International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 20s, 2025
https://theaspd.com/index.php

Effect Of Spraying With Seaweed And Phosphorus On The Growth And Production Of Strawberry (Fragaria X Ananassa Duch.) Of Albion Cultivar

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Abstract
A factorial study was conducted to assess the response in development and production of strawberry (Fragaria × ananassa Duch.) cultivar "Albion", to foliar spray applications of 6 g P_2O_5 L^{-1}), under unheated protected cultivation conditions, within the facilities Dep. / Hort. and Landscape Architecture, College of Agric. and Forestry/ Univ. of Mosul, while the 2023–2024 vegetative and crop season. Strawberry plants were subjected to foliar sprays of three concentrations of seaweed extract (0, 4, 8 g SW L^{-1}) and three concentrations of phosphorus (0, 4, 6 g P_2O_5 L^{-1}), either individually or in combination. Three seaweed extract sprays and two phosphorus sprays were applied, 20 days apart, starting on December 15, 2023. The results showed that applying the treatments under study—either individually or in combination—led to significant improvements in vegetative growth indicators, plant productivity, and fruit quality. However, the combination of the highest concentration of seaweed extract (8 g SW .L^{-1}) and the mean phosphorus concentration (4 g P_2O_5 .L^{-1}) was the most effective, recording the highest values for total chlorophyll content, leaf area, count of stems per plant, weight of fruit, total production per plant, percentage of total soluble solids, juice percentage, and the lowest treatable acidity. The combination of the highest concentration of both factors (8 g SW .$L^{-1}$and 6 g P_2O_5 .L^{-1}) also showed the highest averages for the a count of leaves per plant, and fruit content of anthocyanins, ascorbic acid (vitamin C), and total sugars.
Keywords: *seaweed, phosphorus, strawberry, Albion*

INTRODUCTION

Strawberries (Fragaria × ananassa Duch.) are a highly economically important horticultural crop, widely cultivated worldwide, with global production reaching approximately 9,175,384 tons (FAO, 2024). China tops the list of producing countries, followed by the United States, while Egypt is among the most prominent Arab countries in the production of this crop. Strawberries are a rich source of vitamins (vitamin C) and minerals and contain a high percentage of phenolic compounds and flavonoids that are important for human health (Al-Shatri et al., 2020). Strawberries are distinguished from other fruits by their attractiveness and distinctive flavor (Al-Shatri et al., 2020). By nature, the strawberry plant is a relatively short-lived perennial herbaceous plant compared to other fruit plants. Its leaves are tripartite and the strawberry plant contains a superficial root system close to the soil surface, which consists of 20-35 main roots. The root system of the strawberry plant, in addition to containing a main root system, also contains secondary roots (Basu et al., 2014). It is considered one of the varieties that are characterized by its high tolerance. It is a hybrid between the "Diamante" variety and the "94.16-1" line, which was developed in 1997 (Ordy et al., 2021). It is one of the early maturing varieties, resistant to high temperatures, and highly resistant to fungal diseases such as fungal wilt and crown rot (Hatton et al., 2013).

