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Biostimulants and Nano-Potassium on the Yield and Fruit Quality of Date Palm

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Abstract: Although chemical fertilization has been excessively used for a high yield of fruit trees, it causes many problems such as nitrate accumulation, soil deterioration, and food safety and quality decline; therefore, the dependency on the usage of biostimulants has become paramount when aiming to reduce the usage of chemical fertilizers, improve the fruit quality, and increase the shelf life of the fruits. The present experiment was conducted during the 2021–2022 seasons to study the effect of the foliar of yeast extract (YE), fulvic acid (FA), moringa leaf extract (MLE), seaweed extract (SWE), and nano-potassium (K NPs) alone or after combining each one of them individually with K NPs on the yield and fruit physical and chemical characteristics of date palm cv. Samani. The results show that the application of 0.2% YE + 0.02% K NPs led to the highest results in yield, bunch weight, fruit weight, flesh weight, fruit content from soluble solids, total and reduced sugars, VC, total chlorophyll, and carotene. Additionally, the results also demonstrate that the application of 0.4% SWE + 0.02% K NPs, 0.4% FA + 0.02% K NPs, and 6% MLE positively affected the previously mentioned measurements compared with the control or the other sprayed treatments.

Keywords: date palm; moringa; nano-fertilizers; seaweed extract; yeast

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1. Introduction

The date palm tree holds a significant historical and dietary role as one of the oldest and principal staple crops in regions such as Southwest Asia and North Africa. Moreover, its cultivation extends to countries such as Australia, Mexico, parts of South America, southern Africa, and the United States, particularly in southern California, Arizona, and Texas [1–3]. This tree, scientifically known as *Phoenix dactylifera* L., is a member of the Arecaceae family [4]. Date fruit is a nutritionally-rich food, abundant in carbohydrates, dietary fibers, proteins, and a variety of B-complex vitamins, including thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), and folate (B9). The carbohydrate content, primarily consisting of fructose and glucose, accounts for about 70% of date fruit composition. Additionally, date fruits contain a range of essential minerals such as calcium, iron, magnesium, selenium, copper, phosphorus, potassium, zinc, sulfur, cobalt, fluorine, and manganese. Due to their exceptional nutritional profile, date fruits are considered highly nourishing and may offer various potential health benefits [5,6].

The application of biostimulants offers a promising avenue to decrease the reliance on chemical inputs in agriculture and plant protection [7]. These substances play a crucial role in managing and expediting various life processes within plants, bolstering stress resistance, and facilitating the growth of roots and leaves [8,9]. By triggering biological activity in plants, biostimulants offer a safe and environmentally-friendly approach, fostering sustainable and productive crop yields with minimized resource inputs [7,8]. Furthermore, biostimulants act as natural growth regulators, amplifying the quality characteristics of crops through enhanced nutrient utilization, improved activities in the root zone, and heightened ability to withstand adverse environmental conditions [10].

Yeast extract (YE) is recognized as a natural origin of cytokinins, functioning as a biostimulant that triggers cellular expansion and division, promotes the production of chlorophyll, and facilitates the synthesis of nucleic acids and proteins [11]. Additionally, YE serves as a microbial plant growth promoter, fostering enhanced plant development, elevated yields [12], and mitigation of both biotic and abiotic stressors [13]. Furthermore, YE boasts a wealth of proteins, vitamin B, amino acids, and cytokinins. These components collectively stimulate processes such as cell replication, division, enlargement, and specialization. They also play a role in regulating the growth of shoots and roots, aiding in the maturation of chloroplasts, and facilitating the synthesis of chlorophyll, proteins, and nucleic acids [14]. YE serves as an economical biofertilizer that improves both plant nourishment and vitality, bolstering resilience against non-living stressors. It holds the advantage of being environmentally benign and is applicable through soil or foliar methods across various crops [15–17]. Furthermore, YE aids in the conversion of insoluble phosphorus to a soluble form, a role noted in [18,19].

Fulvic acid (FA) is a naturally occurring substance originating from the decomposition of plants, animals, microbial remnants, and the metabolic processes of soil microbes [20]. This type of humic acid possesses a relatively low molecular weight and a notable oxygen content, allowing it to efficiently traverse microscopic pores in living organisms or synthetic membranes [21]. Due to their compact size and effective nutrient-binding capabilities, FA molecules have the ability to infiltrate plant roots, stems, and leaves, facilitating the transportation of minerals from the plant's exterior to its internal tissues [22]. FA plays a role in potentially enhancing plant growth, increasing yields, and improving fruit quality by enhancing the uptake of essential elements [23,24]. Furthermore, FA is recognized as a biostimulant that promotes plant growth and yield. This is attributed to its ability to augment cell membrane permeability, facilitate nutrient movement within plants, elevate rates of photosynthesis and respiration, and mitigate the absorption of harmful elements by plants. Additionally, FA functions as a harmless, cost-effective, and non-polluting organic acid that can serve as an antitranspirant. These attributes make it particularly valuable in arid conditions [25,26]. FA has the capacity to heighten the uptake of chemical elements, with a specific emphasis on those crucial to photosynthesis, such as iron, zinc, and manganese [27–29]. Additionally, FA is abundant in nitrogen and potassium and serves the role of making phosphorus more soluble, leading to an enhancement in the efficiency of fertilizer utilization [30].

