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Early and Total Yield Enhancement of the Globe Artichoke Using an Ecofriendly Seaweed Extract-Based Biostimulant and PK Fertilizer

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Abstract: This study evaluated the effect of phosphorus and potassium (PK) fertilizer levels and foliar seaweed extract on early and total yield productivity and the growth of globe artichoke plants. Field experiments were conducted over two seasons on loamy–clay soil at the vegetable research farm, of the Faculty of Agriculture, Alexandria University, Egypt. Fertilizer levels of 0, 25, 50 and 75 mL L^{-1}, and seaweed extract concentrations of 0, 5 and 10 mg L^{-1}, individually and in combination, were used. Globe artichoke plants treated with PK liquid fertilizer, with and without seaweed extract, showed critical increases in growth (plant height and number of leaves per plant as well as foliage dry weight), yield, and some chemical constituents compared to untreated plants. The PK_3 fertilizer level and 10 mL L^{-1} seaweed extract as a foliar spray showed greater effects than other combinations.

Keywords: fertilizer; seaweed; biostimulant; globe artichoke; head quality; yield; inulin; total phenols; mineral content

1. Introduction

Although Egypt produces approximately one-fifth of the world's globe artichokes, this volume is not commensurate with exports because production comes after the appropriate export time. The globe artichoke (*Cynara scolymus* L.), a member of the Compositae family, is one of the most important vegetable crops in Egypt for local consumption and export, either fresh or processed. It is especially distributed around the Mediterranean and to South America and the United States [1,2]. The artichoke is rich in inulin, fiber, minerals, and especially, polyphenols, so it is perceived as healthy and nutritious [3].

The modification or redistribution of artichoke yield patterns, coupled with increasing the yield potential, is of great relevance for production and crop quality. The artichoke plant is sensitive to the nutritional balance of macro-elements due to its huge size and high productivity [1,4,5].

Egyptian soil, like many soils in the Mediterranean region, has a high limestone content, a factor that is often associated with strong, positive responses to phosphorus fertilization [4,6]. A lack of phosphorus in the soil leads to a decrease in the total yield [7,8], and most phosphorus is in forms unavailable to plants and has a moderate to high calcium content [9]. Potassium is an essential mineral for plants due to its importance in biochemical and physiological processes: growth, flowering, yield and quality [4]. Potassium also enhances the earliness of the yield and improves artichoke head quality [10,11].

Currently, the accepted plant biostimulants are seaweed extracts, humic substances, amino acids, protein hydrolysates, and microbes. The application of seaweed extracts for vegetables is very important because they contain macro- and microelements and vitamins [12]. They also evoke phytohormonal responses due to their specific components and role in regulating plant growth. Natural plant growth hormones were detected in seaweed extracts, especially abscisic acid, auxins, cytokinins and gibberellins [13,14]. Abscisic acid stimulates growth, increases yield, enhances tolerance for environmental stresses, and increases the uptake of nutrients [15]. Moreover, it has also a significant role in the physiological health of vegetables [16]. Whereas chemical fertilizers, directly and indirectly, harm the air, soil, water and living organisms, seaweed extracts are highly nutritive and biodegradable, making them environmentally friendly [17].

Seaweed, a species of algae, has been used as a fertilizer for a long time in coastal areas, but seaweed extracts represent a new generation of organic fertilizers that improve growth, germination and yield [18,19]. The effects of the extracts may be ascribed to the synergistic activity of its compounds: hormones, betaines, polyamines, alginates, carrageenans, fucans and phlorotannins [20]. Recently, the use of algae, one of the main natural biostimulants, has led to increased crop productivity and quality [20,21] and improved protection [16,22]. Studies also found that foliar applications of seaweed extracts effectively increased plant height, number of leaves per plant, the bulb weight of onion plants and the carbohydrate concentration of potato plants [13].

The period from December to February in Egypt is the best time to export to European countries since artichoke production is low and prices are relatively high [15,16]. Therefore, farmers use a variety of agricultural treatments (gibberellin foliar spray and increased ground or foliar fertilization).

The present study aims to investigate the effect of PK fertilizer levels with seaweed extract on the growth, earliness, yield and quality of artichoke heads.

2. Materials and Methods

2.1. Soil Analysis

A field research trial was conducted over two years (2016–2017 and 2017–2018 at the vegetable research farm (31.2001° N and 29.9187° E) at the University of Alexandria, Egypt. Surface soil samples from the two experimental planting sites at a maximum depth of 40 cm were collected and analyzed for chemical and physical properties according to the standard procedures of Page et al. [23]. The physical and chemical characteristics of the samples are given in Table 1.

Table 1. Pre-experiments soil characterization, during two growing seasons: 2016–2017 and 2017–2018.

Seasons of Experiments		2016–2017	2017–2018
Physical	**Texture**	**Clay Loam**	**Clay Loam**
Chemical	pH	8.11	8.09
	EC (dSm^{-1})	2.64	2.87
	Total N (%)	0.18	0.14
	Phosphorus (ppm)	0.28	0.30
	K^+ (m eq L^{-1})	0.35	0.31
	Ca^{++} (m eq L^{-1})	2.11	2.17
	HCO_3 (m eq L^{-1})	1.29	1.35

2.2. Preparation of Seaweed Extract Formulation

Fresh samples of common algae (*Ulva lactuca*, *U. faciata* and *Peterocladia caplicia*) were collected from the Eastern Harbor of Alexandria, Egypt (31.2001° N and 29.9187° E). They were washed with seawater at the sampling site to remove sediment and impurities and then put in polyethylene bags. A quick rinse with tap water was carried out in the laboratory on the same day to get rid of any remaining impurities and epiphytes. The samples were air-dried in the shade at room temperature on absorbent paper then cut into pieces of about 2 mm. Microscopic identification of the algae was carried out according to the literature [24,25].

Extraction was performed by soaking the material in 70% ethanol (1:10 *w*/*v*) on a rotary shaker at 150 rpm at room temperature for 72 h. The extract from consecutive soakings was pooled and filtered using filter paper (Whatman No. 4), and then the filtrate was air-dried to evaporate the solvent.

In addition, humic acid was isolated from the samples according to another study [26], and the final solution contained both humic and fulvic acids. Afterward, the formulation of seaweed extract with humic substances was designed as follows:

- The seaweed extract was first mixed in equal ratios.
- The mixture was added to the humic substances in solution form and stirred well in a ratio of 3:1 *v*/*v*.
- This formula was stored at −20 °C until use.

The biochemical composition of the humic and fulvic acid was determined according to Van Zomeren and Comans [27]. Total protein was determined according to Hartree [28]; total carbohydrates and total lipids were determined according to de Pádua et al. [29]; alginic acid and vitamin C were analyzed based on Okimasu [30] and Levine et al. [31].

2.3. Treatments

The Balady cultivar was planted in the middle of August in both seasons. The cutting stems of the artichoke were planted 1 m apart on a ridge (1 m). The experimental design was a split-plot system in a Randomized Complete Blocks Design (RCBD) with three replicates, with each replicate comprising 12 treatments distributed as follows; PK fertilizer levels (PK_0: control, PK_1: 25, PK_2: 50 and PK_3: 75 mL L^{-1}) were randomly arranged in the main plots. Phosphoric acid (58% P_2O_5 *w*/*v*) was used as the source of phosphorus fertilizer at 0, 25, 50 and 75 mL L^{-1}. Potassium thiosulphate (51% K_2O *w*/*v*) was the source of potassium fertilizer at levels 0, 25, 50 and 75 mL L^{-1}). The phosphoric acid was added once to the soil (as a drench) two weeks after planting, and potassium thiosulphate was added three times as a drench: the first time was after the complete establishment of offshoots and the second and third additions after the plant had formed 15 and 25 leaves, respectively. Each plant took about 0.2 L of the final solution (the fertilizer dissolved in water) for each type of fertilizer separately in each addition.