The main components of seaweed extract are auxins, cytokinins, gibberellins, and abscisic acid (which are natural hormones), phenolic compounds, and sugar alcohols. They also contain amino acids, organic acids, and antimicrobial compounds, as well as both micro and macro elements. Seaweed extracts are safe for humans and the environment and are inexpensive compared to other compounds or fertilizers used for this purpose (Othman and Al-Bajary, 2019). They are also important in terms of their positive effects on plants, especially from a physiological perspective, in terms of resistance to stress, increasing the plant's ability to absorb nutrients, seed germination, and plant growth. Seaweed extracts also have the ability to increase gas exchange rates, photosynthesis, and chlorophyll content in leaves (Bagh et al., 2024). There are many researchers who have proven that spraying with seaweed extract improves the growth and high production of strawberry plants. Al-Menyawi et al. (2014) reported that when strawberry plants were sprayed with seaweed extract at a concentration of 2 g SW L^{-1}, there was a significant increase in leaf area, number of leaves and chlorophyll content in the leaf per plant. There was also a significant increase in fruit weight and total production per plant. There was also an increase in the percentage of total soluble solids in the fruits, total acidity in the fruits and vitamin C when strawberry plants were sprayed three times per season compared to the control treatment and the 1 g SW L^{-1} treatment. Al-Shatri et al. (2020) showed that there were significant differences in leaf chlorophyll content, number of leaves per plant, leaf area, number of stems per plant, fruit weight, total production per plant, total soluble solids, total acidity, and total sugars when strawberry plants were sprayed with 4 g SW L^{-1} with seaweed extract compared to other treatments. Four concentrations of seaweed extract were used (0, 2, 3, and 4 g SW L^{-1}). Alomar et al. (2023) found that treating strawberry plants with seaweed extract at concentrations of (0, 1, and 2 g SW L^{-1}) for greenhouse-grown strawberry plants resulted in an increase in the number of leaves per plant, leaf area, total production per plant, TSS, total acidity, vitamin C, and total sugars when strawberry plants were treated with 2 g SW L^{-1} compared to other treatments. Aziz and Taha (2023) found that foliar spraying of seaweeds on two strawberry cultivars (Festival and Sabrina) at three concentrations (0, 3, 6 g SW.L^{-1}) significantly increased leaf chlorophyll content and leaf area when foliar sprayed with 6 g SW.L^{-1} compared to other treatments.

Phosphorus (P) is one of the major nutrients, which is an important and essential element in plants and plays a vital role in plant growth and development. Its concentration in plant tissues ranges between 0.05% and 0.5% of dry weight (Bhat et al., 2024). Although the concentration of phosphorus in soil can be nearly 2,000 times higher than in plants, most of it is found in insoluble forms such as aluminum, iron, calcium, and magnesium phosphates, making it biologically unavailable to plants (Bhat et al., 2024). Phosphorus plays multiple roles in vital physiological processes. It contributes to the stability of cell membranes, the formation of essential organic compounds, and the production of high-energy molecules such as adenosine triphosphate (ATP). Phosphorus plays an effective role in the development of the plant's root system. Phosphorus also helps seeds germinate, and is of great importance in increasing the number of flowers and fruits, and improving productions. Phosphorus also has the ability to synthesize nucleic acids (DNA and RNA) and proteins, and has the ability to divide cells and transfer energy.

Good vegetative growth and reproduction in strawberry plants, may be improved by applying phosphorus fertilizer which was effective in this indicator. May and Marvin (1993) reported that applying phosphorus at a rate of 123 kg P_2O_5 .ha^{-1} resulted in a considerable improvement in leaf area, fruit weight, and total plant production relative to other treatments that ranged from 11 to 123 kg P_2O_5 .ha^{-1}. Mohamed et al. also demonstrated that (2011) in their experiment on the "Sweet Charlie" cultivar showed that fertilization at four levels (0, 60, 80, 100 kg P_2O_5 .$acre^{-1}$) showed significant differences in stem number, leaf area, fruit weight, total production, and fruit quality characteristics such as juice content, total sugars, acidity, and vitamin C, especially at the 100 kg P_2O_5 .$acre^{-1}$ level In another study, Mederos et al. (2015) evaluated the effect of five phosphorus levels (0.3, 0.58, 1.2, 1.8, 2.1 g P_2O_5 .$plant^{-1}$) on the growth of the "Osogrande" strawberry cultivar. The results showed considerable increases in leaf number, total soluble solids, vitamin C, and total sugars, while total acidity decreased with increasing phosphorus fertilization. Molai et al. also demonstrated that (2020) found that using monoammonium phosphate (MAP) at a level of 0.01 g .L^{-1} in a hydroponic system resulted in significant improvements in leaf area, total production, anthocyanin concentration, and vitamin C, with a significant decrease overall fruit acidity In the same context, Bai et al. (2023) demonstrated that phosphorus fertilization at a level of 68 kg P_2O_5/ha significantly improved leaf area compared to other levels (0, 124, 180 kg .ha^{-1}), indicating an optimal phosphorus level that promotes growth without inhibiting or causing physiological stress. depending on the over, the research focused to determine the optimal phosphorus concentration when used in combination with seaweed extract to promote plant growth, productivity, and quality characteristics of Albion strawberry cultivar under unheated, protected cultivation conditions.