Moringa leaf extract (MLE) holds potential as a growth stimulant, effectively enhancing growth and quality characteristics across diverse plant species. Its application has demonstrated the capability to elevate the yield of various plants [31–34]. Furthermore, MLE showcases its efficacy as a potent biostimulant due to its rich content of osmoprotectants. These constituents encompass an array of elements such as total free amino acids, phenolics, proteins, fibers, free proline, soluble sugars, and essential minerals, with a notable focus on calcium, magnesium, phosphorus, copper, and sulfur. Additionally, MLE incorporates antioxidants, key vitamins including B, C, and E, and phytohormones such as zeatin, cytokinins, gibberellic acid, and indole acetic acid. This composition lends itself to improving growth characteristics, enhancing mineral contents, and optimizing the biochemical compositions of plants [35]. Hence, MLE is acknowledged as an effective regulator of plant growth, a point supported by studies conducted by [36,37]. Its capacity to enhance plant nutrition and growth, bolster seed germination, influence flowering patterns, elevate photosynthetic rates, stimulate fruiting, optimize gas exchange rates, delay fruit senescence, regulate water content, and enhance utilization efficiency is notable. Furthermore, MLE holds the capacity to enhance root growth, increase the components contributing to yield, and improve attributes related to fruit quality, particularly under adverse circumstances such as salinity, drought, and exposure to heavy metal stress. These effects can be attributed to its capability to enhance the activity of antioxidant enzymes and elevate sugar content [38–40].

Seaweed extract (SWE) comprises a diverse array of macroscopic, multicellular marine algae, encompassing various shades of brown, red, or green. These extracts are nutrient-rich and possess the capability to heighten plant growth, boost photosynthetic rates, and enhance the plant's ability to withstand both biotic and abiotic stressors. Consequently, SWE has the potential to elevate yield and enhance the quality of fruits [41–44]. Due to its composition abundant in polysaccharides, auxins, gibberellins, cytokinins, indole-3-acetic acid, vitamins, oils, fats, acids, amino acids, polyphenols, antioxidants, pigments, and antimicrobial agents, coupled with the presence of elements such as iron, copper, zinc, cobalt, molybdenum, manganese, and nickel, SWE holds the capability to augment not only crop yield but also its related constituents [45–50]. The application of either 0.3% or 0.4% SWE to Anna cultivar apple trees, conducted before flowering, during full bloom, and one month later, yielded significant enhancements in various aspects of growth and yield measurements. Notably, shoot length, shoot thickness, leaf chlorophyll content, fruit set percentage, fruit yield, and fruit weight, size, length, and diameter exhibited positive responses. Additionally, improvements were observed in fruit properties such as total soluble solids percentage and total sugar content, as well as reduced and non-reduced sugars. This treatment also positively impacted the nutritional status of leaves in comparison to untreated trees [51].

Nanoparticles possess the capability to traverse cell barriers and facilitate the transport of elements by connecting them to proteins through ion channels or binding them to organic compounds within plant tissues [52]. Leveraging nanobiotechnology offers the potential to augment crop yield, elevate the plant's nutritional profile, improve nutrient absorption, and enhance the plant's response to environmental factors and pesticides [53]. Nano-fertilizers exhibit a high degree of efficacy in enhancing the dispersion and solubility of elements. As a result, they are capable of amplifying photosynthesis rates, promoting growth in fruit-bearing trees, enhancing pollination and flower fertility, elevating productivity, improving fruit quality, and extending the shelf life of harvested fruits [54–58]. Potassium plays a crucial role in facilitating the movement of water, vital nutrients, and various compounds from the plant's roots to its leaves through the stem. It participates in a range of metabolic and biochemical functions within plant cells [59,60] encompassing both regulatory and transport mechanisms [61].

Therefore, the present study was conducted to investigate the role of YE, MLE, FA, and SWE as ecofriendly biostimulants as well as K NPs on improving the yield and the fruit quality attributes of date palm cv. Samani to reduce the full dependency on chemical fertilization and to avoid their side effects on the soil composition and fruit quality.

2. Materials and Methods

2.1. Applied Treatments, Location, and Experimental Design

The present study was carried out during the 2021 and 2022 seasons on ten-year-old date palm trees (*Phoenix dactylifera* L.). cv. Samani that grow at Nubaria, El Beheira governorate, Egypt. The dates were planted in the permanent orchard at the age of 4 years old. Fifty palms were selected carefully to be in the same growth and size and they were cultivated in sandy soil at a distance of 7 × 7 under a drip irrigation system; they were distributed randomly and organized in a randomized complete block design (RCBD), where each treatment was applied on five palms (replicates). The trees were sprayed with 0.2% YE, 0.2% FA, 6% MLE, 0.4% SWE, 0.02% K NPs, 0.02% K NPs + 0.2% YE, 0.02% K NPs + 0.2% FA, 0.02% K NPs + 6% MLE, and 0.02% K NPs + 0.2% SWE. To increase the surface area and the rate of absorption of the sprayed materials, they were mixed with diffuse material at the rate of 3 mL/L water. These treatments were sprayed three times: at the beginning of bisir, three weeks later, and three weeks after the second spray. Each palm was fertilized with 50 kg manure, 1 kg superphosphate calcium, 0.5 kg sulfur, 1 kg N, 1 kg potassium sulphate, 0.5 kg magnesium sulphate, and 150 g phosphoric acid. The analysis of the experimental soil is shown in Table 1

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

Parameter	**Soil Depth (cm)**	
	0–30	**30–60**
Mechanical analysis %		
Sand	93.0	92.0
Silt	5.0	4.0
Clay	2.0	4.0
Textural class	Sandy	Sandy
$CaCO_3$ (%)	4.2	5.4
Organic matter (%)	0.35	0.20
pH	7.7	7.8
EC, dS/m(Soil extraction 1:5)	0.801	0.823
Available nutrients (mg/kg)		
N	117.5	117.5
P	18.4	18.0
K	405	190
Soluble cations (meq/L)		
Ca++	2.30	2.15
Mg++	1.70	1.30
Na+	3.78	3.54
K+	0.45	0.40
Soluble anions (meq/L)		
HCO_3^-	3.22	3.02
CL^-	4.00	3.5
SO_4^-	4.20	4.00

The impact of the administered treatments was assessed by examining their effects on the subsequent parameters.

2.2. Palm Yield (kg/Tree)

At the harvesting time, the yield of palms was measured in kg, and by calculating the number of palms × average yield of palms, the yield of each hectare was obtained.

2.3. Fruit Quality

Forty fruits from each tree (replicate), were picked in October (time of the fruit ripening) of 2021 and 2022 and transferred directly to the lab to measure the fruits' physical and chemical characteristics.

