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The Response of Globe Artichoke Plants to Potassium Fertilization Combined with the Foliar Spraying of Seaweed Extract

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Abstract: This work investigated the effects of potassium mineral fertilizers, combined with biofertilizers (T1–T4 treatments) and the foliar spraying of seaweed extract (at 1 g/L, 2 g/L, and 3 g/L) on the vegetative growth characters, chemical constituents of foliage, and the yield and quality parameters of globe artichoke. The maximum height, and the fresh and dry weight of the leaves, was recorded in plants that received only soil with added potassium (T1 treatment) and sprayed with seaweed extract at 3 g/L. Furthermore, the highest number of offshoots per plant was registered in the T2 treatment combined with seaweed extract (3 g/L). T1 and T2 treatments resulted in the highest values of leaf N, P, K, and total carbohydrate content when combined with seaweed extract (3 g/L). The highest numbers of early, late, and total heads per plant were obtained for the T1 treatment and seaweed extract (3 g/L). Similarly, most of the head quality parameters were beneficially affected by the T2 treatment and seaweed extract (3 g/L). In conclusion, it is suggested that soil application of mineral potassium fertilizer (75% of RD) combined with biofertilizer (25% of RD) and the foliar spraying of seaweed extracts at 3 g/L, was most beneficial for the yield and quality parameters of globe artichoke plants.

Keywords: biofertilizers; inulin; *Cynara cardunculus* subsp. *scolymus*; total phenolic content; total flavonoids; yield parameters

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1. Introduction

Globe artichoke (*Cynara cardunculus* (L.) subsp. *scolymus*) is widely cultivated throughout the Mediterranean region, and it is usually consumed in fresh and processed forms. Its high content of phenolic compounds, flavonoids, inulin, dietary fiber, and numerous minerals make it suitable for multiple uses in the industrial sector [1,2]. Cynarin, which is usually found in various plant parts, exhibits beneficial effects against hepatobiliary disorders, hyperlipidemia, dropsy, rheumatism, and blood cholesterol levels [3–5]. According to FAO statistics for the 2020 season, Egypt ranked second in the world with regards to total production and harvested area, with a total of 308,884 tons produced from 16,103 hectares [6]. Nowadays, there is increasing demand on promoting artichoke production to meet rising needs for local consumption, as well as for export due to consumer awareness of functional foods with positive health effects [7]. Moreover, the valorization of crop by-products has been suggested as a means to increase the added value of this valuable and resilient crop within the climate change context [8,9].

Potassium (K) is an essential macronutrient for cultivated plants, with variable responses related to plant growth and yield parameters previously recorded [10–12]. The major role of K in plant cells and cell compartments is to maintain electrochemical balance and to regulate enzyme activity [13]. Potassium plays a crucial part in the transport and storage of assimilation products, as well as in tissue water balance, gas exchange regulation, protein synthesis, and enzyme activation [11]. Due to its role in boosting root growth and increasing the size of fruits, K is critical for product quantity and quality [14]. It is also required for the production of carbohydrates and the transportation of sugars in plants, while it may improve the earliness and quality of the final product, such as for artichoke heads [15–17]. Due to economic and environmental concerns, the excessive use of nutrient fertilizers is not recommended as it results in environmental pollution and increased production cost [18]. In contrast, insufficient amounts of nutrient fertilizers cannot meet plant requirements throughout the growing season, ending in reduced yields and quality of the final product [19]. Apart from providing the proper amounts of nutrients, the time of application and the applied doses, as well as the form of nutrients, may affect crop productivity and quality [20]. Previously, many studies found strong links between the amount of N and K in the soil and the production of artichokes [21–23].

The climate crisis the world is facing, combined with soil degradation and the increase in the world population, urge for the adoption of sustainable farming techniques [24]. Especially for Mediterranean farming, land fragmentation and labor shortages necessitate minimizing production costs while increasing the added value of the crops at the same time [25,26]. In this regard, biofertilizers are an environmentally friendly option for providing the adequate nutrients to crops and also improving soil quality [27,28]. Recently, Mohamed et al. [28] suggested the combined application of mineral potassium fertilizers and biofertilizers as an effective means to improve the yield and quality of broccoli, while Ali et al. [20] reported a similar response to combined fertilization regimes in potato crops. The use of biofertilizers that contain potassium solubilizing bacteria (PSB), i.e., silicate bacteria, has been proposed as a long-term solution for improving plant growth and nutrition, as well as plant tolerance to biotic and abiotic stress factors [29,30]. Furthermore, inoculation with PSB is associated with soil improvement through the creation of humus and the dissolution of minerals bound to organic matter [31]. Another sustainable and environmentally friendly agronomic practice is the use of biostimulants, which is of particular interest in horticultural crop production [32]. As suggested by Du Jardin [11], biostimulants are used to improve nutrient uptake and increase yield and crop quality, via various mechanisms, and also show variable responses depending on the crop–biostimulant combination [32]. Seaweed extracts are a promising group of biostimulant products with several beneficial effects on horticultural crops, especially under stressful conditions [33–35]. The recorded effects are associated with the presence of mineral elements (N, P, Fe, Cu, Zn, Co, Mo, Mn, Ni), and metabolites, such as hormones (IAA and IBA), vitamins, enzymes, and amino acids [36–38]. Therefore, the main goal of this study was to investigate the effect of the combined application of mineral potassium fertilizers and biofertilizers with the foliar spraying of seaweed extracts, on plant growth and yield parameters of globe artichoke.

2. Materials and Methods

2.1. Experimental Site and Plant Material

Two field experiments were conducted at a private farm in Qaha, Qalubia Governorate, Egypt. The experimental area was located at an altitude of 45 m above sea level (30.45 N latitude and 31.10 E longitude) during the 2018/2019 and 2019/2020 growing seasons. Before planting, random soil samples were taken from the experimental soil at a depth of 0–30 cm for the assessment of the physical and chemical parameters. Mechanical analysis was determined following the protocols of Jackson [39], while chemical analysis assays were carried out according to Black et al. [40]. In brief, soil pH and electrical conductivity

(EC) were determined from the soil paste, whereas organic matter content was determined using potassium chromate, and then titrated with ferrous sulfate. Table 1 illustrates the physical and chemical characteristics of the soil used.

Table 1. Physical and chemical analysis of the experimental soil.

Physical Parameters	Unit	Seasons	
		2018/2019	2019/2020
Coarse sand	%	6	5
Fine sand	%	15	17
Silt	%	24	25
Clay	%	55	54
Textural class	——	Clay	Clay
Chemical Parameters			
$CaCO_3$	%	1.12	1.07
Organic matter	O.M. %	2.13	2.27
Available nitrogen	N mg/kg	43.2	44.2
Available phosphorus	P mg/kg	21.2	22.1
Available potassium	K mg/kg	118	121
Electrical conductivity (E.C.)	dS/m	1.13	1.17

In both seasons, old crowns (removed from mother plants) were used as plant material for propagation, and were planted in mid-August. Each experimental plot consisted of five ridges, with a width of 1.0 m, a length of 4.0 m, and a total area of 20 m^2. The experimental layout was designed according to the split-plot design, using potassium fertilization treatments as the main plot and foliar spraying as the sub-plot. All treatments were repeated three times (n = 3). The crowns were planted at a spacing of 1 m apart (20 plants per plot). During the preparation of the soil, organic fertilizer (compost at 35.7 m^3/ha) and phosphorus fertilizer (superphosphate calcium at 714 kg/ha) were applied as base dressing. Nitrogen fertilizer was applied in the form of ammonium sulphate (20.6% of N) at a rate of 286 kg/ha. The potassium fertilizer treatments (main plots) were evenly dispersed throughout the plots as side-dressing at three equal doses, i.e., 60 days after transplanting and at 30-day intervals after the first dose, in both seasons. The foliar spraying of seaweed extract treatments (sub-plots) was randomly allocated within each main plot. The study included 16 treatments in total, as described below.

2.2. Experimental Treatments

2.2.1. Potassium Fertilization Treatments

1. T1: 100% of the recommended dose (RD) of mineral K (229 kg K_2O/ha added in the form of potassium sulphate (K_2SO_4) 48% K_2O).
2. T2: 75% of the RD of mineral K (171 kg K_2O/ha added in the form of potassium sulphate (K_2SO_4) 48% K_2O) + Biofertilizer.
3. T3: 50% of the RD of mineral K (114 kg K_2O/ha added in the form of potassium sulphate (K_2SO_4) 48% K_2O) + Biofertilizer.
4. T4: 25% of the RD of mineral K (57 kg K_2O/ha added in the form of potassium sulphate (K_2SO_4) 48% K_2O) + Biofertilizer.

The biofertilizers were kindly provided by the Microbiology department, Faculty of Agriculture, Benha University, Benha, Egypt. The product used contained potassium-dissolving bacteria (Potassine), such as *Bacillus circulans*, or potassium-mobilizing bacteria. Potassine treatments (*Bacillus circulans*) were prepared by growing the bacterial strains in nutrient broth medium with continuous shaking (140 rpm) at 30 °C up to optimum growth. Then the cells were collected by centrifugation (4000 rpm) at 4 °C for 10 min. The cells were suspended using water peptone to prepare a suspension that contained 108 CFU/mL, as assessed by the optical density method, and then applied by directly dipping the artichoke crowns for approximately 10 min before transplantation into the liquid solution [28].

2.2.2. Foliar Spraying Treatments

The foliar spraying of seaweed extract included the following treatments:

1. Control treatment (spraying with tap water);
2. Seaweed extract at 1 g/L;
3. Seaweed extract at 2 g/L;
4. Seaweed extract at 3 g/L.

The spraying solution was applied in amounts that completely covered the plant foliage until it began to drip. Each treatment was applied eight times throughout the growing season, the first at 30 days after planting, and the following at two-week intervals. All tested solutions, including the control, were applied using a surfactant (Tween 20) at a concentration of 0.01%, to improve the adhesion of solution on the leaf surface. The seaweed extract is commercially available (Alga 600; Technogreen; Heliopolis, Cairo, Egypt), and is a mixture of three seaweeds, namely: *Ascophyllum nodosum*, *Laminaria* spp., and *Sargassum* sp. The tested seaweed extract also contains N (1%), K (18.5%), Ca (0.17%), Mg (0.42%), Fe (0.06%), S (2.2%), and alginic acids (10–12%).

2.3. Measurements and Recorded Data

2.3.1. Vegetative Growth Parameters

After 120 days from planting, a representative sample of five plants from each experimental plot was taken to estimate the following growth parameters according to the method described by Pandino et al. [41]:

1. Plant height was determined by measuring the distance between the soil surface and the tip of the plant's greatest linear blade. The results were expressed in cm.
2. At the end of harvesting period, the number of offshoots per plant was counted.
3. Fresh and dry weights of leaves per plant were determined. The results were expressed in kg (fresh weight) and g (dry weight).

2.3.2. Mineral Elements of Plant Foliage

Determination of N, P, and K concentrations was carried out on the plant foliage dry matter. The wet digestion of 0.2 g plant material with sulfuric and perchloric acids was carried out on plant foliage according to the methods described by Pregl [42].

Total nitrogen (N) content was determined from dried leaf tissue using the micro-Kjeldahl method as previously described by Pregl [42]. Briefly, 5 mL from the digested extract was added to 5 mL NaOH 40%. Subsequently, 10 mL of boric acid 4% was added, and N content was determined via titration with 1 M HCl.

Phosphorus (P) content was determined from dried leaf tissue according to the methods described by John [43]. In brief, P was determined colorimetrically via the ascorbic acid method. For the reagent preparation, 20 mg of ammonium molybdate was dissolved in 300 mL of water. Following this, 450 mL of 10 N sulfuric acid was added while stirring, after which 100 mL of 0.5% antimony potassium tartrate was added. Finally, 1.5 g of L-ascorbic acid was added to 100 mL of this solution. Phosphorus content was determined by mixing 1 mL sample + 1 mL reagent + 8 mL distilled water, and measuring transmittance at 650 nm (Model UV752/UV754-single beam UV/Vis spectrophotometer, YK Scientific, Shanghai, China).

Potassium (K) content was determined using a flame photometer (AAS4, Carl Zeiss Jena GmbH, Jena, Germany), with 5 mL from wet digested samples inserted directly into the equipment [44].

Total carbohydrate content was determined from the dry matter of plant foliage using the phenol–sulfuric acid method. In brief, 0.2 g of dry sample was extracted with HCl 0.1 M in Eppendorf tubes (25 mL) for 4 h. The extract was filtrated and transferred into a flask.

Subsequently, 1 mL of extract was mixed with 1 mL of concentrated sulfuric acid and 1 mL of phenol 5%, and measured using a spectrophotometer at 490 nm (Model UV752/UV754-single beam UV/Vis spectrophotometer, YK Scientific, Shanghai, China) [45].

