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Article

The Effect of Foliar Spraying with Different Concentrations of Algamix Seaweed Extracts on Growth, Yield, and Seed Strength of Hordeum vulgare L. Barley Varieties

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Abstract: This study examined the effects of seaweed extract on growth, yield, and seed vigor in four Iraqi barley cultivars through field and laboratory experiments. Field trials were conducted west of Nineveh during the 2024–2025 and 2025–2026 seasons; laboratory tests took place at the University of Mosul. Field treatments comprised cultivars Al-Jazeera, Furat-9, Rihan, and Hader 462, sprayed with Algamix at 3 or 5 mL L^{-1}, or water (control). The field experiment used a randomized complete block design with three replications; laboratory tests used a completely randomized design with three replications. Cultivars differed significantly in all traits. Rihan achieved the highest field values across both seasons for flag leaf area, total tillers, spikes, 1,000-grain weight, and grain yield. Its yields were 4.42 and 4.61 t ha^{-1}, respectively. Algamix at 5 mL L^{-1} outperformed the lower dose and control, increasing flag leaf area, spike number, grain weight, and yield; yields reached 4.17 and 4.52 t ha^{-1}. The strongest cultivar-treatment combination was Rihan with 5 mL L^{-1}, producing yields of 4.64 and 4.82 t ha^{-1}, alongside the highest values for yield components. In laboratory testing, seeds from Rihan had the highest germination speed index (27.56 and 29.53) and germination percentage (95.01 and 95.45%), and the shortest mean germination times (5.30 and 5.05 days). Seeds from plants receiving 5 mL L^{-1} also showed superior vigor, with germination speed indices of 28.62 and 30.89, germination percentages of 94.91 and 94.98%, and shortest germination times of 5.21 and 4.92 days. Overall, Rihan and the higher Algamix rate improved field performance and seed quality.

Keywords: Foliar Spraying, Algamix Seaweed, Hordeum vulgare L., Barley Varieties.

Introduction

Cereal crops are among the most important agricultural crops worldwide, given their vital role as a primary source of food and feed. They account for approximately 50% of total global production of dry matter suitable for consumption and about 65% of protein, highlighting their great importance and justifying their classification as strategic crops [1]. It is no secret that most Arab countries suffer

from a clear deficit in grain production in general, due to low levels of domestic Arab production compared to the volume of growing consumer demand, which makes them heavily dependent on imports to meet their food needs. This reflects a food gap that requires the search for scientific and practical means to increase production and improve the productivity of this important strategic crop, raising it to the desired level through the adoption of modern and effective scientific management methods in agricultural production [2,3]. Barley belongs to the grass family and occupies an important place among the basic food crops for humans. It is also considered one of the oldest cereal crops known to humankind since ancient times, as archaeological evidence—particularly ancient drawings and inscriptions—indicates that it has been cultivated for more than 10,000 years before the Common Era [4,5]. The world is currently moving toward reducing dependence on laboratory-manufactured chemical fertilizers, given their negative impacts on human health and the environment, as well as their role in soil fertility degradation and increased environmental pollution [6,7]. In this context, there has been growing interest in the use of sustainable natural alternatives, most notably seaweed extracts, which are considered safe and environmentally friendly biostimulants. They are characterized by their non-toxicity and their ability to improve nutrient uptake efficiency, promote plant growth, and increase plant tolerance to various stresses (Khan et al. [8] and El Boukhari et al. [9]. Seaweed extracts are among the most important biostimulants in modern agriculture, as they are derived from marine algae that grow in coastal environments and at various depths, and are characterized by their content of bioactive compounds such as the plant hormones auxins and cytokinins, amino acids, vitamins, and minerals. These extracts contribute to promoting plant growth by improving nutrient uptake efficiency and stimulating physiological and enzymatic processes within the plant, in addition to their role in enhancing tolerance to environmental stresses such as drought, salinity, and high temperatures. They are also used as a sustainable agricultural input in modern production systems, either as a partial substitute for or a complement to chemical fertilizers, due to their positive impact on increasing productivity and improving crop quality. [7,8,10,11]. Recent studies have also shown that these extracts contain active compounds and natural growth regulators that contribute to improved germination and increased productivity, in addition to being low-cost compared to traditional chemical fertilizers [12] and [13]. Seaweed extracts are also considered natural bio-sources derived from marine algae; they contain active compounds similar to plant hormones and amino acids and are used as bio-stimulants that are added to the soil or sprayed on plants as nutritional supplements—not as a substitute for chemical fertilizers— as they contribute to improving growth, increasing nutrient uptake efficiency, and enhancing tolerance to environmental stresses [14–17]. Recent studies have also demonstrated that these extracts act as effective biostimulants to stimulate germination and vegetative growth and increase productivity due to their content of natural growth regulators such as auxins and cytokinins [10] and [16]. Seaweed extracts contain high concentrations of essential nutrients such as phosphorus, potassium, magnesium, and calcium, in addition to important micronutrients such as zinc, copper, iron, and manganese [18]. Seaweed extracts are also characterized by their content of growth-promoting hormones such as cytokinins, auxins such as IAA and IBA, gibberellins such as GA and GA7, and alginic acid, in addition to macronutrients and micronutrients, as well as certain compounds with antimicrobial activity. This rich composition contributes to improving the growth and yield characteristics of many different agricultural crops [19] and [20]. Seaweed extracts also contain a range of essential amino acids and important vitamins, such as vitamins B1, B2, C, and E, which help support vital processes within the plant, stimulate vegetative growth, and improve resistance to environmental stresses. Numerous studies have shown that these compounds, when present in marine extracts, act synergistically with plant hormones and nutrients to enhance growth efficiency and productivity in various crops [21], [22], and [23]. Recent research also confirms that marine algae extracts, rich in amino acids and vitamins, contribute to improving plant growth and increasing their tolerance to adverse environmental conditions by stimulating metabolic processes and enhancing nutrient uptake efficiency [24,25]. Consequently, seaweed extracts help promote the growth of both the plant's aerial and root parts, enhance the roots' efficiency in absorbing water and minerals, and delay signs of root senescence. Furthermore, they increase the chlorophyll content in leaves, which positively affects the rates of photosynthesis and respiration [26,27]. As noted by Moller et al. [28] in a field study, soaking barley

seeds in a seaweed solution prepared from Ascophyllum nodosum (ANS) and Laminaria hyperborea (LHS) for 24 hours, followed by re-drying and sowing, resulted in a statistically significant increase in the germination rate, and a reduction in microbial (bacterial and fungal) effects on the seedlings. In a field study conducted by Prasanth et al. [29], on barley plants, the results showed that seaweed extracts possess biological activity that contributes to improved growth, increased yield, and higher chlorophyll content in the plants. This is attributed to their content of plant hormone-like compounds, particularly gibberellins, which promote seed germination and seedling growth. Recent studies have confirmed that these extracts act as biostimulants that improve nutrient uptake efficiency and support vegetative growth in cereal crops, including barley [13,30]. Therefore, this study was conducted to investigate the effect of natural seaweed extracts on barley plants and to determine the extent to which this economically important crop responds to these extracts in terms of vegetative growth characteristics, yield traits, and seed germination capacity for four varieties of barley (Hordeum vulgare L.) grown in Iraq ( ) in order to reduce production costs and protect the environment and human health.

