Influence of Some Biostimulants Combined with Zinc and Boron Oxides on the Performance of Date Palm

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Although chemical fertilizers increase plant growth and crop yields, their usage over a long period harms soil health, damages the beneficial microorganisms, and reduces soil fertility. Therefore, there is interest in using natural biostimulants in agriculture instead of chemical fertilizers. This study aimed to examine how spraying with zinc (ZnO) and boron (B_2O_3) oxides, as well as the biostimulants yeast extract (YE) and seaweed extract (SWE), and their combinations affect the yield and fruit quality of Barhi date palm. The trees were sprayed four times starting from mid of February with one month between each two sprays with 50 mg/L ZnO + 50 mg/L B_2O_3; 100 mg/L ZnO + 100 mg/L B_2O_3; 0.2% or 0.4% YE; 0.2% or 0.4% SWE; 50 mg/L ZnO + 50 mg/L B_2O_3 + 0.2 % YE + 0.2 % SWE, (combination 1); 100 mg/L ZnO + 100 mg/L B_2O_3 + 0.4% YE + 0.4% SWE (combination 2) compared to not-treated trees. The results indicated that applying ZnO and B_2O_3, YE and SWE either individually or in combination effectively enhanced the productivity and fruit quality of the date palm cv. Barhi compared to the control. The results also showed that the combined application gave a larger improvement in the measured parameters, particularly combination 2, which was the best treatment, followed by combination 1.

DOI: 10.15376/biores.20.4.9785-9803

Keywords: Date palm; Productivity; Fruit quality; Seaweed extract; Zinc; Yeast extract

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INTRODUCTION

Although synthetic fertilizers boost crop yields and support development, their extensive application can cause serious issues, such as soil salinity and compaction, which decrease soil fertility, enhance pesticide reliance, and pollute water sources (Shambhavi *et al.* 2017). The use of traditional mineral fertilizers has surged significantly due to rapid global population growth and rising food demand (Benson *et al.* 2018). Consequently, there is a pressing need to develop and implement new alternative inputs for crop production, such as biostimulants that improve the nutrition of plants, absorption of nutrients, productivity, and fruit (Al-Saif *et al.* 2023a).

A plant biostimulant is any substance or microorganism that, when applied to plants, enhances nutrient uptake, improves nutritional efficiency, boosts yield, improves fruit quality, and increases tolerance to abiotic stresses. The use of biostimulants is considered an effective alternative to minimize the reliance on chemical fertilizers. These biostimulants provide necessary macro- and micronutrients, as well as plant hormones such as gibberellins, auxins, and cytokinins. They are safe for soil and do not negatively impact soil properties (Caradonia *et al.* 2019; Rouphael and Colla 2020). In addition, they are inexpensive and simple to prepare and apply (Suhail 2013).

The date palm (*Phoenix dactylifera* L.) has served as a vital food security crop in the Middle East and North Africa for over 5,000 years (Ghnimi *et al*. 2017). In Egypt, it is one of the most significant fruit crops, covering an area of 72,395 thousand hectares and yielding approximately 1,867 million tons (FAO 2023). The fruit is rich in dietary fibers, carbohydrates, proteins, vitamins, minerals, phenolic and tannin compounds, along with antioxidants (Al-Alawi *et al*. 2017; Bentrad and Hamida-Ferhat 2020). Date fruits are highly nutritious, rich in carbohydrates (mainly fructose and glucose, ~70%), dietary fiber, protein, and vitamin B-complex. They also provide fundamental minerals including Ca, Fe, Mg, K, Zn, and Se, which make them valuable food with potential health benefits (Aljaloud *et al*. 2020).

Seaweed extract (SWE) is a natural and inexpensive source of plant growth regulators; cytokinins, auxins, and gibberellins, which are related to nutrient solubility; thus, much more attention should be given to the usage of SWE to raise the immunity of the plants and improve their growth under environmental stress (Gullón *et al*. 2020). SWEs are large, multicellular organisms that are rich in lipids, proteins, carbohydrates, and enzymes, and can withstand extreme conditions like heat, salinity, drought, frost, and intense light (Patel *et al*. 2020), and a shortage of necessary elements (Battacharyya *et al.* 2015). The application of SWE improved the elongation and division of the plant cell which consequently increased the shoot length and leaf area (Colavita *et al.* 2011). SWE has been found to promote absorption of nutrients from the soil (El Boukhari *et al*. 2020). SWE is distinguished by its high content from organic and amino acids, and antioxidants, such that it can be considered a plant growth stimulator (Spinelli *et al*. 2009). Other macro- and micronutrients present in SWE include phosphorus, potassium, magnesium, carbon, sulfur, calcium, boron, cobalt, iron, silicon, molybdenum, selenium, manganese and zinc (Parthiban *et al.* 2013). Using biostimulants, such as natural extracts from SWE, offers a sustainable way to increase food production without harming the environment (Hernández-Herrera *et al.* 2014). SWE is considered a natural and inexpensive biostimulant that is rich in different components such as sterols, nitrogen-containing compounds, micro- and macronutrients, amino acids, vitamins, cytokinin, auxin, and abscisic acid. Therefore, it enhances the growth of roots, root hairs, and secondary roots, which consequently improves the fruit setting, nutrient uptake, facilitates water absorption, increases chlorophyll content, and boosts flowering and fruit formation. Additionally, SWE enhances photosynthetic activity, as well as the quantity and quality of the fruit (Begum *et al.* 2018; Nikoogoftar-Sedghi *et al.* 2023). Murtic *et al*. (2018) reported that SWE contains aspartic acid, isoleucine, proline, valine, amino acids, along with micronutrients and vitamins that enhance crop tolerance to environmental stress.