MATERIALS AND METHODS

On-farm trials was performed inside an unheated greenhouse located within the Greenhouse Unit of the Department of Horticulture and Landscape Architecture, College of Agriculture and Forestry, University of Mosul, Iraq. The total zone of the greenhouse was 486 m2, with dimensions of 54 m in length and 9 m in width. The soil was subjected to physical and chemical analysis before the start of the experiment to determine its basic properties, in order to ensure homogeneity of the cultivation conditions. The structural and element attributes of the soil are condensed in Table (1).

Table (1) : structural and element attributes of the soil.

Pararmeter	Unit	Value
EC	dsm m^{-1}	0.523
pH	------	7.32
Organic mater	gm kg^{-1}	11.22
Sand	gm kg^{-1}	619.4
Clay	gm kg^{-1}	246.66
Silt	gm kg^{-1}	168.44
Soil texture	-------	Cilty Clay Loam
available N	mg kg^{-1}	57.00
available P	mg kg^{-1}	6.33
available K	mg kg^{-1}	231.00

This study used Albion strawberry runners (Fragaria × ananassa Duch. cv. Albion), selected from the fields of the Department of Horticulture and Landscape Architecture, College of Agriculture and Forestry, University of Mosul. runners with uniform growth and similar phenotypic characteristics were selected to ensure experimental uniformity. the experiment was conducted in an unheated greenhouse using a randomized complete block design (RCBD) involving two factors : Bulitem seaweed extract and phosphorus, at three levels of each factor, resulting in nine treatments (3 × 3). The treatments were distributed into three replicates, with each experimental unit containing six seedlings. Planting took place at the end of October 2023. as a preventative measure to reduce fungal disease, seedling roots were dipped in a fungicide solution containing 1 ml/L Benomyl for 60 seconds before planting. transplanting were sown at a distance of 30 x 30 cm between plants, and the basins were irrigated immediately after planting and then as needed during the growth period. The chemical properties of the seaweed extract used in the research were determined, as shown in Table (2).

Table(2): Components of Bulitem seaweed extract.

components	value	Components	Value
Asccphyllm nodosum	57.5 %	chelated Fe	0.5 %
total N	6.1 %	chelated Mn	0.5 %
organic N	1.3 %	chelated Zn	0.5 %
free amino acids	6.5 %	IAA	0.3 %
P_2O_5	4.0 %	GA_3	0.3 %
K_2O	5.0 %	Cytokinin	0.8 %

The experimental treatments were applied using three concentrations of polythene seaweed extract (0, 4, 8 g $SW{\cdot}L^{-1}$) and three concentrations of phosphorus as (0, 4, 6 g $P_2O_5\ .L^{-1}$), either individually or in combination. the foliar sprays with the seaweed extract were applied three times during the growing season, while the phosphorus was applied only twice, with regular intervals at 20- day intervals between treatments. The primary treatment was carried out on December 15, 2023, using a knapsack sprayer, ensuring complete coverage of the foliage to the point of complete wetness.

Data recorded:

Vegetative growth:

Data collection was conducted 150 days after planting, and several physiological and vegetative stage traits of strawberry plants were evaluated, as follows: Total chlorophyll concentration ($mg{\cdot}g^{-1}$ fresh weight): Estimated in young leaves using the spectrophotometric, using a Bausch & Lomb-20 visible spectrophotometer. Chlorophyll was obtained using 80% acetone, and optical density was assessed at wavelengths of 645 and 663 nm Al-Zuhairi et al (2025). Count of leaves per plant: The total a count of active leaves on each plant at the time of taking the readings was calculated using the direct counting method. Leaf area (cm2/$plant^1$): Calculated according to the formula proposed by Patton (1985), using the dimensions of the largest representative leaf, and multiplying the result by the correction factor appropriate for the cultivar. a Count of runners per plant: The count of runners formed on each plant was enumerated at the end of the growing season, on October 1, 2024, using the direct count method Al-Zuhairi et al (2025) .

