



Influence of Seaweed Extract on Physiological Growth, Yield, and its Components of Wheat (*Triticum aestivum* L.)

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Received: June 25, 2025	Abstract A field experiment was conducted during the 2022 growing season at the Qlyasan Research Center, College of Agricultural Engineering Sciences, to investigate the effects of foliar application of seaweed extract (SE) on the phenological, physiological, biochemical, and reproductive traits of wheat. The study involved four wheat varieties (Sulaimani-2, Rizgari, Alaa, and Hasad) and three SE concentrations (0.0, 1, and 2g L ⁻¹), arranged in a randomized complete block design with three replications. Results showed that the highest SE concentration (2g L ⁻¹) significantly enhanced plant height, flag leaf area, specific leaf area, dry matter accumulation, root-shoot ratio, and relative growth rate. Reproductive parameters such as spike length, number and weight of spikes per m ² , spikelets per spike, grain number and weight, grain yield, biological yield, and harvest index also improved. Furthermore, increasing SE concentration positively influenced physio-biochemical traits, including soluble sugar content, total chlorophyll content, carotenoid content, and protein percentage. The interaction between SE levels and wheat varieties was significant across all traits, with Rizgari showing the most pronounced response, likely due to its superior morphological features and genetic capacity for nutrient uptake and physiological efficiency. Keywords: <i>Triticum aestivum</i> L., organic fertilizer, biostimulant, yield components.
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Introduction

Cereals serve an essential function in the global food demands of expanding populations, particularly in developing nations where the cereal-centric agricultural system constitutes the primary source of sustenance [1]. Wheat (*Triticum aestivum* L.) is among the most important global cereal crops, ranking third in production after corn and rice. It plays a vital role in human nutrition, providing over 50% of caloric intake and 25% of protein requirements in many populations. Approximately 65% of global wheat production is used for food, 17% for animal feed, and 12% for industrial purposes, including biofuel [2]. Its adaptability to diverse agro-climatic

condition supports widespread cultivation. Global wheat production is estimated at around 600 million metric tons annually, with total consumption reaching approximately 791.2 million tons [3, 4].

Numerous bio-stimulants facilitate the augmentation of essential plant nutrients, including nitrogen, phosphorus, potassium, and various critical micronutrients, thereby enhancing both formulations to encompass extracts derived from marine algae, advantageous microorganisms (such as bacteria and fungi), organic acids, amino acids, and proteins [5]. In modern agriculture, nutrients are provided for the growth and development of crops, such as using some organic compounds and then Seaweed Extracts (SE) are effective fertilizers to provide essential nutrients and growth regulators [6]. Nowadays, the utilization of SE as bio-stimulants for plants is one of the most common applications. This effect can be determined by the appearance of plant growth-promoting molecules such as indole acetic acid (IAA), gibberellic acid (GA), abscisic acid (ABA), cytokinins, and polyamines in algal extracts [7]. The application of algal extract as a biofertilizer possesses the potential to influence the trajectory of global agriculture considerably. This form of organic fertilizer enhances soil fertility and contributes to environmental preservation [8].

More than 15 million tons of SE are produced annually in large quantities as biofertilizers in the agricultural and horticultural sectors [9]. Alga-600 is an extract of seaweed. This approach has numerous applications and advantages in horticulture, particularly concerning vegetable crops such as *Solanum tuberosum*, *Allium sativum*, *Vigna unguiculata*, *Vicia faba*, and *Pisum sativum*. Cowpea specimens treated with Algae-600 exhibited statistically significant improvements in vegetative development and overall yield [10]. The SE includes phytochemicals such as phenols, betaines, lipids, proteins, sugar, alginates, and laminarins [11]. These chemical compounds lead to positive physiological reactions in different crops to enhance growth rates, production, and their ability to tolerate stress [12]. The SE includes a variety of bioactive substances, including poly, oligo, and monosaccharides, proteins, peptides, and phenols. These chemicals have the potential for a variety of applications, particularly in the food industry. Enzymatic activity has also been shown to enhance the amount of polyphenols, hydrolyzed proteins, and oligosaccharides in various extracts [13]. This study aims to better understand how these wheat varieties respond to different levels of SE on growth physiology and yield.