2.3.1. Fruit Physical Characteristics

Average fruit weight (kg) was determined by calculating the mean weight of 40 individual fruits. Flesh weight (g), seed weight (g), and fruit size (cm^3) were measured and the flesh/fruit ratio was calculated. Fruit size (cm^3) was assessed by weighting the removed water after dipping the fruits. 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 (0–2 lb, Alfonsine, Italy).

2.3.2. Fruit Chemical Characteristics

Total soluble solids percentage in fresh fruits was determined using a hand refractometer (ATAGO Co., Ltd., Tokyo, Japan). Fruit acidity, measured as a percentage and quantified in terms of malic acid content, was assessed in fruit juice using a titration method with 0.1 N sodium hydroxide. This process was conducted with the inclusion of phenolphthalein as an indicator [62]. The TSS/acidity ratio was calculated by dividing the total soluble solids by the total titratable acids within the same sample. Fruit total sugars %: were determined by using phenol sulfuric acid and fruit reducing sugar contents were determined colorimetrically according to Nelson [63]. Non-reducing sugars were calculated according to the difference between total sugars and reducing sugars. The content of ascorbic acid in the juice (expressed as vitamin C in milligrams per 100 mg of juice) was determined through titration using 2,6-dichloro phenol-indo-phenol. The calculated measurement was presented as milligrams per 100 mm of juice [64]. The soluble tannin content, represented as a percentage relative to the fresh weight of date pulp, was determined using a method as described by [65]. The estimation of total chlorophyll content (measured in milligrams per 100 g of peel fresh weight) was conducted using the methodology outlined by Richardson et al. [66] and was chromatically measured by using a spectrophotometer at a wavelength of 650 nm. Additionally, fruit content from carotene was measured using the method of [67] at a wavelength of 440 nm.

2.4. Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) using RCBD. Duncan's test was performed at a significance level of 0.05 to assess the differences among treatment means. The means were further compared using the least significant difference method at a probability of 5% [68]. The statistical analysis was conducted using CoHort Software, version 6.311 (Pacific Grove, CA, USA).

3. Results

The results in shown Figure 1 show that the foliar application of 0.2% YE + 0.02% K NPs resulted in the most significant values for bunch weight, palm yield in kg, and ton per hectare in comparison to the other applied treatments in 2021–2022. Moreover, it was noticed from the results that the application of 6% MLE significantly increased the bunch weight and the yield over control. Additionally, 6% MLE was more effective than the application of YE, SWE, and FA in 2021–2022. Furthermore, the application of foliar spray containing 0.4% SWE + 0.02% K NPs, along with 0.2% FA + 0.02% K NPs, demonstrated a significant enhancement in bunch weight and yield, both in kilograms and tons per hectare, when compared to untreated trees.

The results in Table 2 show that spraying of 0.2% YE + 0.02% K NPS remarkably increased the weights of fruit, seed and flesh weights rather than the other treatments applied in the two study seasons. Additionally, the application of 0.4% SWE + 0.02% K NPs and 0.2% FA + 0.02% K NPs markedly increased their weights over untreated trees. The foliar application of solely 6% MLE caused positive increments in their weights, which was not found for the application of YE, FA, or SWE in both experimental seasons.

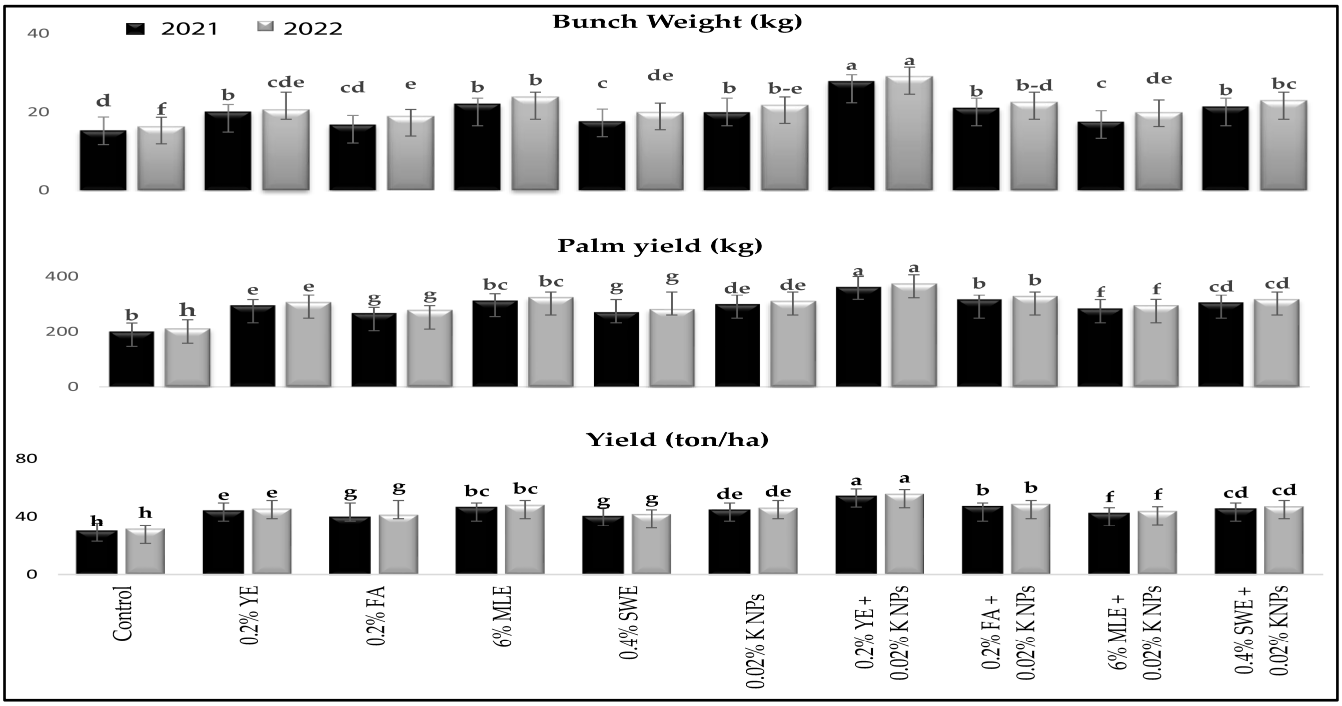

Figure 1. Effect of the spraying of YE, FA, MLE, SWE, and K NPs alone or in combination with K NPs on the bunch weight and yield in kg and in ton per hectare of date palm cv. Samani during 2021–2022. Treatments that have the same letters indicate there are no significant differences between them.