2.3.3. Yield Parameters

The early yield was calculated from the beginning of harvest to the end of February, while the late yield was assessed from March to the end of May. For yield parameter estimation, the following measurements took place:

- Number of early heads/plant;
- Number of late heads/plant;
- Number of total heads/plant;
- Total head yield (ton/ha).

2.4. Head Quality

2.4.1. Physical Parameters of Heads

For physical parameter evaluation, ten heads were randomly selected from each plot at each harvest phase (early and late harvest). The estimated parameters included: head fresh weight (g), edible fresh weight (g), head length (cm), head diameter (cm). Fresh weight of the heads, and the edible fresh weight, was determined with a laboratory precision balance, while head dimensions were measured with a Vernier caliper [46].

2.4.2. Chemical Composition of Heads

Samples of heads (only the edible part from ten heads from each plot) were pooled, and all the analyses were performed in triplicate for each plot. The estimated parameters included:

Total soluble solid content (TSS, expressed as %) was determined according to the protocol previously described in the literature [47]. In brief, a random sample of 10 heads from each experimental plot at marketable maturity stage was taken to determine the percentage of soluble solid content using a hand refractometer (38–01 OPTi multiple scale digital handheld refractometer, Bellingham + Stanley, Xylem Analytics Germany Sales GmbH and Co. KG, WTW, Weilheim, Germany);

Total phenolic content was determined by the Folin—Ciocalteu protocol, as described by AOAC (official method: AOAC SMPR 2015.009), with minor adjustments [48]. Polyphenol extraction was performed by adding 10 mL of methanol (85%) to 1 g of frozen head tissue. Sterile refined water (250 µL) was added to 250 µL of concentrate, and afterwards, 2.5 mL of diluted Folin–Ciocalteu reagent (10%) and 2 mL of 7.5% sodium carbonate was added. Samples were shaken for 1.5–2 h, and the absorbance of samples was estimated at 765 nm using a spectrophotometer (Model UV752/UV754-single beam UV/Vis spectrophotometer, YK Scientific, Shanghai, China). Gallic acid was used to obtain the calibration curve, and results are expressed as mg/100 g fresh weight (f.w.);

Total flavonoid content (mg of catechin/100 g f.w.) of methanol extracts were determined using Folin–Ciocalteu and aluminum chloride methods and fractions, and the bleaching of purple-colored methanol solution of 1,1-diphenylpycryl hydrazyl (DPPH) was measured by spectrophotometric assay according to Zhishen et al. [49].

Fiber content (%) was estimated according to the non-enzymatic-gravimetric method [50]. Dried samples, or isolated fiber sources, were suspended in water and incubated for 90 min at 37 °C to solubilize sugars and other water-soluble components. Then, water-soluble fiber components were precipitated with ethanol. Residue was washed sequentially with 78% ethanol, 95% ethanol, and acetone, and then dried at 105 °C. One duplicate was analyzed for crude protein, the other for ash. Total dietary fiber (TDF) was calculated as weight of residue minus weight of protein and ash;

Inulin content (%) was determined according to the protocol of Redondo-Cuenca et al. [51]. In brief, the head extracts, obtained under optimized conditions, were analyzed by liquid chromatography using an Agilent 1100 Series HPLC, equipped with a refractive index detector (RID) on a RezexTM ROA-Organic Acid H+ (8%), 300 mm × 7.8 mm column, protected with a Carbo-H 4 × 3.0 mm ID security guard cartridge (Phenomenex España, Madrid, Spain). Ultrapure Milli-Q water (Milli-Q Integral 5 Water Purification System from Millipore), acidified with 2.5 mM H_2SO_4, was used as mobile phase, at a flow rate of 0.4 mL/min. The column was maintained in a thermostatic oven at a constant temperature of 25 °C. Both standards and samples were filtered through 0.45 µm syringe filters for aqueous solutions, and a 5 µL volume was injected into the HPLC. Inulin and different low-molecular-weight carbohydrate standards (DP4 = stachyose, DP3 = raffinose, DP2 = cellobiose, DP2 = sucrose, DP1 = fructose, and glucose) were injected in triplicate at various concentrations (1.0, 0.5, and 0.25 mg/mL) and used for calibration. Sample extracts were diluted in ultrapure water (5 mg/mL), filtered, and then injected. Regression standard curves were obtained for concentration versus area (mV × s). Peaks in chromatograms of samples were identified by coincidence of their retention times with available LMWC standards, and they were quantified by comparison of their areas with the corresponding calibration curves.

2.5. Statistical Analysis

All data collected during both seasons of the study were subjected to a two-way ANOVA, while the comparison of means was performed with the Duncan multiple range test (DMRT) at $p = 0.05$. For all the statistical analyses, the M-stat v.4 program for Windows (Informer Technologies, Inc., Los Angeles, CA, USA) was implemented.

3. Results and Discussion

The ANOVA for all the tested parameters detected significant effects of potassium application and seaweed extract application, as well as of their interaction, during both growing seasons, as presented in Tables 2 and 3. The detailed effects of the tested factors are presented in the following sections.

3.1. Vegetative Growth Parameters

The data presented in Table 4 show that all the studied vegetative growth parameters were positively affected by the combined application of mineral potassium fertilizer (at 100% or 75% of the RD) and biofertilizer (0% or 25% RD, respectively). Regarding the seaweed extract application, plant height was beneficially affected at all the applied rates, especially at 3 g/L (2018–2019 season), or 2 g/L and 3 g/L (2019–2020 season), where maximum plant heights were recorded. The number of offshoots per plant was also benefited by seaweed application compared to the control treatment, while the dry weight of the leaves per plant was maximal at the highest seaweed application rate (3 g/L). In contrast, the fresh weight of the leaves per plant was not affected by seaweed application. The combined effects of potassium application and seaweed extract showed varied responses for the tested parameters. In particular, the highest values of the growth parameters were recorded when only mineral fertilizer (T1; 100% of the RD) and seaweed extract at 3 g/L were applied, whereas the lowest values were obtained for the T4 treatment (25% of the RD of mineral K + biofertilizer), and no seaweed extract applied. However, no significant differences were detected with the other combinations. According to Anwar et al. [52], potassium availability is associated with improved vegetative parameters in globe artichoke, since this element is involved in CO_2 assimilation, as well as in enzyme and hormone activities and nutrient uptake [15]. Moreover, Saleh et al. [23] suggested that adjusting the potassium fertilizer dose depending on growth stage showed better results of artichoke plant growth compared to equal doses throughout the growing season. Finally, Elsharkawy et al. [15] reported that the combined application of potassium and phosphorus fertilizers, with the foliar application of seaweed extracts, resulted in improved growth parameters of globe artichoke (plant height, number of leaves, and leaf dry weight) compared to their control treatment; similar effects were suggested by Madian et al. [47] for seaweed extracts applied at rates up to 750 mg/L. Mzibra et al. [53] tested various seaweed extracts on tomato plants, and associated their beneficial effects with the presence of polysaccharides, which may regulate nitrogen metabolism or exhibit chelating properties to minerals that may improve the nutrient status of the plant. Moreover, the seaweed extracts themselves may include macro- and micronutrients that contribute to plant nutrition, or include hormones that may regulate plant growth [54,55]. Other studies suggest that, apart from hormone-like activities, the beneficial effects of seaweed extracts on plant growth could be associated with the improved potassium uptake and water use efficiency, as well as with the increased activity of soil microbes [32]. Therefore, it could be suggested that the positive effects of the combined application of mineral fertilizers and seaweed extracts could be attributed to the increased potassium availability at various growth stages of artichoke plants, as well as to improved nutrient uptake due to the hormone-like and chelating properties of the applied seaweed extracts.

3.2. Chemical Composition of Leaves

Table 5 presents the chemical composition of globe artichoke leaves in relation to potassium fertilization and the application of biofertilizer and seaweed extract. The application of T1 and T2 treatments, where 100% and 75% of the RD was added in the form of mineral potassium fertilizer, resulted consistently in the highest content of N, P, K, and total carbohydrates of the globe artichoke leaves, although no significant differences were recorded for P content between T1, T2, and T3 treatments in the 2018–2019 season, or between all the treatments in the 2019–2020 season. The foliar spraying of seaweed extract had a variable effect on mineral content. In particular, N content was the highest at the highest seaweed extract application rate (3 g/L), while P and K content did not differ between the different seaweed extract application rates (1–3 g/L), despite the high potassium content (18.5%) of the tested seaweed extract. Moreover, total carbohydrate content showed a varied response between the growing seasons, with the highest values recorded at the medium to high rates (2 g/L and 3 g/L) in 2018–2019, and at low to medium rates (1 g/L and 2 g/L) in 2019–2020. The combined application of potassium mineral fertilizer and biofertilizer with seaweed extract had a consistently positive effect when T1 treatment was combined with the highest rate of seaweed extract application (3 g/L), except for the case of P content in the 2019–2020 season, where no significant differences were observed among the tested treatments. Total carbohydrate content was highest when T2 treatment was combined with the application of 3 g/L of seaweed extract. Finally, the lowest overall values for all the macronutrients and total carbohydrate content were recorded for the T4 treatment when no seaweed extract was applied. Our results indicate that the partial substitution of mineral K (up to 25% of the RD of K) with biofertilizer may increase the macronutrient and total carbohydrate content, as well as nutrient uptake, especially when combined with the foliar spraying of seaweed extract at medium to high rates (2–3 g/L). According to the literature, this could be due to the increased availability of K when applied in inorganic form, as well as to the positive role of biofertilizers and seaweed extracts in nutrient uptake in plants [56]. Similar to our study, Saif Eldeen et al. [57] suggested that the application of seaweed extracts at 2 g/L increased macronutrient content in plant tissues. Moreover, Rincón et al. [58] reported that globe artichoke is a very demanding crop in terms of potassium fertilization, and the K content in plant tissues is very high throughout the growing season. However, soil properties and nutrient status may affect the K availability and the use efficiency of the applied fertilizers [23], while the form of the applied potassium could also affect nutrient availability [20]. The macronutrients and total carbohydrate content of leaves is essential to plant growth and crop yield, since they act as sources and sinks for various physiological and biosynthetic processes during the growth period, depending on plant demands [59,60]. Considering that leaves may act as sinks or sources, depending on their developmental stage [61], more studies are needed to evaluate the effect of potassium availability on carbohydrate storage.

Table 2. The analysis of variance (ANOVA) for the effect of potassium sources (Factor A), seaweed extract application (Factor B), and their interaction (AB) on different parameters studied during the 2019 (1st) and 2020 (2nd) season.

Source of Variance	DF	Plant Height (cm)		No. of Shoots/Plant		Leaves Fresh Weight/Plant (kg)		Leaves Dry Weight/Plant (g)		N%		P%		K%	
		Mean Square		Mean Square		Mean Square		Mean Square		Mean Square		Mean Square		Mean Square	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Replicate	**2**	1.40	5.12	0.170	0.050	0.085	0.026	16.203	17.51	0.008	0.004	0.000	0.000	0.005	0.023
Factor A	**3**	281.57 **	586.65 **	1.809 **	10.850 **	2.083 **	3.087 **	60,590.55 **	266,668.30 **	0.089 **	0.190 **	0.004 **	0.002 **	0.190 **	0.415 **
Factor B	**3**	416.190 **	492.30 **	3.112 **	3.940 **	0.324 **	0.279 **	9423.84 **	13,650.07 **	0.633 **	0.233 **	0.002 **	0.002 **	0.171 **	0.194 **
AB	**9**	17.52 **	7.93*	0.340 **	0.309 **	0.015	0.026	440.698 **	2145.52 **	0.003 **	0.014 **	0.000 *	0.000 **	0.011 *	0.023 **
Error	**30**	2.53	3.52	0.096	0.085	0.045	0.041	81.54	508.94	0.005	0.008	0.000	0.000	0.008	0.006

Source of Variance	DF	Total Carbohydrates %		Early Heads/Plant (no)		Total Yield (ton/ha)		Total Heads/Plant (no)		Late Heads/Plant (no)		Edible Fresh Weight (g)		Head Fresh Weight (g)	
		Mean Square		Mean Square		Mean Square		Mean Square		Mean Square		Mean Square		Mean Square	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Replicate	**2**	0.477	1.032	0.159	0.055	0.092	0.009	1.077	1.088	0.432	0.598	14.81	17.06	2.19	0.99
Factor A	**3**	73.51 **	92.11 **	4.209 **	4.807 **	3.327 **	4.88 **	8.28 **	7.25 **	452.10 **	416.89 **	13,294.6 **	11,618.2 **	843.21 **	1275.77 **
Factor B	**3**	70.092 **	44.64 **	2.060 **	3.84 **	10.63 **	10.56 **	11.89 **	10.87 **	236.65 **	222.95 **	2835.6 **	2497.2 **	380.68 **	274.78 **
AB	**9**	3.30	0.917 **	0.150 **	0.197 *	0.360 **	0.583 **	3.27 **	3.20 **	22.12 **	21.35 **	196.18 **	130.75 **	22.044 **	27.54 **
Error	**30**	1.63	1.40	0.032	0.071	0.047	0.058	0.579	0.532	0.22	0.167	15.54	17.32	2.69	2.19

DF, degrees of freedom; N, nitrogen; P, phosphorus; K, potassium. Comparison between the means of the treatments was performed with the Duncan multiple range test. * significant difference at 0.5%; ** significant difference at 1%.