Materials and methods

The present study was conducted at the Qlyasan (The research station of the College of Agricultural Science, University of Sulaimani, Iraq), during the winter season of 2022-2023 to study the performance of four wheat varieties were selected based on their wide-spread cultivation in the region and their contrasting agronomic traits, such as drought tolerance, maturity period, and yield potential. This allowed for evaluating genotype-specific responses under the tested treatments to evaluate the impact of spraying by SE on growth. Some chemicals and properties of the soil are shown in

Table 1. The field experiment design was Randomized Complete Block Design (CRBD) with three replications; treatments applied at elongation and flowering stages. Each experimental unit area was 1m x 2m, including 4 rows. All data were statistically analyzed and means were compared using the Least Significant Difference Test (LSD) at a 5% level according to [14]. The first factor included wheat varieties (Sulaimani-2 (V1), Rizgari (V2), Alaa (V3), Hasad (V4), and the second factor with bio stimulator soluble SE powder (Alga600) produced by China with different concentrations, including (0.0, 1, and 2g L⁻¹) represented as (S0, S1, and S2), respectively. The sowing date is on (November 21, 2022). Nitrogen fertilization was applied with 120 kg ha⁻¹ (as urea 46% N). The total amount of Phosphate fertilizer (Triple superphosphate) was applied during final land preparation with sowing seeds by 80 kg P₂O₅ ha⁻¹ (46%P). The foliar applications were conducted during two distinct phases of growth, with the initial application occurring during the elongation growth phase and the following application administered during the flowering phase. To decrease the effects of high temperatures, the spraying process was used in the morning or evening. To improve the spray solution efficiency, a cleaning solution was added to lower the water's surface tension and make sure the leaves were completely soaked. The components of SE are shown in Table 2. Some metrological data for the growing season 2022-2023 are shown in Table 3.

Table (1): Physical and chemical properties of soil

Physicochemical properties		Value
Particle size distribution (g kg ⁻¹)	Sand	87
	Silt	435
	Clay	458
	Textural Name	SiC
PH		7.59
ECe (Micro Siemens cm ⁻¹) or (μS cm ⁻¹)		490
O.M. (g kg ⁻¹)		22.4
CaCO ₃ (g kg ⁻¹)		304.3

Table (2): Acadian fertilizer components containing Seaweed Extract (SE)

The ingredients	Content
Sea-Weeds	100% Organic Product
Organic matter	35%-40%
Alginic acid	12%-15%
Potash (k ₂ O)	17%

Table (3): Some metrological data for the growing season 2022-2023

Years	Months	Temperature °C			Relative humidity %			Precipitation mm
		Max	Min	Average	Max	Min	Average	
2022	November	22.5	7.4	13.9	85	15.1	57.6	45.8
	December	18.5	1	10.0	85	16.2	43.8	129.9
2023	January	14.5	-0.4	7.0	85	54.1	42.0	201.9
	February	21.7	-2	7.3	75	50.1	38.2	318.4
	March	24.4	2.4	13.6	74	45.2	52.9	462.0
	April	27.1	4.6	16.9	65	50.1	47.8	649.3
	May	33.6	11.6	23.2	45	25.0	35.0	695.1
	June	41	18.9	30.2	43.8	2.2	16.4	0.001

Measurement of studied criteria

Evaluation of Morpho-physiological characters

Plant height (cm)

Flag leaf area (cm²): was calculated according to [15].

$$\text{FLA (cm}^2\text{)} = \text{maximum length} \times \text{maximum width} \times 0.75 \quad \text{Eq. (1)}$$

Specific Leaf Area (cm² g⁻¹): was calculated according to [16].

$$\text{SPL} = \text{Leaf area} / \text{Leaf dry weight (cm}^2 \cdot \text{g}^{-1}\text{)} \quad \text{Eq. (2)}$$

Dry matter accumulation (g)

$$\text{Root /Shoot ratio} = \frac{\text{Root dry weight}}{\text{shoot dry weight}} \quad \text{Eq. (3)}$$

Relative Growth Rate (RGR) g.day⁻¹: measured during the linear phase of growth by [17].

$$\text{Relative Growth Rate} = \text{W2-W1} / \text{T2-T1} \quad \text{Eq. (4)}$$

Where: W1: first weight, W2: second weight, T1: first time, and T2: second time

Determination of yield and yield component characters:

At post-harvesting, yield and its components were measured, such as:

- Spike length (cm)
- Number of spike plant m⁻²
- Weight of spike plant m⁻²
- Number of spikelet spike⁻¹
- Number of grain spikes⁻¹
- Weight of 1000 grain(g)
- Biological yield (kg ha⁻¹)
- Grain yield (kg ha⁻¹)
- Harvest Index: calculated according to [18].