Table 2. Effect of the spraying of YE, FA, MLE, SWE, and K NPs alone or in combination with K NPs on the fruit weight, seed weight, and flesh weight of date palm cv. Samani during 2021–2022.

Treatment	Fruit Weight (g)		Seed Weight (g)		Flesh Weight (g)	
	2021	2022	2021	2022	2021	2022
Control	19.75h ± 0.20	20.69h ± 0.20	1.87f ± 0.03	1.79f ± 0.05	17.88g ± 0.21	15.52g ± 0.12
0.2% YE	29.08e ± 0.92	30.02e ± 0.92	2.81c ± 0.07	2.72b ± 0.04	26.26d ± 0.85	24.08d ± 0.99
0.2% FA	26.30g ± 0.48	27.24g ± 0.48	2.67d ± 0.04	2.56d ± 0.06	23.63f ± 0.45	21.24f ± 0.37
6% MLE	30.79bc ± 0.48	31.73bc ± 0.49	2.68d ± 0.02	2.64c ± 0.04	28.12b ± 0.46	25.82b ± 0.47
0.4% SWE	26.65g ± 0.52	27.59g ± 0.52	2.85bc ± 0.05	2.78 b ± 0.02	23.80f ± 0.48	21.48f ± 0.33
K NPs 0.02%	29.50de ± 0.55	30.44de ± 0.54	2.55e ± 0.06	2.47e ± 0.03	26.96cd ± 0.49	24.58cd ± 0.50
0.2% YE + 0.02% K NPs	35.80a ± 0.77	36.74a ± 0.77	2.90ab ± 0.01	2.86a ± 0.03	32.90a ± 0.75	30.95a ± 0.38
0.2% FA + 0.02% K NPs	31.20b ± 0.33	32.14b ± 0.33	2.95a ± 0.03	2.77b ± 0.08	28.25b ± 0.31	26.08b ± 0.37
6% MLE + 0.02% K NPs	27.99f ± 0.24	28.94f ± 0.24	2.65d ± 0.02	2.59cd ± 0.02	25.35e ± 0.22	22.93e ± 0.25
0.4% SWE + 0.02% K NPs	30.10cd ± 0.28	31.04cd ± 0.28	2.81c ± 0.02	2.74b ± 0.01	27.29c ± 0.26	24.89c ± 0.34
LSD at $_{0.05}$	0.82	0.83	0.06	0.08	0.78	0.66

In one column, the treatments that have the same letters indicate there were no significant differences between treatments.

The results presented in Table 3 indicate that among the various treatments applied, the foliar application of 0.2% YE + 0.02% K NPs resulted in the most significant increases in fruit volume, length, and diameter in 2021–2022, surpassing the effects of other treatments. Additionally, the data reveal that both the treatments involving 0.4% SWE + 0.02% K NPs and 0.2% FA + 0.02% K NPs were effective in enhancing the same physical characteristics compared to the control. In terms of fruit firmness, notable improvements were observed with the application of 0.2% YE + 0.02% K NPs, 0.4% SWE + 0.02% K NPs, 0.2% FA + 0.02% K NPs, 6% MLE, and 0.02% K NPs, surpassing the results from trees that were not subjected to any spraying during the 2021–2022 period. Remarkably, the most effective treatment across all the sprayed treatments was a combination of 0.2% YE + 0.02% K NPs and the application of 0.4% SWE.

Table 3. Effect of the spraying of YE, FA, MLE, SWE, and K NPs alone or in combination with K NPs on the fruit volume, length, diameter, and firmness of date palm cv. Samani during 2021–2022.

Treatment	Fruit Volume (cm^3)		Fruit Length (cm)		Fruit Diameter (cm)		Fruit Firmness ($Ib/inch^2$)	
	2021	2022	2021	2022	2021	2022	2021	2022
Control	17.37f ± 0.57	15.82f ± 0.55	4.50f ± 0.06	4.15f ± 0.05	2.88e ± 0.03	2.69e ± 0.08	17.00e ± 1.00	16.67f ± 0.72
0.2% YE	33.13c ± 0.61	31.73c ± 0.62	5.72c ± 0.07	5.20d ± 0.05	3.45bc ± 0.02	3.36b ± 0.02	18.23e ± 0.25	19.77de ± 0.25
0.2% FA	29.10 d ± 0.36	27.65d ± 0.46	5.34e ± 0.03	4.93e ± 0.13	3.33c ± 0.02	3.24c ± 0.01	20.13d ± 1.10	18.67e ± 0.35
6% MLE	33.66bc ± 0.35	32.23bc ± 0.34	5.74c ± 0.05	5.41c ± 0.08	3.54ab ± 0.05	3.40ab ± 0.05	22.17abc ± 1.04	22.17c ± 0.15
0.4% SWE	29.10d ± 0.36	27.73d ± 0.54	5.64d ± 0.03	5.22d ± 0.08	3.42bc ± 0.08	3.34bc ± 0.06	21.50bcd ± 0.5	18.83e ± 0.57
0.02% K NPs	33.67bc ± 0.76	32.42bc ± 0.70	5.56d ± 0.03	5.10d ± 0.05	3.41bc ± 0.01	3.29bc ± 0.04	21.10bcd ± 0.85	22.67c ± 0.58
0.2% YE + 0.02% K NPs	38.07a ± 0.50	36.63a ± 0.84	6.28a ± 0.03	6.08a ± 0.08	3.63a ± 0.03	3.51a ± 0.06	23.30a ± 0.61	25.33a ± 1.04
0.2% FA + 0.02% K NPs	34.57d ± 0.35	33.13b ± 0.69	5.68d ± 0.16	5.37c ± 0.10	3.51ab ± 0.01	3.41ab ± 0.01	21.70bc ± 0.61	21.97c ± 0.06
6% MLE + 0.02% K NPs	25.37e ± 0.78	24.17e ± 0.82	5.36e ± 0.06	5.14d ± 0.04	3.13d ± 0.2	3.04d ± 0.12	20.80cd ± 0.2	20.65d ± 0.44
0.4% SWE + 0.02% K NPs	34.50b ± 0.3	32.98b ± 0.68	5.95b ± 0.13	5.80b ± 0.05	3.48b ± 0.12	3.40ab ± 0.05	22.43ab ± 0.55	24.07b ± 1.05
LSD at $_{0.05}$	0.88	1.09	0.14	0.13	0.13	0.11	1.29	1.11