Production components:

Marketable fruits were harvested periodically throughout the growing season, at two- to three-day intervals, when they reached marketable maturity. Fruits were collected from each plant separately and counted and weighed at each harvest date. The average total production per plant (g .plant^{-1}) was computed by summing the fruit weights from all harvests throughout the season. The average fruit weight (g) was estimated by dividing the total production per plant by the number of fruits produced from the same plant during the season.

Fruit quality:

At the end of April of the 2024 season, 20 fully ripe fruits from each treatment were randomly collected and used as subsamples for quality analysis. The following quality attributes were evaluated :Total soluble solids (TSS%): fruit juice was estimated using a hand refractometer, and results were indicated as a rate Al-Zuhairi et al (2025) .Titratable acidity (TA%): Determined by the basic titration method using sodium hydroxide solution, as described by Özçort & Altuntaş (2018), and results were indicated as a rate of citric acid. Juice content (%): a count by the relationship of the weight of the juice obtained to the overall fruit weight, and indicated as a rate. Anthocyanin pigment (mg/100 g fresh weight): overall anthocyanin amount was estimated following the methodology described by Ranjana (1986). Ascorbic acid (vitamin C) (mg 100g^{-1} fresh weight): Also determined using the Ranjana (1986) procedur, which is based on dichromate titration. Total sugars (%): Estimated using the Joslyn (1970) method, which is based on colorimetric reactions using special chemical reagents.

Statistical analysis:

The observations were statistically analyzed using the SAS statistical analysis program (SAS, 2002), where an analysis of variance (ANOVA) was conducted to statistical significance of the variation among studies parameters. When statistically significant difference were found, the means were compared using Duncan's Multiple Range Test according to the method described by Waller and Duncan (1969). A likelihood level of 0.05 ($P \leq 0.05$) was adopted to estimate the significance of the statistical differences.

RESULTS AND DISCUSSION

Vegetative growth: The observation in Tables 3 and 4 showed that foliar spraying with seaweed extract and phosphorus, each separately, resulted in significant increases in all vegetative traits studied. Regarding the impact of seaweed extract, the 8 g SW L^{-1} concentration recorded the highest significant averages for total leaf chlorophyll content, a count of leaves per plant, leaf area, and a count of stems, relative to both the untreated treatment and the 6 g SW L^{-1} concentration. These findings are consistent with the results of El-Menyawy et al. (2014), El-Shatri et al. (2020), El-Omar et al. (2023), and Aziz and Taha (2023), who validated the beneficial impact of seaweed extracts in enhancing vegetative development of various cultivated plants. The 6 g of $P_2O_5 \cdot L^{-1}$ treatment gave the highest significant difference in the total chlorophyll content in the leaves of each plant. The 4 g of $P_2O_5 \cdot L^{-1}$ treatment also achieved the highest averages of leaf area and number of branches in relation to the effect of foliar spraying with phosphorus. These results were confirmed with the studies of Muhammad et al. (2011), Medouros et al. (2015), Moulay et al. (2020), and Bai et al. (2023). These results showed that the strawberry plant, when fertilized with phosphate, had clearly improved vegetative growth. It cannot be hidden from us that the seaweed extract, when interacting with phosphorus, had a clear effect on all vegetative growth traits. The interaction treatment between 8 g SW L^{-1} and 4 g $P_2O_5 \cdot L^{-1}$ recorded the highest averages for total leaf chlorophyll content (12.65 $mg \cdot g^{-1}$ dry weight), leaf area (5468 cm2), and a count of stems per plant (16.55). In contrast, the interaction treatment between 8 g SW .L^{-1} and 6 g $P_2O_5 \cdot L^{-1}$ attained the maximum a count of leaves per plant (44.68), outperforming all other treatments.

Table (3): Effect of foliar spray with seaweed and phosphorus on leaves total chlorophyll and number of leaves per plant of strawberry plant cv. Albion*.