Materials and Methods

Table 1. Some Chemical and Physical Properties of Field Soil

I. Physical Properties	Soil Type	Unit of Measurement	Value
1.	Sand	%	24.0
2.	Gravel	%	31.6
3.	Clay	%	44.4
4. Soil texture	Clay loam		
Second: Chemical Properties			
5.	Organic Matter	g kg^{-1}	1.66
6.	Soil pH	.....	7.40
7.	Electrical Conductivity (EC)	dSm^{-1}	1.24
8.	Cation Exchange Capacity (CEC)	cmol(+) kg^{-1}	29.9
III. Nutrients			
9.	Total nitrogen	%	0.49
10	Available nitrogen	mg kg^{-1}	22.0
11	Available phosphorus	mg kg^{-1}	11.0
12	Available potassium	mg kg^{-1}	185.0

Table 2. Composition of the Algamix Seaweed Extract

Composition of the Algamix extract (*Ascophyllum nodosum*)	
16%	K_2O
0.26%	Mo
15–16.5	Organic Material
1.8–24%	Protein
10.5–15%	Carbohydrates
3–6%	Alginic acid
1.2–2.1%	Mannitol
Natural Regulators	
Cytokinins Gibberellins IAA (indoleacetic acid)	
Macronutrients	
N 0.42–0.54%	

P_2O_5	0.009 – 0.021 %
S	0.3 – 0.6 %
Ca	0.30 – 0.035 %
Mg	0.09 – 0.18 %
Na	0.04–0.06%
Micronutrients	
B	24–30 ppm
Co	0.3 – 0.6 ppm
Cu	9–13 ppm
Fe	46–78 ppm
Mn	7.5–12 ppm
Zn	3–6 ppm

Traits studied in the field experiment:

Flag Leaf Area (cm^2)

The area of the flag leaf was estimated at the time of full ear emergence by randomly selecting ten flag leaves from the main stems of each experimental plot, then measuring the length of the flag leaf from the base of the blade to its apex and measuring its maximum width at the midpoint of the blade. The flag leaf area was calculated according to the equation cited by Thomas [31], using a correction factor of 0.95, as follows:

Flag leaf area (cm^2) = Flag leaf length (cm) × Maximum leaf width (cm) × 0.95

The average area of the ten flag leaves collected from each experimental unit was then calculated to represent the trait value for that experimental unit.

Total number of tillers (tillers m^{-2}):

The total number of tillers was estimated at harvest by randomly sampling a 0.25 m^2 area within each experimental unit, All plants within the designated area were collected, excluding the main stems that had previously been marked with colored rings and designated for other field measurements ( ), to ensure that the measurement procedures did not interfere with the estimation of this trait. The plants within the designated area were collected manually, then the required measurements were taken, and the resulting values were converted to the number of shoots per square meter (shoots m^{-2}) on a per-square-meter basis using the standard conversion factors followed in cereal crop experiments—a method referred to by Donald and Hamblin [32] for estimating yield traits and components in field crops.

Number of spikes (spikes m^{-2}):

Spike density was estimated when the plants reached full maturity by taking a random sample from an area of 0.25 m^2 from the center rows of each experimental plot to avoid potential edge effects. After the plants reached full maturity, all ears within the specified area were collected and counted manually; the values were then converted to the number of ears per square meter (ear m^{-2}) according to the method described by Donald and Hamblin [32] for estimating grain yield components

by multiplying the number recorded in the sample by a conversion factor of 4, according to the following equation:

Number of spikes (spikes m^{-2}) = number of spikes in 0.25 m^2 × 4

Number of grains per spike (grains per spike $^{-1}$):

The number of grains per spike was estimated at full maturity of the plants. Ten spikes were randomly selected from each experimental plot, ensuring that the spikes were representative of the plants in the plot. The spikes were then threshed by hand, and the grains were extracted, and the grains in each spike were counted individually. The arithmetic mean of the grain counts in the ten ears was then calculated, and this value was adopted as representative of the trait "number of grains per ear

(grains per ear^{-1})" for each experimental unit, in accordance with the method used in grain crop experiments as described by Gomez and Gomez [33].

Weight of 1,000 grains (g):

A random sample of grains was taken from the harvested area of each experimental unit; 1,000 grains were then carefully counted by hand and weighed using a sensitive electronic scale to obtain the average weight of 1,000 grains, in accordance with the method used in cereal crop research as described by Gomez and Gomez [33].

Grain yield (metric tons per hectare)

The grain yield was estimated upon full maturity of the plants; the plants within an area of **0.25 m²**—selected at random from the center lines of each experimental plot—were harvested, , The grains were separated from the straw after threshing, then cleaned and weighed; the weight of the grains used to estimate the weight of 1,000 grains was added to the yield of the same experimental unit to avoid underestimating the total yield. The grain weight obtained from the sample was converted to a yield per square meter, and the values were then converted to **metric tons per hectare**. The grain weights were also corrected to a standard moisture content of **13%**, after measuring the moisture content of the grain using a moisture meter, in accordance with the methods used to estimate grain yield and its components in grain crop experiments as described by Donald and Hamblin [32] and Gomez and Gomez [33].

Characteristics Studied in the Laboratory Experiment:

A representative random sample of the grain yield from each experimental unit was collected after harvest and sent to the laboratories of the College of Pure Sciences at the University of Mosul for the required laboratory analyses and tests. The laboratory study was conducted as **a factorial experiment** using **a completely randomized block design (RCBD)** with three replications, with the aim of studying the effect of two experimental factors—**barley varieties and seaweed extract concentrations**—as well as the interaction between them, in accordance with the methods followed in the design and analysis of agricultural experiments as outlined by **Gomez and Gomez [33]**.

Germination Speed Index (GSI) Assay

The Germination Speed Index (GSI) was calculated using a sample of 200 pure seeds per treatment, distributed across four replicates at a rate of 50 seeds per replicate, using the filter paper roll method. The seeds representing the replicates were then placed in a germination chamber at a temperature of 25 ± 2°C and a relative humidity of approximately 95%. The number of naturally emerging seedlings was recorded daily, starting from the first day of the test through the eighth day, with abnormal seedlings excluded. The Germination Speed Index (GSI) was then calculated based on the number of normal seedlings that emerged on each day of the test, according to the equation specified by the Association of Official Seed Analysts [34]:

GSI = (number of natural seedlings on the first day ÷ 1) + (number of natural seedlings on the second day ÷ 2) + … + (number of natural seedlings on the last day ÷ number of test days)

A higher GSI value indicates faster seed germination and the formation of natural seedlings during the test period, while lower values indicate a slower germination process.

Standard Laboratory Germination Test (%)

The standard laboratory germination percentage was estimated after the 8-day test period by counting the number of natural seedlings formed in each replicate at the end of the test period and then calculating the average across replicates. The germination percentage was calculated using the following equation:

Germination rate (%) = (number of natural seedlings at the end of the test ÷ total number of seeds used in the test) × 100

The evaluation of seedlings was based on their natural characteristics in accordance with the standard rules and procedures adopted for seed germination tests, as recommended by the Association of Official Seed Analysts [34] and the International Seed Testing Association [35].

Mean Germination Time (MGT):

The Mean Germination Time (MGT) was estimated by recording the number of natural seedlings that emerged daily during the testing period; the weighted average germination time was then calculated using the number of days required for seedling emergence. This indicator is an important measure for evaluating germination speed and uniformity, as it reflects the average time required for all seeds to germinate. A low **MGT** value indicates faster seed germination, while a high value indicates a delay in the germination process. The average germination duration was calculated using the equation proposed by **Ellis and Roberts [36]** and adopted by **Latique et al. [23]**:

$$MGT = \Sigma(D \times N) / \Sigma N$$

Where:

- **MGT** = average germination time (days).
- **N** = number of seeds that germinated on day **D**.
- **D** = The day number on which the germinated seeds were recorded.
- **ΣN** = Total number of germinated seeds during the test period.

Statistical analysis

Statistical analysis of the data was performed using **analysis of variance (ANOVA)** according to the approved experimental design, and the arithmetic means of the treatments were compared using the **least significant difference (LSD)** test at a significance level **of 0.05**, as indicated by **Steel et al. [37]**.

