, with measurements for the experimental replicates conducted independently.

D. Determination of Protein Content in Grains

The protein content in barley grains was determined using the colorimetric method based on the Folin–Ciocalteu reaction, according to the methodology described by Schacterle and Pollack [20]. The determination was based on measuring the intensity of the color formed in the extract using a spectrophotometer at a wavelength of 650 nanometers. The resulting absorbance values were used to determine the protein content in the samples according to the standard procedures of the method, with measurements for the experimental replicates conducted independently.

E. Assessment of Nutrients in Barley Grains:

The concentrations of certain nutrients in barley grains were determined after the experiment was completed. The plant samples were dried and finely ground to obtain a homogeneous powder. 0.5 g of each sample was weighed and subjected to wet digestion according to the method described by Herbert *et al.* [19]. After digestion, the concentrations of potassium (K^+) and sodium (Na^+) were determined using a flame photometer, while the concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined by the EDTA (Versenate) correction method, as described by Jadou [21].

Statistical Analysis

The data from the greenhouse experiment were statistically analyzed using a factorial experiment within a completely randomized design (CRD), with three replicates per treatment. The experiment included two factors: the first factor was the concentrations of the Kelpmax seaweed extract (0.0, 2.5, and 5) $mL L^{-1}$, while the second factor was the two barley varieties (Al-Jazira 1 and Rayhan).

Statistical analysis of the data was performed using the SAS statistical software (1997), in accordance with statistical procedures for factorial experiments. When significant differences between the means were observed, they were compared using Duncan's Multiple Range Test at a significance level of 0.05 ($P \leq 0.05$) to determine the significance of the differences between the means, in accordance with the statistical methodology described by Antar [22].

Results

The effect of Kelpmax extract spraying on plant height and leaf area

The results in Table (2) indicate a significant effect of the levels of the Kelpmax seaweed extract on plant height and leaf area, with the two varieties responding differently to the spray concentrations used. For plant height, spraying at a concentration of 5 $mL L^{-1}$ resulted in a clear, statistically significant increase compared to the control treatment and the 2.5 $mL L^{-1}$ concentration, with the average plant height reaching 115.49 cm at a concentration of 5 $mL L^{-1}$, compared to 92.96 and 93.84 cm for the control and 2.5 $mL L^{-1}$ treatments, respectively. Meanwhile, the 2.5 $mL L^{-1}$ concentration did not show a significant effect on plant height compared to the control. The interaction terms between concentration and variety showed varying responses in plant height; for , the Al-Jazira 1 variety, when sprayed at a concentration of 5 mL/L , reached a height of 115.18 cm, compared to 87.70 and 88.39 cm in the control and 2.5 mL/L treatments, respectively. As for the Rayhan variety, plant height reached 115.79 cm at a concentration of 5 mL/L , compared to 98.22 and 99.28 cm in the control treatments and at 2.5 mL/L , respectively. The 'Rihan' variety also significantly outperformed the 'Al-Jazira 1' variety in average plant height, reaching 105.43 cm compared to 97.09 cm, respectively. With regard to leaf area, the results showed a significant effect of Kelpmax extract concentrations, as leaf area increased with increasing extract concentration; the 5 mL/L concentration recorded the highest mean of 37.01 cm^2 , while it was 31.00 cm^2 at a concentration of 2.5 mL/L and 21.32 cm^2 in the control treatment. The interaction between variety and extract concentration also showed that the treatment with a 5 mL/L concentration outperformed the others in both varieties, with leaf area reaching 37.57 and 36.45 cm^2 for the Al-Jazira 1 and Rayhan varieties, respectively, compared to 20.87 and 21.76 cm^2 in the control treatments. Based on the variety means, the Al-Jazira 1 variety was statistically superior in leaf area, with a mean of 30.63 cm^2 compared to 28.91 cm^2 for the Rayhan variety. The difference in response between the two varieties indicates genetic variation in vegetative growth traits, as the Rayhan variety showed

a greater ability to increase plant height, while the Al-Jazira 1 variety was characterized by a larger leaf area. Overall, the results indicate that the use of Kelpmax extract at a concentration of 5 mL L⁻¹ was more effective in improving the vegetative growth traits studied—particularly plant height and leaf area—compared to the lower concentrations and the control treatment, indicating a positive response of barley plants to foliar spraying with the extract at this concentration level.