The seaweed extract was randomly distributed in the sub-plots at different rates (Control: 0, SW_1: 5, and SW_3: 10 mL L^{-1}) and each sub-plot consisted of 6 ridges (4 m length × 1 m width) and the number of plants was 24. Extract as a foliar application was applied six times: the first after one month and once every two weeks during the growth stages. Tween 20 (0.5% *v*/*v*) was added as a wetting agent to all solutions including the control. Nitrogen fertilization (ammonium sulphate, 20.5% *w*/*v*) was added at a rate of 90 N units ha^{-1} twice after 30 and 60 days of planting.

2.4. Data Collection

Vegetative growth attributes were measured, including plant height, number of leaves per plant and foliage dry weight (tissues were held for 48 h in an oven at 100 °C), reproductive parameters at the peak of harvesting in March, number of heads per plant fresh head weight, head diameter, and the early and total yield ha^{-1}.

2.5. Mineral Nutrient Analyses

Sample heads of globe artichokes from each sub-plot were collected, washed with distilled water, oven-dried at 70 °C to a constant weight, then ground to measure the nitrogen, phosphorus and potassium composition according to Chapman and Parker [32].

For nitrogen analyses, the head was digested with sulfuric acid followed by Kjeldahl distillation. For phosphorus and potassium, the samples were digested with a di-acid ($HClO_4$:HNO_3) in a 2:1 mixture. Finally, a colorimetric method was used and concentrations were assessed at 430 nm using a spectrophotometer for phosphorus analysis. For potassium, digested samples were run on a flame photometer after filtration [32]. Nitrogen, phosphorus and potassium contents were expressed as a percentage of the dry weight.

2.6. Inulin Content

Samples of dried cores of heads were taken and ground into a fine powder with a coffee grinder; 0.1 g of powder of the sample was weighed in a 100 mL volumetric flask and dissolved in 100 mL of distilled water. After shaking well, 5 mL of the aliquot was diluted to 50 mL, again from this well-mixed stock, and 1 mL of the aliquot was put into a 20 mL volumetric flask for color development, after which the rest of the inulin test component was added. Inulin content of the extract was designed according to Araya et al. [33].

2.7. Total Phenols Content

The phenolic compounds were extracted with methanol (containing HCl 0.1% v/v) as a solvent. One gram of the sample from the core of the head was individually blended with the solvent at a ratio of 1:20 (w/v). Extraction was carried out twice at room temperature, and then the extract was stored at (−18 °C) until use.

Total phenolic content was measured at 750 nm with a spectrophotometer (Optizin UV–Vis Spectrophotometer model, Thermo Electron Corporation, Korea) according to A.O.A.C. [34] using the Folin–Ciocalteu reagent and gallic acid as standard. The results were expressed as equivalent (mg gallic acid 100 g^{-1} fresh weight).

2.8. Statistical Analysis

All data were statistically analyzed using SPSS version 24 statistical software [35]. The data means (±SE) were compared with the split-plot design. Duncan's multiple range tests were used to compare the differences among the means of the different treatments as elucidated in a previous study [36].

3. Results and Discussion

3.1. Growth Parameters

The growth parameters (plant height, number of leaves and foliage dry weight) are summarized in Figure 1. Significant differences were observed based on the PK fertilizer levels. Increasing it from 50 to 75 mL L^{-1} raised all influential parameters in both growing seasons. The enhancing effect of potassium—activating phytohormones and enzymatic systems, regulating cellular pH, and enhancing nitrogen uptake—might have been attributed to its association with the efficiency of leaves as an assimilator to CO_2 [37]. These results agree with [2], who found that potassium fertilizer improved the growth characteristics of the globe artichoke. These results were also somewhat in harmony with the findings of [5], who found that the highest height values (cm), number of leaves per plant, and leaf dry weight were produced by the increased application with potassium fertilizer. Phosphorus increases plant growth development by taking part in metabolic activity, enhancing photosynthesis and photosynthetic assimilation [38]. Mohamed and Ali [9] reported that globe artichoke vegetative growth increased with higher phosphorus levels. Similarly, rapid plant growth and development were observed with the highest rate of phosphorus level [39].

The results showed that the foliar applications of the seaweed extract rates were within the same range as those for the control treatment. The foliar application of seaweed extract on plant vegetative growth characteristics (Figure 2) recorded the highest value for a rate of 10 mL L^{-1}, but it was the lowest compared with the two other foliar applications in both seasons. This result can be attributed to the benefits of the amino acids, vitamins and plant growth regulators in the extract. The chemical composition of the seaweed extract in

(Table 2) showed an appropriate amount of nutrients, carbohydrates, vitamins, protein and humic acid that indicated its potential use as a natural biostimulant and fertilizer. These results generally agreed with those of a similar study [17,40] which also found that growth characteristics improved with the use of seaweed extract on cucumber and tomato plants. There was an interest in recent years in using seaweed extract as a biostimulant for various vegetable crops to enhance growth [41–43]. They found that using foliar of algae extract for globe artichoke plants leads to significant increases in height, dry weight and number of leaves per plant.

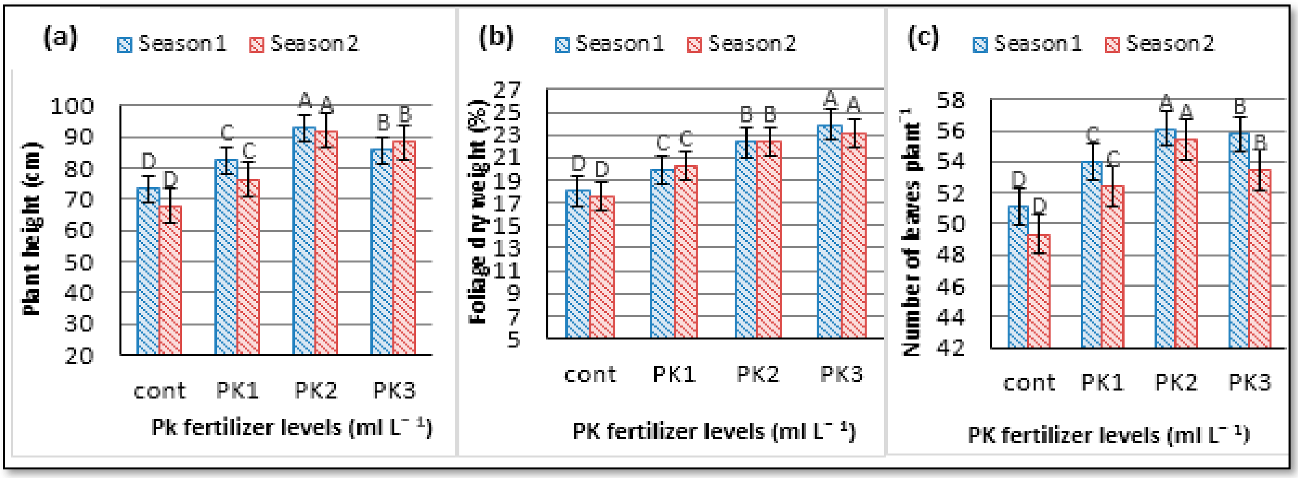

Figure 1. Vegetative growth parameter (means ± SE) of the globe artichoke as affected by the application of PK fertilizer levels (Control: without, PK_1: 25, PK_2: 50 and PK_3: 75 mL L^{-1}) on (**a**) Plant height (cm); (**b**) Foliage dry weight (%) and (**c**) Number of leaves per plant. Letters in the figures indicate that the mean ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