In one column, the treatments that have the same letters indicate there were no significant differences between treatments.

The data presented in Table 4 indicate that the application of 0.2% YE + 0.02% K NPs resulted in the highest values for fruit total soluble solids percentage and TSS–acid ratio during the 2021–2022 seasons. This was closely followed by the treatments involving the spraying of 0.4% SWE + 0.02% K NPs, as well as 0.2% YE alone and 0.02% K NPs. Furthermore, these same treatments contributed to a reduction in fruit acidity during both seasons. Conversely, the control treatment exhibited a significant increase in total fruit acidity over the two seasons. Additionally, the combination of 6% MLE + 0.02% K NPs spraying demonstrated improvements in TSS percentage and TSS–acidity ratio, in comparison to unsprayed trees. Notably, this treatment effectively minimized fruit acidity levels.

The data presented in Table 5 clearly demonstrate that the application of 0.2% YE combined with 0.02% K NPs led to a substantial increase in fruit content in terms of total sugars, reduced sugars, and vitamin C content, surpassing the effects of other applied treatments during both seasons. Moreover, notable improvements were observed with the application of 0.4% SWE + 0.02% K NPs, particularly in terms of the concentration of total and reduced sugars, as well as fruit vitamin C content, when compared to trees that were not subjected to any treatment. Interestingly, the results also indicate that the highest value of fruit content from non-reduced sugars was observed in the control group, surpassing the values registered in the applied treatments.

Table 4. Effect of the spraying of YE, FA, MLE, SWE, and K NPs alone or in combination with K NPs on fruit content from TSS and acidity percentages and the TSS–acidity of date palm cv. Samani during 2021–2022.

Treatment	TSS (%)		Acidity (%)		TSS–Acid Ratio	
	2021	2022	2021	2022	2021	2022
Control	19.13e ± 0.86	20.70f ± 1.08	0.46a ± 0.05	0.48a ± 0.04	103.83g ± 2.56	105.83f ± 2.35
0.2% YE	26.47b ± 1.50	27.90b ± 1.30	0.22ef ± 0.01	0.25fg ± 0.01	168.94ab ± 11.36	154.99b ± 4.27
0.2% FA	22.20d ± 0.79	23.63e ± 0.66	0.27de ± 0.02	0.29def ± 0.02	136.80de ± 1.54	134.16c ± 2.55
6% MLE	24.40 b ± 0.2	25.90cd ± 0.17	0.32c ± 0.01	0.36bc ± 0.03	128.70e ± 1.81	123.72d ± 3.03
0.4% SWE	26.40b ± 0.43	27.13bc ± 0.35	0.22f ± 0.03	0.24g ± 0.02	159.94bc ± 3.48	157.44b ± 3.34
0.02% K NPs	27.2b ± 0.52	28.33b ± 0.06	0.30cd ± 0.03	0.32cd ± 0.02	142.62d ± 6.75	137.97c ± 6.61
0.2% YE + 0.02% K NPs	30.27a ± 1.10	31.40a ± 0.53	0.25def ± 0.03	0.27efg ± 0.02	176.76a ± 6.34	169.44a ± 4.18
0.2% FA + 0.02% K NPs	23.47cd ± 0.97	25.17d ± 1.05	0.37b ± 0.02	0.39b ± 0.01	117.15f ± 2.47	113.44e ± 0.45
6% MLE + 0.02% K NPs	26.13b ± 0.45	27.20bc ± 1.00	0.27de ± 0.02	0.31de ± 0.04	145.97d ± 7.30	131.94c ± 2.23
0.4% SWE + 0.02% K NPs	26.93b ± 0.38	27.83b ± 0.76	0.26def ± 0.01	0.29def ± 0.02	157.33 c ± 8.07	138.64c ± 4.14
LSD at $_{0.05}$	1.44	1.41	0.05	0.04	10.68	6.21

In one column, the treatments that have the same letters indicate there were no significant differences between treatments.

Table 5. Effect of the spraying of YE, FA, MLE, SWE, and K NPs alone or in combination with K NPs on the fruit content from total, reduced, and non-reduced sugar percentages and the vitamin C of date palm cv. Samani during 2021–2022.