Table 2. Effect of spraying with different concentrations of the Kelpmax seaweed extract and interaction terms on plant height (cm) and leaf area (cm²) in two barley varieties

Extract	Variety	Extract	Varieties		Effect of Parameters
		Concentrations ml/L	Al-Jazira 1	Basil	
Kelpmax	Plant	0.0	87.70 c	98.22 b	92.96 b
	Height	2.5 ml/L	88.39 c	99.28 b	93.84 b
	(cm)	5 ml/L	115.18 a	115.79 a	115.49 a
	Effect of Varieties		97.09 b	10543. a	
Kelpmax	Leaf	0.0	20.87 d	21.76 d	21.32 c
	area/cm ²	2.5 ml/L	33.46 b	28.54 c	3100. b
		5 ml/L	37.57 a	36.45 a	37.01 a
	Effect of Varieties		30.63 a	28.91 b	

Means followed by the same letter are not significantly different from one another, while means followed by different letters are significantly different at the 0.05 probability level, according to Duncan's Multiple Range Test.

Effect of Kelpmax extract spraying on chlorophyll content

The results in Table (3) showed that foliar spraying with the Kelpmax seaweed extract had a significant effect on the chlorophyll a and b content in the leaves of the two barley varieties, and that the magnitude of the response varied depending on the variety and the extract concentration. The concentration of 5 mL L⁻¹ yielded the highest chlorophyll a contents in the Al-Jazira 1 and Rayhan varieties, reaching 2.072 and 2.285 mg g⁻¹ of fresh weight, respectively, compared to 1.408 and 1.586 mg g⁻¹ in the control treatment. With regard to chlorophyll b, a concentration of 5 mL L⁻¹ yielded the highest values in both varieties, reaching 0.682 mg g⁻¹ in the Al-Jazira 1 variety and 0.873 mg g⁻¹ in the Rayhan variety, compared to 0.587 and 0.523 mg g⁻¹ in the control treatment, respectively. The 2.5 mL/L concentration also resulted in a significant increase in chlorophyll b content in the Rayhan variety, reaching 0.810 mg g⁻¹, whereas no statistically significant increase was observed in the Al-Jazira 1 variety, where the value was 0.591 mg g⁻¹ compared to 0.587 mg g⁻¹ in the control treatment. As evident from the mean values for the varieties, the Rayhan variety significantly outperformed the Al-Jazira 1 variety in chlorophyll a and b content, with mean values of 1.900 and 0.734 mg g⁻¹, respectively, compared to 1.721 and 0.620 mg g⁻¹ for the Al-Jazira 1 variety. This indicates a genetic difference between the two varieties in the level of chlorophyll pigment accumulation and their response to spraying with seaweed extract. Overall, the results showed that increasing the concentration of Kelpmax extract to 5 mL L⁻¹ was more effective in increasing the chlorophyll a and b content in the leaves of both varieties, reflecting a positive response to the extract in enhancing the levels of

pigments responsible for photosynthesis, though it should be noted that the response was not uniform between the two varieties at a concentration of 2.5 mL L⁻¹.

Table 3. Effect of spraying with different concentrations of the Kelpmax seaweed extract and interaction terms on the concentrations of chlorophyll a and b (mg/g fresh weight) in the leaf tissues of two barley varieties

Extract	Description	Extract Concentrations mL/L	Varieties		Effect of Parameters
			Al-Jazira 1	Basil	
Kelpmax	Chlorophyll a	0.0	1.408 e	1.586 d	1.497 c
		2.5 ml/L	1.684 cd	1.828 c	1.756 b
		5 ml/L	2.072 b	2.285 a	2.179 a
	Effect of Varieties		1.721 b	1.900 a	
Kelpmax	Chlorophyll b	0.0	0.587 d	0.523 e	0.555 c
		2.5 ml/L	0.591 d	0.810 b	0.701 b
		5 ml/L	0.682 c	0.873 a	0.728 a
	Effect of Varieties		0.620 b	0.734 a	

Means followed by the same letter are not significantly different from one another, while means followed by different letters are significantly different at the 0.05 probability level ($P \leq 0.05$), according to Duncan's Multiple Range Test.