$$\text{Harvest Index (\%)} = \text{Grain yield} / \text{Biological yield} \times 100 \quad \text{Eq. (5)}$$

Estimation of physio-biochemical parameters

Soluble sugar content (SSC) ($\mu\text{g g}^{-1}$)

The quantification of soluble sugar content was conducted utilizing the method defined by [19, 20]. A sample comprising one gram of pulverized grain was soaked in 5ml of deionized water and subjected to boiling for 30 minutes at 100 °C, after that cooled and centrifuged for 15 minutes at 400 rpm. After that, 300 μL of the supernatant sample was taken and mixed with 2.7 mL of Anthrone combination and boiled for 5 minutes. Then the mixture was cooled at room temperature. The standard solution was prepared to produce a standard curve and calculated at 60 nm with a UV-visible spectrophotometer (UV-365, SHIMADZU, Japan), and the soluble sugar content was calculated by a formula:

$$\text{SSC } (\mu\text{g g}^{-1} \text{ LFW}) = \frac{V}{W} \times C \quad \text{Eq. (6)}$$

Where: V represents the volume of the extract (in milliliters), W means the mass of the sample, and C reflects the concentration derived from the established standard curve.

Total chlorophyll content (mg/g LFW): It was measured by using a SPAD-meter for the entire last apical leaf.

Carotenoid contents (CAC) ($\mu\text{g g}^{-1}$ FM): it was calculated utilizing the strategies expressed by [21]. The carotenoid concentrations were communicated as ($\mu\text{g g}^{-1}$ of dry weight) and evaluated by this equation:

$$\text{CAC} = \frac{\text{The absorbance reading} \times \text{Total volum (mL)} \times 1000}{\text{Carotene extension coefficient in methanol (g)}} \quad \text{Eq. (7)}$$

Protein%:

Fourier transform near-infrared spectroscopy (FT-NIR) is one of the most important tools that can be used for analyzing wheat for different quality parameters such as protein, moisture content, and starch content [22].

The statistical analysis:

The data were statistically analyzed according to XLSTAT version 2019 (Boston, USA). In addition, the comparison between the effects of the studied treatment means was carried out by using the Least Significant Differences (LSD) test at the probability of 0.05 [23].

Result and discussion

Growth characters

The data in Table 4 reveal the significant differences in morpho-physiological characteristics among wheat varieties due to the effect of SE compared to the control treatment. Rizgari variety exceeded the other varieties that recorded maximum value

with SE from 2g L⁻¹ in plant height, flag leaf area, and specific leaf area by (113.667 cm, 28.457 cm², and 7.823 cm²/g), respectively. The Alaa variety recorded the minimum values for both flag leaf area (12.890 cm²) and specific leaf area (4.070 cm²/g), respectively, compared to the control treatment, except for plant height (73.333 cm), which was recorded by the Sulaimani-2 variety.

The effect of SE was evaluated positively in terms of plant height, which contributes to increased growth of the total plant, as reflected in the increase in plant height. This result has been found by [24]. The plant height, flag leaf area, and specific leaf area increased positively with an increase in spraying concentration of SE from 1 g L⁻¹ to 2 g L⁻¹. SE ability to increase the activity of several enzymes involved in the phylogenetic process, which as a result causes an increase in photosynthesis, which contributes to an increase in the products and better growth, leading to an increase in both flag leaf area and specific leaf area. Previous results have been found by [25].

Table (4): Effect of SE, varieties, and their interaction on some morphophysiological characters.

Varieties	Treatment	Plant height (cm)	Flag leaf area (cm ²)	Specific Leaf area (cm ² g ⁻¹)
Sulaimani-2	Control	73.333	13.967	4.873
	1g L ⁻¹	82.333	18.567	4.627
	2gL ⁻¹	96.333	23.217	5.767
Rizgari	Control	85.667	18.330	4.960
	1g L ⁻¹	95.000	20.633	5.523
	2gL ⁻¹	113.667	28.457	7.823
Alaa	Control	83.667	12.890	4.070
	1g L ⁻¹	90.333	16.303	4.907
	2gL ⁻¹	106.000	24.677	5.773
Hasad	Control	84.333	18.700	5.670
	1g L ⁻¹	92.000	23.367	6.127
	2gL ⁻¹	97.000	27.167	7.417
LSD (p _{≤0.05})		2.971	1.859	0.391

* LSD: Least Significant Differences

Dry matter Accumulation (g)

