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Effect of Nano-chelated Iron and Potgrond Organic Fertilizer on the Growth Characteristics of Date Palm (*Phoenix dactylifera* L.) cv. Khalas

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ABSTRACT

Improper uses of fertilizers and unskilled practices in date palm orchard management usually result in nutrient depletion, leading to reduced productivity. To address this issue, a study was conducted to assess the impact of nano-chelated iron and organic fertilizer (Potgrond) on physiological, biochemical, physical characteristics, and productivity of date palm. The experiment took place in a private orchard located in Al-Haritha District, Basra, Iraq (2022-2023). A combination of foliar nano-chelated iron (180 mg L^{-1}) and the field application of organic fertilizer (potgrond) (8 kg $tree^{-1}$) caused maximum values of leaf chlorophyll content (9.99 mg 100 g^{-1}), carbohydrates (49.15 mg g^{-1}), nitrogen (3.06%), phosphorus (0.223%), potassium (2.15%), and iron (0.198%), compared to the control treatment. The lowest values of leaf chlorophyll content (6.81 mg 100 g^{-1}), carbohydrates (26.27 mg g^{-1}), nitrogen (1.58%), phosphorus (0.126%), potassium (1.13%), and iron (0.105%) occurred in response to the absence of nano-chelated iron and potgrond. The foliar application of nano-chelated iron (180 mg L^{-1}) and potgrond (8 kg $tree^{-1}$) caused the highest values of fruit length (3.91 cm), diameter (2.92 cm), weight (11.40 g), size (12.11 cm^3), dry matter (64.77%), total soluble solids (62.69%), and total sugars (59.26%). The absence of nano-chelated iron and potgrond caused the lowest values of fruit length (3.39 cm), diameter (2.50 cm), weight (8.05 g), size (8.36 cm^3), dry matter (58.63%), total soluble solids (56.42%), and total sugars (54.59%). These findings underscored the significant of utilizing these substances to enhance date palm growth while increasing yield production and quality.

Introduction

The date palm (*Phoenix dactylifera* L.) holds significant cultural importance in Arab society and is referenced in the Holy Quran. Botanically, it is a dioecious species thriving within latitudes of 10° to 30° north of the equator, with certain varieties extending as far as 20° in the south latitude. As a member of the Arecaceae family and Palmae order, the date palm belongs to one of the oldest families of monocotyledonous flowering vascular plants. Its cultivation plays a pivotal role in Iraq's agricultural economy, providing essential nutritional and economic value through fruit production (Zaid and De Wet, 2002). Various studies, including those by Al-Douri and Al-Rawi (2000), Ibrahim (2008), and Ibrahim (2014),

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*Corresponding author's email: hassan.faisal1969@gmail.com highlight the significant contributions of date palm cultivation to Iraq's national income. However, Iraq, despite being a leading date-producing nation, has experienced a decline in production due to adverse environmental conditions and the inefficient use of agricultural resources. Traditional production methods, slow adoption of advanced technologies, and inefficiencies in agricultural service processes have further exacerbated the challenges in palm cultivation (Al-Rawi, 1998). Moreover, mismanagement in fertilization and maintenance has contributed to a gradual decline in both production and fruit quality. Neglecting proper fertilization depletes essential soil nutrients, hindering fruit production unless fertilizers are applied to replenish the soil.

Organic and nano-fertilizers are critical to enhancing productivity. Organic fertilizers improve soil's physical and chemical properties, including its water retention capacity, positive ion exchange, and cation exchange capacity (CEC). They regulate soil temperature, increase organic matter, boost biological efficiency, and even help eliminate certain pathogens in the soil (Hu and Cao, 2007). These fertilizers also enhance nutrient availability, providing a rich source of nutrients for the soil (Yagodin, 1984). Nanotechnology, a revolutionary advancement, offers unique advantages over conventional fertilizers by promoting plant growth, increasing yields, and reducing dependency on chemical fertilizers (Al-Wakil, 2013). The remarkable chemical and physical properties of nano-materials, such as their nanoscale size and large surface area, contribute to these benefits (Khan et al., 2017).

One prominent example of nano-fertilizers is chelated iron nano-fertilizer, a stable and efficient source of divalent iron. It releases iron gradually across a broad pH range (3-11) without containing ethylene, a compound known to inhibit plant growth and cause leaf yellowing. Its small particle size facilitates rapid absorption by plants, while its stability under various environmental conditions allows for the application of smaller quantities compared to traditional fertilizers, reducing costs (Guru et al., 2015). Iron is only effective as a fertilizer when applied in chelated or encapsulated forms, as chelated compounds combine organic molecules with mineral elements, making them both absorbable and mobile within the plant (Imtiaz et al., 2010). Filipponi and Sutherland (2013) found that nano-iron compounds are 10 to 1000 times more effective than traditional iron fertilizers due to their larger surface area. Organic fertilizers, derived from animal or plant waste, also offer a sustainable nutrient source, reducing reliance on chemical fertilizers. They support essential plant processes, such as respiration, nutrient absorption, and nutrient conversion into metabolizable forms (Mishra and Dadlich, 2010). The use of organic fertilizers adds organic matter to the soil, improving its structure, aeration, and nutrient content, which enhances plant resistance to drought and mitigates soil salinity.