Effect of Spraying with Kelpmax Extract on Carbohydrate and Protein Content in Grains

The results in Table (4) showed that the levels of the Kelpmax seaweed extract had a significant effect on the carbohydrate and protein content of barley grains, as well as a significant difference between the two varieties in these two traits. With regard to carbohydrate content, spraying at a concentration of 5 mL L⁻¹ resulted in the highest mean value of 63.691 mg g⁻¹, compared to 57.086 and 50.757 mg g⁻¹ at a concentration of 2.5 mL L⁻¹ and the control treatment, respectively. The results of the interaction between variety and extract concentration also showed that the highest carbohydrate content was recorded in the Rayhan variety at a concentration of 5 mL/L, reaching 68.300 mg/g, while it reached 59.082 mg/g in the Al-Jazira 1 variety at the same concentration. As evident from the variety means, the Rehan variety was statistically superior in carbohydrate content, with a mean of 62.268 mg g⁻¹ compared to 52.132 mg g⁻¹ for the Al-Jazira 1 variety. As for protein content, the highest average was observed at a spray concentration of 5 mL L⁻¹, reaching 4.231 mg g⁻¹, whereas it was 4.052 mg g⁻¹ at a concentration of 2.5 mL L⁻¹ and 3.337 mg g⁻¹ in the control treatment. Statistical comparisons indicate that the concentrations of 2.5 and 5 mL/L did not differ significantly from each other in terms of average protein content, but they did differ significantly from the control treatment, suggesting that the protein response was not associated with an increase in extract concentration from 2.5 to 5 mL/L. In terms of interaction, the Rayhan variety recorded the highest protein value at a concentration of 2.5 mL/L, reaching 4.248 mg/g, while the Al-Jazira 1 variety recorded its highest value at a concentration of 5 mL/L, reaching 4.276 mg/g. The Rayhan variety also significantly outperformed the Al-Jazira 1 variety in average protein content, reaching 4.075 mg g⁻¹ compared to 3.725 mg g⁻¹ for the Al-Jazira 1 variety. Overall, the results indicate that foliar spraying with Kelpmax extract

improved the carbohydrate and protein content of barley grains, with a more pronounced effect on carbohydrate content when using a concentration of 5 mL/L, while the 2.5 and 5 mL/L concentrations yielded similar responses in protein content, with the Rayhan variety outperforming the Al-Jazira 1 variety in both traits.

Table 4. Effect of spraying with different concentrations of the Kelpmax seaweed extract and interaction terms on the carbohydrate and protein concentrations (mg/g) in grains of two barley varieties.

Extract	Characteristic	Extract Concentrations mL/L	Varieties		Effect of Parameters
			Al-Jazira 1	Basil	
Kelpmax	Carbohydrates	0.0	47.414 f	54.101 d	50.757 c
		2.5 mL/L	49.573 e	64.600 b	57.086 b
		5 mL/L	59.082 c	68.300 a	63.691 a
	Effect of Varieties		52.132 b	62.268 a	
Kelpmax	Protein	0.0	3.046 d	3.629 c	3.337 b
		2.5 mL/L	3.856 bc	4.248 ab	4.052 a
		5 mL/L	4.276 ab	4.186 a	4.231 a
	Effect of Varieties		3.725 b	4.75	

Means followed by the same letter are not significantly different from one another, while means followed by different letters are significantly different at the 0.05 probability level ($P \leq 0.05$), according to Duncan's Multiple Range Test.