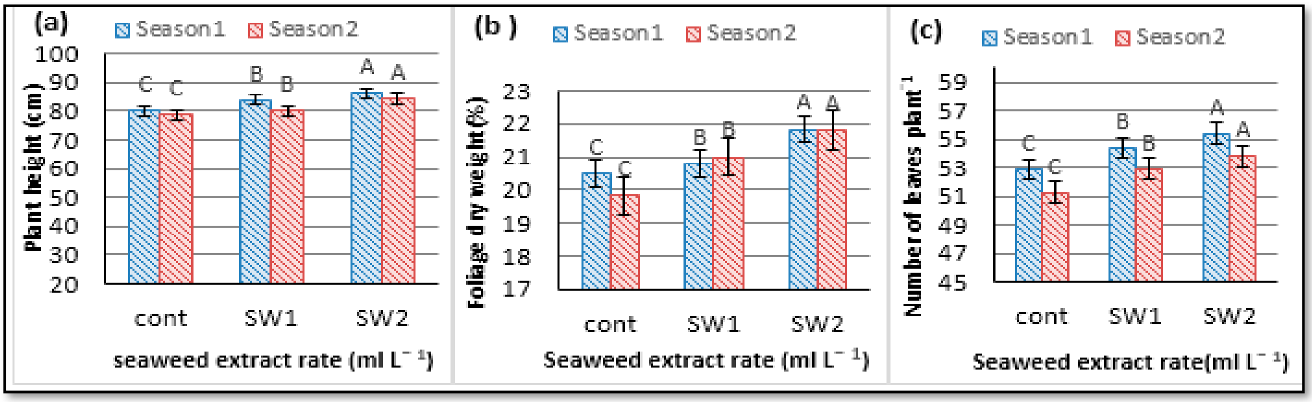

Figure 2. Vegetative growth parameters (means ± SE) of globe artichoke as affected by the application of seaweed extract rate (Control: without, SW_1: 5 and SW_2: 10 mL L^{-1}) on (**a**) Plant height (cm); (**b**) Foliage dry weight (%) and (**c**) Number of leaves plant^{-1}. Letters in the figures indicate that the mean ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

Table 3 shows how the interaction of the PK_2 level (50 mL L^{-1}) with 5 mL L^{-1} of seaweed extract affected the growth parameters. The results indicated that PK_3 at (75 mL L^{-1}) with any level of seaweed extract recorded the highest foliage dry weight in both growing seasons.

Table 2. Chemical composition of seaweed extract and humic substances formulation.

Parameter	Value
Odor	Humic to seaweed-like odor
Color	Dark brown
Texture	Dense (near to oily)
Humus (Humic acid + fulvic acid)	10% (*w*/*v*)
Alginic acid	10% (*w*/*v*)
Suspended matter	<15%
Total protein	1 g L^{-1}
Total carbohydrates	30% (*w*/*v*)
Total lipids	5–7% (*w*/*v*)
Vitamin C	4 mg L^{-1}
Total N content	0.16%
P	111.6 mg L^{-1}
K	7.56 mg L^{-1}
Mg	25.3 mg L^{-1}
Fe	120.1 mg L^{-1}
Mn	60.0 µg L^{-1}
Zn	42.0 µg L^{-1}
Ash	10% (*w*/*v*)
pH	5–6

Table 3. Vegetative growth parameters of globe artichoke as affected by interaction between PK fertilizer levels and seaweed extract rates.

Treatments		Plant Height (cm)	No. Leaves Plant^{-1}	Foliage DM (%)
PK Levels	Seaweed Extract Rate		Season 1	
Control	Control	68.88 ± 1.15 g	17.40 + 2.20 e	48.66 + 1.17 i
	SW_1	73.66 + 3.05 f	17.67 ± 1.44 e	52.00 ± 2.01 h
	SW_2	77.33 ± 2.30 e	19.00 ± 1.21 d	52.56 ± 1.15 gh
PK_1	Control	78.67 ± 2.33 e	19.63 ± 2.30 d	53.36 ± 1.14 fg
	SW_1	83.32 ± 3.06 d	19.93 ± 2.75 d	54.00 ± 0.51 ef
	SW_2	84.65 ± 1.16 cd	20.21 ± 0.52 cd	54.66 ± 1.13 de
PK_2	Control	90.00 ± 2.01 b	21.43 ± 1.71 bc	54.33 ± 1.15 e
	SW_1	93.00 ± 2.02 a	21.83 ± 1.33 b	56.00 ± 2.01 bc
	SW_2	94.01 ± 1.15 a	23.73 ± 2.01 a	58.00 ± 0.11 a
PK_3	Control	83.67 ± 1.17 cd	23.53 ± 1.10 a	55.34 ± 1.15 cd
	SW_1	85.34 ± 1.18 c	23.73 ± 2.21 a	55.68 ± 1.17 bc
	SW_2	88.35 ± 3.06 b	24.43 ± 1.28 a	56.38 ± 1.17 b
			Season 2	
Control	Control	66.64 ± 306 i	16.50 ± 1.38 h	47.66 ± 1.16 h
	SW_1	67.63 ± 1.15 hi	17.83 ± 1.51 gh	49.66 ± 1.15 g
	SW_2	68.70 ± 1.17 h	18.46 ± 2.00 fgh	50.56 ± 3.01 fg
PK_1	Control	72.64 ± 1.19 g	19.53 ± 2.64 efg	51.67 ± 1.13 ef
	SW_1	75.00 ± 2.00 f	20.46 ± 4.95 def	52.33 ± 1.15 de
	SW_2	81.32 ± 3.01 e	20.86 ± 2.10 cde	53.37 ± 1.15 cd
PK_2	Control	88.00 ± 2.10 c	20.85 ± 1.33 cde	53.46 ± 1.17 cd
	SW_1	92.00 ± 2.21 b	23.00 ± 1.03 ab	55.70 ± 1.15 b
	SW_2	95.67 ± 1.16 a	23.43 ± 1.13 ab	57.33 ± 1.15 a
PK_3	Control	87.02 ± 2.01 cd	22.40 ± 2.50 bcd	52.45 ± 1.16 de
	SW_1	86.03 ± 2.12 d	22.73 ± 1.17 abc	54.00 ± 2.01 c
	SW_2	92.00 ± 4.31 b	24.51 ± 0.53 a	54.04 ± 2.00 c

PK: fertilizer levels (Control: without, PK_1: 25, PK_2: 50 and PK_3: 75 mL L^{-1}) and SW: seaweed extract rate (Control: without, SW_1: 5 and SW_2: 10 mL L^{-1}). Letters in the table mean that the means ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

3.2. Yield Parameters

3.2.1. Head Characteristics

The PK fertilizer levels were applied to the plant directly to drench the soil and observe its effects on globe artichoke head characteristics, in both seasons (See Figure 3). Significant variation was observed according to treatments where PK_2 (50 mL L^{-1}) resulted in a significant number of heads per plant and high fresh head weight (See Figure 3a,b); however, increasing the fertilizer level to PK_3 significantly improved head diameter (See Figure 3c) in both growing seasons. Generally, the control treatment had significantly lower head characteristics.