Table 3. The analysis of variance (ANOVA) for the effect of potassium sources (Factor A), seaweed extract application (Factor B), and their interaction (AB) on different parameters studied during the 2019 (1st) and 2020 (2nd) season.

Source of Variance	DF	Inulin (%)		Total Sugars (%)		TSS (%)		Total Phenolic Content (mg of Gallic Acid/100 g f.w.)		Fiber (%)		Total Flavonoids (mg of Catechin/100 g f.w.)	
		Mean Square		Mean Square		Mean Square		Mean Square		Mean Square		Mean Square	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Replicate	**2**	0.029	0.029	0.007	0.005	0.029	0.002	0.007	0.010	0.000	0.014	0.913	0.057
Factor A	**3**	1.005 **	1.028 **	4.005 **	3.432 **	0.177 **	0.203 **	0.899 **	0.152 **	0.027 **	0.036 **	9.13 **	28.43 **
Factor B	**3**	0.518 **	0.524 **	1.359 **	1.355 **	0.143 **	0.265 **	0.928 **	0.181 **	0.073 **	0.054 **	18.12 **	13.80 **
AB	**9**	0.036	0.033	0.234 **	0.168 **	0.004 **	0.007 **	0.075 **	0.003 **	0.001	0.005	0.202	0.694 **
Error	**30**	0.24	0.016	0.018	0.018	0.005	0.021	0.006	0.011	0.005	0.007	0.162	0.221

DF, degrees of freedom; TSS, total soluble solids. Comparison between the means of the treatments was performed with the least significant difference (LSD) test. ** significant difference at 1%.

Table 4. The effect of potassium fertilizer, biofertilizer, and foliar spraying of seaweed extract on globe artichoke vegetative growth parameters.

Treatments		First Season (2018–2019)				Second Season (2019–2020)			
Potassium Fertilizer	Foliar Spraying	Plant Height (cm)	No. of Shoots/Plant	Leaves Fresh Weight/Plant (kg)	Leaves Dry Weight/Plant (g)	Plant Height (cm)	No. of Offshoots/Plant	Leaves Fresh Weight/Plant (kg)	Leaves Dry Weight/Plant (g)
T1 *		103 ± 1 A	6.6 ± 0.3 A	2.8 ± 0.2 A	522 ± 17 A	112 ± 1 A	7.1 ± 0.2 A	3.3 ± 0.1 A	587 ± 7 A
T2		100 ± 1 B	6.8 ± 0.2 A	2.7 ± 0.2 B	446 ± 8 B	108 ± 1 B	7.0 ± 0.2 A	2.9 ± 0.2 B	521 ± 6 B
T3		96 ± 1 C	6.2 ± 0.3 B	2.3 ± 0.2 C	389 ± 4 C	101 ± 1 C	5.8 ± 0.3 B	2.3 ± 0.4 C	418 ± 3 C
T4		92 ± 1 D	6.0 ± 0.2 C	2.2 ± 0.1 C	369 ± 4 D	96 ± 2 D	5.2 ± 0.1 C	2.2 ± 0.1 C	390 ± 5 D
	Control	93 ± 1 A	5.7 ± 0.2 C	2.4 ± 0.2 C	404 ± 5 D	97 ± 2 D	5.6 ± 0.2 C	2.5 ± 0.2 B	442 ± 5 C
	Seaweed extract 1 g/L	95 ± 1 B	6.5 ± 0.1 B	2.5 ± 0.1 BC	425 ± 2 C	101 ± 2 C	6.1 ± 0.3 B	2.6 ± 0.2 A	476 ± 2 B
	Seaweed extract 2 g/L	98 ± 1 C	6.7 ± 0.2 AB	2.6 ± 0.2 AB	450 ± 8 B	107 ± 2 B	6.6 ± 0.2 A	2.7 ± 0.2 A	490 ± 2 AB
	Seaweed extract 3 g/L	106 ± 2 D	6.8 ± 0.2 A	2.7 ± 0.2 A	468 ± 3 A	111 ± 1 A	6.6 ± 0.2 A	2.8 ± 0.2 A	507 ± 3 A

Table 4. *Cont.*

Treatments		First Season (2018–2019)				Second Season (2019–2020)			
Potassium Fertilizer	**Foliar Spraying**	**Plant Height (cm)**	**No. of Shoots/Plant**	**Leaves Fresh Weight/Plant (kg)**	**Leaves Dry Weight/Plant (g)**	**Plant Height (cm)**	**No. of Offshoots/Plant**	**Leaves Fresh Weight/Plant (kg)**	**Leaves Dry Weight/Plant (g)**
T1	Control	97 ± 1^{g}	5.2 ± 0.3^{g}	2.9 ± 0.2^{bc}	486 ± 17^{d}	103 ± 1^{de}	6.1 ± 0.2^{c}	2.9 ± 0.1^{bc}	529 ± 7^{e}
	Seaweed extract 1 g/L	100 ± 2^{de}	6.9 ± 0.3^{ab}	$3.0 \pm 0.1^{a\text{–}c}$	505 ± 7^{c}	109 ± 1^{c}	6.9 ± 0.1^{b}	3.2 ± 0.1^{ab}	583 ± 9^{bc}
	Seaweed extract 2 g/L	103 ± 1^{c}	7.1 ± 0.2^{a}	3.2 ± 0.3^{ab}	539 ± 9^{b}	116 ± 1^{b}	7.6 ± 0.2^{a}	3.4 ± 0.2^{a}	608 ± 4^{ab}
	Seaweed extract 3 g/L	114 ± 1^{a}	7.3 ± 0.3^{a}	3.3 ± 0.2^{a}	559 ± 9^{a}	119 ± 1^{a}	7.9 ± 0.4^{a}	3.5 ± 0.2^{a}	626 ± 5^{a}
T2	Control	94 ± 1^{hi}	6.2 ± 0.2^{de}	2.4 ± 0.2^{de}	416 ± 8^{f}	99 ± 2^{ef}	6.0 ± 0.2^{c}	2.6 ± 0.2^{cd}	470 ± 6^{e}
	Seaweed extract 1 g/L	96 ± 1^{gh}	$6.8 \pm 0.2^{a\text{–}c}$	2.6 ± 0.1^{cd}	449 ± 8^{e}	105 ± 1^{d}	6.9 ± 0.2^{b}	2.9 ± 0.2^{bc}	517 ± 3^{d}
	Seaweed extract 2 g/L	99 ± 1^{ef}	7.0 ± 0.2^{a}	2.9 ± 0.1^{bc}	486 ± 3^{d}	112 ± 1^{c}	7.6 ± 0.2^{a}	2.9 ± 0.1^{bc}	529 ± 5^{d}
	Seaweed extract 3 g/L	112 ± 1^{b}	7.3 ± 0.2^{a}	$3.0 \pm 0.1^{a\text{–}c}$	513 ± 6^{c}	115 ± 1^{b}	7.8 ± 0.2^{a}	3.2 ± 0.1^{ab}	569 ± 5^{c}
T3	Control	91 ± 1^{ij}	5.8 ± 0.3^{ef}	2.1 ± 0.2^{e}	$364 \pm 4^{j \pm k}$	95 ± 1^{gh}	5.3 ± 0.3^{d}	2.2 ± 0.4^{e}	396 ± 3^{fg}
	Seaweed extract 1 g/L	$94 \pm 1^{g\text{–}i}$	$6.2 \pm 0.2^{c\text{–}e}$	2.3 ± 0.2^{de}	386 ± 5^{hi}	96 ± 1^{g}	5.4 ± 0.3^{d}	2.3 ± 0.1^{de}	416 ± 6^{fg}
	Seaweed extract 2 g/L	96 ± 1^{gh}	$6.4 \pm 0.3^{b\text{–}e}$	2.3 ± 0.2^{de}	398 ± 5^{gh}	103 ± 1^{de}	6.1 ± 0.3^{c}	2.4 ± 0.1^{de}	428 ± 6^{f}
	Seaweed extract 3 g/L	102 ± 1^{cd}	$6.5 \pm 0.4^{b\text{–}d}$	2.4 ± 0.2^{de}	410 ± 5^{fg}	110 ± 1^{c}	6.3 ± 0.2^{c}	2.4 ± 0.2^{de}	432 ± 5^{f}
T4	Control	89 ± 1^{j}	5.5 ± 0.2^{fg}	2.1 ± 0.1^{e}	350 ± 4^{k}	92 ± 1^{h}	5.0 ± 0.1^{d}	2.1 ± 0.1^{e}	374 ± 5^{g}
	Seaweed extract 1 g/L	91 ± 1^{ij}	$6.0 \pm 0.2^{d\text{–}f}$	2.1 ± 0.2^{e}	360 ± 5^{k}	93 ± 1^{h}	5.1 ± 0.1^{d}	2.2 ± 0.1^{e}	391 ± 5^{fg}
	Seaweed extract 2 g/L	92 ± 1^{ij}	6.1 ± 0.2^{de}	2.2 ± 0.1^{e}	376 ± 6 ij	98 ± 1^{f}	5.3 ± 0.3^{d}	2.2 ± 0.1^{e}	394 ± 2^{fg}
	Seaweed extract 3 g/L	97 ± 1^{fg}	6.1 ± 0.2^{de}	2.3 ± 0.2^{de}	389 ± 4^{hi}	102 ± 1^{de}	5.5 ± 0.3^{d}	2.2 ± 0.1^{e}	401 ± 4^{fg}

* T1, 100% of the recommended dose (RD) of mineral K; T2, 75% of the RD of mineral K + Biofertilizer; T3, 50% of the RD of mineral K + Biofertilizer; T4, 25% of the RD of mineral K + Biofertilizer. Means of the same treatments and in the same column followed by the same capital or small caps letter are not significantly different according to Duncan multiple range test (DMRT) at $p \leq 0.05$. The main effects are identified with uppercase letters and the interactions are identified with lowercase letters, unless otherwise mentioned.

Table 5. The effect of potassium fertilizer, biofertilizer, and foliar spraying of seaweed extract on chemical composition of globe artichoke leaves.