Effect of Kelpmax extract spraying on calcium and magnesium content in grains:

The results in Table (5) indicate that the Kelpmax seaweed extract had a significant effect on the calcium and magnesium content of barley grains, whereas the variety did not show a significant effect on either element. With regard to calcium, spraying at a concentration of 5 mL L⁻¹ resulted in the highest mean value of 3.386%, which was significantly higher than the control treatment and the 2.5 mL L⁻¹ concentration, which recorded 2.313% and 2.982%, respectively. Interaction analyses also showed that the highest calcium content was recorded in the Al-Jazira 1 variety at a concentration of 5 mL/L, reaching 3.357%, while it reached 3.416% in the Rayhan variety at the same concentration; the two varieties did not differ significantly at this concentration. As for magnesium, spraying with the Kelpmax extract led to a statistically significant increase in its content in barley grains, with the average rising from 2.599% in the control treatment to 2.925% and 3.074% when using at concentrations of 2.5 and 5 mL/L, respectively. The 5 mL/L concentration recorded the highest average magnesium content, significantly exceeding that of the control treatment, while it did not differ significantly from the 2.5 mL/L concentration. Interaction analyses showed that magnesium content increased in both varieties as the extract concentration increased, reaching 3.033% and 3.115% for the Al-Jazira 1 and Rayhan varieties, respectively, at a concentration of 5 mL/L, compared to 2.601% and 2.597% in the control treatment. No significant differences were observed between the two varieties in terms of average calcium or magnesium content; the average calcium content was 2.941% and 2.846% for the Al-Jazira 1 and Rayhan varieties, respectively, while the average magnesium content was 2.845% and 2.884%, respectively. Overall, the results indicate that foliar spraying with Kelpmax extract contributed to increasing the calcium and magnesium content of barley grains, and the effect of the 5 mL L⁻¹

concentration was more pronounced, whereas the variety had no significant effect on the mean values of these two elements, indicating that the two varieties responded similarly to this treatment under the experimental conditions.

Table 5. Effect of foliar spraying with different concentrations of Kelpmax seaweed extract and interaction treatments on calcium and magnesium concentrations (%) in grains of two barley varieties

Extract	Variety	Extract Concentrations ml/L	Varieties		Effect of Parameters
			Al-Jazira 1	Basil	
Kelpmax	Calcium	0.0	2.181 c	2.445 c	2.313 c
		2.5 ml/L	3.286 ab	2.678 bc	2.982 b
		5 ml/L	3.357 a	3.416 a	3.386 a
	Effect of Varieties		2.941 a	2.846 a	
Kelpmax	Magnesium	0.0	2.601 b	2.597 b	2.599 c
		2.5 ml/L	2.903 a	2.940 a	2.925 b
		5 ml/L	3.033 a	3.115 a	3.074 a
	Effect of Varieties		2.845 a	2.884 a	

Means followed by the same letter are not significantly different from one another, while means followed by different letters are significantly different at the 0.05 probability level ($P \leq 0.05$), according to Duncan's Multiple Range Test.

Effect of Kelpmax extract spraying on sodium and potassium content in grains:

The results in Table (6) showed that spraying with the Kelpmax seaweed extract had a significant effect on the sodium and potassium content of barley grains. With regard to sodium, the use of the extract led to a significant increase in its content compared to the control treatment, as the average increased from 1.212% in the control treatment to 1.503% and 1.508% when using concentrations of 2.5 and 5 mL L⁻¹, respectively. No significant difference was observed between the 2.5 and 5 mL/L concentrations, indicating that increasing the extract concentration from 2.5 to 5 mL/L did not result in a further significant increase in sodium content. The interaction coefficients between variety and extract concentration showed that the highest sodium content values were recorded for the Rayhan variety at concentrations of 2.5 and 5 mL/L, reaching 1.611% and 1.628%, respectively, while the values for the Al-Jazira 1 variety were 1.395% and 1.389% at the same two concentrations. As evident from the variety averages, the Rayhan variety significantly exceeded the Al-Jazira 1 variety in sodium content, with an average of 1.503% compared to 1.312% for the Al-Jazira 1 variety. As for potassium, spraying with Kelpmax extract led to a statistically significant increase in its content, with the average rising from 2.226% in the control treatment to 2.463% and 2.588% at concentrations of 2.5 and 5 mL L⁻¹, respectively. The 5 mL/L concentration also recorded the highest average, significantly outperforming the control treatment and the 2.5 mL/L concentration. The interaction analyses showed that the highest potassium content was achieved in the Rehan variety at a concentration of 5 mL/L, reaching 2.811%, while it was 2.365% in the Al-Jazira 1 variety at the same concentration. The variety averages also showed a statistically significant advantage for the Rayhan variety in potassium content, with an

average of 2.600% compared to 2.252% for the Al-Jazira 1 variety. Thus, it is evident that the Rayhan variety showed a higher response to spraying with Kelpmax extract in terms of sodium and potassium accumulation in the grains.