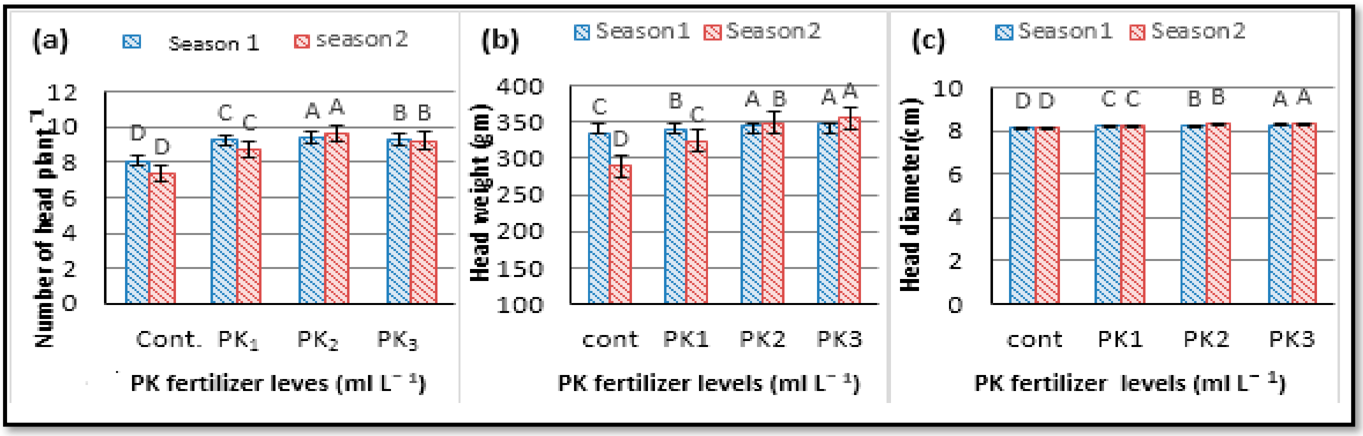

Figure 3. Head characteristics (means ± SE) of globe artichoke as affected by the PK fertilizer levels (Control: without, PK_1: 25, PK_2: 50 and PK_3: 75 mL L^{-1}) on (**a**) Number of head plant $^{-1}$, (**b**) Head weight (g) and (**c**) Head diameter (cm). Letters in the figures indicate that the mean ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

Studies showed that phosphorus and potassium fertilizer had a positive effect on earliness [11,44]. However, there was some ambiguity in the experiments concerning the effect of PK fertilizer on artichokes, and the lack of uniformity of the results may have been due to different soil fertility conditions. For artichoke productivity, the balance between levels of each mineral element is vital [45]. While an increase in phosphorus availability in the soil depended on soil properties (e.g., pH, soil carbonates) which are negatively influenced, the phosphorus fertilizer depended on the uptake ratio [39]. Some studies also reported a positive effect of fertilizer levels on mineral content [11,45].

It is clear from such data (See Figure 4) that most measured head characteristics were significantly different among the rates of seaweed extract. In this respect, 10 mL L^{-1} recorded the highest head number of head per plant, head fresh weight and head diameter followed by 5 mL L^{-1}, compared with control, which achieved the lowest values in these parameters during the two seasons of study.

The chemical analyses of seaweed extract in Table 2 showed that a combination of carbohydrates and protein may have controlled plant growth by affecting nitrogen assimilation and basal metabolism. The present results also showed that all rates of seaweed extract exhibited higher yield parameters. Furthermore, the positive influence of biostimulants (humic, fulvic, and carboxylic acids) on apricot yield was proven [46]. This could have been due to the composition of the seaweed, which enhanced cell division, differentiation, and elongation in addition to enhancing the uptake of higher proteins and nucleic acids [47,48]. The effects of the seaweed extracts were reported in different growth environments and farming solutions for various crops, which means that their mode of action is conserved with inherent plasticity when used as a soil application or foliar spray [49]. The identification of new plant growth molecules in different seaweed extracts ensures a diverse composition of extracts and complex modes of action [50]. The interaction between PK fertilizer levels and the different rates of seaweed extract on head characteristics was found to be significant, but with different magnitudes in both growing seasons. The results illustrated that the PK_2 or PK_3 treatments combined with 10 mL L^{-1} seaweed extract rate gave the highest mean value for head characteristics in both seasons (Table 4).

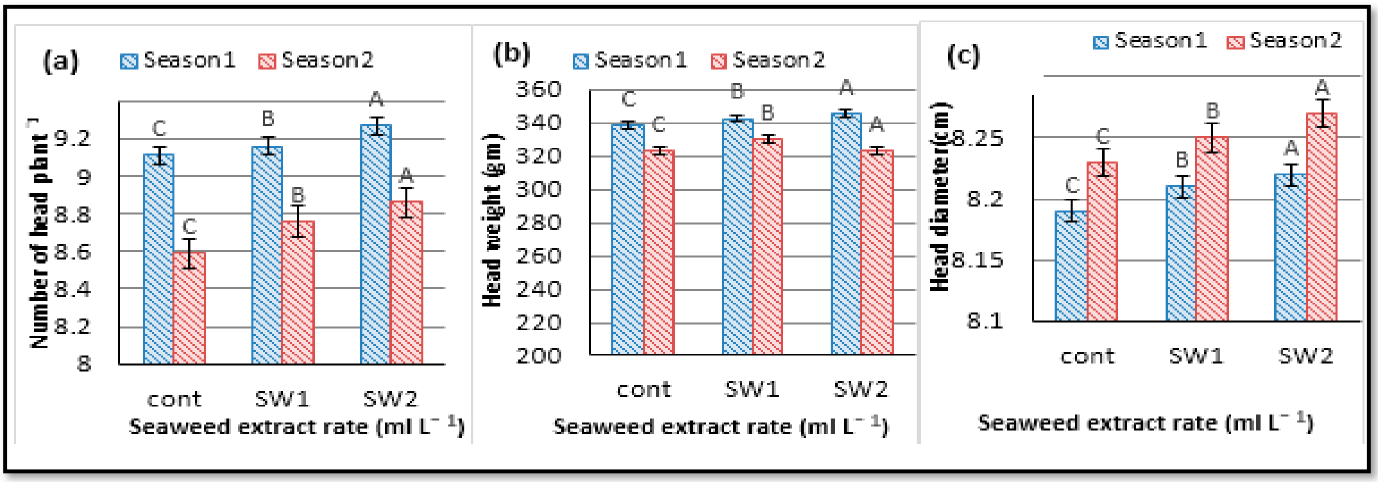

Figure 4. Head characteristics (mean ± SE) of globe artichoke as affected by the seaweed extract rate (Control: without, SW_1: 5 and SW_2: 10 mL L^{-1}) on (**a**) Number of heads plant $^{-1}$; (**b**) Head weight (g) and (**c**) Head diameter (cm). Letters in the figures indicate that the mean ± SE of treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

Table 4. Head characteristics of globe artichoke as affected by the interaction between PK fertilizer levels and seaweed extract rate.