Figure 1, 2, and 3 show the significant variation in the rate of dry matter accumulation of wheat varieties (Sulaimani-2, Rizgari, Ala, and Hasad) under the effect of different SE concentrations including (Control, 1g L⁻¹, and 2g L⁻¹) at different growth stages (tillering, stem elongation, heading, anthesis, milk stage and maturity). The SE of (2g L⁻¹) increased the rate of biomass accumulation at the flowering stage, which was partitioned into root, leaf, and shoot. Dry matter accumulation and its partitioning to leaves and other parts of the plant are closely related to an increase in leaf area, which positively affected dry matter accumulation via increasing the area of light capturing and photosynthesis generally. Dry Matter Partitioning refers to the transport of

accumulated photosynthesis by leaves to different organs. Previous results have been found by [26].

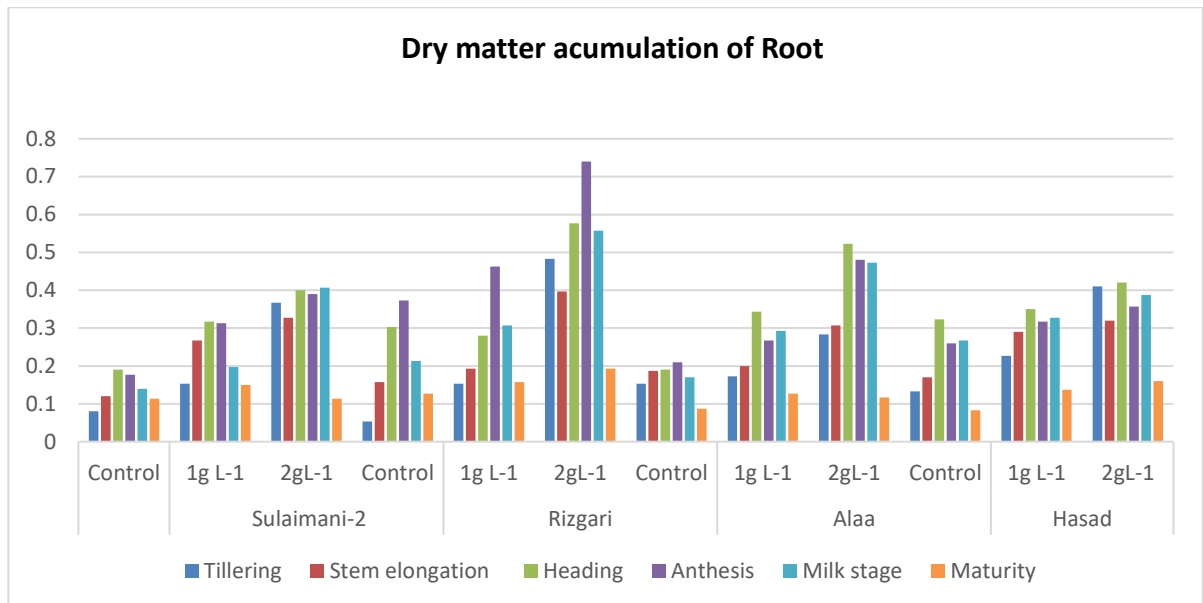


Figure (1): Influence of the interaction between wheat varieties SE on the dry matter accumulation of root.