Varietal Response to the Traits Studied

The results in Tables 2, 3, 4, 5, and 6 show significant differences between the two varieties in a number of the studied traits. The Rayhan variety significantly outperformed the Al-Jazira 1 variety in plant height, leaf chlorophyll a and b content, and grain content of carbohydrates, protein, sodium, and potassium. In contrast, the Al-Jazira 1 variety significantly outperformed the Rayhan variety in leaf area. No significant differences were observed between the two varieties in grain calcium and magnesium content, indicating a similar response in the accumulation of these two elements under the experimental conditions.

Overall, the results indicate that the response of barley plants to spraying with Kelpmax extract was influenced by both the variety and the extract concentration; a concentration of 5 mL L⁻¹ was more effective in improving most of the traits studied, while the degree of response differed between the two varieties depending on the plant or chemical trait measured.

Table 6. Effect of spraying with different concentrations of Kelpmax seaweed extract and interaction treatments involving sodium and potassium concentrations (%) on the grains of two barley varieties

Extract	Trait	Extract Concentrations ml/L	Varieties		Effect of Parameters
			Al-Jazira 1	Basil	
Kelpmax	Sodium	0.0	1.154 d	1.271 c	1.212 b
		2.5 ml/L	1.395 b	1.611 a	1.503 a
		5 ml/L	1.389 b	1.628 a	1.508 a
	Effect of Varieties		1.312 b	1.503 a	
Kelpmax	Potassium	0.0	2.183 d	2.270 cd	2.226 c
		2.5 ml/L	2.208 d	2.719 b	2.463 b
		5 ml/L	2.365 bc	2.811 a	2.588 a
	Effect of Varieties		2.252 a	2.600 b	

Means followed by the same letter are not significantly different from one another, while means followed by different letters are significantly different at the 0.05 probability level, according to Duncan's Multiple Range Test.

Discussion

The results of the study showed that foliar spraying with the Kelpmax seaweed extract had a positive effect on a number of growth, physiological, and chemical traits of the barley variety Al-Jazira 1 and basil plants. This response can be explained by the bioactive compounds and growth-promoting substances present in seaweed extracts, as well as their content of a range of nutrients, organic compounds, and growth regulators, which may positively affect the efficiency of biological processes within the plant. Thirumaran *et al.* [2], noted that seaweed extracts are widely used in agriculture as growth stimulants, either through foliar spraying or by adding them to the soil. The results in Table (2) showed a significant increase in plant height and leaf area of barley plants, particularly when using a concentration of 5 mL L⁻¹ of the Kelpmax. This increase may be related to the stimulatory role of seaweed extracts in promoting vegetative growth by improving the efficiency of certain growth-related