Sarhan and Abdullah (2010) documented that because Yeast Extract (YE) is characterized by a high content of many active compounds such as amino acids, hormones, and vitamins, which improve plant growth, it is considered a biostimulant. Because YE contains a combination of carbohydrates, amino acids, minerals, enzymes, vitamins, sugars, B complex vitamins, and peptides, it could be a biostimulant (Marzauk *et al*. 2014). YE functions as a microbial plant growth enhancer, promoting development and boosting productivity (El-Serafy 2018), and alleviating biotic and abiotic stresses (Fu *et al.* 2016). Moreover, YE is rich in different components, such as vitamins, minerals, amino acids, cytokinins, and auxin, so it has a remarkable influence on improving the vegetative growth, flower formation, productivity, and carbohydrate accumulation (Dawood *et al.* 2019). Foliar application of YE enhanced growth, flower development, and final yield, due to its rich content of vitamins, amino acids, minerals, and phytohormones, particularly cytokinins and gibberellins (Hamed *et al.* 2019). Besides, YE helps in the conversion of insoluble phosphorus to a soluble form (Kalayu 2019). Because it is rich in proteins, B vitamins, amino acids, and cytokinins, YE promotes cell growth, the development of shoots and roots, chloroplast maturation, and the synthesis of nucleic acids, proteins, and chlorophyll (Hassan *et al.* 2020). YE acts as a cost-effective biofertilizer that enhances plant nourishment and vitality, increasing their resistance to abiotic stress. It is environmentally friendly and can be applied *via* soil or foliar techniques on diverse crops (Abd-Alrahman and Aboud 2021).

Boron is an immobile element that transfers with difficulty from source organs to young buds. The resulting shortage of B results in small flowers, incomplete pistils, floral abortion, reduced pollen viability, and ultimately depression in fruit set percentage (Botelho *et al*. 2022). These problems are related to the depletion of carbohydrate translocation and lower starch content in them (Rerkasem *et al*. 2020). It also affects key metabolic processes, resulting in reduced shoot growth, lower fruit set percentages, diminished fruit quality, and altered nutrient composition of the fruits (Davarpanah *et al.* 2016). Additionally, boric acid enhances root growth by supplying carbohydrates needed for root development (Hasanuzzaman *et al.* 2018). It is an essential, immobile micronutrient vital for plant growth, particularly in pollen germination, tube elongation, and overall reproductive development (Saini *et al.* 2019; Sharafi and Raina 2021). The shortage of boron in plants delays pollen germination, reduces the growth of the pollen tube, and disrupts the flowering and fruit set (Brdar-Jokanović 2020). In fruit trees, boron supports key stages such as pollination, fertilization, and fruit set, while also playing a crucial role in carbohydrate metabolism, sugar transport, cell wall formation, and respiration. Additionally, it supports pollen viability, leaf elongation, pollen germination, and pollen tube growth, as well as being essential for flower production and retention, seed and fruit development, and facilitating the transport of water, nutrients, and carbohydrates to actively growing tissues (Hadi and Saleh 2021).

Zhao *et al*. (2012) stated that zinc enhances chlorophyll and carotenoid biosynthesis, improves the rate of photosynthesis, and inhibits interveinal chlorosis. Many authors previously stated that zinc organizes hormones, such as gibberellins, cytokinins, and auxins, which are necessary for growth and differentiation of the plant cells. It induces plant growth as well as the accumulation of fresh and dry weight by preserving the balance between these hormones (Safarzadeh *et al.* 2013). Additionally, it is fundamental for plant physiology, where it helps the organization of auxin content, reducing the oxidation process, and improving enzymatic reactions, such as carbohydrate transfer and cellulose formation (Bhalerao *et al*. 2014). Through boosting chlorophyll levels, Zn contributes to higher photosynthetic activity, which ultimately promotes better crop growth and increased yields (Yu *et al.* 2015). Additionally, zinc is important for aiding in cell division and preserving the integrity of membrane structures (Lacerda *et al.* 2018) and synthesizing photosynthetic pigments (Liu *et al.* 2022). Zinc is important in the synthesis of proteins, chlorophyll, and various enzymes (Singh *et al*. 2018). It supports hormone organization, including the synthesis of tryptophan, and it facilitates signaling through mitogen-activated protein kinases (Kaur and Garg 2021), activates enzymes, and maintains ion balance (Alsafran *et al.* 2022).