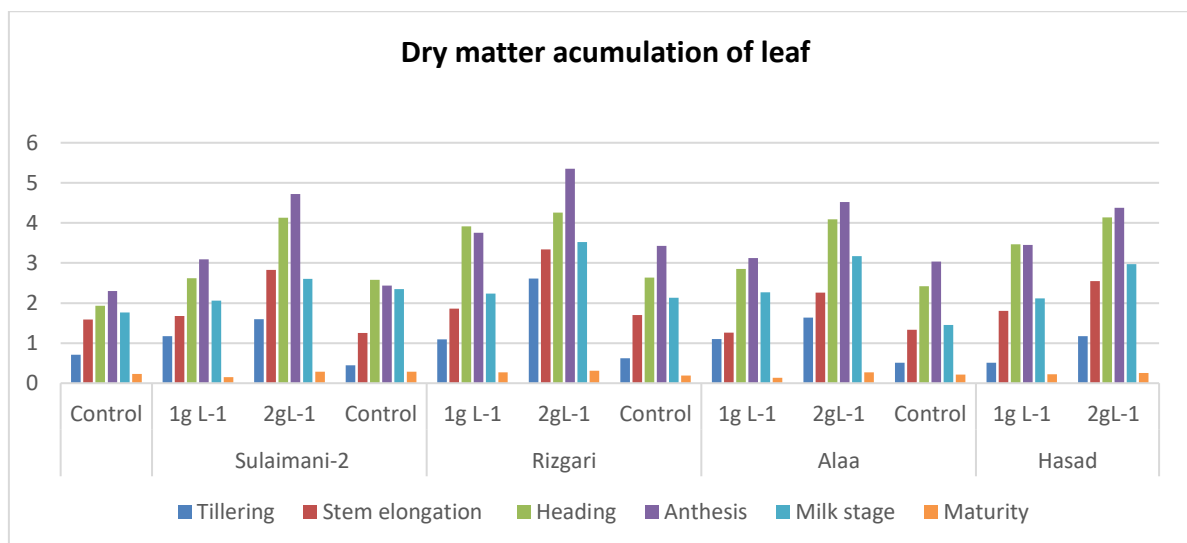


Figure (2): Influence of the interaction between wheat varieties and SE on the dry matter accumulation of leaves.

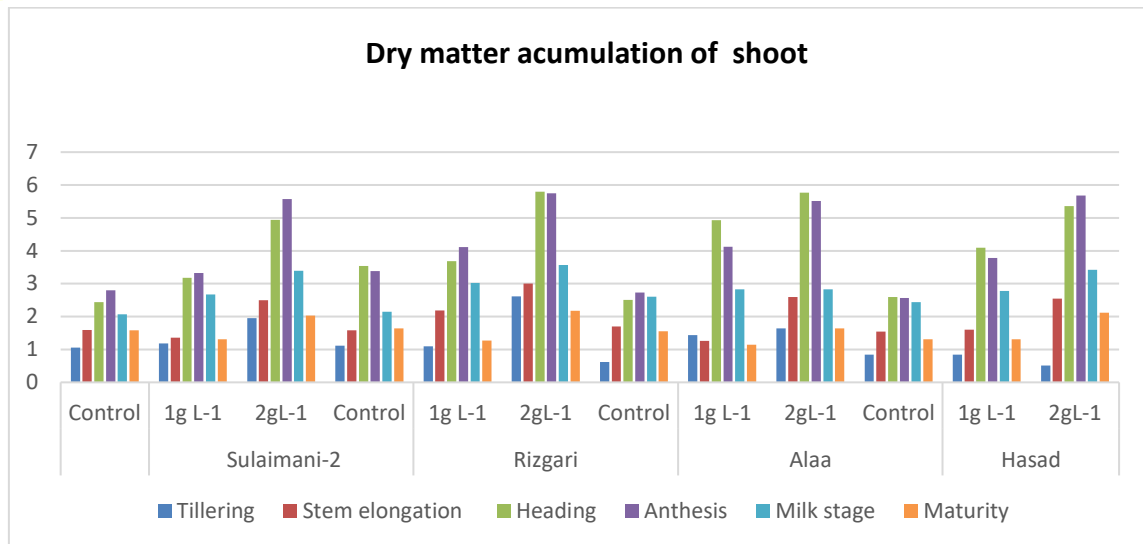


Figure (3): Influence of the interaction between wheat varieties and SE on the dry matter accumulation of shoot.

Root-shoot ratio

The interaction between the effect of SE and the response of wheat varieties and the impact of SE was organized in Table 5. The treatment of 2g L⁻¹ of SE showed a significant interaction in the ratio of roots to shoots compared to the control treatment and 1g L⁻¹ of SE at the Anthesis stage, except for Tillering, Stem elongation, Heading, and Milk stage. The Rizgari variety recorded the maximum root-shoot ratio at the anthesis stage, reaching (0.130), while the minimum value of the root-shoot ratio in the comparison treatment for the Sulaimani-2 variety was (0.063).

The growth of roots is subject to the influence of various external factors, such as soil moisture and nutrient availability, which are pivotal to plant root development. SE represents a superior organic resource, comprising both macro and micronutrients, as well as auxins, cytokinins, and other compounds that promote growth. This result was found by [27]. Root dry weight development may occur from the elongation of the roots under the effect of the seaweed, which induced the uptake ability of the roots to nutrients and a positive increase in yield parameter because of improving the root system relationship to the reproductive part (shoot). The result was found by [28]. The favorable effect of the application of SE could be due to an increase in root weight, which was positively correlated with grain yield, and that could provide a better supply of water and nutrients for wheat plants. Previous results have been found by [29].