Treatments		**First Season (2018–2019)**				**Second Season (2019–2020)**			
Potassium Fertilizer	**Foliar Spraying**	**N%**	**P%**	**K%**	**Total Carbohydrates %**	**N%**	**P%**	**K%**	**Total Carbohydrates %**
T1		2.2 ± 0.0^{A}	0.26 ± 0.01^{A}	1.5 ± 0.1^{A}	23 ± 2^{B}	2.4 ± 0.0^{A}	0.24 ± 0.01^{A}	1.7 ± 0.1^{A}	21 ± 1^{B}
T2		2.1 ± 0.1^{B}	0.25 ± 0.01^{B}	1.5 ± 0.1^{A}	24 ± 1^{A}	2.3 ± 0.0^{B}	0.24 ± 0.01^{B}	1.6 ± 0.0^{A}	22 ± 1^{A}
T3		2.0 ± 0.1^{C}	0.23 ± 0.01^{C}	1.3 ± 0.1^{B}	21 ± 1^{C}	2.2 ± 0.1^{C}	0.22 ± 0.01^{C}	1.4 ± 0.0^{B}	19 ± 1^{C}
T4		2.0 ± 0.0^{C}	0.22 ± 0.01^{D}	1.3 ± 0.1^{B}	18 ± 1^{D}	2.1 ± 0.1^{D}	0.22 ± 0.10^{D}	1.3 ± 0.0^{C}	16 ± 1^{D}
	Control	1.8 ± 0.0^{D}	0.22 ± 0.01^{D}	1.3 ± 0.0^{B}	20 ± 1^{B}	2.1 ± 0.0^{C}	0.22 ± 0.01^{D}	1.3 ± 0.0^{C}	17 ± 1^{D}
	Seaweed extract 1 g/L	2.0 ± 0.0^{C}	0.23 ± 0.01^{C}	1.3 ± 0.1^{B}	20 ± 1^{B}	2.2 ± 0.1^{C}	0.23 ± 0.01^{C}	1.4 ± 0.0^{B}	19 ± 1^{C}
	Seaweed extract 2 g/L	2.2 ± 0.1^{B}	0.24 ± 0.01^{B}	1.5 ± 0.0^{A}	23 ± 1^{A}	2.3 ± 0.1^{B}	0.23 ± 0.01^{B}	1.6 ± 0.0^{A}	20 ± 1^{B}
	Seaweed extract 3 g/L	2.4 ± 0.1^{A}	0.26 ± 0.01^{A}	1.5 ± 0.1^{A}	23 ± 1^{A}	2.4 ± 0.0^{A}	0.25 ± 0.01^{A}	1.6 ± 0.1^{A}	17 ± 1^{A}
T1	Control	1.9 ± 0.0^{ghi}	0.23 ± 0.01^{h}	1.3 ± 0.1^{bc}	20 ± 2^{ef}	2.2 ± 0.0^{efg}	0.23 ± 0.01^{e}	1.4 ± 0.1^{de}	18 ± 1^{de}
	Seaweed extract 1 g/L	2.1 ± 0.0^{ef}	0.25 ± 0.01^{e}	1.4 ± 0.0^{b}	22 ± 1^{cde}	2.3 ± 0.1^{cde}	0.24 ± 0.01^{c}	1.6 ± 0.1^{c}	20 ± 1^{c}
	Seaweed extract 2 g/L	2.3 ± 0.0^{cd}	0.26 ± 0.01^{c}	1.7 ± 0.0^{a}	24 ± 1^{abc}	2.5 ± 0.1^{abc}	0.25 ± 0.01^{b}	1.8 ± 0.1^{ab}	22 ± 1^{bc}
	Seaweed extract 3 g/L	2.5 ± 0.1^{a}	0.28 ± 0.01^{a}	1.7 ± 0.1^{a}	25 ± 1^{ab}	2.6 ± 0.1^{a}	0.26 ± 0.01^{a}	1.9 ± 0.1^{a}	23 ± 1^{ab}
T2	Control	1.9 ± 0.1^{hij}	0.23 ± 0.01^{j}	1.3 ± 0.1^{bc}	21 ± 1^{de}	2.1 ± 0.0^{fg}	0.22 ± 0.00^{fg}	1.4 ± 0.1^{de}	21 ± 1^{c}
	Seaweed extract 1 g/L	2.0 ± 0.1^{gh}	0.24 ± 0.01^{f}	1.4 ± 0.1^{b}	23 ± 1^{bcd}	2.1 ± 0.0^{fg}	0.23 ± 0.01^{d}	1.5 ± 0.1^{cd}	22 ± 1^{bc}
	Seaweed extract 2 g/L	2.2 ± 0.1^{cde}	0.25 ± 0.00^{d}	1.6 ± 0.1^{a}	25 ± 1^{ab}	2.4 ± 0.0^{bcd}	0.24 ± 0.00^{c}	1.7 ± 0.0^{b}	23 ± 1^{ab}
	Seaweed extract 3 g/L	2.4 ± 0.0^{ab}	0.27 ± 0.01^{b}	1.6 ± 0.1^{a}	26 ± 1^{a}	2.5 ± 0.1^{ab}	0.25 ± 0.01^{b}	1.8 ± 0.0^{ab}	24 ± 1^{a}
T3	Control	1.8 ± 0.1^{ij}	0.22 ± 0.01^{k}	1.2 ± 0.1^{bc}	18 ± 1^{fg}	2.1 ± 0.1^{fg}	0.21 ± 0.01^{h}	1.3 ± 0.1^{ef}	$16 \pm 1^{f \pm gh}$
	Seaweed extract 1 g/L	1.9 ± 0.0^{ghi}	0.22 ± 0.01^{l}	1.3 ± 0.0^{bc}	18 ± 1^{fg}	2.1 ± 0.0^{fg}	0.22 ± 0.01^{ef}	1.3 ± 0.1^{ef}	18 ± 1^{ef}
	Seaweed extract 2 g/L	2.1 ± 0.0^{def}	0.23 ± 0.01^{i}	1.4 ± 0.1^{b}	25 ± 1^{ab}	2.2 ± 0.1^{def}	$0.22 \pm 0.0^{f \pm g}$	1.4 ± 0.0^{de}	20 ± 1^{cd}
	Seaweed extract 3 g/L	2.3 ± 0.0^{bc}	0.24 ± 0.01^{g}	1.4 ± 0.0^{b}	22 ± 1^{bcd}	2.3 ± 0.1^{ede}	0.24 ± 0.01^{c}	1.4 ± 0.1^{de}	22 ± 1^{bc}
T4	Control	1.8 ± 0.1^{j}	0.21 ± 0.01^{n}	1.2 ± 0.1^{c}	16 ± 1^{gh}	2.0 ± 0.1^{g}	0.20 ± 0.01^{i}	1.2 ± 0.1^{f}	14 ± 1^{h}
	Seaweed extract 1 g/L	1.9 ± 0.1^{hij}	0.22 ± 0.01^{m}	1.2 ± 0.1^{bc}	15 ± 1^{h}	2.1 ± 0.0^{g}	0.21 ± 0.01^{h}	1.3 ± 0.1^{ef}	15 ± 1^{gh}
	Seaweed extract 2 g/L	2.0 ± 0.1^{fg}	0.22 ± 0.00^{k}	1.3 ± 0.0^{bc}	20 ± 1^{ef}	2.1 ± 0.0^{fg}	0.22 ± 0.01^{g}	1.3 ± 0.1^{ef}	17 ± 1^{efg}
	Seaweed extract 3 g/L	2.3 ± 0.1^{bc}	0.23 ± 0.01^{i}	1.3 ± 0.0^{bc}	21 ± 1^{de}	2.2 ± 0.1^{efg}	0.23 ± 0.01^{de}	1.3 ± 0.0^{ef}	18 ± 1^{ef}

T1, 100% of the recommended dose (RD) of mineral K; T2, 75% of the RD of mineral K + Biofertilizer; T3, 50% of the RD of mineral K + Biofertilizer; T4, 25% of the RD of mineral K + Biofertilizer. Means of the same treatments and in the same column followed by the same capital or small caps letter are not significantly different according to Duncan multiple range test (DMRT) at $p \leq 0.05$. The main effects are identified with uppercase letters and the interactions are identified with lowercase letters, unless otherwise mentioned.

3.3. Yield Parameters

Table 6 presents the results of yield parameters and yield allocation (early and late yield) throughout the harvesting period. Early and late yield, as well as total yield of heads, increased when potassium was applied in inorganic form (100% of the RD) or partially substituted (25% of the RD) with biofertilizer. Furthermore, the application of seaweed extract at 2–3 g/L (or 2 g/L in the season of 2019–2020) resulted in the highest yield parameters recorded. Moreover, there was a profound positive effect on yield with the combined application of T1 and T2 treatments (100% and 75% of the RD of inorganic potassium fertilizer) with foliar spraying of seaweed extract at 3 g/L, whereas the lowest yield values were recorded for the plants in the T4 treatment and not sprayed with seaweed extract. The observed results are in agreement with the results of the vegetative growth and chemical composition of the leaves (see Tables 4 and 5), a finding which indicates that increased plant growth and high contents of macronutrients and carbohydrates in leaves is associated with higher yield, as expressed by the higher number and total fresh weight of heads, due to the higher availability of assimilates for biosynthetic processes [59,60]. This could be due to the increasing availability of potassium, which is associated with increased yields in artichoke plants [51,62]; meanwhile, Saleh et al. [23] suggested that, alongside the application rates of potassium fertilizers, the distribution of doses throughout the growing season is equally important for the improvement of yield parameters. According to Saif Eldeen et al. [57], the application of seaweed extracts at 2 g/L significantly improved yield distribution and total yield of globe artichoke, while Madian et al. [23] suggested that lower rates (750 mg/L) may also have beneficial effects on yield parameters. Moreover, Elsharkawy et al. [15] reported that the application of seaweed extracts combined with potassium and phosphorus fertilizers increased the earliness of artichoke plants, as well as the early and total yield of heads. The beneficial effects of seaweed extracts could be attributed to their composition, since, according to Arthur et al. [63], seaweed extracts usually contain auxins and cytokinins that may induce the formation of flowers and consequently increase the number of fruits and fruit yield. Therefore, the partial substitution of mineral potassium fertilizer with biofertilizer and the foliar application of seaweed extract seems to be a promising eco-friendly practice that, as well as the environmental benefits, may also retain high yields in artichoke crops due to the hormone-like activities of seaweed extracts and the improved nutrient uptake and assimilation rates of the plants.

3.4. Physical Quality Parameters of Heads

Data related with the effect of potassium fertilizer, biofertilizer, and foliar spraying of seaweed extract on physical parameters of artichoke heads are presented in Table 7. All the studied physical parameters of heads were significantly higher when plants were treated with T1 or T2 treatments, without significant differences between these two fertilization regimes. On the other hand, the foliar spraying of 3 g/L of seaweed extract resulted in the highest values of all the parameters. However, no significant differences were observed between the different rates of seaweed extract (1–3 g/L) in the case of head fresh weight, while head dimensions (length and diameter) did not differ between the medium (2 g/L) and high (3 g/L) application rate. Moreover, the edible fresh weight did not differ between the application rates of 1 g/L and 3 g/L in the 2018–2019 growing season and between the rates of 2 g/L and 3 g/L in the 2019–2020 growing season. Regarding the effect of combined application of potassium fertilizer + biofertilizer and foliar spraying of seaweed extract, the highest overall values for the studied parameters were recorded when plants were treated with 75% of the RD of K with inorganic fertilizer + biofertilizer and 3 g/L of seaweed extract. In contrast, the lowest values were observed in the case of unsprayed plants that received the T4 treatment. As mentioned for the results of yield and yield allocation, the higher availability in assimilates (see results in Table 5) results in improved vegetative growth which consequently results in higher total yield due to higher number of heavier heads [58,59]. According to the literature, the availability of potassium is pivotal for head formation in artichoke plants [23,52,58,64], especially when most of the required amounts are provided in mineral form [63]. In addition, the application of biostimulants, such as seaweed extracts, may have an effect on head weight as well as on head dimensions [46], whereas Elsharkawy et al. [15] suggested that the combined application of seaweed based biostimulants and phosphorus and potassium fertilizers on artichoke plants may increase the average head weight without affecting the diameter of heads. Therefore, the physical quality parameters of artichoke heads can be improved by the partial substitution of mineral potassium fertilizers, providing that seaweed extracts are applied with foliar spraying. This positive effect is probably attributed to the higher assimilation rates of plants that receive these treatments which eventually result in improved quality of heads.

3.5. Head Quality Parameters

The results related to the quality of the artichoke heads are presented in Tables 8 and 9. Total soluble solids (TSS) and total sugars were significantly higher for the T1 and T2 treatments, whereas inulin content was not affected by the potassium fertilization regime (Table 6). Moreover, total flavonoid content was the highest in the T2 treatment, while a varied effect was observed for fiber and total phenolic content depending on the growing season (Table 8). In particular, fiber content was significantly higher in T1 and T2 treatments during the 2018–2019 season, while the next year, the best performing treatments were T2 and T3. Similarly, total phenolic content did not differ between T1, T2, and T3 treatments in 2018–2019, whereas no significant differences were observed between the potassium fertilization treatments in 2019–2020. The application of seaweed extract at rates of 2–3 g/L was also beneficial to TSS and total sugar content, while it did not affect the inulin content of the artichoke heads (Table 8). Regarding the total flavonoid content, the application rates of 3 g/L and 2–3 g/L gave the best results in 2018–2019 and 2019–2020 seasons, respectively (Table 9). Fiber content was the highest for the control treatment (no seaweed extract added) in both seasons, although no significant differences were recorded for the application rates of 1–2 g/L and 1 g/L in 2018–2019 and 2019–2020 seasons, respectively. In addition, total phenolic content increased upon the foliar application of seaweed extract in both seasons (at rates 2–3 g/L and 1–3 g/L in 2018–2019 and 2019–2020 seasons, respectively). The combined application of potassium fertilizer + biofertilizer and seaweed extract also affected TSS and total sugar content, with the highest values being recorded for the T2 treatment and 3 g/L of seaweed extract (Table 8). In contrast, the lowest values were measured in the combination of T4 and control (no seaweed extract added) treatments, while the inulin content was not affected by any combination of treatments. Total flavonoids and total phenolic content was the highest for the combination of T2 and seaweed extract at 3 g/L, whereas the lowest values were recorded for the T4–control treatment combination. Finally, fiber content was the highest in the plants that received T1 treatment and no foliar spraying of seaweed extract in both seasons, whereas the combination of T4 and seaweed extract at 3 g/L resulted in the lowest overall values.

Table 6. The effect of potassium fertilizer, biofertilizer, and foliar spraying of seaweed extract on yield parameters of globe artichoke.