Treatments		Number Head Plant^{-1}	Head Fresh Weight (g)	Head Diameter (cm)
PK Levels	**Seaweed Extract Rate**		**Season 1**	
Control	Control	8.60 ± 0.20 f	330.33 ± 0.51 g	8.15 ± 0.01 a
	SW_1	8.76 ± 0.23 f	332.66 ± 0.43 fg	8.18 ± 0.02 a
	SW_2	9.03 ± 0.11 e	336.01 ± 0.34 ef	8.20 ± 0.01 a
PK_1	Control	9.22 ± 0.04 d	339.35 ± 0.61 de	8.22 ± 0.01 a
	SW_1	9.25 ± 0.02 cd	341.34 ± 0.62 d	8.23 ± 0.01 a
	SW_2	9.27 ± 0.01 cd	342.40 ± 0.23 cd	8.23 ± 0.02 a
PK_2	Control	9.30 ± 0.01 cd	341.66 ± 0.54 d	8.24 ± 0.01 a
	SW_1	9.32 ± 0.05 bcd	349.37 ± 0.63 b	8.26 ± 0.01 a
	SW_2	9.35 ± 0.01 bc	350.66 ± 0.43 ab	8.28 ± 0.02 a
PK_3	Control	9.38 ± 0.05 b	344.00 ± 0.63 cd	8.18 ± 0.02 a
	SW_1	9.38 ± 0.05 b	347.04 ± 0.41 bc	8.20 ± 0.03 a
	SW_2	9.48 ± 0.05 a	354.67 ± 0.43 a	8.22 ± 0.02 a
			Season 2	
Control	Control	7.33 ± 0.11 g	283.33 ± 0.45 f	8.14 ± 0.02 a
	SW_1	7.38 ± 0.01 g	291.41 ± 0.43 f	8.15 ± 0.02 a
	SW_2	7.42 ± 0.01 g	293.00 ± 0.65 f	8.18 ± 0.01 a
PK_1	Control	7.49 ± 0.01 f	318.67 ± 0.43 e	8.20 ± 0.01 a
	SW_1	8.80 ± 0.05 e	326.01 ± 0.54 de	8.24 ± 0.01 a
	SW_2	8.83 ± 0.05 e	328.00 ± 0.62 de	8.26 ± 0.03 a
PK_2	Control	9.01 ± 0.05 d	338.29 ± 0.34 cd	8.29 ± 0.01 a
	SW_1	9.24 ± 0.01 c	345.33 ± 0.33 bc	8.31 ± 0.05 a
	SW_2	9.42 ± 0.05 b	358.69 ± 0.53 a	8.32 ± 0.01 a
PK_3	Control	9.53 ± 0.01 b	351.33 ± 0.34 ab	8.29 ± 0.01 a
	SW_1	9.65 ± 0.01 a	358.68 ± 0.22 a	8.30 ± 0.01 a
	SW_2	9.72 ± 0.01 a	357.66 ± 0.25 ab	8.31 ± 0.01 a

PK: fertilizer levels (Control: without, PK_1: 25, PK_2: 50 and PK_3: 75 mL L^{-1}) and SW: seaweed extract rate (Control: without, SW_1: 5 and SW_2: 10 mL L^{-1}). Letters in table indicate that the mean ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

3.2.2. Early and Total Yield Pattern

It is clear from Figure 5a,c that the control plants grown in untreated PK fertilizer levels and seaweed extract yielded a low number of heads till the end of February (early yield). On the contrary, it is also clear from the distribution of the yield that the plants, treated with PK fertilizer levels and seaweed extract, yielded as early as December (early yield). It might be concluded that the artichoke plants treated with PK_3 fertilizer with 10 mL L^{-1} of seaweed extract gave the highest early yield, in both seasons. The percentage of yield was 40.4 and 42.6% in the first three months as shown in Figure 5b,d for the first and second seasons, respectively. The corresponding values for the control plants in the same three months were 36.4% and 36.5%, respectively (Figure 5b,d). The data in the Figures indicate that most of the artichoke yield for the control plants was concentrated in February, March and April, which was because the percentages were 67 and 61% compared with 65 and 59% for the plants treated with PK_3 fertilizer and 10 mL L^{-1} seaweed extract.

Our results showed seaweed extract enhanced total yield, which supported the findings of Hassan et al. [17], Mzibra et al. [40], and La Bella et al. [51]. These studies also reported significantly improved yields for cucumber, tomato and spinach treated with seaweed extract in a protected environment. In addition, Mohamadpoor et al. [52] concluded that quinoa seed yield increased with humic acid and seaweed extract under drought stress.

3.2.3. Head Quality

Concerning the fertilizer levels in the artichoke head, data showed that PK_3 produced the highest increase in nitrogen, phosphorus and potassium (%) as well as inulin (%), and total phenols in both seasons (Figures 6 and 7).

Data in Figures 8 and 9 indicate that the 10 mL L^{-1} seaweed extract foliar spray significantly increased the percentage mineral and inulin content in the head compared to the 5 mL L^{-1} treatment and control for both seasons.

Similarly, total phenols rose significantly because of the 10 mL L^{-1} seaweed extract, which resulted in increased osmotic stress and hormone activity [53]. In general, seaweed extracts enhance plant growth and quality and improve the resistance to climatic changes because they are rich in fatty acids, minerals and polysaccharides [54]. The chemical and biochemical constituents of any seaweed extract act as biostimulants that work synergistically [55,56]. There was a good agreement with the results of previous studies that indicated the beneficial effects of diluted seaweed extracts on plants such as artichoke [15,42]. However, the study carried out by Canellas et al. [57] concluded that humic acid was ineffective in improving vegetable crop nutrient uptake.

Regarding the mineral content in the head of the globe artichoke, the results showed that the seaweed extract enhanced the amount of nitrogen and potassium but had no effect on phosphorus. Our outcomes are partially consistent with those of La Bella et al. and Elsharkawy et al. [58], who found that seaweed extract application caused an increase in nitrogen, phosphorus and potassium in peas. These results could be attributed to the fact that seaweed extract changed the root architecture, resulting in improved plant nutrient uptake [19]. According to the results in Table 5, significant increases in nitrogen and potassium were observed when the artichoke was drenched with PK_2 or PK_3 and 10 mL L^{-1} seaweed extract foliar spray in the first season. However, fertilizer level PK_1 with any concentration of seaweed extract gave the highest nitrogen and potassium content in the second season.