Treatments	P Conc. (g P_2O_5 L^{-1})			**Means of SW**
	0	4	6	

SW Conc. (g SW L^{-1})	Leaves total chlorophyll (mg g^{-1} FW)			
0	6.79 h	7.53 g	8.64 f	**7.65 c**
4	9.03 e	9.53 d	9.15 e	**9.24 b**
8	10.15 c	12.65 a	11.94 b	**11.57 a**
Means of P	**8.65 c**	**9.50 b**	**9.91 a**	
SW Conc. (g SW L^{-1})	Number of Leaves per plant			
0	36.75 i	37.61 h	38.27 g	**37.54 c**
4	39.42 f	40.72 e	41.70 d	**40.61 b**
8	42.83 c	43.86 b	44.68 a	**43.79 a**
Means of P	**39.67 c**	**40.73 b**	**41.55 a**	

*Means of each factor and their interaction each alone for each parameter followed by the same letters are not significantly different from each other according to Duncan's multiple ranges test at 5% level.

Table (4): Effect of foliar spray with seaweed and phosphorus on the plant leaves area (cm^2 $plant^{-1}$) and number of runners per plant of strawberry plants cv. Albion*.

Treatments	P Conc. (g P_2O_5 L^{-1})			**Means of SW**
	0	4	6	
SW Conc. (g SW L^{-1})	Plant leaves area (cm^2 $Plant^{-1}$)			
0	3094 i	3235 h	3395 g	**3241 c**
4	3578 f	3968 d	3812 e	**3786 b**
8	4222 c	5468 a	4559 b	**4750 a**
Means of P	**3631 c**	**4224 a**	**3922 b**	
SW (g SW L^{-1})	Number of runners per plant			
0	8.39 i	9.66 h	10.75 g	**9.60 c**
4	11.71 f	13.90 d	12.74 e	**12.78 b**
8	15.08 c	16.55 a	16.08 b	**15.90 a**
Means of P	**11.72 c**	**13.37 a**	**13.19 b**	

*Means of each factor and their interaction for each parameter followed by the same letters are not significantly different from each other according to Duncan's multiple ranges test at 5% level.

Production components: The data in Table (5) showed that foliar spraying with seaweed isolate at a level of 8 g SW L^{-1} and phosphorus at a level of 4 g $P_2O_5 \cdot L^{-1}$, whether used alone or in combination, resulted in significant improvements in average fruit weight and total plant productivity compared to the other treatments.The combination of 8 g SW L^{-1} seaweed extract and 4 g $P_2O_5 \cdot L^{-1}$ recorded the highest values for productivity traits, with the average fruit weight reaching 20.83 g, while the total plant productivity reached 816.5 g $plant^1$. This improvement is attributed to the synergistic effect of the active ingredients in the seaweed extract, which promote vegetative growth and physiological functions, along with the vital function of phosphorus in promoting mitosis and the formation of high-energy compounds, which positively impacted fruit formation and size. In contrast, the control treatment (without adding seaweed extract or phosphorus) showed the lowest values, recording an average fruit weight of 10.69 g and a total plant production of 445.00 g $plant^1$, confirming the importance of balanced foliar fertilization in improving the productive performance of strawberry plants. These findings are compatible with the studies of Al-Minyawi et al. (2014), Al-Shatri et al. (2020), and Al-Omar et al. (2023) regarding the effect of seaweed extracts in enhancing growth and production traits. They are also supported by the results reached by Medouros et al. (2015), Moulay et al. (2020), and Bai et al. (2023) on the positive effect of phosphate fertilization on improving strawberry productivity.

Table (5): Effect of foliar spray with seaweed extract and phosphorus on the fruit weight and plant production of strawberry plant cv. Albion*.