Therefore, the present study has been performed to investigate the role of some biostimulants alone or combined with zinc and boron oxides to improve the productivity of date palm cv. Barhi and reduce the dependency on mineral fertilizers.

EXPERIMENTAL

Applied Treatments, Location, and Experimental Design

The present study was performed during the 2023 and 2024 seasons on ten-year-old date palm trees cv. Barhi grown in the Wadi El-Natroun region, El-Behera governorate, Egypt, at the age of 12 years in sandy soil at a distance of 7 × 7 m^2 under a drip irrigation system. Forty-five palms in the same growth and size were selected carefully to perform this study. The trees were sprayed with 50 mg/L ZnO + 50 mg/L B_2O_3; 100 mg/L ZnO + 100 mg/L B_2O_3; 0.2 and 0.4% YE; 0.2 and 0.4% Seaweed Extract (SWE); 50 mg/L ZnO + 50 mg/L B_2O_3 + 0.2 % YE + 0.2 % SWE, (combination 1); 0.4% YE + 0.4% SWE + 100 mg/L ZnO + 100 mg/L B_2O_3 (combination 2) as compared to trees that were not sprayed as a control. Yeast Extract (YE): Nutritional Additive Organic Pure Powder Yeast Extract Powder (Hangzhou Natur Foods Co., Ltd., Xiaoshan District, Hangzhou City, Zhejiang Province, China). Seaweed Extract (SWE): Plant Extract *Ascophyllum Nodosum* Flake/Powder Water Soluble Seaweed Extract Organic Fertilizer (Shenyang Everest Corporation Ltd., Shenyang, Liaoning, China).

The treatments were arranged in a randomized complete block design (RCBD), where each treatment was applied on five palms (five replicates). The trees were sprayed four times: starting from mid-February with one-month intervals between sprays. The analysis of the experimental soil is shown in Table 1.

Table 1. Physical and Chemical Characteristics of the Experimental Soil

Textural class			O.M (%)		pH		CaCO3 (%)			EC (dS/m)		
Sandy loam			0.25		8.3		5.8			2.8		
Soluble anions (meq/L)			Soluble cations (meq/L)				Available nutrients (mg/kg)					
							Macro nutrients			Micronutrients		
HCO_3^-	CL^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+	N	P	K	Fe	Zn	Mn
6.12	5.5	16.91	19.22	4.50	1.66	4.42	75.5	5.2	230	0.9	0.38	0.85

O.M.: Organic matter; EC: Electrical conductance

Table 2. Weather Data during the 2023 and 2024 Seasons

Year	2023		2024		2023	2024	2023	2024
Months	Temperature (°C)		Temperature (°C)		Average Relative Humidity (%)		Total Precipitation (mm)	
	Minimum	Maximum	Minimum	Maximum				
January	9.21	20.31	9.26	19.46	70.27	64.46	26.70	26.20
February	7.75	18.91	8.73	20.54	68.94	69.41	29.90	6.70
March	11.14	24.42	10.46	24.04	59.23	62.43	14.20	8.80
April	12.96	27.79	14.01	29.94	54.04	57.87	10.20	2.20
May	16.05	31.75	16.80	32.44	52.39	48.06	0.40	0.00
June	20.11	35.29	20.94	38.67	52.70	50.40	1.90	0.20
July	22.11	38.48	22.98	38.03	54.11	53.71	0.00	0.00
August	22.65	37.37	22.75	37.71	55.20	55.06	0.00	1.50
September	22.28	36.39	22.08	35.17	54.88	56.40	0.20	0.00

The impact of the aforementioned treatments was evaluated by examining their effects on the subsequent parameters.

Palm Yield

At harvest, palm yield was measured in kg by weighing the weight of bunches, and the total yield per hectare was calculated by multiplying the number of palms by their average yield.

Fruit Quality

Forty fruits from each tree (replicate), were picked in September (time of the fruit ripening) of 2023 and 2024 and transferred directly to the lab to measure the fruits' physical and chemical characteristics.

Fruit Physical Characteristics

Average fruit weight (g) was determined by calculating the mean weight of 40 individual fruits. Flesh weight (g), and seed weight (g), were measured, and the flesh/fruit ratio was calculated. Fruit length and fruit width (cm) were assessed using a digital vernier caliper (Suzhou Sunrix Precision Tools Co., Ltd., Suzhou, China). Fruit firmness (Ib/inch^2) was assessed using a Magness–Taylor pressure tester (mod. FT 02 (0 to 2 lb, Alfonsine, Italy).