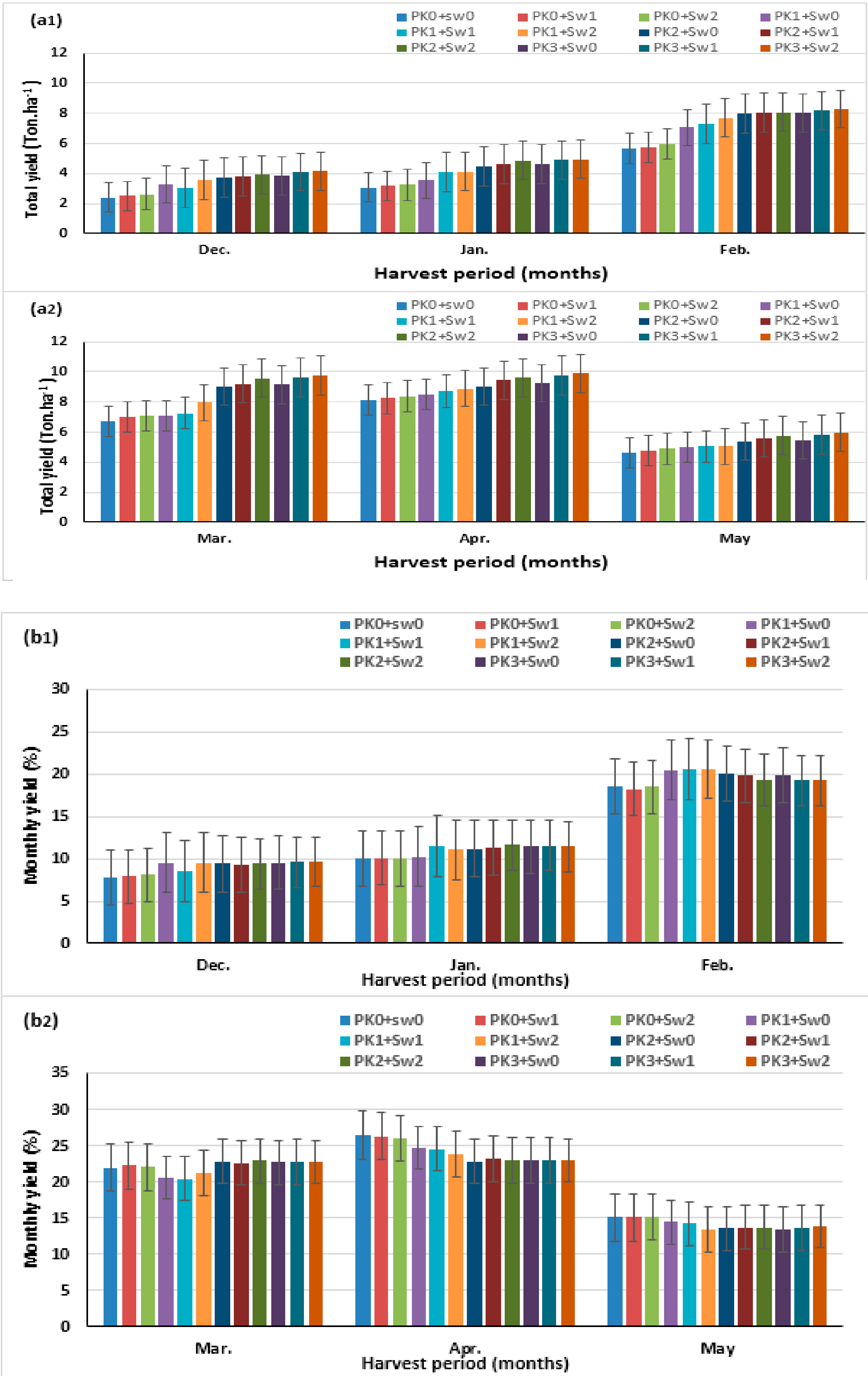

Figure 5. *Cont.*

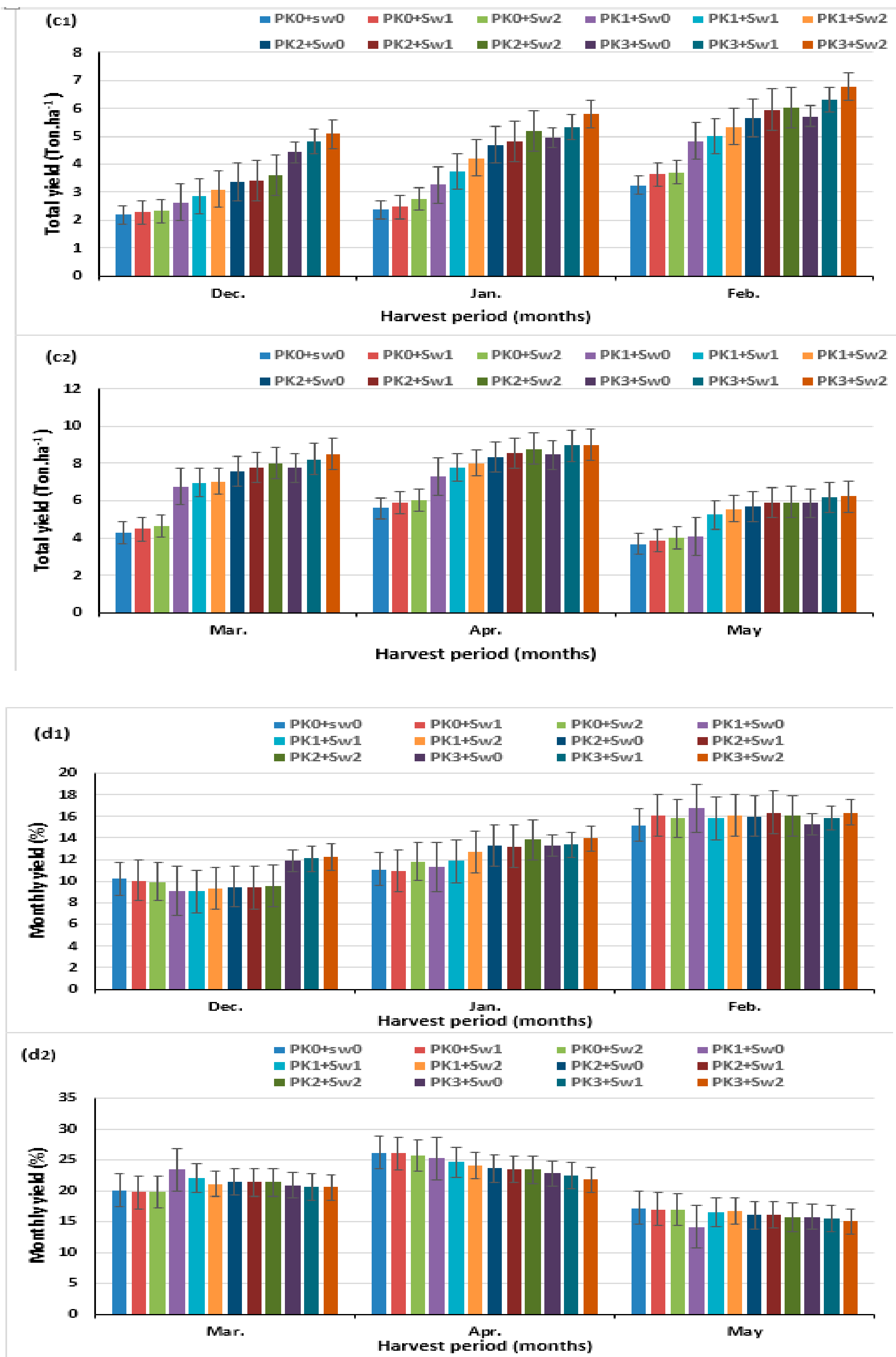

Figure 5. Yield pattern of globe artichoke as affected by the PK fertilizer levels (Control: without, PK_1: 25, PK_2: 50 and PK_3: 75 mL L^{-1}) and seaweed extract rate (Control: without, SW_1: 5 and SW_2: 10 mL L^{-1}) on (**a1**,**a2**) Total yield (Ton ha^{-1}) in season 1; (**b1**,**b2**) Monthly yield (%) in season 1; (**c1**,**c2**) Total yield (Ton ha^{-1}) in season 2 and (**d1**,**d2**) Monthly yield (%) in season 2. Error bars indicate standard deviations of the three replicates.