Table (5): Effect of the interaction of varieties and SE on root-shoot ratio at tillering, stem elongation, heading, anthesis, and milk stages

Varieties	Treat ment	Tillering	Stem elon- gation	Heading	Anthesis	Milk stage
		Root/Shoo t	Root/Shoo t	Root/Shoo t	Root/Shoo t	Root/Shoo t
Sulai- mani-2	Con- trol	0.075	0.098	0.068	0.063	0.058
	1g L ⁻¹	0.25	0.122	0.108	0.095	0.111
	2g L ⁻¹	0.205	0.126	0.077	0.070	0.111
Rizgar i	Con- trol	0.029	0.084	0.074	0.096	0.135
	1g L ⁻¹	0.201	0.103	0.108	0.120	0.114
	2g L ⁻¹	0.213	0.145	0.079	0.130	0.134
Alaa	Con- trol	0.271	0.148	0.140	0.065	0.103
	1g L ⁻¹	0.184	0.142	0.088	0.086	0.140
	2g L ⁻¹	0.223	0.164	0.062	0.091	0.108
Hasad	Con- trol	0.474	0.164	0.106	0.075	0.108
	1g L ⁻¹	0.188	0.120	0.079	0.077	0.117
	2g L ⁻¹	0.535	0.131	0.130	0.088	0.116
LSD (p_{≤0.05})		N.S	N.S	N.S	0.089	N.S

* LSD: Least Significant Differences

*N.S : Non significant

Relative Growth Rate (RGR) g.day⁻¹

The data in Table 6, reveal the significant differences in relative growth rate (RGR) from the starting of the linear stage of growth response to SE compared to control in this study, Rizgari variety exceeded the other varieties significantly with SE from 2g L⁻¹ in ((April 4th to April 14th, April 14th to April 24th, April 24th to May 4th and May 4th to May 14th) recording (0.130, 0.363, 0.180 and 0.050) g respectively. While the Sulai-mani-2 variety recorded a minimum relative growth rate with control treatment from (April 4th to April 14th) by (0.017), except Alaa variety recorded a minimum relative growth rate in (April 14th to April 24th, April 24th to May 4th, and May 4th to May 14th) are (0.077, -0.030 and -0.010) respectively.

The impact of SE was evaluated positively; there was an increase in the linear growth stage of relative growth rate among each variety. The relative growth rate of a plant is articulated as the amount of growing material per unit of dry weight per unit of time. By the application of SE presence of plant growth regulators increases the amount

of assimilates -including roots and young leaves- that are transported to the sink. Previous results have been found by [30].

Table (6): Effect of the interaction between varieties and SE on the Relative Growth Rate.

Varie-ties	Treat-ment	April 4 th to April 14 th	April 14 th to April 24 th	April 24 th to May 4 th	May 4 th to May 14 th
Sulai-mani-2	Control	0.017	0.083	0.080	-0.087
	1g L ⁻¹	0.050	0.180	0.140	-0.060
	2g L ⁻¹	0.053	0.240	0.163	0.014
Rizgari	Control	0.043	0.223	0.093	-0.120
	1g L ⁻¹	0.073	0.277	0.040	-0.113
	2g L ⁻¹	0.130	0.363	0.180	0.050
Alaa	Control	0.093	0.077	-0.030	-0.010
	1g L ⁻¹	0.057	0.277	0.023	- 0.050
	2g L ⁻¹	0.083	0.293	0.020	-0.263
Hasad	Control	0.067	0.107	0.133	-0.011
	1g L ⁻¹	0.100	0.247	0.033	-0.093
	2g L ⁻¹	0.113	0.277	0.060	0.040
LSD (p_{≤0.05})		0.020	0.062	0.087	0.057

* LSD: Least Significant Differences

Yield and its components

The data in Table 7 reveal the significant differences in the response of wheat varieties to the effect of SE on yield and yield components compared to the control treatment. Rizgari variety exceeded the other varieties that recorded maximum value with SE from 2g L⁻¹ in yield components such as Spike length (11.333 cm), No. of spike m⁻² (624.3330), Weight of spike m⁻² (1612.987g), No. of spikelet spike⁻¹ (17.000), No. of grain spike⁻¹ (50.667), Weight of 1000 grain (51.767 g), Grain yield (5297.867 kg ha⁻¹), Biological yield (14173.800 kg ha⁻¹), and Harvest Index (0.437) respectively. While minimum values were recorded with control treatment by Alaa variety in yield components such as Spike length (8.667 cm), No. of spike m⁻² (417.333), Weight of spike m⁻² (775.747g), and No. of spikelet spike⁻¹ (14.333), except No. of grain spike⁻¹ (35.333), Weight of 1000 grain (35.300g), Grain yield (2410.400kg ha⁻¹), Biological yield (7833.867 kg ha⁻¹) and Harvest Index (0.307) that was recorded by Sulaimani-2 variety. The SE was rated positively, with a risen yield and yield component.