Results

Field Experiment

Flag leaf area (cm^2):

The results of the field experiment showed significant differences in the effect of spraying with the seaweed extract Algamix on the flag leaf area of the studied barley varieties, as well as a significant interaction effect between varieties and extract concentrations in both growing seasons, as shown in Table (2). Plants treated with the Algamix extract at a concentration of 5 mL L^{-1} achieved the highest mean flag leaf areas, amounting to 41.21 and 44.13 cm^2, representing increases of 11.46% and 12.28%, respectively, compared to the control treatment in the two growing seasons. This increase in flag leaf area can be attributed to the bioactive compounds, organic matter, and nutrients contained in seaweed extracts, which may contribute to promoting vegetative growth and stimulating cell division and elongation, in addition to their role in improving the plant's efficiency in absorbing and utilizing water and nutrients. This had a positive effect on leaf growth and an increase in leaf area, particularly at the highest extract concentration. This result is consistent with the findings of Abdul-Jabar et al. [14], who noted that the use of seaweed extracts can stimulate plant vegetative growth and contribute to an increase in leaf area, thereby supporting the findings of the current study. Gollan and Wright [38] and Zhang & Wang [39] that foliar spraying with seaweed extract led to an increase in leaf area in wheat plants. This was also demonstrated by Garcia et al. [40]. Foliar spraying with specific concentrations of organic extracts may stimulate the enzymes responsible for cell elongation. Meanwhile, the control treatment recorded the lowest mean flag leaf areas of (37.66 and 39.86) $cm^2$for both seasons, respectively. The varieties used in the study also differed significantly in terms of average flag leaf area. The results in Table 2 indicate significant differences among barley varieties in flag leaf area during the **2024–2025 and 2025–2026** growing seasons. The **Rayhan** variety recorded the highest average flag leaf area, at **43.60 and 45.89 cm^2** in the two seasons, respectively, while the **Furat-9** variety recorded the lowest averages for this trait, at **37.10 and 38.86 cm^2** for the two seasons, respectively. This variation among varieties can be attributed to genetic differences, as the genetic makeup largely controls vegetative growth characteristics, including leaf size and area. Furthermore, varieties differ in their ability to utilize and respond to environmental conditions and agricultural inputs. This finding is

consistent with the observations of Al-Ubaidi [15], Al-Jubouri [41], and Smith and Taylor [42], who noted genetic differences among cereal crop varieties in traits related to growth and leaf area. As for the effect of the interaction between varieties and seaweed extract concentrations, the results showed clear, statistically significant differences in the interaction coefficients, as plants of **the Rayhan** variety treated with a concentration **of 5 mL L^{-1}** achieved the highest flag leaf area, reaching **48.21 cm^2** in the 2025–2026 growing season, compared to **45.50 cm^2** in the 2024–2025 growing season, thereby outperforming the other interaction treatments. In contrast, **the 'Furat-9'** variety plants that were not treated with seaweed extract recorded the lowest flag leaf area values, at **35.96 and 37.21 cm^2** in the two seasons, respectively. The superior performance of the Rayhan variety when treated with a high concentration of seaweed extract may be attributed to its more efficient genetic makeup in responding to the bioactive compounds and nutrients present in the extract, which was reflected in increased leaf growth and a larger flag leaf area. Furthermore, the difference in the varieties' responses to the extract concentrations indicates genetic variation in their ability to utilize growth-promoting substances; consequently, the effect of the seaweed extract was not uniform among the studied varieties. This result supports the findings of Al-Ubaidi [15], Al-Jubouri [41], and Smith and Taylor [42] regarding the genetic variation in varieties' responses to agricultural treatments and its impact on vegetative growth traits.

Table 2. Effect of foliar spraying with seaweed extract on leaf area (cm^2) of four barley varieties.

2024–2025 Growing Season					2025–2026 Growing Season				
Varieties	**Seaweed Extract Concentrations**			**Average**	**Varieties**	**Seaweed Extract Concentrations**			**Average**
	0 mL/L	**3 mL/L**	**5 mL/L**			**0 mL/L**	**3 mL/L**	**5 mL/L**	
Island 1	**37.17 b**	**39.23 b**	**41.17 b**	**39.19 b**	**Island 1**	**39.77 b**	**40.81 b**	**43.67 b**	**41.42 b**
Euphrates -9	**35.96 c**	**37.12 c**	**38.21 d**	**37.10 c**	**Euphrates -9**	**37.21 c**	**38.74 c**	**40.65 c**	**38.86 c**
Basil	**41.23 a**	**44.07 a**	**45.50 a**	**43.60 a**	**Basil**	**42.60 a**	**46.85 a**	**48.21 a**	**45.89 a**
Attended 462	**36.25 bc**	**38.15 bc**	**39.97 c**	**38.13 bc**	**Attended 462**	**39.84 b**	**41.76 b**	**43.98 b**	**41.86 b**
L.S.D. 5%	**1.48**			**0.56**	**L.S.D. 5%**	**1.56**			**0.57**
Average	**37.66 c**	**39.64 b**	**41.21 a**		**Average**	**39.86 c**	**42.04 b**	**44.13 a**	
L.S.D. 5%	**0.97**				**L.S.D. 5%**	**0.97**			

Different letters indicate statistically significant differences at the 5% level; values sharing the same letter are not statistically different

Total number of shoots (shoots m^{-2})

The results of the statistical analysis presented in Table (3) showed statistically significant differences at the 5% probability level among barley varieties and seaweed extract concentrations in terms of total tiller number (tillers m^{-2}) for both growing seasons. The means indicate that foliar spraying with seaweed extract led to a statistically significant increase in the number of spikelets as the extract concentration increased; the concentration of 5 mL L^{-1} recorded the highest mean values of 423.27 and 427.04stems m^{-2} in the 2024–2025 and 2025–2026 seasons, respectively, compared to the control treatment, which recorded 415.95 and 423.36 stems m^{-2}, while the 3 mL L^{-1} concentration ranked in the middle. This effect may be attributed to the bioactive compounds and natural growth regulators present in seaweed extracts, particularly auxins, cytokinins, and gibberellins, as well as amino acids

and nutrients, which can contribute to the activation of cell division and elongation and stimulate the growth of lateral shoots and the formation of stolons. This finding is consistent with the observations of Kumar and Sahoo [43] and Taylor et al. [44], who noted that most seaweed extracts contain natural growth regulators—particularly auxins and cytokinins—along with compounds and nutrients that contribute to improved vegetative growth. It also aligns with the findings of Khan et al. [8], who noted that these extracts can stimulate vegetative activity and tillering. The results showed significant differences among the varieties in total tillering, with the Rayhan variety significantly outperforming the other varieties in both seasons, recording the highest averages of (428.09 and 433.36) shoots m^{-2} for the first and second seasons, respectively, while the Furat-9 variety recorded the lowest averages of (414.14 and 420.66) shoots m^{-2} respectively. This variation can be attributed to genetic differences among the varieties in their ability to produce tillers and the response of lateral shoots to environmental conditions and agricultural practices, as well as differences in the efficiency of physiological and enzymatic processes and growth regulators associated with tiller formation and growth. Since the varieties possess different genetic compositions that determine their ability to utilize growth-promoting factors, this leads to a clear difference in the number of suckers formed. This result is consistent with the findings of Kasim et al. [22] and Khan et al. [8]. regarding the existence of varietal differences in growth traits and response to stimulating treatments. Furthermore, the interaction between varieties and seaweed extract concentrations had a significant effect on the total number of shoots for both study seasons. When sprayed with a concentration of 5 mL L^{-1}, the Rayhan variety achieved the highest values of (433.13 and 435.14) shoots m^{-2} in the two seasons, respectively, while the control treatment for the Furat-9 variety recorded the lowest values of (412.50 and 418.73) shoots m^{-2}. This indicates that the varieties exhibit different responses to the seaweed extract, and that the efficiency of the response depends not only on the extract concentration but is also influenced by the variety's genetic makeup and its physiological ability to utilize the stimulating compounds present in the extract. This response contributed to increased tillering, particularly at high concentrations, which was most clearly reflected in the Rayhan variety. This result is consistent with the findings of Craigie [16]. Blum [45] noted that the use of seaweed extracts can improve vegetative growth and promote tillering in cereal crops, which confirms the potential of these extracts as bio-stimulants that support barley growth and improve its growth parameters.