Treatments		**First Season (2018–2019)**				**Second Season (2019–2020)**			
Potassium Fertilizer	**Foliar Spraying**	**Early Heads/Plant (no)**	**Late Heads/Plant (no)**	**Total Heads/Plant (no)**	**Total Yield (ton/ha)**	**Early Heads/Plant (no)**	**Late Heads/Plant (no)**	**Total Heads/Plant (no)**	**Total Yield (ton/ha)**
T1		4.6 ± 0.9 A	8.3 ± 0.1 A	13 ± 0.3 A	5.0 ± 0.5 B	4.7 ± 0.1 A	8.3 ± 0.1 A	13 ± 0.1 B	4.8 ± 0.3 B
T2		4.5 ± 0.2 A	8.3 ± 0.1 A	13 ± 0.5 A	5.1 ± 0.8 A	4.6 ± 0.2 A	8.2 ± 0.2 A	13 ± 0.2 B	4.9 ± 0.2 A
T3		3.8 ± 0.1 B	7.7 ± 0.1 B	11 ± 0.4 B	3.4 ± 0.2 C	3.6 ± 0.2 B	7.2 ± 0.1 B	11 ± 0.1 A	3.2 ± 0.3 C
T4		3.4 ± 0.1 C	7.4 ± 0.1 B	11 ± 0.3 B	3.1 ± 0.2 D	3.5 ± 0.2 B	7.1 ± 0.1 B	11 ± 0.1 B	3.0 ± 0.6 D
	Control	3.6 ± 0.2 D	6.6 ± 0.1 D	11 ± 0.2 C	3.3 ± 0.3 D	3.5 ± 0.2 D	6.5 ± 0.1 D	11 ± 0.1 B	3.1 ± 0.2 D
	Seaweed extract 1 g/L	4.0 ± 0.2 C	7.7 ± 0.1 C	12 ± 0.2 C	3.8 ± 0.1 C	3.9 ± 0.1 C	7.6 ± 0.1 C	11 ± 0.2 B	3.6 ± 0.2 C
	Seaweed extract 2 g/L	4.3 ± 0.2 B	8.3 ± 0.1 B	13 ± 0.1 B	4.5 ± 0.4 B	4.2 ± 0.1 B	8.1 ± 0.1 B	12 ± 0.1 A	4.2 ± 0.2 B
	Seaweed extract 3 g/L	4.5 ± 0.2 A	8.9 ± 0.2 A	13 ± 0.2 A	5.0 ± 0.1 A	4.8 ± 0.2 A	8.7 ± 0.2 A	14 ± 0.1 A	4.9 ± 0.2 A
T1	Control	3.9 ± 0.2 e	6.9 ± 0.1 g	11 ± 0.3 cd	3.6 ± 0.5 ef	3.8 ± 0.1 de	6.8 ± 0.1 g	11 ± 0.1 b	3.4 ± 0.3 f
	Seaweed extract 1 g/L	4.4 ± 0.1 d	7.9 ± 0.1 cd	12 ± 0.1 c	4.6 ± 0.5 c	4.5 ± 0.2 bc	7.7 ± 0.1 cd	12 ± 0.2 b	4.3 ± 0.3 d
	Seaweed extract 2 g/L	4.9 ± 0.2 bc	8.8 ± 0.4 b	14 ± 0.4 ab	5.6 ± 0.6 b	5.1 ± 0.1 a	8.7 ± 0.4 b	14 ± 0.1 b	5.3 ± 0.6 b
	Seaweed extract 3 g/L	5.3 ± 0.2 a	9.7 ± 0.3 a	15 ± 0.1 a	6.3 ± 0.8 a	5.3 ± 0.1 a	9.8 ± 0.1 a	15 ± 0.1 a	6.1 ± 0.6 a
T2	Control	3.9 ± 0.2 ef	6.9 ± 0.1 g	11 ± 0.5 d	3.7 ± 0.8 e	3.8 ± 0.2 def	6.8 ± 0.1 g	11 ± 0.3 b	3.5 ± 0.2 e
	Seaweed extract 1 g/L	4.3 ± 0.2 d	7.8 ± 0.2 cdef	12 ± 0.2 cd	4.6 ± 0.2 c	4.5 ± 0.1 bc	7.7 ± 0.1 cf	12 ± 0.2 b	4.5 ± 0.3 c
	Seaweed extract 2 g/L	4.8 ± 0.1 c	8.8 ± 0.1 b	14 ± 0.3 b	5.6 ± 0.3 b	4.9 ± 0.1 ab	8.6 ± 0.2 b	14 ± 0.1 b	5.4 ± 0.3 b
	Seaweed extract 3 g/L	5.2 ± 0.1 ab	9.7 ± 0.2 a	15 ± 0.4 ab	6.5 ± 0.2 a	5.3 ± 0.7 a	9.7 ± 0.2 a	15 ± 0.1 a	6.1 ± 0.4 a
T3	Control	3.3 ± 0.1 gh	6.4 ± 0.2 h	11 ± 0.4 d	3.0 ± 0.6 i	3.2 ± 0.1 g	6.3 ± 0.1 c	10 ± 0.1 b	2.8 ± 0.3 f
	Seaweed extract 1 g/L	3.8 ± 0.1 ef	7.5 ± 0.1 ef	11 ± 0.2 cd	3.2 ± 0.1 h	3.3 ± 0.2 fg	7.3 ± 0.2 e	11 ± 0.2 b	2.9 ± 0.1 f
	Seaweed extract 2 g/L	4.0 ± 0.3 e	7.8 ± 0.1 cdef	12 ± 0.4 cd	3.5 ± 0.3 g	3.4 ± 0.1 efg	7.5 ± 0.2 cd	11 ± 0.1 b±	3.2 ± 0.2 g
	Seaweed extract 3 g/L	4.1 ± 0.1 de	8.1 ± 0.1 c	12 ± 0.2 c	3.8 ± 0.2 d	4.6 ± 0.2 bc	7.7 ± 0.2 de	12 ± 0.2 a	3.7 ± 0.4 e
T4	Control	3.2 ± 0.1 h	6.4 ± 0.1 h	11 ± 0.3 c	2.8 ± 0.2 j	3.1 ± 0.1 g	6.2 ± 0.1 e	10 ± 0.1 b	2.7 ± 0.5 h
	Seaweed extract 1 g/L	3.4 ± 0.1 gh	7.5 ± 0.1 f	11 ± 0.2 cd	3.0 ± 0.2 j	3.3 ± 0.1 fg	7.2 ± 0.1 h	10 ± 0.1 b	2.8 ± 0.4 h
	Seaweed extract 2 g/L	3.4 ± 0.1 gh	7.7 ± 0.1 def	12 ± 0.1 cd	3.2 ± 0.4 h	3.3 ± 0.1 fg	7.4 ± 0.1 ef	11 ± 0.1 b	3.0 ± 0.2 e
	Seaweed extract 3 g/L	3.6 ± 0.1 fg	7.9 ± 0.1 cde	11 ± 0.1 cd	3.4 ± 0.4 g	4.1 ± 0.1 cd	7.6 ± 0.3 dc	12 ± 0.1 b	3.4 ± 0.3 b

T1, 100% of the recommended dose (RD) of mineral K; T2, 75% of the RD of mineral K + Biofertilizer; T3, 50% of the RD of mineral K + Biofertilizer; T4, 25% of the RD of mineral K + Biofertilizer. Means of the same treatments and in the same column followed by the same capital or small caps letter are not significantly different according to Duncan multiple range test (DMRT) at $p \leq 0.05$. The main effects are identified with uppercase letters and the interactions are identified with lowercase letters, unless otherwise mentioned.

Table 7. The effect of potassium fertilizer, biofertilizer, and foliar spraying of seaweed extract on head quality of globe artichoke.

Treatments		First Season (2018–2019)				Second Season (2019–2020)			
Potassium Fertilizer	Foliar Spraying	Head Fresh Weight (g)	Edible Fresh Weight (g)	Head Length (cm)	Head Diameter (cm)	Head Fresh Weight (g)	Edible Fresh Weight (g)	Head Length (cm)	Head Diameter (cm)
T1		219 ± 5 ^{B}	64 ± 1 ^{B}	9.5 ± 0.2 ^{A}	8.2 ± 0.1 ^{A}	209 ± 2 ^{A}	61 ± 1 ^{A}	9.4 ± 0.0 ^{A}	8.1 ± 0.1 ^{A}
T2		224 ± 2 ^{A}	65 ± 2 ^{A}	9.5 ± 0.1 ^{A}	8.3 ± 0.1 ^{A}	216 ± 4 ^{B}	63 ± 1 ^{A}	9.5 ± 0.1 ^{A}	8.2 ± 0.1 ^{A}
T3		167 ± 4 ^{C}	52 ± 1 ^{C}	9.1 ± 0.1 ^{B}	7.3 ± 0.1 ^{B}	162 ± 1 ^{C}	45 ± 1 ^{B}	8.9 ± 0.1 ^{B}	7.3 ± 0.1 ^{B}
T4		161 ± 3 ^{D}	48 ± 1 ^{D}	9.0 ± 0.1 ^{B}	7.2 ± 0.1 ^{B}	156 ± 3 ^{D}	44 ± 1 ^{B}	8.9 ± 0.2 ^{B}	7.2 ± 0.1 ^{B}
	Control	175 ± 1 ^{D}	51 ± 1 ^{D}	9.0 ± 0.1 ^{C}	7.4 ± 0.1 ^{D}	168 ± 1 ^{D}	48 ± 1 ^{D}	9.0 ± 0.1 ^{D}	7.3 ± 0.1 ^{D}
	Seaweed extract 1 g/L	187 ± 3 ^{C}	55 ± 1 ^{C}	9.1 ± 0.2 ^{C}	7.6 ± 0.1 ^{C}	180 ± 2 ^{C}	51 ± 1 ^{C}	9.1 ± 0.1 ^{C}	7.5 ± 0.1 ^{C}
	Seaweed extract 2 g/L	201 ± 2 ^{B}	43 ± 1 ^{B}	9.3 ± 0.2 ^{B}	8.0 ± 0.1 ^{B}	194 ± 4 ^{B}	54 ± 1 ^{B}	9.2 ± 0.2 ^{B}	7.9 ± 0.1 ^{B}
	Seaweed extract 3 g/L	210 ± 4 ^{A}	64 ± 1 ^{A}	9.5 ± 0.1 ^{A}	8.1 ± 0.1 ^{A}	201 ± 4 ^{A}	59 ± 1 ^{A}	9.4 ± 0.2 ^{A}	8.0 ± 0.1 ^{A}
T1	Control	192 ± 5 ^{e}	55 ± 1 ^{de}	9.2 ± 0.2 ^{efg}	7.6 ± 0.1 ^{d}	184 ± 2 ^{f}	53 ± 1 ^{d}	9.1 ± 0.0 $^{d–f}$	7.5 ± 0.1 ^{de}
	Seaweed extract 1 g/L	212 ± 4 ^{d}	60 ± 1 ^{c}	9.3 ± 0.1 ^{de}	7.9 ± 0.1 ^{c}	202 ± 4 ^{d}	58 ± 1 ^{c}	9.2 ± 0.1 $^{c–e}$	7.8 ± 0.1 ^{bc}
	Seaweed extract 2 g/L	231 ± 3 ^{c}	67 ± 2 ^{b}	9.6 ± 0.1 ^{bc}	8.6 ± 0.1 ^{b}	221 ± 4 ^{b}	64 ± 1 ^{b}	9.4 ± 0.1 ^{bc}	8.5 ± 0.1 ^{a}
	Seaweed extract 3 g/L	241 ± 4 ^{b}	73 ± 1 ^{a}	9.8 ± 0.1 ^{ab}	8.8 ± 0.1 ^{ab}	230 ± 5 ^{a}	71 ± 2 ^{a}	9.8 ± 0.2 ^{a}	8.7 ± 0.1 ^{a}
T2	Control	196 ± 2 ^{e}	56 ± 2 ^{d}	9.2 ± 0.1 ^{def}	7.6 ± 0.1 ^{d}	191 ± 4 ^{e}	55 ± 1 ^{d}	9.2 ± 0.1 $^{c–e}$	7.6 ± 0.1 ^{cd}
	Seaweed extract 1 g/L	217 ± 3 ^{d}	62 ± 1 ^{c}	9.3 ± 0.1 ^{cd}	8.0 ± 0.1 ^{c}	209 ± 4 ^{c}	60 ± 1 ^{c}	9.3 ± 0.1 $^{b–d}$	7.9 ± 0.1 ^{b}
	Seaweed extract 2 g/L	236 ± 4 ^{bc}	68 ± 1 ^{b}	9.7 ± 0.2 ^{ab}	8.7 ± 0.1 ^{ab}	228 ± 3 ^{a}	64 ± 1 ^{b}	9.5 ± 0.1 ^{b}	8.5 ± 0.1 ^{a}
	Seaweed extract 3 g/L	248 ± 4 ^{a}	74 ± 2 ^{a}	9.9 ± 0.1 ^{a}	8.9 ± 0.2 ^{a}	234 ± 3 ^{a}	72 ± 1 ^{a}	9.9 ± 0.1 ^{a}	8.7 ± 0.1 ^{a}
T3	Control	158 ± 4 ^{hi}	47 ± 1 ^{i}	9.0 ± 0.1 ^{fgh}	7.2 ± 0.1 ^{ef}	152 ± 1 ^{hi}	43 ± 1 ^{g}	8.8 ± 0.1 ^{gh}	7.1 ± 0.1 ^{gh}
	Seaweed extract 1 g/L	161 ± 2 ^{h}	51 ± 1 ^{fg}	9.0 ± 0.2 ^{fgh}	7.3 ± 0.1 ^{ef}	158 ± 1 ^{h}	44 ± 1 ^{g}	8.9 ± 0.0 $^{f–h}$	7.2 ± 0.1 $^{f–h}$
	Seaweed extract 2 g/L	171 ± 3 ^{g}	53 ± 1 ^{ef}	9.1 ± 0.1 $^{d–h}$	7.3 ± 0.1 ^{ef}	167 ± 4 ^{g}	44 ± 1 $^{f \pm g}$	9.0 ± 0.1 $^{e–f}$	7.3 ± 0.1 $^{e–g}$
	Seaweed extract 3 g/L	179 ± 3 ^{f}	56 ± 1 ^{d}	9.2 ± 0.1 $^{d–g}$	7.4 ± 0.1 ^{de}	172 ± 4 ^{g}	48 ± 1 ^{e}	9.1 ± 0.1 $^{d–f}$	7.4 ± 0.1 $^{d–f}$
T4	Control	153 ± 3 ^{i}	45 ± 1 ^{i}	8.8 ± 0.1 ^{h}	7.1 ± 0.1 ^{f}	146 ± 3 ^{i}	43 ± 1 ^{g}	8.7 ± 0.1 ^{h}	7.0 ± 0.1 ^{h}
	Seaweed extract 1 g/L	157 ± 1 ^{hi}	47 ± 1 ^{hi}	8.9 ± 0.1 ^{gh}	7.2 ± 0.1 ^{ef}	151 ± 4 ^{hi}	43 ± 1 ^{g}	8.9 ± 0.2 ^{gh}	7.1 ± 0.1 ^{gh}
	Seaweed extract 2 g/L	164 ± 2 ^{h}	50 ± 2 ^{gh}	9.0 ± 0.1 $^{e–h}$	7.3 ± 0.1 ^{ef}	158 ± 2 ^{h}	44 ± 1 ^{g}	8.9 ± 0.1 ^{fh}	7.3 ± 0.1 $^{f–h}$
	Seaweed extract 3 g/L	171 ± 3 ^{g}	52 ± 1 ^{fg}	9.1 ± 0.1 $^{d–h}$	7.3 ± 0.1 ^{ef}	167 ± 2 ^{g}	47 ± 1 ^{ef}	9.0 ± 0.1 $^{e–g}$	7.3 ± 0.1 $^{e–g}$