The application of SE at the tillering stage and heading stage improved the yield attributing characters and total yield of wheat. Results were consistent with that found by [31], this study has the same results found by [32], that the higher grain yield was obtained by applying the SE at two different stages at the tillering and flowering stages enhances the greater availability of nutrient and the improve growth and yield attributes of SE will lead to increased grain and straw production of wheat. Increasing the number of spike m⁻² may be attributable to the genetic diversity present among species. These



findings are in alignment with those reported by [33]. The effect of the SE in partitioning more assimilation to the spikes and grains may raise the weight of 1000 grains. and has the variation among wheat varieties in weight of 1000 grains, the result was found by [34]. Also, the flag leaf expansion may increase the grain yield, which was positively correlated with the increase in biomass. This result was found in [35].

Table (7): Effect of the interaction between varieties and SE on the yield and its components.

Varie- ties	Treat ment	Spike length (cm)	Num- ber of spikes per m ⁻²	Weight of spike.m - ²	NO. of spike let spike - ¹	NO. of grain spike - ¹	1000 grain weigh t (g)	Grain yield (kg ha ⁻¹)	Biologi- cal yield (kg ha ⁻¹)	HI
Sulai- mani- 2	Con- trol	8.833	472.00 0	793.480	14.66 5	35.33 3	35.30 0	2410.40 0	7833.867	0.30 7
	1g L ⁻¹	9.167	476.00 0	950.960	16.33 3	38.33 3	39.05 7	2737.66 7	7991.867	0.34 0
	2g L ⁻¹	9.900	477.33 3	1068.82 7	16.33 3	44.33 3	41.93 0	2908.93 3	8454.200	0.34 4
Rizga ri	Con- trol	9.200	484.00 0	1271.70 7	14.66 7	40.00 0	38.93 7	3630.60 0	11477.86 7	0.31 7
	1g L ⁻¹	9.867	584.00 0	1406.62 7	15.00 0	41.33 3	45.99 0	4274.20 0	12766.06 7	0.33 3
	2g L ⁻¹	11.33 3	624.33 3	1612.98 7	17.00 0	50.66 7	51.76 7	5297.86 7	12113.80 0	0.43 7
Alaa	Con- trol	8.667	417.33 3	775.747	14.33 3	39.66 7	41.04 0	3609.13 3	10756.53 3	0.33 7
	1g L ⁻¹	9.333	517.00 0	1396.25 3	15.66 3	44.00 0	42.67 0	4266.06 7	11829.40 0	0.36 3
	2g L ⁻¹	10.15 3	577.33 3	1352.09 3	15.00 0	48.33 3	47.68 3	4124.73 3	12445.20 0	0.33 1
Hasad	Con- trol	8.733	458.66 7	1063.42 7	15.61 7	37.66 7	41.32 3	3587.86 7	9386.200	0.38 7
	1g L ⁻¹	9.000	517.33 3	1247.68 0	16.33 3	43.00 0	43.30 0	4193.86 7	10424.00 0	0.41 7
	2g L ⁻¹	9.867	572.00 0	1419.80 0	16.00 0	48.00 0	49.30 3	4800.86 7	11132.06 7	0.43 1
LSD (p≤0.05)		0.347	34.788	182.915	0.491	0.923	1.470	254.814	349.054	0.03 1

* LSD: Least Significant Differences

Physio-biochemical Parameters

The data in Table 8 reveal the significant differences in the response of wheat varieties to the effect of SE on physio-biochemical parameters in control treatment. Rizgari variety exceeded the other varieties that recorded maximum value with SE