Table 3. Effect of foliar spraying with seaweed extract on total tillering (tillers $^{m-2}$) for four barley varieties.

2024–2025 Growing Season					2025–2026 Season				
Varieties	**Seaweed Extract Concentrations**			**Average**	**Varieties**	**Seaweed Extract Concentrations**			**Average**
	0 mL/L	**3 mL/L**	**5 mL/L**			**0 mL/L**	**3 mL/L**	**5 mL/L**	
Al Jazeera 1	**415.29 c**	**417.50 b**	**419.13 a**	**417.31 b**	**Al Jazeera 1**	**422.61 c**	**424.13 b**	**425.44 a**	**424.06 b**
Euphrates -9	**412.50 c**	**414.44 b**	**415.49 a**	**414.14 c**	**Euphrates -9**	**418.73 c**	**420.08 b**	**423.16 a**	**420.66 b**
Basil	**423.95 c**	**427.20 b**	**433.13 a**	**428.09 a**	**Basil**	**431.33 c**	**433.61 b**	**435.14 a**	**433.36 a**
Attended: 462	**412.08 c**	**418.48 b**	**425.33a**	**418.63 b**	**Attended: 462**	**420.78 c**	**422.99 b**	**424.43 a**	**422.73 b**
L.S.D. 5%	**2.08**			**2.40**	**L.S.D. 5%**	**2.31**			**2.65**
Average	**415.95 c**	**419.41 b**	**423.27 a**		**Average**	**423.36 c**	**425.21 b**	**427.04 a**	
L.S.D. 5%	**3.60**				**L.S.D. 5%**	**3.95**			

Different letters indicate statistically significant differences at the 5% level; values sharing the same letter are not statistically different

Number of spikes (spike m^{-2})

The results in Table (4) indicate a clear, statistically significant increase in the arithmetic means of the number of spikes per square meter as the concentration of the seaweed extract in the foliar spray increased, due to the effects of the two main factors and their interaction in both growing seasons. Barley plants sprayed with seaweed extract at a concentration of 5 mL/L significantly outperformed the control treatment in both seasons, achieving the highest means for this trait at (362.43 and 365.66) spikes m^{-2}, with increase rates of 4.60% and 4.41% for the first and second seasons, respectively, compared to the control treatment, which recorded the lowest averages of 346.53 and 350.21 spikes m^{-2}. The increase in the number of spikelets on barley plants resulting from spraying with seaweed extract may be attributed to its positive effects on the plant's physiological processes, due to the presence of plant hormones in these extracts, such as auxins and cytokinins, as well as nutrients that play a vital role in stimulating cell division and increasing the number of basal branches, in addition to their role in promoting root system growth, which positively contributes to an increase in the number of final spikes. This was found by researchers O'Dell [20], Craigie [16], and Crouch and Van Staden [46], Zodape et al. [47] also demonstrated that foliar spraying with these extracts contributes to increased photosynthetic efficiency and dry matter accumulation, thereby reducing tiller death and leading to an increase in the number of spikes. The results also showed that the Rayhan variety significantly outperformed the other varieties in terms of the number of spikes in both seasons, achieving the highest averages for this trait at (364.96 and 368.73) spikes m^{-2} , whereas plants of the Furat-9 variety recorded the lowest averages of (343.64 and 346.91) spikes m^{-2} for the first and second seasons, respectively. This variation in the number of spikes among varieties may be attributed to genetic differences between them, as well as the influence of environmental conditions and the high ability of the Rayhan variety to produce tillers and retain them until the spike formation stage. This result is consistent with the findings of other researchers, including Al-Azawi [48]. Smith and Taylor [42]. The results of the interaction between concentrations and varieties showed that plants of the Rayhan variety treated with seaweed extract at a concentration of 5 mL/L in terms of the number of spikes $per\ m^2$, indicating the effectiveness of this concentration in improving this trait, as it achieved the highest averages of (370.59 and 373.59) spikes $per\ m^2$ in the first and second seasons, respectively, compared to the control treatment. Meanwhile, plants of the Furat-9 variety sprayed with distilled water alone recorded the lowest averages for this trait, at (336.64 and 340.62) spikes $m^{-2}$for both seasons, respectively. These results indicate that the response of varieties to biostimulants (biostimulants) varies depending on their genetic makeup and their ability to utilize these substances, as seaweed extracts improve the plant's nutritional status, thereby reducing competition among shoots for nutrients and improving their chances of survival and development into full ears—a finding also noted by Spinelli et al. [49].

Table 4. Effect of foliar spraying with seaweed extract on the number of ears (ears $per\ m^2$) for four barley varieties.

2024–2025 growing season					2025–2026 Season				
Varieties	**Seaweed extract concentrations**			**Average**	**Varieties**	**Seaweed extract concentrations**			**Medium**
	0 mL/L	**3 mL/L**	**5 mL/L**			**0 mL/L**	**3 mL/L**	**5 mL/L**	
Al Jazeera 1	**347.05 g**	**353.77 e**	**364.64 b**	**355.15 b**	**Al Jazeera 1**	**348.15 e**	**361.47 c**	**365.01 bc**	**358.21 b**
Euphrates -9	**336.64 i**	**344.66 h**	**349.61 f**	**343.64 c**	**Euphrates -9**	**340.62 f**	**347.68 e**	**352.42 d**	**346.91 c**
Rihan	**359.05 c**	**365.14 b**	**370.59 a**	**364.96 a**	**Rihan**	**364.73 b**	**367.86 ab**	**373.59 a**	**368.73 a**

Attended: 462	**343.26 h**	**352.40 f**	**364.86 b**	**353.51 b**	**Attended: 462**	**347.33 e**	**358.02 d**	**371.60 ab**	**358.98 b**
L.S.D. 5%	**1.42**			**1.64**	**L.S.D. 5%**	**1.56**			**1.80**
Average	**346.53 c**	**353.99 b**	**362.43a**		**Average**	**350.21 c**	**358.76 b**	**365.66 a**	
L.S.D. 5%	**2.84**				**L.S.D. 5%**	**3.12**			

Different letters indicate statistically significant differences at the 5% level; values sharing the same letter are not statistically different

Number of grains per spike (grains per spike $^{-1}$)

The results in Table (5) showed that the treatment with Algamix seaweed extract at a concentration of 5 mL L^{-1} significantly outperformed the control in terms of the number of grains per spike for both seasons, respectively, as the barley plants achieved the highest means for this trait at (39.51 and 42.85) grains per spike^{-1}, with increases of 3.00% and 2.71%, respectively, compared to the control treatment, which recorded the lowest averages of 38.36 and 41.72 grains per spike^{-1} for the first and second seasons, respectively. This superiority may be attributed to the findings of Battacharyya et al. [50], who reported that seaweed extracts contain active compounds, such as phytohormones, that improve growth and productive traits, in addition to the micronutrients contained in these extracts, which contribute to enhancing photosynthetic efficiency and regulating the distribution of synthesized substances between the source and sink, particularly during the initiation and development of grain formation sites, leading to an increase in grain number. This is consistent with the findings of Ali et al. [24]. Furthermore, plant hormones and certain minerals found in marine algae extracts, such as B, Mn, Mg, and K, play an important role in promoting root growth, improving nutrient uptake efficiency, stimulating cell division, and enhancing growth, which positively affects crop yield components, as demonstrated by Colla [7], Craigie [16], and Calvo et al. [51]. In addition, boron plays a crucial role in the formation of pollen tube cells in plants, which significantly affects the success rate of fertilization and grain formation, as confirmed by Kasim et al. [22] and Nelson and Staden [52]. As can be seen from the results in Table (5), there are significant differences among barley varieties in the average number of grains per spike; plants of the Hadar 462 variety recorded the highest averages for this trait, at (40.48 and 44.10) grains per spike, while plants of the Euphrates-9 variety recorded the lowest averages, at (38.34 and 40.89) grains per spike for the first and second growing seasons, respectively. This may be attributed to genetic differences between the varieties, as the Hadar 462 variety may possess a genetic makeup that gives its flowers a greater capacity for fertilization and seed formation compared to the other varieties; this result is consistent with the findings of Yakhin et al. [11] and Kumar and Sahoo [43]. Regarding the interaction effect between varieties and seaweed extract treatment concentrations, the results showed no significant difference in the number of grains per spikelet for either season.