Al-Zubaidi (2018) demonstrated the positive effects of nano-fertilizers on the vegetative and fruiting characteristics of the Khastawi date palm cultivar, leading to improved fruit quality and yield. Similarly, Taha (2018) found that spraying chitosan and applying synthetic organic fertilizer, amino acids, and seaweed extract on date palm seedlings (cv. Barhi) enhanced vegetative growth, mineral content, and chlorophyll levels in the leaves, while also affecting drought tolerance and the activity of the peroxidase enzyme.

The present study focuses on the date palm cultivar 'Khalas,' a rare and highly sought-after horticultural variety in Iraq. The objective of the research was to evaluate the effects of two types of fertilizers, i.e., nano-chelated iron and Potgrond organic fertilizer, on improving the chemical and physiological properties of palm leaves and enhancing both the quantitative and qualitative characteristics of Khalas date fruits.

Material and Methods

The plant material for the present study was located in a private orchard in Al-Haritha District, Al-Mashab region, Basra Governorate, from June to October (2022-2023). Potgrond organic fertilizer, manufactured by the renowned Dutch company Klasmann. Chelated nano-iron was applied as a foliar treatment on palm leaves to induce changes in the physical, chemical, and physiological characteristics of "Khalas" date palms. The study was conducted outdoors in the Basra Governorate. Twenty-seven healthy, productive, and uniform date palms were carefully selected as specimens for the experiment. This study was conducted as a factorial experiment with two factors. The first factor consisted of three concentrations of nano-chelated iron (0, 90, 180 mg L^{-1} as leaf spray), and the second factor consisted of three levels of the organic fertilizer Potgrond (0, 4, and 8 kg $tree^{-1}$) applied to the soil. The experiment was arranged in a randomized complete block design (RCBD) with three replications. All necessary procedures and operations were carried out systematically and symmetrically, following established practices in date palm orchards of the region.

The date palm trees were pollinated with male pollen (Ghannami Akhdhar) in March 2023. After pollination, we reduced the reproductive organs to 8 inflorescences tree^{-1}. Applying the organic fertilizer (Potgrond) to the soil involved first digging a trench around the trunk of each palm. The trench measurements were 30 cm deep, 40 cm wide, and one meter away from the palm trunk. Organic fertilizer (0, 4, and 8 kg tree^{-1}) was then added to the trench, and the trench was covered with a layer of soil in mid-January. Solutions of nano-chelated iron (0, 90, and 180 mg L^{-1}) were added with Tween 20 (0.01%) to the solution. The first spraying began in the middle of March, while the second was four weeks after the pollination. Measurements of vegetative and reproductive characteristics were conducted in early mornings. Fruit characteristics were measured during the Khalal stage. Leaf characteristics were measured at the end of June by collecting pinnae from the front in the third line, beyond which apical leaves developed (Al-Ani, 1998). Orchard soil was analyzed before the experiment (Table 1).

Table 1. Some physical and chemical properties of orchard soil at a depth of 0-60 cm.

Characteristics	Value
Electrical conductivity (E.C) ds m^{-1}	9.27
Soil acidity (pH)	8.02
Available nitrogen (mg kg^{-1})	196.00
Available phosphorus (mg kg $^{-1}$)	22.53
Available potassium (mg kg $^{-1}$)	131.85
Clay %	50.09
Silt %	37.62
Sand %	11.65
Organic matter %	0.31

ds m^{-1} = desi Siemens m^{-1}, mg Kg^{-1}.

Chemical and physiological characteristics of the leaves

Total leaf chlorophyll content (mg 100 g^{-1}) was determined using Holden's method, as described by Howertiz (1975). First, 0.5 g of fresh leaves were taken and cut into small pieces with scissors. These leaf pieces were then ground in a ceramic mortar with 15 mL of 80% acetone. Subsequently, the resultant filtrate was separated from the precipitate using a centrifuge at 1600 rpm for 10 min. The extraction process was repeated until the precipitate no longer contained any dye. The extract was collected in glass test tubes covered with opaque paper to prevent light exposure and subsequent photo-oxidation of the dye. Acetone was added to bring the volume to 15 mL. The optical density (absorbance) of the filtrate was measured using a Shimadzo spectrophotometer UV-1700 at wavelengths of 645, 663, and 480 nm to determine the total chlorophyll content based on a specific equation.