from 2g L^{-1} in physio-biochemical parameters such as Total chlorophyll content pre-Anthesis ($25.833\ \mu\text{g g}^{-1}$), Total chlorophyll content post-Anthesis ($18.533\ \mu\text{g g}^{-1}$), Soluble sugar content ($907.160\ \mu\text{g g}^{-1}$), Carotenoids contents ($10.083\ \mu\text{g/g}$), and Protein% by (10.880%) respectively. While minimum value was recorded with control treatment by Alla variety in Total chlorophyll content pre-Anthesis ($15.03\ \mu\text{g g}^{-1}$), Total chlorophyll content post-Anthesis ($9.367\ \mu\text{g g}^{-1}$), and protein% (7.660%), except Soluble sugar content ($228.559\ \mu\text{g g}^{-1}$) and Carotenoids contents ($6.127\ \mu\text{g/g}$), each recorded by Sulaimani-2. These responses may indicate that Rizgari possesses genetically superior traits, such as enhanced enzyme activity, better nutrient assimilation efficiency, and a more balanced source-sink relationship. Although not explicitly examined in this study, the consistent high performance across developmental stages and treatments implies inherent genetic potential for greater physiological responsiveness and yield-forming capacity. Further genetic or molecular studies are recommended to confirm whether these advantages are due to specific gene expressions or regulatory mechanisms. The effect of SE was evaluated positively; there was an increase in Total chlorophyll content, Soluble sugar content, carotenoid content, and Protein. Chlorophyll, the green pigment essential to light absorption and photosynthesis, exhibits sensitivity to relative chlorophyll content across various development stages of the plant, demonstrating an initial increase followed by a resulting decrease corresponding to growth stage progression and phenotypic alteration. Results were found by [36]. The components of SE affect enzyme activity, especially enzymes found in chlorophyll, which helps to raise the amount of chlorophyll in the leaves. The results were reported by [37].

A notable enhancement in soluble sugar concentration was recorded with the application of the bio stimulator, potentially attributable to increased nutrient availability and the acceleration of physiochemical processes, which facilitated a rise in net photosynthesis and growth respiration, culminating in the accumulation of soluble sugars and starches within wheat grains [38]. The higher own content of SE from nutrients, especially magnesium, as well as amino acids and vitamins, surely reflected on enhancing the biosynthesis of plant pigments, results were found by [39]. The protein content increase could be associated with the absorption of many components in this extract, especially magnesium, which could have activated chlorophyll synthesis and increased the rate of photosynthesis, or it could be the result of biostimulator application in increasing the plant uptake of nitrogen. Previous results have been found by [40].

Table (8): Effect of the interaction between varieties and SE on some physio-biochemical parameters:

Varie-ties	Treat-ment	Total chlorophyll content (TCC) pre-Anthesis ($\mu\text{g g}^{-1}$)	Total chlorophyll content (TCC) post-Anthesis ($\mu\text{g g}^{-1}$)	Soluble sugar content (SSC) ($\mu\text{g g}^{-1}$)	Carote-noids con-tents ($\mu\text{g g}^{-1}$)	Pro-te-in %
Sulai-mani-2	Control	15.250	10.833	228.559	6.127	7.753
	1g L ⁻¹	16.833	13.467	675.061	7.081	7.890
	2g L ⁻¹	21.267	17.600	746.666	7.208	9.547
Rizgari	Control	15.800	10.633	769.506	7.058	7.817
	1g L ⁻¹	18.833	12.967	861.275	9.009	8.327
	2g L ⁻¹	25.833	18.533	907.160	10.083	10.880
Alaa	Control	15.033	9.367	596.666	6.830	7.660
	1g L ⁻¹	18.000	14.000	766.164	7.183	8.313
	2g L ⁻¹	18.967	17.067	766.164	7.054	9.677
Hasad	Control	18.033	13.367	434.320	7.583	7.673
	1g L ⁻¹	20.000	14.967	592.345	8.402	8.067
	2g L ⁻¹	22.817	15.667	710.864	7.798	9.740
LSD ($p \leq 0.05$)		0.687	0.927	4.643	0.094	0.450

* LSD: Least Significant Differences

Based on the results of the study, it was found that the maximum growth characteristics, yield components, and biochemical parameters of the wheat plants were achieved at a concentration of (2g L⁻¹). SE also improved the physico-chemical characteristics and yield of wheat varieties. The Rizgari variety was only one of four wheat varieties whose response to the SE differed significantly. The superior performance of the Rizgari variety under the influence of SE can be attributed to both morphological adaptability and potential genetic superiority. Morphologically, Rizgari exhibited greater plant height, larger flag leaf and specific leaf area, and more efficient dry matter accumulation, which are key traits for enhancing light interception and photosynthetic capacity. Physiologically, Rizgari responded more positively to SE in terms of chlorophyll content, soluble sugar accumulation, and relative growth rate, suggesting a more efficient photosynthetic apparatus and metabolic activity.

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