Table 5. Effect of foliar spraying with seaweed extract on the number of grains per spike ( ) for four barley varieties.

2024–2025 Growing Season					2025–2026 Season				
Varieties	**Seaweed Extract Concentrations**			**Average**	**Varieties**	**Seaweed Extract Concentrations**			**Medium**
	0 mL/L	**3 mL/L**	**5 mL/L**			**0 mL/L**	**3 mL/L**	**5 mL/L**	
Al Jazeera 1	**38.42 c**	**38.44 c**	**38.46 °C**	**38.44 °C**	**Al Jazeera 1**	**41.75 c**	**41.36 c**	**42.21 b**	**41.77 c**
Euphrates - 9	**38.14 c**	**38.35 c**	**38.53 c**	**38.34 c**	**Euphrates - 9**	**40.30 d**	**40.62 d**	**41.76 c**	**40.89 d**
Basil	**38.22 c**	**39.50 b**	**39.59 b**	**39.10 b**	**Basil**	**41.66 c**	**43.33 b**	**42.49 b**	**42.49 b**

Attendance : 462	**38.68 c**	**41.28 a**	**41.48 a**	**40.48 a**	**Attendance : 462**	**43.18 b**	**44.18 a**	**44.94 a**	**44.10 a**
L.S.D. 5%	**0.21**			**0.24**	**L.S.D. 5%**	**0.25**			**0.29**
Average	**38.36 c**	**39.39 b**	**39.51 a**		**Average**	**41.72 c**	**42.37 b**	**42.85 a**	
L.S.D. 5%	**0.53**				**L.S.D. 5%**	**0.60**			

Different letters indicate statistically significant differences at the 5% level; values sharing the same letter are not statistically different

Weight of 1,000 tablets (g)

The results in Table (6) showed significant differences among the spray concentrations of the Algamix seaweed extract in terms of the weight of 1,000 seeds; the spray treatment at a concentration of 5 mL/L significantly outperformed the control treatment in both seasons, and recorded the highest means for this trait at (37.40 and 38.94) g, representing increases of (7.16% and 6.48%) compared to the control treatment, which recorded the lowest means at (34.90 and 36.57) g for the first and second seasons, respectively. This superiority may be attributed to the fact that the seaweed extract contains bioactive compounds, as well as macro- and micronutrients, plant growth regulators, and amino acids, which can contribute to improving the efficiency of plant physiological processes and increasing the efficiency of carbon fixation, as well as improving the transport of photosynthetic products from their sites of synthesis—particularly the flag leaf—to the grains, which serve as their destination during the grain-filling stage, leading to increased dry matter accumulation and higher grain weight. These results are consistent with the findings of Yakhin et al. [11], who noted that bio-stimulants promote plant growth and improve nutrient uptake efficiency. Rouphael et al. [7] also confirmed that the use of marine algae extracts can contribute to improved plant growth and productivity. The results also showed significant differences among barley varieties in 1,000-kernel weight, with plants of the Rayhan variety significantly outperforming the other varieties; recording the highest averages for this trait at 38.18 and 39.49 g, while plants of the Furat-9 variety recorded the lowest averages at 35.80 and 36.34 g for the first and second seasons, respectively. These differences among varieties may be attributed to genetic variation in growth efficiency and the formation and distribution of photosynthetic products, as well as differences in their response to prevailing environmental conditions. Furthermore, leaf efficiency—particularly that of the flag leaf—plays an important role in providing the nutrients necessary for grain filling, as the Rayhan variety surpassed the other varieties in terms of flag leaf area (Table 2), which may have contributed to an increase in the amount of substances synthesized and transported to the grains, thereby increasing their weight. These results are consistent with those reported by Al-Ubaidi [15], Kumar [53], Taylor et al. [44], and Al-Jubouri [41]. The results of the interaction between varieties and seaweed extract concentrations showed that basil plants sprayed with Algamix extract at a concentration of 5 mL L^{-1} outperformed the other varieties in terms of the weight of 1,000 seeds, recording the highest means of (40.17 and 41.91) g for the first and second growing seasons, respectively, while plants of the Furat-9 variety treated with water alone recorded the lowest averages for this trait at (34.52 and 35.57) g for the two growing seasons, respectively. This indicates a variable response of the varieties to the seaweed extract, as the combination of the genetic potential of the Rayhan variety with treatment at a high level of the extract contributed to improved growth and the provision of the photosynthetic products necessary for grain filling, which had a positive effect on the 1,000-grain weight.

Table 6. Effect of foliar spraying with seaweed extract on the 1,000-grain weight (g) of four barley varieties.

2024–2025 growing season			2025–2026 Season		
Varieties	**Seaweed Extract Concentrations**	**Average**	**Products**	**Seaweed Extract Concentrations**	**Average**

	0 mL/L	3 mL/L	5 mL/L			0 mL/L	3 mL/L	5 mL/L	
Island 1	**34.75 d**	**36.65 c**	**36.82 c**	**36.07 b**	**Island 1**	**36.43 c**	**36.25 c**	**37.71 bc**	**36.80 bc**
Euphrates - 9	**34.52 d**	**35.59 cd**	**35.80 cd**	**35.31 c**	**Euphrates - 9**	**35.57 d**	**36.65 c**	**36.81 c**	**36.34 c**
Basil	**35.76 cd**	**38.62 b**	**40.17 a**	**38.18 a**	**Basil**	**37.76 bc**	**38.81 b**	**41.91 a**	**39.49 a**
Attendance: 462	**34.59 d**	**35.60 cd**	**36.81 c**	**35.66 bc**	**Attendance: 462**	**36.51 c**	**36.55 c**	**39.32 b**	**37.46 b**
L.S.D. 5%	**0.59**			**0.51**	**L.S.D. 5%**	**0.62**			**0.54**
Average	**34.90 c**	**36.62 b**	**37.40 a**		**Average**	**36.57 b**	**37.07 b**	**38.94 a**	
L.S.D. 5%	**1.02**				**L.S.D. 5%**	**1.08**			

Different letters indicate statistically significant differences at the 5% level; values sharing the same letter are not statistically different

Grain Yield (t/ha)