physiological and enzymatic processes, including the activation of antioxidant defense systems, such as the enzymes superoxide dismutase (SOD), ascorbate peroxidase (APX), and glutathione reductase (GR), as well as their content of various bioactive compounds, including polysaccharides, phenolic compounds, and growth regulator-like substances, which can contribute to the regulation of hormonal signaling and the improvement of nutrient uptake and plant physiological activity [4, 23], confirmed that extracts from brown algae, including *Ecklonia maxima*, act as bio-stimulants for growth, and that their effect is linked to the regulation of hormonal signaling, the enhancement of antioxidant defense systems, and the improvement of nutrient uptake efficiency, which positively impacts plant growth and its ability to tolerate various environmental conditions. The positive growth response can also be attributed to the extract's effect on stimulating root system growth and development, as previous studies have indicated that seaweed extracts can increase root length and the number of lateral roots, which may enhance the plant's ability to obtain water and nutrients [2]. These results are consistent with the findings of Hussain *et al.* [24], who reported that treatment with seaweed extracts improved tomato plant growth, including increased root length and dry weight of the root system, which positively impacted overall growth and productivity. Arioli *et al.* [25], also explained that marine extracts act as biostimulants capable of stimulating growth processes, promoting root system development, and improving nutrient uptake through their effects on a number of physiological and molecular pathways within the plant. Another possible explanation for the improvement in vegetative growth is that marine algae extracts may influence the plant's anatomical development by increasing stem thickness and vascular bundle size and stimulating cell division and expansion [26]. These results are consistent with those reported by Asirselvin and Saravana [27], and Sivasankari *et al.* [28], whose studies showed that the use of seaweed extracts led to improvements in a number of growth parameters in various plants, including rice and legumes. As for the increase in leaf area, this can be attributed to the ability of marine extracts to stimulate cell division and expansion and to activate physiological processes associated with vegetative growth, as well as their content of bioactive compounds and substances with effects similar to plant growth regulators, which contribute to increasing leaf area and improving the plant's efficiency in utilizing light. This is consistent with the findings of Rouphael *et al.* [29], who reported that foliar spraying with marine algae extracts led to a clear increase in leaf area by regulating processes related to cell division and expansion, which had a positive effect on the plant's vegetative growth. This increase may be linked to the presence of growth-regulating compounds in seaweed extracts, including compounds with phytohormone-like activity, which can contribute to stimulating cell division and expansion, in addition to the importance of these compounds in regulating plant tissue growth [30]. This was demonstrated by Rasool [31], who noted that seaweed extracts contain nutrients and bioactive compounds with growth-promoting effects that can contribute to improving plant physiological activity. This may be reflected in increased photosynthetic efficiency and the formation of a larger leaf area. This finding is consistent with the observations of Abdul-Jabbar *et al.* [32], and Aboud *et al.* [33], in their studies on various plants, as well as with the results of Al-Taie [34], and is supported by the findings of Deolu-Ajayi *et al.* [35]. They explained that marine algae extracts contain a diverse range of bioactive compounds, including polysaccharides, polyphenols, and plant hormone-related compounds, and that these compounds can influence growth pathways, hormonal signaling, and processes associated with photosynthesis, thereby contributing to enhanced plant growth and physiological performance. They also noted that the effect of marine extracts is not associated