Treatment	Total Sugars (%)		Reducing Sugars (%)		Non-Reduce Sugars (%)		Vitamin C (mg/100 mL)	
	2021	2022	2021	2022	2021	2022	2021	2022
Control	22.35i ± 0.59	23.48h ± 0.60	15.58h ± 0.52	15.80h ± 0.72	6.77a ± 0.30	7.68a ± 0.14	2.72e ± 0.08	2.41f ± 0.09
0.2% YE	33.35e ± 0.87	36.55de ± 0.54	27.98e ± 0.40	30.50e ± 0.50	5.37bc ± 1.04	6.05d ± 0.14	4.31b ± 0.21	4.11bc ± 0.15
0.2% FA	26.20h ± 0.26	27.63g ± 0.07	22.60g ± 0.56	24.53g ± 0.05	3.60d ± 0.53	3.10i ± 0.10	3.55cd ± 0.19	3.35e ± 0.13
6% MLE	27.32g ± 0.51	28.75g ± 0.83	23.88f ± 0.28	24.68g ± 0.74	3.43d ± 0.23	4.07h ± 0.10	3.77c ± 0.21	3.78d ± 0.12
0.4% SWE	33.30e ± 0.46	35.80e ± 0.85	28.05e ± 0.51	31.48de ± 0.97	5.25bc ± 0.18	4.32g ± 0.15	3.80c ± 0.24	3.79d ± 0.13
0.02% K NPS	36.12d ± 0.17	37.55d ± 0.61	31.20d ± 0.25	32.02cd ± 0.55	4.92c ± 0.24	5.53e ± 0.12	3.42d ± 0.14	3.35e ± 0.08
0.2% YE + 0.02% K NPS	44.67a ± 0.50	48.49a ± 0.79	38.68a ± 0.45	41.11a ± 0.73	5.98ab ± 0.84	7.38b ± 0.14	4.89a ± 0.19	5.02a ± 0.12
0.2% FA+ 0.02% K NPS	30.83f ± 0.91	32.25f ± 1.00	27.32e ± 0.75	27.43f ± 0.85	3.52d ± 0.15	4.82f ± 0.15	3.78c ± 0.12	3.93cd ± 0.08
6% MLE + 0.02% K NPS	37.27c ± 0.32	39.23c ± 0.54	33.62c ± 0.48	33.13c ± 0.61	3.65d ± 0.48	6.10d ± 0.07	4.18b ± 0.18	4.30b ± 0.18
0.4% SWE + 0.02% K NPS	40.17b ± 0.60	41.86b ± 0.88	35.70b ± 0.78	35.31b ± 0.74	4.47cd ± 0.42	6.55c ± 0.15	3.55cd ± 0.22	3.31e ± 0.22
LSD at $_{0.05}$	0.93	1.23	0.84	1.17	0.94	0.23	0.29	0.23

In one column, the treatments that have the same letters indicate there were no significant differences between treatments.

Based on the results provided in Figure 2, it is evident that the foliar application of 0.2% YE along with 0.02% K NPs resulted in the most significant increases in fruit content of carotene and total chlorophyll, surpassing both the control group and the other applied treatments. Additionally, the application of 0.4% SWE in combination with 0.02% K NPs also demonstrated considerable improvements in these attributes when compared to trees that were not treated. Furthermore, the treatment involving the application of 6% MLE along with 0.02% K NPs notably increased the pH of the fruits. Following this, the treatment of 0.2% YE along with 0.02% K NPs and the application of 0.4% SWE combined with 0.02% K NPs also led to significant increases in fruit pH during the 2021–2022 seasons.

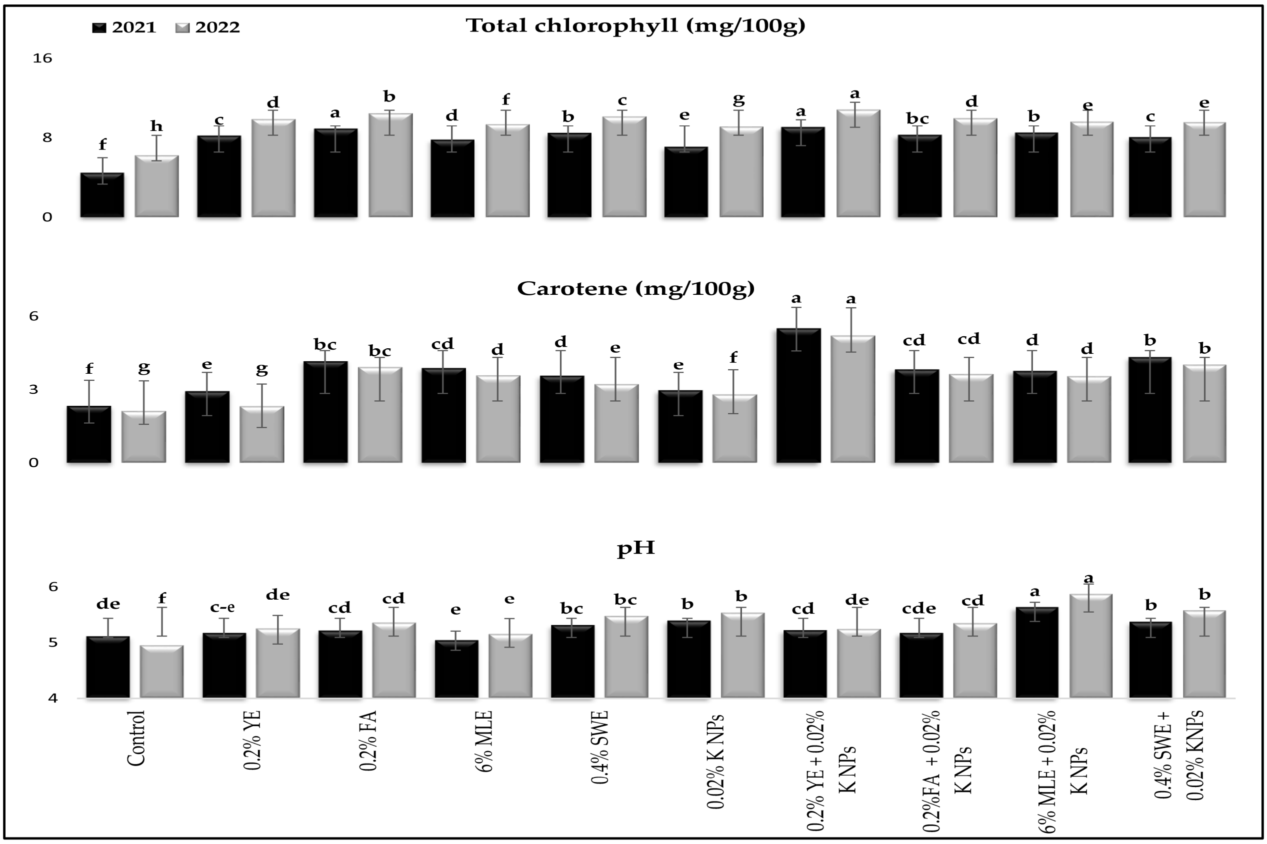

Figure 2. Effect of the spraying of YE, FA, MLE, and SWE alone or in combination with K NPs on fruit content from carotene, total chlorophyll, and juice pH of date palm cv. Samani during 2021–2022. Treatments that have the same letters indicate there are no significant differences between them.