Treatments	P Conc. (g P_2O_5 L^{-1})			**Means of SW**
	0	4	6	
SW Conc. (g SW L^{-1})	Fruit weight (g)			
0	10.69 i	12.34 h	13.34 g	**12.12 c**

4	14.56 f	16.67 d	15.51 e	**15.58 b**
8	17.68 c	20.83 a	19.73 b	**19.41 a**
Means of P	**14.31 c**	**16.61 a**	**16.19 b**	
SW Conc. (g SW L^{-1})	Plant production (g $plant^{-1}$)			
0	445.0 h	532.6 g	571.1 f	**516.2 c**
4	596.4 f	606.2 e	643.6 d	**615.4 b**
8	686.5 c	816.5 a	764.9 b	**756.0 a**
Means of P	**576.0 b**	**664.2 a**	**659.8 b**	

*Means of each factor and their interactions for each parameter followed by the same letters are not significantly different from each other according to Duncan's multiple ranges test at 5% level.

Fruit quality: The data shown in Tables 6, 7, and 8 showed that foliar treatments with seaweed extract and phosphorus, whether applied individually or in combination, had a significant effect on improving all studied fruit quality indicators. With regard to the seaweed extract, the 8 g SW .L^{-1} spray treatment outperformed the other treatments, achieving the highest values for total soluble solids (TSS), juice percentage, anthocyanin content, ascorbic acid (vitamin C), and a count sugars, in addition to the minimum average titratable level of acidity (TA). We note that the seaweed extract contains many compounds, including auxins and cytokinins, as well as amino acids, which all work to improve the vital processes occurring within the plant, such as metabolism and the accumulation of nutrients in the fruits. These results support the results of El-Meniawy et al. (2014) and El-Shatri et al. (2020), where significant differences were obtained in TSS, anthocyanins, ascorbic acid, and total sugars, in addition to the lowest titratable acidity when spraying at a concentration of 6 g $P_2O_5 \cdot L^{-1}$, while we note that the highest juice content was recorded at a concentration of 4 g $P_2O_5 \cdot L^{-1}$. This reflects the vital role of phosphorus in physiological processes and the formation of high-energy compounds within the fruit.. These results are consistent with studies by Medeiros et al. (2015), Mollayi et al. (2020), and Bai et al. (2023). When studying the interaction between seaweed extract and phosphorus, it was found that the combined treatment of 8 g SW L^{-1} and 4 g $P_2O_5 \cdot L^{-1}$ recorded the highest values for both TSS (11.42%) and juice percentage (88.39%). Meanwhile, the highest values for anthocyanin content (44.82 mg·100 g^{-1} fresh weight), ascorbic acid (22.48 mg·100 g^{-1}), and total sugars (9.54%), and the lowest titratable acidity (0.53%), were achieved when 8 g SW L^{-1} and 6 g $P_2O_5 \cdot L^{-1}$ were combined. These results confirm the positive interaction between seaweed extract and phosphorus in improving fruit quality by enhancing the physiological processes associated with ripening and the accumulation of chemical compounds that improve taste and nutritional value.

Table (6): Effect of foliar spray with seaweed extract and phosphorus on TSS and juice percentage on the fruit of strawberry plants cv. Albion.

Treatments	P Conc. (g P_2O_5 L^{-1})			**Means of SW**
	0	4	6	
SW Conc.(g SW L^{-1})	TSS (%)			
0	9.63 e	9.78 e	10.17 d	**9.86 c**
4	10.34 d	10.97 b	10.74 c	**10.68 b**
8	11.25 a	11.42 a	11.32 a	**11.33 a**
Means of P	**10.41 b**	**10.72 a**	**10.75 a**	
SW Conc.(g SW $L.^{-1}$)	juice percentage			
0	64.79 h	71.64 g	74.64 fg	**70.36 c**
4	76.62 ef	81.86 cd	78.91 de	**79.13 b**
8	83.90 bc	88.39 a	86.89 ab	**86.39 a**
Means of P	**75.10 b**	**80.63 a**	**80.15 a**	

*Means of each factor and their interaction for each parameter followed by the same letters are not significantly different from each other according to Duncan's multiple ranges test at 5% level.

Table (7): Effect of foliar spray with seaweed extract and phosphorus on the anthocyanin and titrable acidity on the fruit of strawberry plants cv. Albion*.