with a single compound but rather results from the interaction between a group of bioactive compounds that work synergistically to regulate physiological processes and plant growth. The results in Table 3 also showed a significant increase in the concentration of chlorophyll a and b in the leaf tissues of barley plants treated with a 5 mL/L concentration of the Kelpmax seaweed extract compared to the other treatments. This improvement may be related to the extract's ability to promote vegetative growth and enhance the plant's nutritional status, as well as its potential contribution to maintaining the integrity and efficiency of leaf tissues. Marine extracts may also play a role in improving root growth and increasing the efficiency of nutrient uptake from the soil, including magnesium, which is an essential component in the synthesis of chlorophyll molecules, thereby increasing the concentration of chlorophyll a and b. Additionally, the extract contains a range of macro- and micronutrients and bioactive compounds that may contribute to improving the efficiency of photosynthesis [26, 36]. This finding is consistent with the findings reported by Deolu-Ajayi *et al.* [35], regarding the physiological role of seaweed extracts in improving the plant's efficiency in utilizing minerals essential for growth, particularly magnesium and iron, which may positively affect chlorophyll pigment formation and enhance photosynthetic efficiency in the leaves. This is attributed to the complex nature of these extracts and their composition of a mixture of compounds and bioactive components that can interact synergistically to support the plant's nutritional status and stimulate a number of physiological processes related to growth and photosynthesis. An increase in chlorophyll content in the leaves is considered an important indicator of improved efficiency in the plant's photosynthetic system, as higher concentrations of chlorophyll pigments may enhance the leaves' ability to utilize light energy, which in turn stimulates photosynthesis and increases the formation of carbohydrates [37]. From this perspective, the increase in carbohydrate content observed in barley grains treated with Kelpmax extract can be explained by enhanced photosynthetic efficiency and improved plant ability to synthesize and transport carbon metabolism products to the grains, particularly at the 5 mL/L concentration, which showed clear superiority compared to the other treatments. This result is consistent with the findings of Afonso *et al.* [38], who reported that the use of seaweed extracts contributed to enhancing photosynthetic activity and improving the physiological status of plant leaves, which can provide more favorable conditions for the formation and accumulation of photosynthetic products. Recent studies also suggest that the stimulatory effect of seaweed extracts may be linked to the activation of carbon fixation processes and increased accumulation of non-structural carbohydrates, thereby supporting growth and energy storage in plant tissues. The results also showed an increase in protein content in barley grains in response to spraying with Kelpmax extract, which can be explained by an improvement in the plant's ability to acquire and utilize nutrients, particularly nitrogen, which is essential for the formation of amino acids and, consequently, protein synthesis. The stimulation of vegetative growth and improved efficiency of metabolic processes may also have contributed to increased production and transport of accumulated substances from vegetative organs to the grains during the filling stage, which was reflected in the higher protein content. This explanation is consistent with the findings of Stirk *et al.* [39], who noted that seaweed extracts contain bioactive compounds that can influence a number of physiological and metabolic processes in plants. This is also the conclusion reached by Shukla *et al.* [40], who demonstrated that the use of a bioextract derived from the red alga *Kappaphycus alvarezii* contributed to improved nitrogen uptake within the plant, as well as its effect on regulating processes related to nitrogen metabolism and redistribution, thereby confirming the potential

of marine extracts to improve plant nutrition and promote the formation of nitrogen-containing compounds, including proteins. The results in Tables (5 and 6) indicated that spraying with Kelpmax extract led to an increase in the content of the studied minerals in barley grains, most notably at a concentration of 5 mL L⁻¹. This can be explained by the fact that marine extracts contain a range of nutrients and compounds that may contribute to improving the plant's nutritional status. Spraying the extract onto the aboveground parts may supply certain elements directly through the leaf surface, in addition to the extract's indirect effects on root system growth and the efficiency of nutrient uptake from the soil. Rathore *et al.* [41], that the use of marine algae extracts can improve plant growth and nutritional status, while Polat *et al.* [42], demonstrated positive effects of marine extracts on plant growth and nutrient uptake by stimulating root growth and development. These findings are consistent with those reported by Tanmayi *et al.* [43], in their study on wheat, as they demonstrated that treating wheat plants with seaweed extracts via foliar spraying contributed to improved nutrient uptake—particularly nitrogen, phosphorus, and potassium—as well as improvements in a number of growth traits and yield. Recent studies have also shown that the stimulatory effect of seaweed extracts on mineral nutrition is not only related to the elements contained in the extract but may also result from the activation of transport and absorption pathways within the plant and the improvement of root system growth, thereby enhancing the efficiency of nutrient utilization and their transfer to growing organs and grains. The results revealed a clear difference in the response of the two barley varieties to the different treatments, as their responses were not similar across all traits studied. The Rayhan variety showed a statistically significant advantage in plant height and leaf chlorophyll a and b content, as well as in grain content of carbohydrates, protein, sodium, and potassium, whereas the Al-Jazira 1 variety outperformed in leaf area; however, no significant differences were observed between the two varieties in grain concentrations of calcium and magnesium. This variation can be explained by genetic differences between the varieties that affect growth efficiency, physiological activity, and the plant's ability to absorb, transport, and distribute nutrients among its various parts, as well as differences in how effectively each genetic makeup responds to environmental conditions and the applied treatments. This is consistent with the findings of Ashraf [44], who noted that genetic differences among varieties may lead to variations in physiological traits and in their level of response to different conditions and treatments. This finding also supports the conclusions reached by Hajibarat *et al.* [45], who demonstrated clear differences among barley varieties in a number of morphological and physiological traits, including chlorophyll and protein content, as well as in the mechanisms of nitrogen uptake and utilization, confirming that differences in genetic composition may be one of the key factors responsible for variations in variety performance and response to different nutritional conditions.