4. Discussion

The obtained results of the current experiment demonstrate that the fruit yield and fruit physical and chemical properties were obviously improved by spraying the trees with YE, MLE, FA, SWE, and K NPs solely or after combining each one of these biostimulants individually with K NPs during the 2021–2022 seasons compared to unsprayed trees.

The application of YE through foliar spraying has been demonstrated to yield positive effects on various aspects of plant development, encompassing growth parameters, flower formation, and productivity. This improvement can be attributed to the nutritional composition of YE, which includes minerals, amino acids, vitamins, and phytohormones, notably cytokinins and gibberellins [16,69,70]. Furthermore, this treatment has the potential to stimulate physiological processes within plants, such as augmented cell division, enlargement, protein and nucleic acid synthesis, and the formation of chlorophyll. These mechanisms collectively contribute to the enhanced growth of plants [13,32,71–73]. The application of YE has demonstrated significant potential in enhancing the growth parameters of date palm (*Phoenix dactylifera* L.) [74]. When YE was sprayed at concentrations of 10 and 20 g/L during April, May, and June, following full bloom, notable improvements were observed in various aspects. These included an increase in leaf count, branch length, leaf area, fruit dry matter percentage, fruit weight, fruit oil percentage, and the number of hermaphrodite flowers, as well as leaf carbohydrate content for the "Ashrassi" olive cultivar [75]. Applying YE through foliar spraying at concentrations of 1% and 2% to *Ziziphus jujuba* trees led to notable improvements to the yield, physical fruit attributes, and chemical characteristics of the fruit. This treatment yielded enhancements in parameters such as moisture content, chlorophyll a, chlorophyll b, and total chlorophyll, evident across two seasons when compared to the control group [76]. Applying YE through foliar application to pomegranate cv. Wonderful, specifically at the onset of flowering, full bloom, and one month later, at concentrations of 0.2%, 0.3%, and 0.4%, yielded a range of improvements across various parameters. These improvements encompassed amplified shoot dimensions including length and diameter, elevated overall chlorophyll levels within leaves, an increase in the proportion of successfully set fruits, larger and heavier fruits with enhanced dimensions including length, number, and width, and an overall boost in fruit yield. Additionally, the treatment resulted in reductions to the occurrences of fruit drop, cracking, sunburn, and in total acidity. Furthermore, it positively impacted the mineral content of leaves, specifically in terms of nitrogen, phosphorus, and potassium. Furthermore, advancements were observed in attributes such as fruit firmness, anthocyanin levels, total soluble solids, both total and reducing sugars, and the balance between total soluble solids and acidity [77].

Fulvic acid (FA) holds a significant role in the promotion of root hair growth, impacting both the length and number of root hairs in plants [78]. Moreover, it contributes to an enhanced rate of photosynthesis while concurrently reducing the aperture of stomata, transpiration rate, and overall water loss. This ability enables it to stimulate plant growth in conditions characterized by drought and water scarcity [79,80]. Additionally, FA has the capacity to augment the availability, absorption, and movement of mineral elements within plants, leading to improved growth and productivity of plants [28,29,81–83]. Consequently, FA has a positive impact on root development [84], thereby contributing to overall plant growth, development, and productivity [85–87]. The impact of FA on plants can be likened to the effect of auxins, assisting in the uptake of potassium and consequently affecting starch metabolism [82]. FA exhibits hormonal activity [30,88], and its key biological effects encompass promoting growth, facilitating mineral nutrient uptake, and bolstering plant resistance to environmental stress [26,89,90]. The application of FA through foliar spraying at concentrations of 0.1 or 0.2% to apple trees has been shown to enhance vegetative growth, fruit set percentage, fruit yield, and the physical and chemical attributes of the fruit [51]. Additionally, it facilitates the transfer of nutrients across cell membranes into plant cells, rendering it suitable for foliar spraying, particularly when efficient absorption of nutrients such as copper, iron, manganese, and zinc through plant leaves is required [91]. Application of FA through spraying on red delicious apple trees (*Malus domestica* Borukh.) at concentrations of 1.5%, 2.5%, and 3.5% resulted in an increase in fruit yield as well as the leaf mineral content of N, P, K, Zn, Fe, and Mn compared to non-sprayed trees [92].

MLE is abundant in cytokinins, auxins, gibberellins, antioxidants, and essential nutrients [33,34], endowing it with the capability to enhance plant metabolism and thereby bolster resistance to adverse environmental conditions [34]. It has been documented that the abundance of nutrients in moringa, including nitrogen, phosphorus, potassium, calcium, magnesium, zinc, manganese, and iron, along with vitamins, β-carotene, flavonoids, phenolic acids, proteins, amino acids, and fatty acids, plays a significant role in boosting various aspects of plant development. This richness contributes to improved plant growth, higher fruit set percentages, enhanced fruit quality and quantity, and favorable yield characteristics. Furthermore, MLE stands out for its elevated levels of auxins, gibberellins, cytokinins, sugars, tannins, proline, flavonoids, sterols, proteins, minerals, vitamins, essential amino acids, phenols, and ascorbates, further accentuating its potential benefits [93–95]. This extensive composition classifies it as a natural biostimulant [33,96,97]. Consequently, MLE presents a potential alternative for reducing reliance on chemical fertilizers [98]. The effective application of 3% and 6% MLE yielded positive outcomes for mandarin fruit quality by enhancing its AA content and concurrently reducing the percentage of fruit drop [99–101]. MLE plays a crucial role in enhancing multiple facets of plant performance.