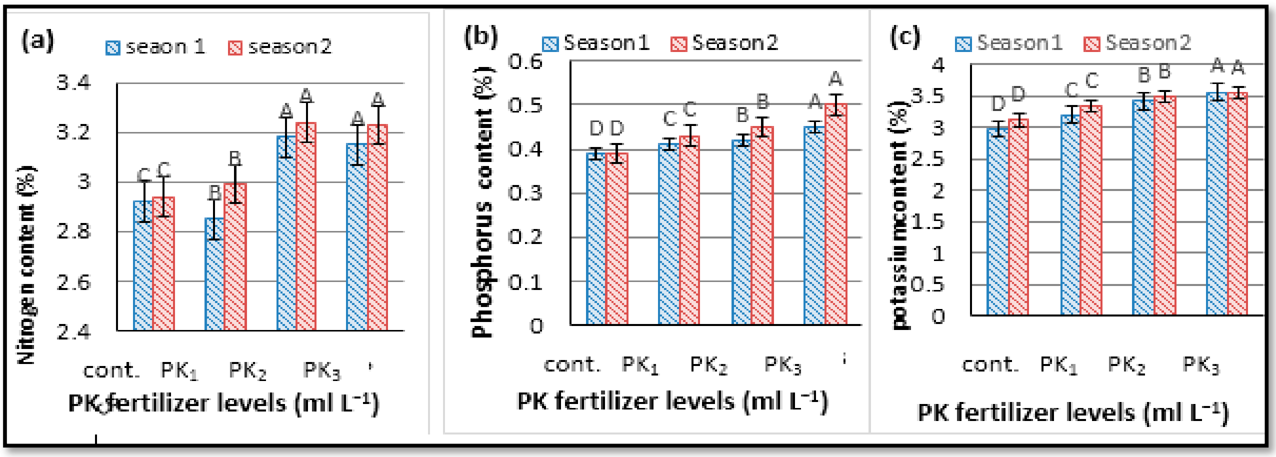

Figure 6. Head minerals contents (mean ± SE) of globe artichoke as affected by the PK fertilizer levels (Control: without, PK1: 25, PK2: 50 and PK3: 75 mL L^{-1}) on (**a**) Nitrogen content (%); (**b**) Phosphorus content (%) and (**c**) Potassium content (%). Letters in the figures indicate that the mean ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

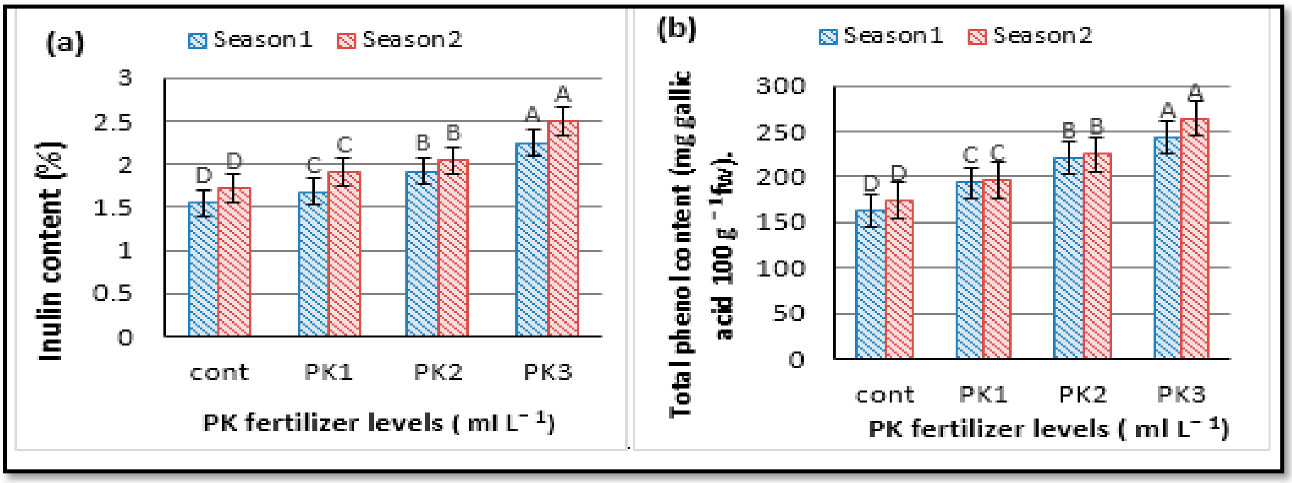

Figure 7. Head quality (mean ± SE) of globe artichoke as affected by the PK fertilizer levels (Control: without, PK_1: 25, PK_2: 50 and PK_3: 75 mL L^{-1}) on (**a**) Inulin content (%) and (**b**) Total phenols content (mg gallic acid 100 g^{-1} fw). Letters in the figures indicate that the mean ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

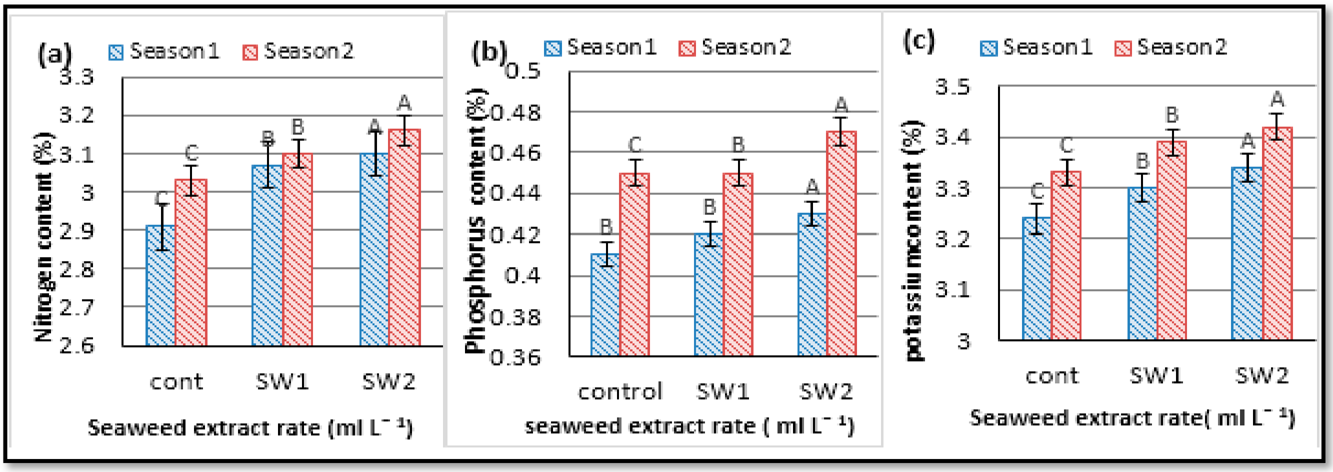

Figure 8. Head mineral contents (mean ± SE) of globe artichoke as affected by seaweed extract rate (Control: without, SW_1: 5 and SW_2: 10 mL L^{-1}) on (**a**) Nitrogen (%); (**b**) Phosphorus (%) and (**c**) Potassium (%). Letters in the figures indicate that the mean ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