Overall, the study's results indicate that foliar spraying with the Kelpmax seaweed extract had a positive effect on a range of morphological, physiological, and chemical traits of barley plants, and the concentration of 5 mL L⁻¹ was the most effective in improving most of the studied traits, including plant height, leaf area, and leaf chlorophyll content, as well as increasing the accumulation of carbohydrates, proteins, and certain minerals in the grains. This response appears to be related to the combined effects of the extract on vegetative growth, improvement of the plant's nutritional status, and stimulation of a number of physiological processes associated with photosynthesis, the formation of metabolic products, and their transport to the grains.

Furthermore, the variation in the response of the two varieties to certain traits suggests that the benefits derived from the extract may be influenced by the plant's genetic makeup and its ability to respond to biostimulants. These results are consistent with the findings of Mughunth *et al.* [46]. They demonstrated that seaweed extracts possess growth-promoting properties due to their content of a diverse range of bioactive compounds, elements, and growth regulators, and that their application can support plant growth and root development and improve nutritional status and productivity, confirming the potential to use these extracts as biostimulants to enhance the physiological and productive performance of crops.

Conclusion

The study concluded that foliar spraying with the Kelpmax seaweed extract had a significant and positive effect on a number of morphological, physiological, and chemical traits of barley plants of the Al-Jazira 1 and Rayhan varieties under greenhouse conditions, and that the level of response was influenced by the extract concentration and the plant variety. The 5 mL L⁻¹ concentration generally showed the best response, as it led to a significant increase in plant height and leaf area, and raised the chlorophyll a and b content in the leaves compared to the control treatment, indicating the effectiveness of this concentration in improving vegetative growth and the physiological condition of the plant. In contrast, the 2.5 mL/L concentration did not show a significant effect on plant height compared to the control treatment, despite its positive impact on a number of other traits. Spraying with the Kelpmax extract also contributed to improving the chemical composition of barley grains, resulting in a significant increase in carbohydrate and protein content, and the effect of the 5 mL/L concentration was more pronounced in increasing carbohydrate content, whereas no significant differences were observed between the 2.5 and 5 mL/L concentrations in protein content. The treatments also showed a significant increase in the concentrations of mineral elements in the grains, as the calcium, magnesium, sodium, and potassium contents increased in response to spraying with the extract, with the 5 mL/L 25 concentration being the most effective in increasing calcium and potassium; however, the 2.5 and 5 mL/L concentrations did not differ significantly in sodium content, nor did the 5 mL/L concentration show a significant advantage over the 2.5 mL/L concentration in magnesium content. The study also concluded that there was a clear genetic difference between the two barley varieties in their response to spraying with the Kelpmax extract, as the Rayhan variety significantly outperformed the other in plant height and leaf chlorophyll a and b content, as well as in grain content of carbohydrates, protein, sodium, and potassium, whereas the Al-Jazira 1 variety significantly outperformed it in leaf area; no significant differences were observed between the two varieties in grain calcium and magnesium content. These results confirm that the response to the Kelpmax extract does not depend solely on the extract concentration but is also influenced by the genetic makeup of the variety and the nature of the trait under study. Based on the overall results, it can be concluded that the Kelpmax extract, particularly at a concentration of 5 mL/L, is a promising biostimulant for improving the growth, physiological condition, and chemical composition of barley grains under the experimental conditions, through its positive effects on vegetative growth, chlorophyll content, and the accumulation of carbohydrates, proteins, and certain minerals in the grains. The results also highlight the importance of considering varietal differences when using seaweed extracts in crop management programs, as the Rayhan variety showed a better

response in most chemical and physiological traits, while the Al-Jazira 1 variety was distinguished by its larger leaf area. Therefore, foliar spraying with Kelpmax extract at a concentration of 5 mL L⁻¹ may be a suitable option for improving a number of growth traits and chemical components of barley grains under the experimental conditions in which the study was conducted; however, this concentration needs to be evaluated under different field and environmental conditions before the agronomic recommendation can be generalized.

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