T1, 100% of the recommended dose (RD) of mineral K; T2, 75% of the RD of mineral K + Biofertilizer; T3, 50% of the RD of mineral K + Biofertilizer; T4, 25% of the RD of mineral K + Biofertilizer. Means of the same treatments and in the same column followed by the same capital or small caps letter are not significantly different according to Duncan multiple range test (DMRT) at $p \leq 0.05$. The main effects are identified with uppercase letters and the interactions are identified with lowercase letters, unless otherwise mentioned.

Table 8. The effect of potassium fertilizer, biofertilizer, and foliar spraying of seaweed extract on total soluble solids, total sugars, and inulin content of globe artichoke heads.

Treatments		First Season (2018–2019)			Second Season (2019–2020)		
Potassium Fertilizer	Foliar Spraying	TSS (%)	Total Sugars (%)	Inulin (%)	TSS (%)	Total Sugars (%)	Inulin (%)
T1		7.3 ± 0.0^{B}	6.5 ± 0.1^{B}	1.4 ± 0.0^{B}	7.5 ± 0.0^{A}	6.3 ± 0.0^{B}	1.3 ± 0.1^{B}
T2		7.4 ± 0.0^{A}	6.6 ± 0.1^{A}	1.5 ± 0.1^{A}	7.6 ± 0.0^{A}	6.5 ± 0.1^{A}	1.4 ± 0.0^{A}
T3		7.2 ± 0.0^{C}	6.2 ± 0.0^{C}	1.4 ± 0.1^{B}	7.4 ± 0.0^{B}	6.3 ± 0.1^{C}	1.3 ± 0.1^{AB}
T4		7.1 ± 0.1^{D}	6.0 ± 0.1^{D}	1.3 ± 0.1^{B}	7.3 ± 0.0^{B}	6.2 ± 0.1^{D}	1.3 ± 0.1^{A}
	Control	7.2 ± 0.1^{C}	6.1 ± 0.0^{D}	1.3 ± 0.0^{C}	7.3 ± 0.0^{C}	6.2 ± 0.0^{B}	1.3 ± 0.1^{B}
	Seaweed extract 1 g/L	7.2 ± 0.0^{C}	6.2 ± 0.0^{C}	1.4 ± 0.0^{B}	7.4 ± 0.1^{B}	6.3 ± 0.1^{B}	1.3 ± 0.0^{B}
	Seaweed extract 2 g/L	7.3 ± 0.1^{B}	6.5 ± 0.1^{B}	1.4 ± 0.1^{A}	7.5 ± 0.1^{AB}	6.4 ± 0.1^{A}	1.4 ± 0.1^{A}
	Seaweed extract 3 g/L	7.4 ± 0.0^{A}	6.6 ± 0.1^{A}	1.5 ± 0.1^{A}	7.6 ± 0.1^{A}	6.5 ± 0.1^{A}	1.4 ± 0.1^{A}
T1	Control	$7.2 \pm 0.0^{e–g}$	6.1 ± 0.1^{fg}	1.3 ± 0.1^{fg}	$7.3 \pm 0.1^{e–g}$	$6.3 \pm 0.0^{c–e}$	1.2 ± 0.0^{de}
	Seaweed extract 1 g/L	$7.3 \pm 0.1^{c–e}$	$6.3 \pm 0.0^{c–e}$	$1.3 \pm 0.0^{c–g}$	$7.5 \pm 0.1^{b–f}$	$6.2 \pm 0.0^{c–e}$	$1.3 \pm 0.0^{c–e}$
	Seaweed extract 2 g/L	7.4 ± 0.1^{bc}	6.8 ± 0.1^{b}	$1.4 \pm 0.0^{b–g}$	$7.6 \pm 0.1^{a–d}$	6.4 ± 0.1^{bc}	$1.3 \pm 0.0^{b–e}$
	Seaweed extract 3 g/L	7.5 ± 0.1^{b}	6.9 ± 0.0^{ab}	$1.4 \pm 0.0^{b–d}$	7.7 ± 0.1^{ab}	6.5 ± 0.1^{ab}	$1.4 \pm 0.0^{a–d}$
T2	Control	$7.3 \pm 0.1^{c–f}$	$6.2 \pm 0.1^{d–g}$	$1.3 \pm 0.0^{c–g}$	$7.4 \pm 0.1^{d–g}$	$6.3 \pm 0.1^{b–d}$	$1.3 \pm 0.0^{b–e}$
	Seaweed extract 1 g/L	$7.3 \pm 0.1^{b–d}$	6.3 ± 0.1^{cd}	$1.4 \pm 0.0^{b–e}$	$7.5 \pm 0.1^{b–f}$	6.4 ± 0.1^{bc}	$1.4 \pm 0.1^{a–e}$
	Seaweed extract 2 g/L	7.4 ± 0.1^{b}	6.9 ± 0.0^{ab}	1.0 ± 0.0^{ab}	$7.7 \pm 0.1^{a–c}$	6.5 ± 0.1^{ab}	1.4 ± 0.0^{ab}
	Seaweed extract 3 g/L	7.6 ± 0.1^{a}	7.0 ± 0.1^{a}	1.6 ± 0.0^{a}	7.8 ± 0.1^{a}	6.6 ± 0.1^{a}	1.5 ± 0.0^{a}
T3	Control	$7.1 \pm 0.1^{f–h}$	6.1 ± 0.0^{gh}	$1.3 \pm 0.1^{e–g}$	7.3 ± 0.1^{fg}	$6.1 \pm 0.1^{d–f}$	$1.3 \pm 0.2^{a–d}$
	Seaweed extract 1 g/L	7.1 ± 0.0^{gh}	$6.2 \pm 0.0^{e–g}$	$1.4 \pm 0.1^{b–g}$	$7.4 \pm 0.1^{c–g}$	$6.3 \pm 0.1^{c–e}$	$1.3 \pm 0.1^{c–e}$
	Seaweed extract 2 g/L	$7.3 \pm 0.0^{c–e}$	$6.2 \pm 0.0^{e–g}$	$1.4 \pm 0.1^{b–f}$	$7.4 \pm 0.1^{d–g}$	6.4 ± 0.1^{bc}	$1.4 \pm 0.1^{a–e}$
	Seaweed extract 3 g/L	$7.3 \pm 0.1^{c–e}$	6.4 ± 0.1^{c}	$1.5 \pm 0.0^{a–c}$	$7.6 \pm 0.1^{a–e}$	$6.4 \pm 0.1^{a–c}$	$1.4 \pm 0.0^{a–c}$
T4	Control	7.0 ± 0.1^{h}	5.8 ± 0.1^{i}	1.3 ± 0.0^{g}	7.1 ± 0.0^{g}	6.0 ± 0.1^{f}	1.2 ± 0.1^{e}
	Seaweed extract 1 g/L	7.1 ± 0.0^{gh}	6.0 ± 0.0^{h}	$1.3 \pm 0.0^{d–g}$	7.3 ± 0.1^{fg}	6.1 ± 0.1^{ef}	1.2 ± 0.1^{de}
	Seaweed extract 2 g/L	$7.2 \pm 0.0^{e–g}$	$6.2 \pm 0.1^{e–g}$	$1.4 \pm 0.1^{b–g}$	7.4 ± 0.2^{dg}	$6.3 \pm 0.1^{c–e}$	$1.3 \pm 0.0^{b–e}$
	Seaweed extract 3 g/L	$7.2 \pm 0.1^{d–g}$	$6.2 \pm 0.1^{d–f}$	$1.4 \pm 0.1^{b–e}$	7.4 ± 0.1^{cg}	$6.3 \pm 0.1^{b–d}$	$1.4 \pm 0.0^{a–d}$

T1, 100% of the recommended dose (RD) of mineral K; T2, 75% of the RD of mineral K + Biofertilizer; T3, 50% of the RD of mineral K + Biofertilizer; T4, 25% of the RD of mineral K + Biofertilizer. Means of the same treatments and in the same column followed by the same capital or small caps letter are not significantly different according to Duncan multiple range test (DMRT) at $p \leq 0.05$. The main effects are identified with uppercase letters and the interactions are identified with lowercase letters, unless otherwise mentioned.

Anwar et al. [52] reported that potassium fertilization practices (soil application and foliar spraying) may affect inulin content in artichoke heads, a difference that could be attributed to the different forms of fertilizers used compared to our study. Moreover, the same authors suggested that the increasing amounts of potassium applied with foliar spraying significantly decreased total sugars and reduced the sugar content in artichoke receptacles, a finding that could be attributed to the lower availability of potassium, which consequently results in reduced metabolic rates and biosynthesis [52]. Moreover, Michalska-Ciechanowska et al. [65] suggested that the effect of potassium fertilization on inulin content in Jerusalem artichoke showed a genotype-dependent response that was associated with the earliness of the tested cultivars, as well as with the potassium application rates. Therefore, the lack of effect in our study could be attributed to the genotype tested. According to the study of Saif Eldeen [57], the application of seaweed extracts at rates up to 2 g/L had a variable effect on inulin and total sugar content in artichoke receptacles, depending on the growing season, while Elsharkawy et al. [15] suggested that the increasing rates of potassium and phosphorus fertilizers (up to 75 mL/L) or seaweed extracts (up to 10 mL/L) may increase the inulin content in artichoke heads. Similar to our study, Madian et al. [46] reported that increasing rates of seaweed extracts resulted in increased amounts of total and reducing sugars in artichoke heads; however, the same authors suggested that inulin content also increased, which is in contrast with our study. These differences could probably be attributed to the higher increments of application in our study (1 g/L) and the higher application rates (up to 3 g/L), compared to the study of Madian et al. (250 mg/L and 750 mg/L, respectively), or the different composition of the seaweed extracts studied in the reports of Madian et al. [47] and Elsharkawy et al. [15]. Considering the role of the aerial parts as sources and sinks of assimilates [60,61], the findings of our study indicate that the high availability of potassium in the T1 and T2 treatments allowed high vegetative growth rates and assimilation rates (see results in Tables 2 and 3), and the accumulation of assimilates in metabolically active tissues throughout the growing season.

Table 9. The effect of potassium fertilizer, biofertilizer, and foliar spraying of seaweed extract on total flavonoids, total phenolic and fiber content of globe artichoke heads.