Fruit Chemical Characteristics

Total soluble solids percentage in fresh fruits was determined using a hand refractometer (ATAGO Co., Ltd., Tokyo, Japan). Fruit acidity was determined as a percentage based on malic acid content and measured in the fruit juice through titration using 0.1 N sodium hydroxide, with phenolphthalein serving as the indicator (AOAC 2005). Total sugar content (%) was measured using the phenol-sulfuric acid method, while reducing sugars were colorimetrically determined following the procedure described by Nelson (2010).

The percentage of non-reducing sugars was calculated by subtracting reducing sugars from total sugars. The content of ascorbic acid in the juice (vitamin C) was determined through titration using 2,6-dichloro phenol-indo-phenol (Nielsen 2017). The soluble tannin content was determined using a method as described by Ogawa and Yazaki (2018).

Total chlorophyll content was estimated following the method described by Richardson *et al*. (2002), with absorbance measured spectrophotometrically at 650 nm. Similarly, fruit carotene content was determined using the procedure outlined by Aquino *et al*. (2018), with absorbance recorded at 440 nm using a spectrophotometer (Zhengzhou Resound Photoelectric Technology Research Institute Company, China).

Statistical Analysis

The results were statistically analyzed using One-Way analysis of variance (ANOVA) in a randomized complete block design (RCBD), and Least Significant Difference (LSD) at 0.05 was used compare between the means of the treatments (Snedecor and Cochran 1990) using CoHort Software 6.311 (Pacific Grove, CA, USA).

RESULTS AND DISCUSSION

The external spraying of ZnO + 50 mg/L B_2O_3, YE, SWE, and their combinations significantly improved the bunch weight, yield in kg per palm, and tons per hectare compared to unsprayed trees (Table 3). Moreover, the best treatment that achieved the most significant increments in the yield was the spraying of combination 2 over the other applied treatments.

The highest doses from the sprayed materials were more effective than the lower ones. Additionally, the effect of SWE was higher than the influence of YE. The differences between the influence of 0.4% SWE and combination 1 were insignificant in the two seasons.

Table 3. Influence of the Foliar Spraying of ZnO + B_2O_3, YE, SWE, and their Combinations on the Bunch Weight and Fruit Yield of Date Palm cv. Barhi during 2023 and 2024 Seasons

Treatments	Bunch Weight (kg)		Yield (kg/palm)		Yield (ton/h)	
	2023	2024	2023	2024	2023	2024
Control	15.88f	16.12f	158.80f	161.20f	30.97f	31.43f
50 mg/L ZnO + 50 mg/L B_2O_3	16.42ef	16.96def	164.20ef	169.60def	32.02ef	33.07def
100 mg/L ZnO + 100 mg/L B_2O_3	18.84bc	19.12c	188.4bc	191.20c	36.74bc	37.28c
0.2% YE	16.00f	16.52ef	160.00f	165.20ef	31.20f	32.21ef
0.4% YE	17.90cd	18.10cd	179.00cd	181.00cd	34.90cd	35.29cd
0.2% SWE	17.26de	17.80de	172.60de	178.00de	33.66de	34.71de
0.4% SWE	19.62b	20.4b	196.2b	204.00b	38.26b	39.78b
Combination 1	19.96b	20.68b	199.60b	206.80b	38.92b	40.33b
Combination 2	21.76a	22.12a	217.60a	221.20a	42.43a	43.13a
$LSD_{0.05}$	1.08	1.25	10.84	12.55	2.11	2.45

Treatments with the same letter in a column are not significantly different.

The spraying of B_2O_3 + ZnO, YE, SWE, and their combinations had a positive effect on fruit weight, fruit firmness, and flesh weight, in Barhi date palms (Table 4). The results also showed that combination 2 yielded the best result, with the highest increments in the measured parameters. Additionally, the spraying of high concentrations of B_2O_3 + ZnO, YE, and SWE was more effective than the lowest concentrations in both seasons. The seed weight was markedly increased with combination 2 compared to control. The differences between the effects of combination 1, 0.4% SWE, 0.2 SWE, and 0.4 YE on the seed weight were so slight to be significant.

The spraying of ZnO + B_2O_3, YE, SWE, and their combinations improved the fruit physical characteristics in terms of flesh-fruit weight, fruit length, and diameter compared to the control (Table 5). The highest fruit length was greatly increased by the spraying of combination 2 rather than the sprayed treatments. There were no significant differences detected between combination 2 and combination 1 on the flesh-fruit ratio and fruit diameter.