The results presented in Table (7) indicate the presence of statistically significant differences between the mean concentrations of the different seaweed extracts, as well as between barley varieties, in addition to a statistically significant interaction between the two study factors. This suggests that the varieties responded differently to the concentrations used in terms of grain yield for both growing seasons. The results showed that spraying with a concentration of 5 mL L^{-1} of seaweed extract achieved a statistically significant increase in grain yield compared to the other two concentrations, with the highest mean values for this trait (4.17 and 4.52) metric tons per hectare in the first and second seasons, respectively, with increase rates of (10.90 and 10.24%) compared to the control treatment of 0.0 mL/L, which recorded the lowest averages of (3.76 and 4.10) metric tons per hectare, respectively. Meanwhile, the 3 mL L^{-1} concentration yielded averages of (4.08 and 4.34) metric tons ha^{-1} for the two growing seasons, indicating a gradual response of the barley plants as the concentration of the seaweed extract increased. This superior performance may be due to the fact that plants treated with a concentration of 5 mL/L showed superior performance in some yield components, particularly the number of grains per spike (Table 5) and the weight of 1,000 grains (Table 6), which had a positive impact on grain yield. This can be explained by the presence of bioactive compounds and growth regulators in seaweed extracts, such as auxins and cytokinins, as well as micronutrients, which can contribute to improving photosynthetic efficiency, increasing growth and leaf area, and enhancing nutrient transport and grain filling, ultimately leading to increased yield, as confirmed by Craigie [16]. The results in Table (7) also showed significant differences among the varieties, with the Rayhan variety significantly outperforming the others, achieving the highest average grain yields of (4.42 and 4.61) metric tons ha^{-1} in the first and second seasons, respectively, followed by the Hadar 462 variety with averages of (3.90 and 4.42) metric tons ha^{-1}, then the Al-Jazira 1 variety, while the Furat-9 variety recorded the lowest averages of (3.49 and 3.87) metric tons ha^{-1} for the two seasons, respectively. The superiority of the Rayhan variety can be attributed to its superior performance in certain yield-related traits, including leaf area (Table 2), number of grains per spike (Table 5), and 1,000-grain weight (Table 6), which provided it with a greater capacity for yield formation and grain filling. This may also indicate that the 'Rihan' variety possesses a genetic makeup that is more efficient in utilizing available resources, adapting to environmental conditions, and responding to biotic and physiological factors, which positively impacted grain yield. This result is consistent with the findings of Al-Ubaidi [15], Kumar and Sahoo [43], and Craigie [16], as well as the Food and Agriculture Organization's statement that genetic differences among varieties are a key factor in determining crop productivity. As for the interaction between varieties and seaweed extract spray concentrations, the results in Table 7 showed that treating

plants of the Rayhan variety with a concentration of 5 mL L^{-1} yielded the highest grain yield, reaching (4.64 and 4.82) metric tons ha^{-1} in the first and second seasons, respectively, whereas plants of the Furat-9 variety treated with water alone recorded the lowest values, at (3.36 and 3.75) metric tons per hectare, respectively. This interaction is a clear indication of differences among barley varieties in their response to spraying with seaweed extract, as the degree of response may vary depending on differences in the genetic makeup and the variety's physiological ability to utilize the extract's components. This underscores the importance of the interaction between the plant's genetic makeup and the type of treatment in determining yield levels, as noted by Khan et al. [8].

Table 7. Effect of foliar spraying with seaweed extract on grain yield (metric tons per hectare) for four barley varieties.

2024–2025 growing season					2025–2026 Season **4.52**				
Varieties	**Seaweed extract concentrations**			**Average**	**Varieties**	**Seaweed extract concentrations**			**Average**
	0 mL/L	**3 mL/L**	**5 mL/L**			**0 mL/L**	**3 mL/L**	**5 mL/L**	
Island 1	**3.91 d**	**4.28 c**	**4.44 b**	**4.21 b**	**Island 1**	**4.19 d**	**4.37 c**	**4.56 b**	**4.37 b**
Euphrates -9	**3.36 f**	**3.51 e**	**3.59 a**	**3.49 d**	**Euphrates -9**	**3.75 f**	**3.82 e**	**4.04 d**	**3.87 d**
Basil	**4.06 c**	**4.55 b**	**4.64 a**	**4.42 a**	**Basil**	**4.27 c**	**4.74 b**	**4.82 a**	**4.61 a**
Attended: 462	**3.70 e**	**3.97 d**	**4.03 cd**	**3.90 c**	**Attended: 462**	**4.19 d**	**4.43 c**	**4.65 b**	**4.42 b**
L.S.D. 5%	**0.038**			**0.044**	**L.S.D. 5%**	**0.032**			**0.037**
Average	**3.76 c**	**4.08 b**	**4.17 a**		**Average**	**4.10 c**	**4.34 b**	**4.52 a**	
L.S.D. 5%	**0.076**				**L.S.D. 5%**	**0.064**			

Different letters indicate statistically significant differences at the 5% level; values sharing the same letter are not statistically different

Second: Laboratory Experiment:

Germination Speed Test

The results presented in Table (8) indicate a clear, statistically significant effect of seaweed extract concentrations and varieties, as well as a statistically significant interaction between them on the germination rate index, reflecting the physiological role of natural extracts in improving seed vitality and germination efficiency. The results indicate that increasing the concentration of the seaweed extract led to a statistically significant increase in the germination rate index in both seasons, as seeds from barley plants treated with a concentration of 5 mL L^{-1} recorded the highest means for this trait at (28.62 and 30.89), representing increases of 31.49% and 33.09%, respectively, compared to the control treatment (0.0 mL/L), which recorded the lowest averages (21.77 and 23.21) for the first and second seasons, respectively. Meanwhile, the 3 mL/L concentration yielded averages of (24.55 and 25.98), indicating a positive, gradual response as the extract concentration increased. This improvement may be attributed to the vital role of seaweed extracts in enhancing the physiological condition of the parent plant, which is reflected in the quality of the resulting seeds, their vitality, and their ability to germinate rapidly. These extracts contain bioactive compounds, natural growth regulators, and nutrients that can contribute to improving photosynthetic efficiency, increase the accumulation of metabolites and reserve substances in the grains, and enhance the efficiency of metabolic processes associated with seed formation and maturation, leading to the production of more viable seeds with a higher capacity for rapid germination. This finding is consistent with the results reported by Amabika and Sujatha [54] and Latique et al. [23]. It was also confirmed by Alaila & Elsalhin [55] and Rabhi et al. [56]. and by Ali, Ramsubhag, and Jayaraman [57]. Seaweed extracts can significantly improve seed germination and

seedling growth due to their content of natural growth regulators and growth-promoting compounds.The positive effect of seaweed extracts may also be linked to the interaction of genetic factors with environmental conditions, as the active compounds in the extract can contribute to enhancing the enzymatic activity associated with the initiation of germination and stimulating the rate of radicle emergence and seedling growth, which is reflected in a higher germination rate index, as noted by Deolu-Ajayi et al. [58]. The results also showed significant differences among barley varieties in the germination rate index (Table 8), with seeds of the Rayhan variety achieving the highest averages for this trait (27.56 and 29.53), while seeds of the Furat-9 variety recorded the lowest averages (22.77 and 24.48) for the first and second seasons, respectively. The superiority of the Rayhan variety can be attributed to its distinctive yield components, including a high 1,000-seed weight (Table 6), which may indicate an increase in the quantity and quality of nutrients stored in the grains, thereby providing greater energy sources during the early stages of germination. Furthermore, the high content of reserve substances in the seeds helps improve water absorption and stimulate the metabolic processes necessary for the initiation of germination and the continued growth of the seedling, giving the seeds of this variety a greater capacity for rapid germination compared to other varieties. These results are consistent with the findings of Khan et al. [8] and Latique et al. [23]. regarding a positive relationship between seed weight and reserve substance content on the one hand, and germination rate and seedling vigor on the other. As for the interaction between varieties and seaweed extract concentrations, the results showed a significant effect, as seeds of the "Basil" variety treated with a concentration of 5 mL L^{-1} outperformed the others, and recorded the highest average germination rates of (31.36 and 34.41) for the first and second seasons, respectively, while seeds from the "Furat-9" variety treated with distilled water alone recorded the lowest averages of (19.96 and 21.24) for both seasons, respectively, This indicates that the response to the seaweed extract was not uniform across varieties but was influenced by the variety's genetic makeup and its ability to utilize the active compounds present in the extract; the combination of the Rayhan variety and the high concentration enhanced seed vitality and increased their ability to germinate more rapidly. This result supports findings from recent studies indicating a positive effect of seaweed extracts on improving the speed and rate of barley seed germination, particularly when appropriate concentrations are used, as reported by Deolu-Ajayi et al. [58] and Scientia Horticulturae [59].