$$Total\ chlorophyll\ (mg\ L{-}1\ ) \\ = 20.2(OD_{645}) + 8.02\ (OD_{663})$$

Total carbohydrate content in the leaves (mg g^{-1}) was estimated following a method outlined by Watanabe et al. (2000). Initially, 0.5 g of finely crushed dry leaves were placed into test tubes with a capacity of 90 mL. Subsequently, 70 mL of distilled water was added to each tube, which were then securely sealed. The test tubes were carefully immersed in a water bath (90 °C) and were left for an h to facilitate carbohydrate extraction. Then, the tubes were allowed to cool down at room temperature. The extract was filtered using filter paper, and 5 mL of the filtrate was collected. Then, 25 mL of distilled water was added, and 1 mL of the mixture was combined with 1 mL of phenol (5%) and 5 mL of concentrated sulfuric acid. The resultant solution was allowed to cool down at room temperature.

Absorbance values in each sample were measured at a wavelength of 490 nm (Shimadzo UV 1700 spectrophotometer). A standard curve of glucose was utilized to estimate the total dissolved carbohydrates in the leaves. The concentration was expressed as mg g^{-1} dry matter.

Determination of mineral elements in the leaves

Measuring mineral elements in leaf samples involved a specific procedure outlined by Cresser and Parsons (1979). First, 0.2 g of finely ground, dry plant sample was added to 5 mL of concentrated sulfuric acid. The solution was allowed to sediment overnight. Then, it was placed on a heat source and heated for 30 min until a white smoke was observed. The samples were removed from the heat and allowed to cool down. Three mL of the digestion mixture, comprising 96 mL H_2SO_4 and 4 mL $HClO_4$, were added to the samples. The digestion flasks were placed on a hot plate until the solution became clear in color. Once the digestion process was complete, the samples were removed from digestion and allowed to cool down. Then, the samples were supplemented with 50 mL distilled water.

The measurement of nitrogen percentage was carried out using a Micro Kjeldal device, as described by Page et al. (1982). Phosphorus percentage was determined according to a method outlined by Murphy and Riley (1962) through which a blue color appeared using a spectrophotometer at 700 nm. Potassium percentage was determined according to Page et al. (1982) using a flame photometer. Iron concentration was determined using atomic absorption spectroscopy (Awad, 1984).

Physical and chemical characteristics of fruits

Twenty-five fruits were randomly selected from each replicate, and their weight was measured using a precise electric balance (Sartorious). Subsequently, the average weight of the fruits in each replicate was determined by dividing the total weight by the number of fruits. For each replicate in each treatment, a sample of 10 fruits was randomly selected, and their length and diameter were measured using a Vernier digital measuring tool. The average length and diameter of each fruit (cm) were then determined. To measure the fruit volume, the graduated cylinder method was used. A 250 mL graduated cylinder was filled with distilled water, and 10 fruits were added to displace the water. The fruit volume was determined by calculating the difference in water level before and after adding the fruits. Then, the average fruit volume was determined, and the results were expressed as cm^3.

Percentage of dry matter

Twenty-five fruits were measured for pulp dry content at the Khalal stage. The fruits were weighed, measured for size and dimensions, and subsequently dried in a vacuum oven at 70 °C for 48 h. Once the weight reached a constant value, the dry matter (%) in the fruits was calculated using the equation below.

$$Percentage\ of\ dry\ matter = \frac{\text{Dry sample wight}}{\text{Fresh } sample\ wight} \times 100$$

Percentage of total soluble solids

Total soluble solids (TSS %) in the fruits was determined using a manual refractometer. The values were read at a temperature of 20 °C, following an approach outlined by Shirokov (1968).

Total sugar content

Total sugar content (%) was calculated according to a method proposed by Howertiz (1975). The total sugar content (%) was estimated via the equation below.

$$Total\ inverted\ sugars(\%) = \frac{\text{mg of sugar(from the table is equivalent to the buret reading)}}{\text{weight of sample } \times 1000} \times dilution \times 100$$

Data analysis

All data were analyzed using the Genstat software. To compare mean values, the Least Significant Difference Test (LSD) was employed ($P < 0.05$).