Table 4. Influence of the Foliar Spraying of ZnO + B_2O_3, YE, SWE, and their Combinations on the Weights of Fruit, Flesh, and Seed and Fruit Firmness of Date Palm cv. Barhi during 2023 and 2024 Seasons

Treatments	Fruit Weight (g)		Flesh Weight (g)		Seed Weight (g)		Fruit Firmness (lb/inch^2)	
	2023	2024	2023	2024	2023	2024	2023	2024
Control	15.1e	15.058f	13.80e	13.78e	1.30b	1.32d	18.77e	19.57e
50 mg/L ZnO + 50 mg/L B_2O_3	16.872d	16.31de	15.48d	14.91de	1.39a	1.388bc	21.30d	21.1d
100 mg/L ZnO + 100 mg/L B_2O_3	18.666c	18.836c	17.24c	17.494c	1.43a	1.402bc	21.77cd	22.33c
0.2% YE	15.678e	15.73ef	14.37e	14.394e	1.30b	1.35cd	19.23e	20.17e
0.4% YE	18.274c	18.498c	16.85c	17.166c	1.42a	1.402bc	21.23d	22.27c
0.2% SWE	17.078d	17.248d	15.65d	15.842d	1.43a	1.396bc	21.20d	21.23d
0.4% SWE	19.998b	20.392b	18.55b	19.068b	1.45a	1.43ab	22.47bc	22.73c
Combination 1	20.862b	21.258b	19.42b	19.848b	1.44a	1.43ab	22.70b	23.87b
Combination 2	22.00a	22.47a	20.56a	21.08a	1.44a	1.48a	23.53a	25.53a
$LSD_{0.05}$	1.00	1.17	1.00	1.21	0.07	0.06	0.79	0.92

Treatments with the same letter in a column are not significantly different.

Table 5. Influence of the Foliar Spraying of ZnO + B_2O_3, YE, SWE, and their Combinations on the Flesh-fruit Ratio, Fruit Length, and Diameter of Date Palm cv. Barhi during 2023 and 2024 Seasons

Treatments	Flesh-fruit Ratio		Fruit Length (cm)		Fruit Diameter (cm)	
	2023	2024	2023	2024	2023	2024
Control	91.40f	91.21e	3.29f	3.30e	2.46b	2.41b
50 mg/L ZnO + 50 mg/L B_2O_3	91.73def	91.47e	3.47e	3.41d	2.59ab	2.51b
100 mg/L ZnO + 100 mg/L B_2O_3	92.32cd	92.54bcd	3.62bc	3.58c	2.46b	2.55b
0.2% YE	91.67ef	91.39e	3.45e	3.39d	2.48b	2.42b
0.4% YE	92.22cde	92.40cd	3.47de	3.46d	2.53b	2.52b
0.2% SWE	91.61ef	91.84de	3.48de	3.44d	2.48b	2.53b
0.4% SWE	92.75bc	92.97abc	3.59cd	3.57c	2.454b	2.54b
Combination 1	93.08ab	93.27ab	3.72b	3.80b	2.61ab	2.57b
Combination 2	93.44a	93.41a	3.86a	3.91a	2.77a	2.77a
$LSD_{0.05}$	0.56	0.76	0.11	0.08	0.22	0.17

Treatments with the same letter in a column are not significantly different.

The fruit content from TSS percentage was improved by the external spraying of ZnO + B_2O_3, YE, SWE, and their combinations as compared to untreated trees (Table 6). Moreover, the results showed that the highest increments in TSS percentage were obtained with the spraying of combination 2 rather than the sprayed treatments in both seasons. The results also showed that there are no significant differences between the effect of combination 1, and 0.4% SWE in their effect. On the opposite side, the results indicate that the spraying of combination 2 markedly decreased the fruit content of acidity and tannin. Additionally, Combination 1, 0.4% SWE, 0.2% SWE, 0.4% YE, and 100 mg/L ZnO + 100 mg/L B_2O_3 positively lowered the fruit content from acidity and tannin percentages compared to untreated trees.

Table 6. Influence of the Foliar Spraying of ZnO + B_2O_3, YE, SWE, and their Combinations on the Fruit Content from TSS, Acidity, and Tannin Percentages of Date Palm cv. Barhi During 2023 and 2024 Seasons

Treatments	TSS (%)		Acidity (%)		Tannin (%)	
	2023	2024	2023	2024	2023	2024
Control	25.70f	27.24e	0.34a	0.32a	1.06a	0.954a
50 mg/L ZnO + 50 mg/L B_2O_3	27.94e	28.50e	0.32ab	0.304ab	0.93b	0.854b
100 mg/L ZnO + 100 mg/L B_2O_3	32.46c	34.40bc	0.29c	0.258d	0.69d	0.7306c
0.2% YE	26.70ef	27.64e	0.34a	0.318a	0.94b	0.9098a
0.4% YE	32.60c	34.30c	0.29bc	0.27cd	0.72d	0.696cd
0.2% SWE	30.16d	31.40d	0.30bc	0.286bc	0.83c	0.804b
0.4% SWE	33.94bc	34.90bc	0.27c	0.25d	0.68d	0.6744d
Combination 1	35.12b	36.00b	0.27c	0.25d	0.66d	0.608e
Combination 2	37.38a	37.88a	0.23d	0.22e	0.57e	0.5448f
$LSD_{0.05}$	1.45	1.57	0.03	0.02	0.08	0.05

Treatments with the same letter in a column are not significantly different.