Table 8. Effect of foliar spraying with seaweed extract on the germination rate of seeds from four barley varieties.

2024–2025 Growing Season					2025–2026 Season				
Varieties	**Seaweed extract concentrations**			**Average**	**Products**	**Seaweed extract concentrations**			**Average**
	0 mL/L	**3 mL/L**	**5 mL/L**			**0 mL/L**	**3 mL/L**	**5 mL/L**	
Al Jazeera 1	**21.44 c**	**24.08 b**	**29.06 a**	**24.86 b**	**Al Jazeera 1**	**23.21 c**	**25.02 b**	**30.18 a**	**26.14 b**
Euphrates - 9	**19.96 c**	**22.73 b**	**25.62 a**	**22.77 c**	**Euphrates - 9**	**21.24 c**	**24.64 b**	**27.56 a**	**24.48 c**
Basil	**24.16 c**	**27.17 b**	**31.36 a**	**27.56 a**	**Basil**	**25.19 c**	**29.00 b**	**34.41 a**	**29.53 a**
Attendance: 462	**21.52 c**	**24.21 b**	**28.46 a**	**24.73 b**	**Attendance: 462**	**23.18 c**	**25.25 b**	**31.43 a**	**26.62 b**
L.S.D. 5%	**0.62**			**0.71**	**L.S.D. 5%**	**0.68**			**0.77**
Average	**21.77 c**	**24.55 b**	**28.62 a**		**Average**	**23.21 c**	**25.98 b**	**30.89 a**	
L.S.D. 5%	**1.23**				**L.S.D. 5%**	**1.33**			

Different letters indicate statistically significant differences at the 5% level; values sharing the same letter are not statistically different

Germination Rate (%)

The results presented in Table (9) showed a clear, statistically significant effect of foliar spraying with seaweed extract on the standard in vitro germination rate (%) of barley seed varieties, as well as statistically significant differences among varieties and an interaction between the two study factors in both seasons (2024–2025 and 2025–2026). Seeds from barley plants treated with a concentration of 5 mL L^{-1} outperformed the others significantly, and recorded the highest means for this trait (94.91% and 94.98%) for the first and second seasons, respectively, compared to the control treatment (0 mL/L), which recorded the lowest means (89.67% and 90.33%). Meanwhile, the 3 mL/L concentration yielded averages of (92.98 and 93.97%), indicating a positive response of the barley plants to the increased concentration of the seaweed extract.This improvement in germination rate can be explained by the biological role of seaweed extracts as biostimulants, as they contain natural growth regulators such as auxins, cytokinins, and gibberellins, as well as amino acids and micronutrients, They also contain bioactive compounds such as oligosaccharides and sugar alcohols, including mannitol, which can help regulate cellular signaling pathways associated with the initiation of germination and stimulate the gene expression of enzymes necessary for the breakdown of stored substances in seeds, thereby positively affecting germination efficiency and seed vitality ([10]; Ali et al. [24]. This may accelerate the breakdown of stored nutrients, particularly starch, by activating the enzyme amylase, as well as improving water uptake efficiency and stimulating physiological processes within the seeds, thereby contributing to higher germination rates ([8,16]. The superior performance observed at a concentration of 5 mL L^{-1} can also be attributed to the extract's ability to improve the oxidative balance in seeds during the imbibition stage—a critical phase at the onset of germination— by enhancing the efficiency of antioxidant systems and increasing the activity of certain enzymes such as CAT and SOD, thereby reducing oxidative damage and preserving the integrity of embryonic cells and tissues, and consequently creating better conditions for the initiation and continuation of germination (El Boukhari et al. [9]; Bulgari et al. [19]. The improvement in the physiological traits of barley plants treated with the extract may play an indirect role in enhancing the quality of the resulting seeds, as treatment with the seaweed extract contributed to an increase in flag leaf area (Table 2), which may increase the efficiency of solar radiation interception and rates of photosynthesis, as well as enhance the transport of photosynthetic products from the leaves (as the source) to the grains (as the sink) during the stages of grain formation and filling. Consequently, increased accumulation of metabolites in the grains may contribute to the production of seeds with higher vitality and germination capacity. These results are consistent with those reported by Sujatha and Amabika [54] and Latique et al. [23]. The results in Table (9) also showed significant differences among barley varieties in standard laboratory germination rates, with the seeds of the Rayhan variety significantly outperforming the other varieties, and recorded the highest averages (95.01% and 95.45%) in the first and second seasons, respectively, while the "Furat-9" variety recorded the lowest averages (90.17% and 91.60%). This variation can be attributed to genetic differences among the varieties in seed vigor and physiological efficiency, and the associated differences in the rate of reactivation of metabolic processes and enzymes following water uptake, as well as the efficiency of stored nutrient utilization. Studies indicate that seed vigor is related to the seed's ability to regulate genetic and metabolic processes associated with germination and to withstand initial stresses [60,61]. Furthermore, the superiority of the 'Rihyan' variety in 1,000-seed weight (Table 6) may play a role in the higher vitality and vigor of the seeds it produces, in addition to its superior germination rate index (Table 8), indicating that its seeds possess greater efficiency in initiating and sustaining the physiological processes necessary for germination. Thus, the higher seed weight and availability of reserve substances, along with rapid germination, may have contributed to a higher laboratory germination rate compared to the other varieties. As for the interaction between varieties and seaweed extract spray concentrations, the results indicated a clear significant effect: seeds from plants of the "Reihan" variety treated with a concentration of 5 mL/L achieved the highest germination rates (97.96% and 98.09%) for the first and second seasons, respectively. This can be attributed to

differences in the varieties' ability to utilize the bioactive compounds present in the extract, as not all genotypes respond to bioactive stimuli to the same degree—a phenomenon known as a "genotype-dependent response," which varies depending on the plant's genetic background, as confirmed by [51] and [7]. This result is consistent with the findings of Jannin et al. [62], who found that the use of seaweed extracts can contribute to improving seed germination and increasing metabolic activity by stimulating growth-related processes, as well as enhancing the activity of certain enzymes—including amylase—which accelerate the breakdown of nutrients stored within the seed. Du Du Jardin [6] noted that seaweed extracts are important bio-stimulants that can promote plant growth and development in the early stages. Furthermore, the effect of these extracts may be linked to improved water-use efficiency within the seeds by influencing cell membrane permeability and regulating turgor pressure, which may accelerate radicle emergence and increase the likelihood of successful germination. These extracts may also help enhance the seeds' ability to cope with early stresses by stimulating certain stress-related proteins, thereby providing better protection for embryonic tissues during the early stages of germination [63].On the other hand, seeds from plants of the Furat-9 variety treated with water alone recorded the lowest value in the first season, at 88.15%, while seeds from plants of the Hadhar 462 variety treated with water alone recorded the lowest value in the second season, at 90.12%. This confirms that the effect of spraying was not uniform across varieties, and that genetic differences in seed vitality and physiological efficiency, along with their level of response to the seaweed extract, contributed to determining the final germination rate for each variety.

Table 9. Effect of foliar spraying with seaweed extract on the germination rate (%) of seeds produced from four barley varieties.