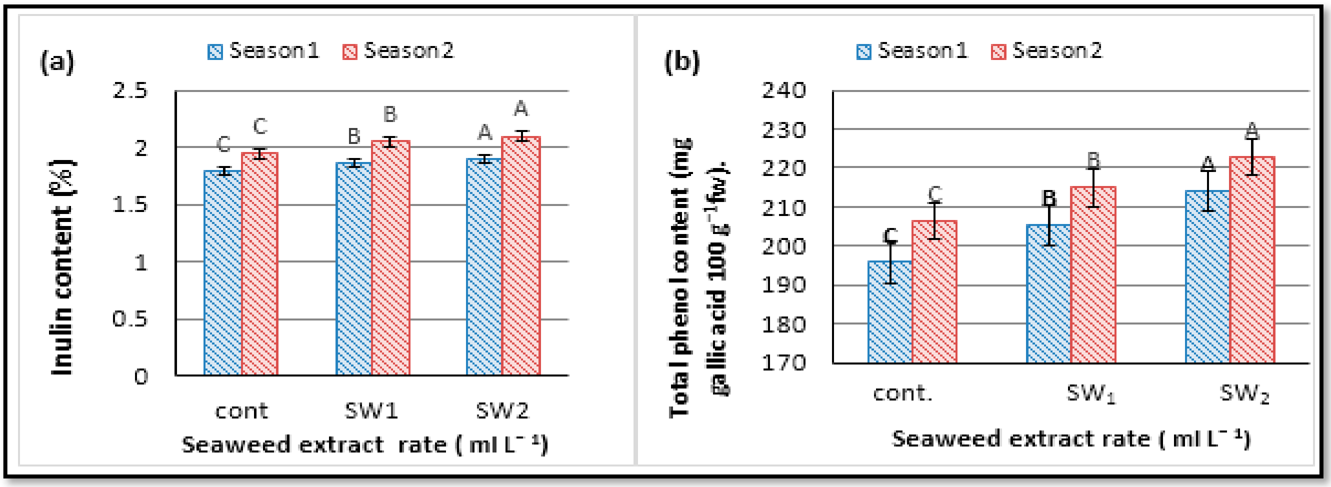

Figure 9. Head quality (mean ± SE) of globe artichoke as affected by the seaweed extract rate (Control: without, SW_1: 5 and SW_2: 10 mL L^{-1}) on (**a**) Inulin (%) and (**b**) Total phenols (mg gallic acid 100 g^{-1} fw). Letters in the figures indicate that the mean ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

Table 5. Head mineral contents and quality of globe artichoke as affected by interaction between PK fertilizer levels and seaweed extract rates.

Treatments		Nitrogen (%)	Phosphorus (%)	Potassium (%)	Inulin (%)	Total Phenols (mg Gallic Acid 100 g^{-1} fw)
PK Levels	Seaweed Extract Rate			Season 1		
Control	Control	2.83 ± 0.06 fg	0.38 ± 0.01 a	2.94 ± 1.05 k	1.50 ± 0.1 k	154.21 ± 0.72 l
	SW$_1$	2.96 ± 0.04 d	0.39 ± 0.01 a	2.97 ± 0.51 j	1.56 ± 0.3 j	162.67 ± 0.61 k
	SW$_2$	2.99 ± 0.02 cd	0.39 ± 0.01 a	3.03 ±0.87 i	1.59 ± 0.1 j	176.35 ± 0.30 j
PK$_1$	Control	3.02 ± 0.04 c	0.40 ± 0.01 a	3.12 ± 0.41 h	1.64 ± 0.8 i	182.91 ± 0.52 i
	SW$_1$	3.20 ± 0.05 b	0.41 ± 0.02 a	3.22 ± 0.40 g	1.68 ± 0.4 h	194.36 ± 0.91 h
	SW$_2$	3.23 ± 0.05 b	0.41 ± 0.01 a	3.28 ± 0.20 f	1.73 ± 0.5 g	203.34 ± 0.98 g
PK$_2$	Control	3.02 ± 0.06 c	0.42 ± 0.01 a	3.38 ± 0.30 e	1.84 ± 0.3 f	211.32 ± 0.30 f
	SW$_1$	3.24 ± 0.05 ab	0.42 ± 0.02 a	3.44 ± 0.81 d	1.93 ± 0.7 e	221.67 ± 0.57 e
	SW$_2$	3.29 ± 0.03 a	0.43 ± 0.01 a	3.46 ± 0.11 d	1.98 ± 0.3 d	230.35 ± 0.11 d
PK$_3$	Control	2.78 ± 0.13 g	0.44 ± 0.01 a	3.55 ± 0.21 c	2.16 ± 0.6 c	236.10 ± 0.21 c
	SW$_1$	2.87 ± 0.50 ef	0.46 ± 0.01 a	3.58 ± 0.35 b	2.27 ± 0.1 b	242.01 ± 0.52 b
	SW$_2$	2.89 ± 0.03 e	0.48 ± 0.03 a	3.63 ± 0.21 a	2.31 ± 0.9 a	252.67 ± 0.50 a
				Season 2		
Control	Control	2.92 ± 0.05 f	0.38 ± 0.01 a	2.98 ± 1.15 g	1.66 ± 0.6 k	167.21 ± 0.52 l
	SW$_1$	2.95 ± 0.05 f	0.40 ± 0.01 a	3.15 ± 2.02 f	1.72 ± 0.6 j	173.71 ± 0.83 k
	SW$_2$	2.97 ± 0.04 e	0.40 ± 0.01 a	3.24 ± 4.03 e	1.79 ± 0.7 i	180.28 ± 0.36 j
PK$_1$	Control	3.15 ± 0.06 c	0.41 ± 0.01 a	3.27 ± 5.03 e	1.84 ± 0.9 h	186.87 ± 0.41 i
	SW$_1$	3.25 ± 0.06 b	0.43 ± 0.01 a	3.38 ± 4.61 d	1.91 ± 0.9 g	197.32 ± 0.42 h
	SW$_2$	3.34 ± 0.08 a	0.43 ± 0.01 a	3.41 ± 4.16 d	1.94 ± 0.9 fg	204.31 ± 0.61 g
PK$_2$	Control	3.17 ± 0.05 c	0.44 ± 0.02 a	3.52 ± 3.29 abc	1.97 ± 0.9 f	214.68 ± 0.91 f
	SW$_1$	3.24 ± 0.07 b	0.46 ± 0.01 a	3.48 ± 1.82 c	2.05 ± 0.8 e	225.03 ± 0.10 e
	SW$_2$	3.30 ± 0.02 a	0.48 ± 0.02 a	3.50 ± 1.15 bc	2.10 ± 0.1 d	236.11 ± 0.11 d
PK$_3$	Control	2.91 ± 0.02 f	0.49 ± 0.02 a	3.56 ± 2.41 a	2.35 ± 0.8 c	256.65 ± 0.41 c
	SW$_1$	3.02 ± 0.05 de	0.52 ± 0.03 a	3.55 ± 1.10 ab	2.53 ± 0.7 b	263.64 ± 0.61 b
	SW$_2$	3.05 ± 0.07 d	0.53 ± 0.03 a	3.56 ± 2.42 ab	2.58 ± 0.9 a	271.73 ± 0.31 a

PK: fertilizer levels (Control: without, PK$_1$: 25, PK$_2$: 50 and PK$_3$: 75 mL L^{-1}) and SW: seaweed extract rate (Control: without, SW$_1$: 5 and SW$_2$: 10 mL L^{-1}). Letters in the table indicate that mean ± SE treatments with the same letters were not significantly different according to Duncan's multiple range test for $p < 0.05$.

4. Conclusions

Over the last few years, seaweed extracts have attracted exceptional interest as biostimulants for improving the growth of different types of vegetables. It also enhances crop quality and yield. In this study, a foliar spray made from seaweed extract enhanced the growth, yield, and quality of the globe artichoke. Therefore, the use of seaweed extract could reduce the dependence on agrochemicals thus making production more sustainable for the environment and the consumer. It was also concluded that treatment with the PK$_3$ fertilizer level and seaweed extract at a rate of 10 mL L^{-1} in both seasons improved total yield by about 40% compared to the control study as well as the time of the early yield.

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