The external spraying of ZnO + B_2O_3, YE, SWE, and their combinations greatly increased the fruit content from total, reduced, and non-reduced sugars compared to untreated trees in the two seasons (Table 7). The spraying of combination 2 remarkably increased the fruit content of total, reduced, and non-reduced sugars, rather than the other sprayed treatments. Moreover, the highest concentrations of ZnO + B_2O_3, YE, and SWE were more effective than the lowest ones in the two seasons.

Table 7. Influence of the Foliar Spraying of ZnO + B_2O_3, YE, SWE, and their Combinations on the Fruit Content from Total, Reduced, and Non-reduced Sugars Percentages of Date Palm cv. Barhi during the 2023 and 2024 Seasons

Treatments	Total Sugars (%)		Reduced Sugars (%)		Non-reduced Sugars (%)	
	2023	2024	2023	2024	2023	2024
Control	21.74f	22.36d	16.56f	17.52f	5.18d	4.84abc
50 mg/L ZnO + 50 mg/L B_2O_3	23.72e	23.77d	18.30e	19.31e	5.42d	4.46c
100 mg/L ZnO + 100 mg/L B_2O_3	29.25c	29.21b	23.94b	24.24bc	5.31d	4.97abc
0.2% YE	22.70ef	22.91d	17.36ef	18.18ef	5.35d	4.73bc
0.4% YE	28.70c	29.41b	22.59c	23.97c	6.11bc	5.43a
0.2% SWE	26.15d	26.17c	20.50d	21.12d	5.65bcd	5.05abc
0.4% SWE	30.09bc	30.14b	24.57b	24.74bc	5.52cd	5.40a
Combination 1	31.22b	30.78b	24.96b	25.52b	6.26ab	5.25ab
Combination 2	33.58a	32.43a	26.78a	26.94a	6.80a	5.48a
$LSD_{0.05}$	1.61	1.54	1.34	1.40	0.58	0.59

Treatments with the same letter in a column are not significantly different.

The spraying of date palm cv. Barhi by ZnO + B_2O_3, YE, and SWE improved fruit chemical characteristics like carotene, total chlorophyll, and vitamin C compared to untreated trees (Table 8). Moreover, the highest results were obtained by spraying the date palm trees with combination 2, which was the best treatment. Additionally, the differences between the effect of combination 1 and 0.4% SWE were so slight not enough to be significant. The effect of the application of 0.4 % SWE or YE was higher than the spraying of 0.2 % SWE or YE, and the impact of 100 mg/L from ZnO + B_2O_3 was higher than 50 mg/L.

Table 8. Influence of the Foliar Spraying of ZnO + B_2O_3, YE, SWE, and their Combinations on the Fruit Content of Carotene, Total Chlorophyll, and Vitamin C of Date Palm cv. Barhi during the 2023 and 2024 Seasons

Treatments	Carotene (mg/100 g)		Total Chlorophyll (mg/100 g)		Vitamin C (mg/100 mL)	
	2023	2024	2023	2024	2023	2024
Control	3.30f	3.23f	4.83d	5.30f	3.36e	3.35e
50 mg/L ZnO + 50 mg/L B_2O_3	3.60ef	3.47f	5.30d	5.68ef	3.68d	3.48e
100 mg/L ZnO + 100 mg/L B_2O_3	4.27cd	4.70cd	6.16c	7.12d	3.98c	4.10c
0.2% YE	3.40ef	3.40f	5.20d	5.48f	3.49de	3.44e
0.4% YE	4.17d	4.50d	6.02c	6.18e	3.73d	3.91d
0.2% SWE	3.63e	4.03e	6.01c	5.79ef	3.65d	3.82d
0.4% SWE	4.53bc	4.83bc	6.63c	7.94c	4.22bc	4.15c
Combination 1	4.80b	5.10b	7.64b	8.56b	4.31b	4.36b
Combination 2	5.61a	5.63a	9.10a	9.12a	4.89a	5.00a
$LSD_{0.05}$	0.30	0.31	0.59	0.52	0.24	0.13

Treatments with the same letter in a column are not significantly different.