Treatments		First Season (2018–2019)			Second Season (2019–2020)		
Potassium Fertilizer	Foliar Spraying	Total Flavonoids (mg of Catechin/100 g f.w.)	Fiber (%)	Total Phenolic Content (mg of Gallic Acid/100 g f.w.)	Total Flavonoids (mg of Catechin/100 g f.w.)	Fiber (%)	Total Phenolic Content (mg of Gallic Acid/100 g f.w.)
T1		12 ± 0.4 C	6.9 ± 0.3 A	292 ± 6 C	12 ± 0.3 C	6.3 ± 0.1 A	303 ± 5 C
T2		13 ± 0.4 A	6.7 ± 0.3 B	307 ± 2 A	14 ± 0.1 A	6.6 ± 0.1 B	291 ± 3 A
T3		12 ± 0.4 B	6.4 ± 0.1 C	297 ± 7 B	13 ± 0.6 B	6.4 ± 0.1 C	318 ± 6 B
T4		11 ± 0.3 D	6.3 ± 0.1 D	274 ± 11 D	11 ± 0.3 D	6.1 ± 0.1 D	311 ± 5 C
	Control	11 ± 0.3 D	6.9 ± 0.3 A	276 ± 2 D	11 ± 0.3 D	6.7 ± 0.1 A	277 ± 4 D
	Seaweed extract 1 g/L	12 ± 0.4 C	6.8 ± 0.1 A	286 ± 4 C	12 ± 0.4 C	6.6 ± 0.1 B	297 ± 8 C
	Seaweed extract 2 g/L	13 ± 0.4 B	6.6 ± 0.1 B	301 ± 3 B	13 ± 0.4 B	6.2 ± 0.1 C	314 ± 4 B
	Seaweed extract 3 g/L	13 ± 0.3 A	6.1 ± 0.1 C	309 ± 4 A	14 ± 0.4 A	5.6 ± 0.1 D	322 ± 5 A
T1	Control	10 ± 0.4 gh	7.1 ± 0.3 a	273 ± 6 hi	11 ± 0.3 gh	7.1 ± 0.1 a	268 ± 5 h
	Seaweed extract 1 g/L	11 ± 0.4 ef	7.1 ± 0.1 a	286 ± 4 e–g	12 ± 0.4 ef	6.8 ± 0.1 b	284 ± 9 g
	Seaweed extract 2 g/L	12 ± 0.3 d	6.8 ± 0.1 a–d	299 ± 4 cd	13 ± 0.2 d	6.4 ± 0.1 d	308 ± 6 d–f
	Seaweed extract 3 g/L	13 ± 0.5 de	6.6 ± 0.1 c–f	308 ± 4 bc	12 ± 0.3 de	6.2 ± 0.1 ef	302 ± 7 ef
T2	Control	12 ± 0.4 d	7.0 ± 0.3 ab	289 ± 2 d–f	13 ± 0.1 d	6.9 ± 0.1 b	295 ± 3 fg
	Seaweed extract 1 g/L	13 ± 0.2 c	6.9 ± 0.1 a–c	296 ± 2 c–e	14 ± 0.2 c	6.7 ± 0.1 bc	311 ± 4 de
	Seaweed extract 2 g/L	14 ± 0.4 b	6.7 ± 0.1 b–c	314 ± 2 b	15 ± 0.4 b	6.4 ± 0.2 de	326 ± 4 bc
	Seaweed extract 3 g/L	15 ± 0.3 a	6.4 ± 0.1 f	328 ± 8 a	16 ± 0.6 a	5.8 ± 0.1 g	341 ± 12 a
T3	Control	10 ± 0.4 ef	6.8 ± 0.1 a–d	279 ± 7 f–h	12 ± 0.5 d–f	6.5 ± 0.1 cd	287 ± 6 g
	Seaweed extract 1 g/L	12 ± 0.4 d	6.7 ± 0.1 b–e	284 ± 9 e–h	13 ± 0.4 d	6.5 ± 0.1 cd	304 ± 2 ef
	Seaweed extract 2 g/L	13 ± 0.2 c	6.4 ± 0.1 ef	307 ± 4 bc	14 ± 0.3 c	6.1 ± 0.1 ef	319 ± 4 cd
	Seaweed extract 3 g/L	13 ± 0.4 b	5.8 ± 0.1 g	319 ± 5 ab	15 ± 0.6 b	5.4 ± 0.1 h	334 ± 10 ab
T4	Control	10 ± 0.3 h	6.7 ± 0.1 c–e	264 ± 11 i	10 ± 0.4 h	6.3 ± 0.1 de	258 ± 5 h
	Seaweed extract 1 g/L	11 ± 0.4 h	6.5 ± 0.1 d–f	276 ± 7 gh	10 ± 0.3 gh	6.3 ± 0.1 de	288 ± 5 g
	Seaweed extract 2 g/L	12 ± 0.4 f ± g	6.3 ± 0.1 f	284 ± 7 e–h	11 ± 0.2 fg	6.0 ± 0.1 f	303 ± 4 ef
	Seaweed extract 3 g/L	12 ± 0.5 ef	5.6 ± 0.1 g	281 ± 7 f–h	12 ± 0.4 ef	5.2 ± 0.1 i	311 ± 4 de

T1, 100% of the recommended dose (RD) of mineral K; T2, 75% of the RD of mineral K + Biofertilizer; T3, 50% of the RD of mineral K + Biofertilizer; T4, 25% of the RD of mineral K + Biofertilizer. Means of the same treatments and in the same column followed by the same capital or small caps letter are not significantly different according to Duncan multiple range test (DMRT) at $p \leq 0.05$. The main effects are identified with uppercase letters and the interactions are identified with lowercase letters, unless otherwise mentioned.

In the study of Elsharkawy et al. [15], it was reported that increasing amounts of potassium and phosphorus fertilizers or seaweed extracts may significantly increase the total phenolic content of artichoke heads. Similar results were recorded by Michalska-Ciechanowska et al. [65] in their study on the effect of potassium fertilization rates on Jerusalem artichoke plants, although a variable effect depending on the genotype was also observed. This finding indicates that high nutrient availability may induce the biosynthesis of polyphenols, which is in agreement with our study. Moreover, the application of seaweed extracts is associated with osmotic stress and increased hormonal activities, which may induce the biosynthesis of phenolic compounds and flavonoids [66].

Therefore, the results of our study indicate that the combined application of potassium fertilizer (partially substituted with biofertilizers or in isolation) and seaweed extract was beneficial to most of the studied chemical composition parameters of artichoke heads, due to the greater availability of nutrients and the hormonal activities of the seaweed extract, which may induce the biosynthesis of bioactive compounds.

4. Conclusions

In conclusion, the results of our study indicate that the foliar application of seaweed extract at 3 g/L, combined with 100% inorganic potassium fertilizer, or 75% potassium fertilizer + biofertilizer, could beneficially affect plant growth and yield parameters, as well as the quality and chemical composition of globe artichoke heads. These findings are of great importance as they indicate that the partial substitution of chemical fertilizers with biofertilizers does not have a severe impact on the yield and quality of globe artichoke crops, while at the same time it may reduce the negative environmental impacts associated with high agrochemical inputs. In the same context, the application of seaweed extract-based biostimulant products may also have a positive effect on plant growth and yield and the quality of the final product, which could allow the adoption of sustainable and environmentally friendly practices in globe artichoke cultivation. However, future research is needed focusing on the evaluation of the effect of different fertilizer rates on nutrient uptake in order to test whether the use of biofertilizers and foliar spraying are effective practices, not only when plants receive the required amounts of nutrients, but also under nutrient deprivation. Moreover, more biostimulatory products with different compositions should be tested on artichoke crops to find the best combinations of fertilizer rates and biostimulants.

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References

1. Barracosa, P.; Barracosa, M.; Pires, E. Cardoon as a Sustainable Crop for Biomass and Bioactive Compounds Production. *Chem. Biodivers.* **2019**, *16*, e1900498. [CrossRef] [PubMed]
2. Petropoulos, S.A.; Pereira, C.; Ntatsi, G.; Danalatos, N.; Barros, L.; Ferreira, I.C.F.R. Nutritional value and chemical composition of Greek artichoke genotypes. *Food Chem.* **2017**, *267*, 296–302. [CrossRef] [PubMed]
3. Kollia, E.; Markaki, P.; Zoumpoulakis, P.; Proestos, C. Antioxidant activity of *Cynara scolymus* L. and *Cynara cardunculus* L. extracts obtained by different extraction techniques. *Nat. Prod. Res.* **2016**, *31*, 1163–1167. [CrossRef]
4. Zhu, X.; Zhang, H.; Lo, R. Phenolic compounds from the leaf extract of artichoke (*Cynara scolymus* L.) and their antimicrobial activities. *J. Agric. Food Chem.* **2004**, *52*, 7272–7278. [CrossRef] [PubMed]
5. Llorach, R.; Espín, J.C.; Tomás-Barberán, F.A.; Ferreres, F. Artichoke (*Cynara scolymus* L.) byproducts as a potential source of health-promoting antioxidant phenolics. *J. Agric. Food Chem.* **2002**, *50*, 3458–3464. [CrossRef] [PubMed]
6. FAOSTAT Production and Trade Statistics. Available online: http://www.fao.org/faostat/en/#data/QC/visualize (accessed on 28 December 2021).
7. Sgroi, F.; Foderà, M.; di Trapani, A.M.; Tudisca, S.; Testa, R. Profitability of artichoke growing in the mediterranean area. *HortScience* **2015**, *50*, 1349–1352. [CrossRef]
8. López-Salas, L.; Borrás-Linares, I.; Quintin, D.; García-Gomez, P.; Giménez-Martínez, R.; Segura-Carretero, A.; Lozano-Sánchez, J. Artichoke by-products as natural source of phenolic food ingredient. *Appl. Sci.* **2021**, *11*, 3788. [CrossRef]
9. Borsini, A.A.; Llavata, B.; Umaña, M.; Cárcel, J.A. Artichoke by products as a source of antioxidant and fiber: How it can be affected by drying temperature. *Foods* **2021**, *10*, 459. [CrossRef]
10. Xu, X.; Du, X.; Wang, F.; Sha, J.; Chen, Q.; Tian, G.; Zhu, Z.; Ge, S.; Jiang, Y. Effects of Potassium Levels on Plant Growth, Accumulation and Distribution of Carbon, and Nitrate Metabolism in Apple Dwarf Rootstock Seedlings. *Front. Plant Sci.* **2020**, *11*, 904. [CrossRef]
11. Wang, M.; Zheng, Q.; Shen, Q.; Guo, S. The critical role of potassium in plant stress response. *Int. J. Mol. Sci.* **2013**, *14*, 7370–7390. [CrossRef]
12. Çalişkan, B.; Çalişkan, A.C. Potassium Nutrition in Plants and Its Interactions with Other Nutrients in Hydroponic Culture. In *Potassium-Improvement of Quality in Fruits and Vegetables Through Hydroponic Nutrient Management*; Asaduzzaman, M., Asao, T., Eds.; IntechOpen: London, UK, 2012; p. 13.
13. Hsiao, C.; Läuchli, A. Role of potassium in plant-water relations. In *Advances in Plant Nutrition*; Tinker, P., Läuchli, A., Eds.; Praeger Publishing: Praeger, NY, USA, 1986; pp. 281–312.
14. Oosterhuis, D.M.; Loka, D.A.; Kawakami, E.M.; Pettigrew, W.T. The physiology of potassium in crop production. In *Advances in Agronomy*; Sparks, D.L., Ed.; Elsevier: Oxford, UK, 2014; Volume 126, pp. 203–233. ISBN 9780128001325.
15. Elsharkawy, G.A.; Ibrahim, H.A.H.; Salah, A.H.; Akrami, M.; Ali, H.M.; Abd-elkader, D.Y. Early and Total Yield Enhancement of the Globe Artichoke Using an Ecofriendly Seaweed Extract-Based Biostimulant. *Agronomy* **2021**, *11*, 1819. [CrossRef]
16. Lombardo, S.; Pandino, G.; Mauromicale, G. Minerals profile of two globe artichoke cultivars as affected by NPK fertilizer regimes. *Food Res. Int.* **2017**, *100*, 95–99. [CrossRef] [PubMed]
17. Lombardo, S.; Pandino, G.; Mauromicale, G. The nutraceutical response of two globe artichoke cultivars to contrasting NPK fertilizer regimes. *Food Res. Int.* **2015**, *76*, 852–859. [CrossRef] [PubMed]
18. Ayoub, A.T. Fertilizers and the environment. *Nutr. Cycl. Agroecosyst.* **1999**, *55*, 117–121. [CrossRef]
19. Bisht, N.; Chauhan, P.S. Excessive and Disproportionate Use of Chemicals Cause Soil Contamination and Nutritional Stress. In *Soil Contamination-Threats and Sustainable Solutions*; Larramendy, M.L., Soloneski, S., Eds.; IntechOpen: London, UK, 2020; pp. 1–10.
20. Ali, M.M.E.; Petropoulos, S.A.; Selim, D.A.F.H.; Elbagory, M.; Othman, M.M.; Omara, A.E.D.; Mohamed, M.H. Plant growth, yield and quality of potato crop in relation to potassium fertilization. *Agronomy* **2021**, *11*, 675. [CrossRef]
21. Ierna, A.; Mauro, R.P.; Mauromicale, G. Improved yield and nutrient efficiency in two globe artichoke genotypes by balancing nitrogen and phosphorus supply. *Agron. Sustain. Dev.* **2012**, *32*, 773–780. [CrossRef]
22. Shinohara, T.; Agehara, S.; Yoo, K.S.; Leskovar, D.I. Irrigation and Nitrogen Management of Artichoke: Yield, Head Quality, and Phenolic Content. *HortScience* **2011**, *46*, 377–386. [CrossRef]
23. Saleh, S.A.; Zaki, M.F.; Tantawy, A.S.; Salama, Y.A.M. Response of artichoke productivity to different proportions of nitrogen and potassium fertilizers. *Int. J. ChemTech Res.* **2016**, *9*, 25–33.
24. Dagar, J.C.; Sharma, D.K.; Sharma, P.C.; Singh, A.K. *Innovative Saline Agriculture*; Springer Nature Switzerland AG: Cham, Switzerland, 2016; ISBN 9788132227700.
25. Guiomar, N.; Godinho, S.; Pinto-Correia, T.; Almeida, M.; Bartolini, F.; Bezák, P.; Biró, M.; Bjørkhaug, H.; Bojnec, Š.; Brunori, G.; et al. Typology and distribution of small farms in Europe: Towards a better picture. *Land Use Policy* **2018**, *75*, 784–798. [CrossRef]
26. Correa, R.C.G.; Di Gioia, F.; Ferreira, I.; SA, P. Halophytes for Future Horticulture: The Case of Small-Scale Farming in the Mediterranean Basin. In *Halophytes for Future Horticulture: From Molecules to Ecosystems towards Biosaline Agriculture*; Marius-Nicusor Grigore, Ed.; Springer Nature Switzerland AG: Cham, Switzerland, 2020; pp. 1–28. ISBN 9783030178543.
27. Labib, B.F.; Ghadour, T.K.; Rahim, I.S.; Wahba, M.M. Effect of Potassium Bearing Rock on the Growth and Quality of Potato Crop (*Solanum tuberosum*). *Int. J. Res. Manag.* **2012**, *2*, 108–119. [CrossRef]