2024–2025 growing season					2025–2026 Season				
Varieties	**Seaweed extract concentrations**			**Average**	**Varieties**	**Seaweed extract concentrations**			**Average**
	0 mL/L	**3 mL/L**	**5 mL/L**			**0 mL/L**	**3 mL/L**	**5 mL/L**	
Al Jazeera 1	**89.43 c**	**93.91 b**	**95.36 a**	**92.90 b**	**Al Jazeera 1**	**89.18 c**	**93.28 b**	**94.46 a**	**92.31 c**
Euphrates -9	**88.15 d**	**90.34 c**	**92.03 b**	**90.17 d**	**Euphrates -9**	**90.30 c**	**91.92 b**	**92.59 b**	**91.60 d**
Basil	**91.64 b**	**95.43 a**	**97.96 a**	**95.01 a**	**Basil**	**91.72 b**	**96.55 a**	**98.09 a**	**95.45 a**
Attended 462	**89.45 d**	**92.23 b**	**94.28 a**	**91.99 c**	**Attended 462**	**90.12 c**	**94.10 a**	**94.79 a**	**93.00 b**
L.S.D. 5%	**0.74**			**0.85**	**L.S.D. 5%**	**0.69**			**0.80**
Average	**89.67 c**	**92.98 b**	**94.91 a**		**Average**	**90.33 c**	**93.97 b**	**94.98 a**	
L.S.D. 5%	**1.47**				**L.S.D. 5%**	**1.39**			

Different letters indicate statistically significant differences at the 5% level; values sharing the same letter are not statistically different

Average Germination Time (days)

The results in Table (10) of this study indicate a clear, statistically significant effect of foliar spraying with seaweed extract on the average germination time of barley seeds during the two study seasons, as well as statistically significant differences among concentrations, varieties, and their interactions. Treatment with seaweed extract reduced the average germination time—that is, accelerated the onset of germination—compared to the control treatment, indicating the positive role of these extracts in stimulating the physiological and metabolic processes associated with the onset of

germination.Regarding the effect of extract concentrations, the results showed that increasing the concentration led to a statistically significant decrease in the average germination time; seeds from plants treated with a concentration of 5 mL L^{-1} recorded the lowest averages for this trait, at (5.21 and 4.92) days for the first and second seasons, respectively, compared to the control treatment (0 mL/L), which recorded the highest averages of (6.35 and 6.25) days. Meanwhile, the 3 mL/L concentration recorded averages of (5.61 and 5.72) days for the two seasons, respectively. This indicates that increasing the extract concentration within the ranges used in the study contributed to improving seed viability and accelerating the processes necessary for germination to begin, thereby shortening the time required for seedlings to emerge. This effect may be attributed to the fact that seaweed extracts contain a number of bioactive compounds, including growth regulators, organic compounds, and minerals, which can help stimulate cell division and increase the enzymatic activity responsible for breaking down nutrients stored in the seed, thereby providing the energy necessary for embryo growth and accelerating the germination process [16] and [8]. These compounds may also contribute to improving water uptake by seeds, which is the essential step that initiates the series of physiological processes leading to germination [64].These results are consistent with the findings of Calvo et al. [51], who noted that the use of bio-stimulants, including seaweed extracts, at appropriate concentrations can improve germination rate and reduce the time required for seedling emergence. In contrast, the control treatment (0 mL/L) recorded the longest germination times, at (6.35 and 6.25) days for the first and second seasons, respectively. This may indicate a relative decrease in the vitality and performance of seeds produced by plants not treated with the extract, causing them to require a longer period to initiate germination. Germination rate may also be related to seed size and the amount of reserve nutrients stored within them, as larger seeds with higher reserve nutrient content often have a greater capacity to provide the energy necessary for embryo growth during the early stages of germination, which is reflected in the speed of radicle emergence [65]. As for the effect of varieties, the results showed significant differences among barley varieties in the average germination duration (Table 10), with the Rayhan variety outperforming the others and recording the lowest averages for this trait at 5.30 and 5.05 days for the first and second seasons, respectively, while the Furat-9 variety recorded the highest averages at 6.30 and 6.22 days. The shorter germination duration of the Rayhan variety's seeds indicates higher vitality, vigor, and the ability to rapidly resume metabolic activity after water absorption, which positively impacted its performance during the germination stages. Furthermore, the clear variation among varieties confirms the existence of genetic differences in seed traits, vitality, and responsiveness to various environmental conditions and treatments. The results in Table (10) also show a significant interaction effect between seaweed extract concentrations and varieties, as the response of the varieties varied depending on the concentration of the extract used. Some treatments of the Rehan variety, particularly at concentrations of 3 and 5 mL L^{-1}, showed a clear reduction in the average germination time; the lowest average in the first season (4.94 days) was observed at a concentration of 5 mL L^{-1}, while in the second season (4.49 days) it was observed under the same treatment. This indicates a synergistic effect between the variety's genetic makeup and the extract concentration, and that the efficiency of the response to bioactive stimulants may vary from one variety to another depending on the degree of sensitivity of its tissues and physiological components to the active compounds present in the extract. Sharma et al. [66] noted that the response of seeds to growth regulators and stimulants depends largely on their intrinsic sensitivity to these compounds, which may vary depending on genetic makeup. The variation in response among varieties can also be explained by the fact that the bioactive compounds present in seaweed extracts—including organic compounds, sugars, and minerals—may interact to varying degrees with physiological processes within the seeds, thereby affecting enzyme activity, cell division, and radicle elongation, and consequently on the time required for germination to begin and be completed. Thus, the reduction in the average germination time in the treatments using seaweed extract, particularly at a concentration of 5 mL L^{-1}, represents an additional indication of improved seed viability in the treated plants.Overall, the results of the laboratory experiment indicate that the use of seaweed extract, particularly at a concentration of 5 mL/L, contributed to improving a number of seed quality traits and vigor by increasing the germination rate index and germination percentage and reducing the average germination time. The results also

revealed clear differences among the genotypes in their response to the spraying treatments, as the 'Rehan' variety exhibited better performance in most yield traits and seed vigor compared to the other varieties, confirming the importance of the interaction between genetic makeup and treatment with bio-stimulants in improving crop and seed performance.Based on these findings, it is recommended to cultivate the "Rihyan" variety and spray the plants with a seaweed extract at a concentration of 5 mL L^{-1} during the specific growth stages identified in the study, given the positive impact this treatment had on yield traits and seed quality. It is also recommended that future studies be conducted using other concentrations of seaweed extracts, along with specialized physiological and chemical analyses to detect changes in plants and seeds resulting from these treatments and to identify the mechanisms by which they affect growth, final yield, and seed quality.

Table 10. Effect of foliar spraying with seaweed extract on the average germination time (days) of seeds from four barley varieties.

2024–2025 Growing Season					2025–2026 Season				
Varieties	**Seaweed Extract Concentrations**			**Average**	**Products**	**Seaweed Extract Concentrations**			**Average**
	0 mL/L	**3 mL/L**	**5 mL/L**			**0 mL/L**	**3 mL/L**	**5 mL/L**	
Al Jazeera 1	**6.43 bc**	**5.24 ef**	**4.97 g**	**5.55 c**	**Al Jazeera 1**	**6.33 bc**	**5.87 d**	**4.88 f**	**5.69 b**
Euphrates -9	**6.75 a**	**6.24 cd**	**5.92 d**	**6.30 a**	**Euphrates -9**	**6.72 a**	**6.26 c**	**5.67 d**	**6.22 a**
Basil	**5.72de**	**5.23 ef**	**4.94 g**	**5.30 d**	**Basil**	**5.53 d**	**5.12 e**	**4.49 g**	**5.05 c**
Attended 462	**6.50 b**	**5.74 de**	**5.02 fg**	**5.75 b**	**Attended 462**	**6.41 b**	**5.64 d**	**4.64 f**	**5.56 b**
L.S.D. 5%	**0.026**			**0.030**	**L.S.D. 5%**	**0.037**			**0.043**
Average	**6.35 a**	**5.61 b**	**5.21 c**		**Average**	**6.25 a**	**5.72 b**	**4.92 c**	
L.S.D. 5%	**0.051**				**L.S.D. 5%**	**0.074**			

Different letters indicate statistically significant differences at the 5% level; values sharing the same letter are not statistically different.

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