Discussion

The results showed the positive influence of the application of SWE individually or combined with YE, ZnO + B_2O_3 on the performance of date palm cv. Barhi. These findings were explained by many authors in their studies. For example, many authors reported that SWE is a natural marine resource and characterized by its high content of variant biologically active substances, such as polysaccharides and hormones, gibberellins, auxins, cytokinins, abscisic acid, sterols, indole acetic acid, and polyamines, which can improve the growth, development of the plants, flowering rate, productivity, the nutritional content and fruit shelf life, and defense abiotic stresses (Górka *et al.* 2015; Ali *et al*. 2021). SWE increases the efficiency of water use and nutrient uptake (Raj *et al.* 2018). SWEs are widely recognized as a nutrient-rich resource of Ca, Mg, K, S, and P, as well as micronutrients, such as iodine, manganese, nickel, selenium, iron, cobalt, zinc, copper, molybdenum, and boron, a valuable source of vitamins A, D, B1, B2, B9, B12, K, C, and E, amino acids, such as aspartic acid, glutamic acid, and alanine, proteins, lipids, carbohydrates, as well as bioactive compounds, such as polyphenols with antioxidants. Therefore, they are utilized in agriculture as liquid fertilizers, promoting higher crop yields (Kumawat and Kumawat 2023; Kumar *et al.* 2024).

The present results agreed with those obtained by many authors who reported that the soil addition of SWE at 3 and 4 g/L improved the vegetative growth, productivity, fruit quality, and the nutritional status of guava trees (Mosa *et al*. 2021). The spraying of SWE ameliorated the vegetative growth parameters, fruit set percentages, fruit productivity, fruit quality characteristics, and the nutritional status of the trees, compared to non-sprayed trees in apple (Mosa *et al.* 2022), olive, and apricot (Al-Saif *et al.* 2023a and b) and orange (Almutairi *et al.* 2024).

As YE contains phytohormones and amino acids, its application can induce tolerance to environmental stress, promote plant growth and chlorophyll content in plants, and increase protein and nucleic acid synthesis (Wanas 2006). YE is a natural source of cytokinins that increases cell division and induces the synthesis of proteins and chlorophyll. Besides, YE was used as a growth enhancer due to its rich composition of both micro- and macronutrients, such as nitrogen, phosphorus, magnesium, iron, and sodium, plant growth regulators including gibberellins and auxins, amino acids, proteins, vitamins, and other essential compounds, all of which positively affect carbohydrate metabolism, photo-synthetic pigment levels, and enzyme activity, thereby promoting better plant growth and development (Lonhienne *et al.* 2014; Mukherjee *et al.* 2020), improve the biosynthesis of chlorophyll and raise nitrogen content, leading to improved levels of assimilation and the accumulation of organic matter (Saad-Allah *et al*. 2017).

These findings are consistent with those reported by several other authors who reported that spraying YE improved the vegetative growth parameters, productivity, fruit quality, leaf composition from nutrients; meanwhile, it markedly lowered the fruit drop and fruit acidity percentages in mango (Abd El-Motty *et al.* 2010), orange (El-Shazly and Mustafa 2015), olive (Mahmoud *et al.* 2015), apricot (Haggag *et al.* 2016), mandarin (Ahmed *et al.* 2018), and pear (Hafez *et al.* 2018). Spraying pomegranate with YE at 0.2%, 0.3% and 0.4% remarkably improved vegetative growth, fruit set percentage, fruit number, weight, size, dimensions, and firmness, productivity, fruit chemical properties from soluble solids, total and reducing sugars, anthocyanin, leaf nutritional composition from macronutrients in the two seasons. Meanwhile, these treatments reduced the percentages of drop, cracking, sunburn, and total acidity of fruits (Harhash *et al.* 2021). Similarly, in another study performed on Jujube trees, the external spraying of 1% and 2% YE markedly ameliorated the productivity, physical and chemical fruit characteristics and markedly minimized the fruit acidity percentages (Ahmed *et al*. 2023). The external application of 0.2% YE on date palm remarkably increased productivity, fruit weight, firmness, size, dimensions, as well as fruit content from soluble solids, total, reduced and non-reduced sugars, ascorbic acid, and carotene, while it decreased the fruit acidity (Al-Saif *et al*. 2023c).