28. Mohamed, M.H.M.; Ali, M.; Eid, R.S.M.; El-Desouky, H.S.; Petropoulos, S.A.; Sami, R.; Al-Mushhin, A.A.M.; Ismail, K.A.; Zewail, R.M.Y. Phosphorus and biofertilizer application effects on growth parameters, yield and chemical constituents of broccoli. *Agronomy* **2021**, *11*, 2210. [CrossRef]
29. Dawwam, G.E.; Elbeltagy, A.; Emara, H.M.; Abbas, I.H.; Hassan, M.M. Beneficial effect of plant growth promoting bacteria isolated from the roots of potato plant. *Ann. Agric. Sci.* **2013**, *58*, 195–201. [CrossRef]
30. Manning, D.A.C. Mineral sources of potassium for plant nutrition. A review. *Agron. Sustain. Dev.* **2010**, *30*, 281–294. [CrossRef]
31. Sattar, A.; Naveed, M.; Ali, M.; Zahir, Z.A.; Nadeem, S.M.; Yaseen, M.; Meena, V.S.; Farooq, M.; Singh, R.; Rahman, M.; et al. Perspectives of potassium solubilizing microbes in sustainable food production system: A review. *Appl. Soil Ecol.* **2019**, *133*, 146–159. [CrossRef]
32. Bulgari, R.; Cocetta, G.; Trivellini, A.; Vernieri, P.; Ferrante, A. Biostimulants and crop responses: A review. *Biol. Agric. Hortic.* **2015**, *31*, 1–17. [CrossRef]
33. Alam, M.Z.; Braun, G.; Norrie, J.; Hodges, D.M. Effect of *Ascophyllum* extract application on plant growth, fruit yield and soil microbial communities of strawberry. *Can. J. Plant Sci.* **2013**, *93*, 23–36. [CrossRef]
34. Colla, G.; Rouphael, Y. Microalgae: New Source of Plant Biostimulants. *Agronomy* **2020**, *10*, 1240. [CrossRef]
35. Goñi, O.; Quille, P.; O'Connell, S. Ascophyllum nodosum extract biostimulants and their role in enhancing tolerance to drought stress in tomato plants. *Plant Physiol. Biochem.* **2018**, *126*, 63–73. [CrossRef]
36. Manaf, H.H. Beneficial effects of exogenous selenium, glycine betaine and seaweed extract on salt stressed cowpea plant. *Ann. Agric. Sci.* **2016**, *61*, 41–48. [CrossRef]
37. Rouphael, Y.; De Micco, V.; Arena, C.; Raimondi, G.; Colla, G.; De Pascale, S. Effect of *Ecklonia maxima* seaweed extract on yield, mineral composition, gas exchange, and leaf anatomy of zucchini squash grown under saline conditions. *J. Appl. Phycol.* **2017**, *29*, 459–470. [CrossRef]
38. Aremu, A.O.; Masondo, N.A.; Rengasamy, K.R.R.; Jir, S.O.A. Physiological role of phenolic biostimulants isolated from brown seaweed *Ecklonia maxima* on plant growth and development. *Planta* **2015**, 1313–1324. [CrossRef] [PubMed]
39. Jackson, M.L. (Ed.) *Soil Chemical Analysis*; Prentice Hall of India Pvt. Ltd.: New Delhi, India, 1973.
40. Black, C.A.; Evans, D.O.; Ensminger, L.E.; White, J.L.; Clark, F.E.; Dinauer, R.C. Chemical and Microbiological Properties. In *Methods of Soil Analysis*; Page, A.L., Ed.; American Society of Agronomy, Inc.; Soil Science Society of America, Inc.: Madison, WI, USA, 1965; pp. 34–41. ISBN 9780891180722.
41. Pandino, G.; Lombardo, S.; Mauro, R.P.; Mauromicale, G. Variation in polyphenol profile and head morphology among clones of globe artichoke selected from a landrace. *Sci. Hortic.* **2012**, *138*, 259–265. [CrossRef]
42. Pregl, F. *Quantitative Organic Microanalysis*, 4th ed.; Chundril: London, UK, 1961.
43. John, M.K. Colorimetric determination of phosphorus in soil and plant material with ascorbic acid. *Soil Sci.* **1970**, *109*, 214–220. [CrossRef]
44. Brown, J.; Lilliland, O. Rapid determination of potassium and sodium in plant materials and soil extracts by flame photometry. *Proc. Am. Soc. Hortic. Sci.* **1946**, *48*, 341–346.
45. Herbert, D.; Phipps, P.J.; Strange, R.E. Chemical Analysis of Microbial Cells. *Methods Microbiol.* **1971**, *5B*, 209–344. [CrossRef]
46. Pandino, G.; Lombardo, S.; Mauromicale, G. Chemical and Morphological Characteristics of New Clones and Commercial Varieties of Globe Artichoke (*Cynara cardunculus* var. *scolymus*). *Plant Foods Hum. Nutr.* **2011**, *66*, 291–297. [CrossRef]
47. Madian, G.K.I.; Abido, A.I.A.; Yousry, M.M.; Abou El Fadl, N.I. Globe Artichoke Yield and Quality as Affected by Foliar Application of Seaweed Extract and Cooling Periods of Crown Pieces. *J. Adv. Agric. Res.* **2020**, *25*, 48–65. [CrossRef]
48. AOAC. *Official Methods of Analysis of Association of Official Analytical Chemists International*; Horwitz, W., Latimer, G., Eds.; AOAC Inter.: Gaithersburg, MD, USA, 2016; ISBN 0935584773.
49. Zhishen, J.; Mengcheng, T.; Jianming, W. The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chem.* **1999**, *64*, 555–559. [CrossRef]
50. Li, B.W.; Cardozo, M.S. Nonenzymatic-Gravimetric Determination of Total Dietary Fiber in Fruits and Vegetables. *J. AOAC Int.* **1992**, *75*, 372–374. [CrossRef]
51. Redondo-Cuenca, A.; Herrera-Vázquez, S.E.; Condezo-Hoyos, L.; Gómez-Ordóñez, E.; Rupérez, P. Inulin extraction from common inulin-containing plant sources. *Ind. Crops Prod.* **2021**, *170*, 113726. [CrossRef]
52. Anwar, R.; Mahmoud, M.; Hussien, N. Effect of Irrigation and Potassium Fertilizer on Vegetative Growth, Yield and Quality of Globe Artichoke Plants under Sandy Soil Conditions. *J. Plant Prod.* **2017**, *8*, 1267–1276. [CrossRef]
53. Mzibra, A.; Aasfar, A.; Khouloud, M.; Farrie, Y.; Boulif, R.; Kadmiri, I.M.; Bamouh, A.; Douira, A. Improving growth, yield, and quality of tomato plants (*Solanum lycopersicum* L.) by the application of moroccan seaweed-based biostimulants under greenhouse conditions. *Agronomy* **2021**, *11*, 1373. [CrossRef]
54. Shahrajabian, M.H.; Chaski, C.; Polyzos, N.; Tzortzakis, N.; Petropoulos, S.A. Sustainable Agriculture Systems in Vegetable Production Using Chitin and Chitosan as Plant Biostimulants. *Biomolecules* **2021**, *11*, 819. [CrossRef] [PubMed]
55. Petropoulos, S.A. Practical applications of plant biostimulants in greenhouse vegetable crop production. *Agronomy* **2020**, *10*, 1569. [CrossRef]
56. El-Sayed, S.F.; Hassan, H.A.; El-mogy, M.M.; Abdel-wahab, A. Growth, Yield and Nutrient Concentration of Potato Plants Grown under Organic and Conventional Fertilizer Systems. *Am. J. Agric. Environ. Sci.* **2014**, *14*, 636–643. [CrossRef]

57. Saif Eldeen, U.; Shokr, M.; el Shotoury, R. Effect of Foliar Spray with Seaweeds Extract and Chitozan on Earliness and Productivity of Globe Artichoke. *J. Plant Prod.* **2014**, *5*, 1197–1207. [CrossRef]
58. Rincón, L.; Pérez, A.; Pellicer, C.; Abadía, A.; Sáez, J. Nutrient uptake by artichoke. *Acta Hortic.* **2007**, 287–292. [CrossRef]
59. Horrocks, R.D.; Vallentine, J.F. Plant growth, development, longevity. In *Harvested Forages*; Horrocks, R.D., Vallentine, J.F.B.T.-H.F., Eds.; Academic Press: San Diego, CA, USA, 1999; pp. 103–123. ISBN 978-0-12-356255-5.
60. Carvalho, M.R.; Woll, A.; Niklas, K.J. Spatiotemporal distribution of essential elements through *Populus* leaf ontogeny. *J. Exp. Bot.* **2016**, *67*, 2777–2786. [CrossRef]
61. Araya, T.; Noguchi, K.; Terashima, I. Effects of carbohydrate accumulation on photosynthesis differ between sink and source leaves of *Phaseolus vulgaris* L. *Plant Cell Physiol.* **2006**, *47*, 644–652. [CrossRef]
62. Öztürk, B.; Zengin, M.; Gökmen Yilmaz, F. Effects of potassium and zinc fertilization on the yield and yield components of artichoke. *J. Tekirdag Agric. Fac.* **2020**, *17*, 180–190. [CrossRef]
63. Arthur, G.D.; Stirk, W.A.; Van Staden, J. Effect of a seaweed concentrate on the growth and yield of three varieties of *Capsicum annuum*. *S. Afr. J. Bot.* **2003**, *69*, 207–211. [CrossRef]
64. Tartoura, E.A.; Seif El-Deen, U.M.; El-Adawy, A.Y. Effect of Irrigation Intervals and Foliar Applications with some Nano-Fertilizers on Growth and Productivity of Globe Artichoke Plant: B-Yield and its quality. *J. Plant Prod.* **2021**, *12*, 217–224. [CrossRef]
65. Michalska-Ciechanowska, A.; Wojdyło, A.; Bogucka, B.; Dubis, B. Moderation of inulin and polyphenolics contents in three cultivars of *Helianthus tuberosus* L. by potassium fertilization. *Agronomy* **2019**, *9*, 884. [CrossRef]
66. Lola-Luz, T.; Hennequart, F.; Gaffney, M. Effect on yield, total phenolic, total flavonoid and total isothiocyanate content of two broccoli cultivars (*Brassica oleraceae* var. *italica*) following the application of a commercial brown seaweed extract (*Ascophyllum nodosum*). *Agric. Food Sci.* **2014**, *23*, 28–37. [CrossRef]