Treatments	P Conc. (g P_2O_5 L^{-1})	**Means of SW**

	0	4	6	
SW Conc. (g SW L^{-1})	Anthocyanin(mg 100g^{-1} FW.)			
0	31.85 i	33.56 h	35.69 g	**33.70 c**
4	37.14 f	39.55 e	41.12 d	**39.27 b**
8	42.85 c	43.85 b	44.82 a	**43.84 a**
Means of P	**37.28 c**	**38.99 b**	**40.54 a**	
SW Conc. (g SW L^{-1})	Titratable acidity (%)			
0	0.63 a	0.61 b	0.60 c	**0.61 a**
4	0.58 d	0.56 e	0.57 e	**0.57 b**
8	0.56 f	0.54 g	0.53 h	**0.54 c**
Means of P	**0.59 a**	**0.57 b**	**0.56 c**	

*Means of each factor and their interaction for each parameter followed by the same letters are not significantly different from each other according to Duncan's multiple ranges test at 5% level.

Table (8): Effect of foliar spray with seaweed and phosphorus on ascorbic acid and total sugars in the fruits of strawberry plants cv. Albion*.

Treatments	P Conc. (g P_2O_5 L^{-1})			**Means of SW**
	0	4	6	
SW Conc.(g SW L^{-1})	ascorbic acid (mg 100 g^{-1} FW)			
0	16.61 i	17.16 h	17.61 g	**17.13 c**
4	18.46 f	19.06 e	19.64 d	**19.05 b**
8	20.53 c	21.44 b	22.48 a	**21.48 a**
Means of P	**18.53 c**	**19.22 b**	**19.91 a**	
SW Conc.(g SW L^{-1})	Total sugars (%)			
0	8.31 i	8.54 h	8.63 g	**8.49 c**
4	8.56 f	8.73 e	8.82 d	**8.70 b**
8	8.74 c	9.11 b	9.54 a	**9.13 a**
Means of P	**8.53 c**	**8.79 b**	**8.99 a**	

*Means of each factor and their interactions for each parameter followed by the same letters are not different from each other according to Duncan's multiple ranges test at 5% level.

The results presented in Tables 2–7 indicate that sprayed on leaves of seaweed extract and phosphorus, either alone or in combination, particularly the combination of 8 g SW·L^{-1} of seaweed extract with 4 or 6 g P_2O_5·L^{-1}, effectively enhanced vegetative development, production components, and quality characteristics of Albion strawberry. This improvement is attributed to the synergistic effects of seaweed extract and phosphorus, which positively impacted various plant physiological processes. Bulitem seaweed extract is a biostimulant rich in a wide range of bioactive compounds, such as plant growth hormones (IAA, GA_3, and cytokinins), polysaccharides, proteins, amino acids, vitamins, and macro- and micronutrients (Table 2). These components work together to enhance vegetative development by promoting mitotic cell division and longitudinal growth, activating chlorophyll formation, and increasing leaf number and area. This increases the efficiency of photosynthesis, which in turn enhances flower formation and fruit set, directly impacting crop traits with respect to fruit weight size, and overall production per plant (Al-Obaidi, 2024) .Furthermore, these compounds contribute to enhancing the absorption capacity of roots and improving the efficiency of nutrient utilization in the soil, as noted by Stevenson and Faber (1968) and Odell (2003), who emphasized the funiction of seaweed extracts in promoting root development and thus supporting overall plant growth. Taha (2008) reported that foliar spraying with seaweeds improves fruit growth and increases their number and weight, contributing to improved overall productivity and fruit quality. Bagh et al. (2024) Seaweeds, as a natural organic fertilizer, contain high concentrations of auxins, cytokinins, amino acids, and minerals, elements that contribute to directing growth toward flowering and fruit formation, thus enhancing production. Ismail and Ghazi (2012) also demonstrated that betaine, found in seaweeds, as an organic source of nitrogen and an osmotic regulator, contributes to enhancing plant development and its capacity to adapt to environmental biotic stress. On the other hand, the results of Ranna et al. (2023) demonstrated that foliar application with seaweed extract increases the buildup of total and reducing sugars in fruits, increasing their weight and improving their market value, and reducing acidity due to the conversion of organic acids to sugars. Vitamin C content also increased in fruits treated with seaweeds, likely due to the effect of betaine in slowing chlorophyll decomposition and stimulating photosynthesis, or due to the specific enzymes in the seaweed extract that enhance the formation of ascorbic acid. Together, these results demonstrate the importance of combining seaweed extract with phosphorus as an effective foliar treatment to improve the physiological, productive and qualitative performance of strawberry plants under protected cultivation conditions.