The positive effect of boron may be because it enhances rates of pollen germination, pollen tube development, and fruit set percentages. In addition, it influences nucleic acids and plant hormones. Additionally, it promotes enzyme activity, boosts phytohormones and nucleic acid production, enhances nutrient uptake, and helps plants tolerate salinity. Besides, it increases carbohydrate and sugar translocation, stimulates phenol metabolism, and ultimately lowers fruit drop percentages and improves productivity (Marschner 2011; Ahmad *et al*. 2012). Besides, it is a fundamental nutrient for increasing the percentage of flowers, fruit set and yield, activation of plant hormones, cell wall synthesis, and cell membrane integrity (Davarpanah *et al*. 2016; Zhang *et al.* 2023). The positive influence of boron is attributed to its vital roles in enhancing the respiration rate, protein metabolism, and the synthesis and metabolism of auxins, such as indole-3-acetic acid (IAA) and phenols (Khalaj *et al.* 2016). It is also vital for raising the pollen grains' viability and pollen tube development (Naeem *et al.* 2020), improving blooming rate, raising the nitrogen absorption rate, the amount of water, and carrying phytohormones more easily, leading to improved cell division and elongation (Taiz *et al.* 2023). The spraying of B_2O_3 markedly improved the vegetative growth attributes, fruit set percentages, productivity, fruit quality in terms of fruit weight, size, length, and diameter as well as fruit content from soluble solids such as sugars. It was noticed that B_2O_3 remarkably reduced the fruit acidity and fruit drop percentages in apple (Mosa *et al*. 2015) and in sweet cherry (Sajid *et al*. 2024). The external application of strawberries with borax at 0.6% markedly increased the fruit set and fruit retention percentages, fruit weight, pulp weights, total sugar, TSS, and fruit productivity. However, it reduced the fruit drop percentage (Tiwari *et al*. 2023).

Zinc is an essential micronutrient for plants because it is involved in the metabolism of starch and nucleic acids, and the biosynthesis of protein, the transfer of carbohydrate, the activity of various enzymes, such as RNA and DNA polymerases, and it plays a role in maintaining membrane structure and improving the photosynthesis process (Ojeda-Barrios *et al.* 2014; Valizadeh and Milic 2016). Besides, it is necessary for plant growth and development by participating in numerous physiological and enzymatic activities. It acts as a component, catalyst, or structural cofactor of enzymes involved in energy generation, macromolecule metabolism, and chlorophyll formation, enhancing root growth, regulating water absorption and transport, and protecting plants against abiotic stresses. Zinc is also essential for the synthesis of necessary plant hormones such as auxins, gibberellins and cytokinins (Szöllösi *et al.* 2020). Besides, zinc application enhances the absorption of nitrogen, phosphorus, potassium, sulfur, and magnesium (Islam *et al.* 2018), stimulates the production of tryptophan and auxins, supports pollen tube development, and promotes higher fruit set (Fei *et al.* 2016). Zn affects the growth of fruit as it is a precursor of tryptophan, which is required for the biosynthesis of indole acetic acid therefore it helps in division and elongation of cells, which can help to ameliorate productivity (Faizan *et al.* 2020). Spraying of orange with ZnO at 75 ppm increased shoot length, leaf area, fruit productivity, number, weight and volume of fruit, the fruit content from total chlorophyll, sugars, free amino acids, soluble phenols and tryptophan compared with the control. Additionally, zinc also significantly increased the concentration of GA_3, IAA, and ABA, and leaf mineral composition from P, K, N, Mg, Fe, Zn, Cu, and Mn (Ahmed *et al*. 2012). The external application of ZnO on apple at 100, 200, and 300 mg/L improved total chlorophyll, fruit set %, yields, fruit weight, size, dimensions, firmness, and fruit content from soluble solids. Meanwhile, these treatments significantly reduced the fruit drop percentages and fruit acidity (Aly *et al*. 2022).

The combined application of Zn and B enhanced the biosynthesis of chlorophyll a and b, total chlorophyll content, and carotenoids, along with leaf area expansion, resulting in increased nut yield in the ‘Bhaskara’ cashew variety (Lakshmipathi *et al.* 2018). The external application of 0.5% $ZnSO_4$ + 0.4% borax on Kagzi lime trees markedly increased the fruit set %, fruit number, and productivity; meanwhile, this treatment notably reduced the fruit drop percentage compared with untreated trees (Venu and Delvadia 2018).

CONCLUSIONS

1. The results indicate that spraying ZnO + B_2O_3, yeast extract (YE), and seaweed extract (SWE) improved both fruit productivity and quality in Barhi date palms compared to the control.

2. The combined application proved more effective than individual treatments, with the best results in yield and fruit quality achieved using combination 2, rather than other treatments.
3. The application of YE and SWE as biostimulants on date palm demonstrates clear potential for improving plant vigor, growth, and productivity. Generally, integrating yeast and seaweed extracts into date palm management programs can support sustainable agriculture by reducing dependence on synthetic fertilizers, enhancing soil fertility, and promoting healthier, more resilient trees. Future studies should focus on optimizing dosage, application frequency, and the combined use of these biostimulants to maximize yield and fruit quality in date palm cultivation.

Funding

This research was funded by Ongoing Research Funding program, (ORF-2025-561), King Saud University, Riyadh, Saudi Arabia

ACKNOWLEDGMENTS

The authors extend their appreciation to Ongoing Research Funding program, (ORF-2025-561), King Saud University, Riyadh, Saudi Arabia.

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Article submitted: August 6, 2025; Peer review completed: August 23, 2025; Revised version received: September 12, 2025; Accepted: September 15, 2025; Published: September 24, 2025.
DOI: 10.15376/biores.20.4.9785-9803