These encompass improvements in areas such as nutritional uptake, seed germination, vegetative growth, flowering intensity, photosynthesis rates, fruit production, gas exchange efficiency, water content regulation, and utilization of resources. This comprehensive effect has the potential to trigger the development of root systems, bolster yield-related factors, and heighten the quality attributes of fruits. Particularly noteworthy is its capability to exert positive effects even under unfavorable conditions such as high salinity, limited water availability, and exposure to heavy metal stresses. These benefits are attributed to the enhancement of antioxidant enzyme activity and sugar content [39,40,102]. Spraying MLE at 2, 4, and 6% on peach remarkably improved fruit diameter, pulp weight, fruit weight and yield, fruit content from TSS, vitamin C, non-reducing sugars, reducing sugars, and total sugars, along with a significant reduction in fruit drop and fruit acidity content percentages, and the superior treatment was 2% over untreated trees [103]. Application of MLE at concentrations of 4% and 6% to apple trees of the "Anna" cultivar resulted in noteworthy improvements across various parameters. These enhancements encompassed shoot length, shoot diameter, leaf chlorophyll content, fruit set, fruit yield, fruit weight, fruit size, soluble solids content, and total sugar content, as well as the leaf content of macronutrients, when compared to untreated trees [51]. In addition, the act of spraying MLE at concentrations of 4% and 6% demonstrated notable improvements in leaf chlorophyll content, higher flower count, greater fruit set percentages, enhanced fruit yields, fruit oil content, fruit firmness, higher percentages of total soluble solids, and augmented levels of both macro- and micronutrients within the leaves [104].

SWE is distinguished by its abundance of micro- and macronutrients, encompassing elements such as iron, copper, sulfur, manganese, nitrogen, and phosphorus. Additionally, it contains gibberellic acid, indole acetic acid, cytokinins, and amino acids. This unique composition classifies it as a biostimulant that is conducive to fostering plant growth. Importantly, its composition also imparts it with the capacity to significantly improve plant cell division processes and productivity [45,47,48,105–107]. Additionally, SWE contains magnesium, a crucial element for chlorophyll synthesis [108]. The utilization of SWE has demonstrated a range of beneficial effects, such as enhancing the leaf's total chlorophyll levels, photosynthesis, transpiration, and stomatal conductance [109–111]. In the case of the "Koroneiki" olive cultivar, the application of SWE led to increased flower set percentages and fruit yield [112]. SWE has also exhibited the capacity to enhance plant resistance to both biotic stresses [113,114] and abiotic stressors [115,116], enhance plants' absorption of nutrients from the soil, stimulate crop growth, and elevate yield [47,117]. Furthermore, SWE has been shown to boost stress resilience, enhance nutrient absorption, promote growth, increase yields, foster root system growth, facilitate flowering [118], and improve fruit quality and flavor [119], ultimately leading to enhanced crop productivity [50]. The application of SWE to oranges has resulted in an increased maturity index and yield, accompanied by a reduction in fruit drop [120,121]. Applying SWE to 'Gala' apple at concentrations ranging from 0.1% to 0.6% resulted in higher fruit set percentage, and increased fruit numbers, weight, and length compared to the control, with the most effective treatment being at 0.3% [122]. Likewise, the method of applying SWE to olive trees at varying concentrations of 0.1, 0.2%, and 0.3% has demonstrated a noteworthy enhancement in various aspects. These improvements encompass heightened levels of leaf chlorophyll content, increased flower count, improved fruit set percentages, elevated fruit yields, enhanced fruit oil content, greater fruit firmness, higher total soluble solid (TSS) percentages, and augmented levels of both macro- and micronutrients within the leaves [104].

Potassium stands as a fundamental fertilizer crucial for the production and quality of crop yields. Its significance in plant functioning is paramount, manifesting through multifaceted roles. This vital nutrient is implicated in the modulation of membrane potential, osmoregulation, sugar transportation, and stress adaptation, as well as plant growth and metabolism [123,124]. Moreover, potassium's involvement extends to the regulation of diverse biochemical and physiological processes. This encompasses participation in enzyme activation, carbohydrate metabolism, and protein synthesis [125]. Furthermore, the K^+ ion plays a central role in photosynthesis and exerts control over the opening and closing of stomata, especially in the context of stress conditions [126,127]. Potassium holds a crucial status as a significant macronutrient, bearing substantial roles within plants such as osmoregulation, regulation of membrane potential, cotransport of sugars, stress adaptation, and growth [128]. Its physiological functions encompass pivotal aspects such as the regulation of stomatal behavior, photosynthesis, and water uptake [124]. Notably, K^+ ions exert a pivotal influence on plants' responses to a range of challenges, spanning both biotic and abiotic stresses, including drought, salinity, cold, and waterlogging [129,130]. Potassium stands as a primary microelement of utmost significance, closely following nitrogen and phosphorus for the sustenance and optimal operation of living organisms. Its contributions are multifaceted, including its involvement in cellular expansion, upkeep of turgor pressure within plants, facilitation of cellular osmoregulation, regulation of stomatal movements, and activation of over 60 enzymes [131]. Potassium takes on the essential task of overseeing the opening and closing of stomata, thereby enhancing photosynthesis through the regulation of CO_2 absorption. Moreover, it holds a pivotal role in the process of photosynthesis, as well as in the translocation and metabolism of carbohydrates. These functions collectively contribute to amplified crop yield and enhanced grain quality [132–135]. In the realm of plant growth and metabolism, potassium is indispensable, overseeing a multitude of biochemical and physiological processes [129].

5. Conclusions

The results show that YE, MLE, FA, and SWE could be used as alternative and eco-friendly biostimulants in reducing the amount of the required chemical fertilizers to alleviate the side effects of the full dependency on chemical fertilization. The obtained results ascertain that the application of YE, SWE, MLE, and nano-potassium greatly improved the performance of date palm in terms of yield and fruit quality. The application of YE and SWE was increased by their combination with nano-potassium. The best results were obtained by the foliar application of 2000 ppm YE + 200 ppm K NPs, 4000 ppm SWE + 200 ppm K NPs and 4000 ppm FA + 200 ppm K NPs in 2021–2022.

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