The positive effect of phosphorus application on vegetative and productive traits, as shown in Tables 3–8, can be explained by its being an essential element in the formation of many vital cell components, such as nucleotides, nucleic acids, and phospholipids. Phosphorus also contributes to stimulating root growth, which enhances the efficiency of nutrient absorption and concentration within plant tissues, positively impacting vegetative growth, flowering, and overall productivity (Al-Maeni, 2024). Blevins (2001) indicated that phosphorus is essential for producing high-quality fruit, as it is a component of several coenzymes involved in energy transfer reactions, particularly in photosynthesis, where it participates in the formation of high-energy molecule (ATP and ADP) necessary for the synthesis of organic compounds. It is also an essential element in the formation of nucleic acids (Havlin et al., 2005; Yaqoub, 2022), which in turn are essential for the synthesis of proteins responsible for cell structure and vital functions. Phosphorus critical an essential function Photosynthesis, magnesium uptake, and chlorophyll synthesis increased when phosphorus was applied to the strawberry plant, directly leading to increased vegetative growth. Phosphorus enhanced chlorophyll synthesis, which improved photosynthesis, increased the food produced by this process, and indirectly increased the accumulation of photosynthetic products in the leaves. (Blevins, 2001). Studies by Jackson (1985) and Abu-Dahi and Al-Younis (1988) indicate that phosphorus contributes to the development of a strong and extensive root system, which enhances the plant's ability to absorb and accumulate mineral elements in vegetative tissues. This improves vegetative growth and, consequently, positively impacts fruit growth, weight, and plant productivity. Phosphorus also participates in the formation of many enzyme cofactors and involved in a prominent function in promoting water and nutrient absorption, increasing the output of amino and nucleic acids, which leads to enhanced carbohydrate formation and transport from leaves to fruits. This transfer helps create an ideal balance between carbon and nitrogen in the plant, which contributes to the morphogenesis of flower buds and the improvement of flower and fruit production (Jackson & Sa, 1985).

CONCLUTION

This research was performed to assess the individual and combined effects of foliar treatment with polythene seaweed extract at three concentrations (0, 4, 8 g $SW \cdot L^{-1}$) and phosphorus as P_2O_5 at three levels (0, 4, 6 g $P_2O_5 \cdot L^{-1}$) on the growth and production, and fruit attributes of strawberry (Fragaria × ananassa Duch.) cultivar Albion, grown in an unheated plastic greenhouse. The data indicated that the combined the effects of treatment was statistically significant outperformed the individual treatments and the control treatment for most of the studied traits. The combined treatment (8 g $SW \cdot L^{-1}$ + 4 g $P_2O_5 \cdot L^{-1}$) showed the highest values for total leaf chlorophyll, leaf area, a count of stems per plant, average yield components including fruit weight, soluble solids (TSS) content, juice percentage, and lower titratable acidity (TA). Meanwhile, the applied treatment (8 g $SW \cdot L^{-1}$ + 6 g $P_2O_5 \cdot L^{-1}$) produced the maximum leaves count was observed in per plant, anthocyanin content, ascorbic acid (vitamin C), and total sugars. These results indicate a clear synergistic effect between seaweed extract and phosphorus, which showed a positive effect reflected on development growth and production components and fruit quality characteristics, supporting the recommendation to use an interaction between 8 g $SW \cdot L^{-1}$ and 6 g $P_2O_5 \cdot L^{-1}$ to improve
strawberry productivity and fruit quality in unheated protected cultivation conditions.

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