Results

Table 2 clearly demonstrates the significant impact of treating with nano-chelated iron and ground fertilization using organic fertilizer potgrond on the levels of total carbohydrates and total chlorophyll in the leaves. The treatment involving nano-chelated iron at a concentration of 180 mg L^{-1} and organic fertilizer Potgrond at 8 kg tree^{-1} showed superior results, with the highest values reaching 49.15 mg g^{-1} and 9.99 mg 100 gm^{-1}, respectively. These values were not significantly different from the treatment combinations involving spraying with nano-chelated iron at a concentration of 180 mg L^{-1}, and organic fertilizer treatment at 4 kg tree^{-1}, or spraying with nano-chelated iron at a concentration of 90 mg L^{-1} and organic fertilizer at 8 kg tree^{-1}. These treatments also showed promising results for both total carbohydrates and total chlorophyll. The other interaction treatments between the two factors outperformed the comparison treatment. While the result of the total chlorophyll (7.59 mg 100 gm^{-1}) of the interaction treatment of spraying with nano-iron (zero) and organic fertilization treatment at 4 kg tree^{-1} was not significantly different from the control treatment (zero nano-chelated iron and zero organic fertilizer potgrond) which had the lowest value at 6.81 mg 100 g^{-1}.

According to Table 3, a notable increase in leaf mineral content of nitrogen, phosphorus, potassium, and iron was observed when applying nano-chelated iron at concentrations of 90 and 180 mg L^{-1}, along with organic fertilizer at 4 and 8 kg $Tree^{-1}$. The treatment involving spraying nano-chelated iron at 180 mg L^{-1} and the organic fertilizer treatment at 8 kg $tree^{-1}$, showed higher values for nitrogen, phosphorus, potassium, and iron at 3.06, 0.223, 2.15, and 0.198%, respectively. This treatment did not significantly differ from spraying with nano-iron at 180 mg L^{-1} and fertilizing with organic fertilizer at 4 kg $tree^{-1}$ in terms of leaf mineral content. Other treatments also showed superiority over the comparison treatment, except for the treatment with zero concentration of chelated iron and organic fertilizer at 4 kg $Tree^{-1}$, which had the lowest iron content at 0.111% compared to the control treatment's 0.105%.

Table 2. Effect of spraying with different concentrations of nano-chelated iron, and ground treatment with organic fertilizer potogrond on the content of total carbohydrates and total chlorophyll of the date palm trees leaves ("Khalas" cultivar).

Nanoparticle iron concentration mg L^{-1}	Potgrond organic fertilizer kg $tree^{-1}$	Total Carbohydrates mg g^{-1}	Chlorophyll mg 100 g^{-1}
0	0	26.27^{f*}	6.81^{e}
	4	33.33^{e}	7.59^{de}
	8	40.49^{cde}	8.17^{cd}
90	0	36.93^{de}	7.97^{cd}
	4	42.26^{bcd}	9.00^{abc}
	8	44.85^{abc}	9.39^{ab}
180	0	38.76^{de}	8.38^{bcd}
	4	47.46^{ab}	9.44^{ab}
	8	49.15^{a}	9.99^{a}

*Similar letters are not significantly different ($P < 0.05$) according to the Least Significant Difference (LSD), mg L^{-1} = milligrams per liter, mg g^{-1} = milligrams per gram of leaf sample.

Table 3. Effect of spraying with different concentrations of nano-chelated iron, and ground treatment with organic fertilizer potgrond on the content of mineral elements including nitrogen, phosphorous, potassium and iron of the dates palm trees leaves ("Khalas" cultivar).

nanoparticle iron concentration mg L^{-1}	Potgrond organic fertilizer kg $tree^{-1}$	Element %			
		N	P	K	Fe
0	0	1.58^{c}	0.126^{e}	1.13^{f}	0.105^{f}
	4	2.21^{b}	0.150^{d}	1.63^{de}	0.111^{f}
	8	2.44^{b}	0.160^{d}	1.93^{bc}	0.124^{e}
90	0	2.22^{b}	0.143^{de}	1.51^{e}	0.138^{d}
	4	2.82^{a}	0.170^{c}	2.03^{ab}	0.144^{d}
	8	2.94^{a}	0.196^{b}	2.08^{ab}	0.163^{c}
180	0	2.28^{b}	0.150^{d}	1.78^{cd}	0.173^{b}
	4	2.97^{a}	0.20^{ab}	2.12^{ab}	0.191^{a}
	8	3.06^{a}	0.223^{a}	2.15^{a}	0.198^{a}

*Similar letters are not significantly different ($P < 0.05$) according to the Least Significant Difference (LSD) test. N = nitrogen, P = phosphorus, K = potassium, Fe = iron.

Table 4 presents the impact of the combined treatment of spraying with nano-chelated iron and ground fertilization with organic fertilizer potgrond on various physical characteristics of Khalas variety date palm fruits. The results indicated that the interaction treatment of spraying with nano-chelated iron at a concentration of 180 mg L^{-1} combined with the organic fertilization treatment at 8 kg tree^{-1} resulted in the highest values for fruit length, diameter, size, and weight, reaching 3.91, 2.92 cm, 12.11 cm^{3}, and 11.40 g, respectively. These values did not significantly differ from the treatment with nano-chelated iron at a concentration of 180 mg L^{-1} and organic fertilization at 4 kg tree^{-1} for fruit length, size, and weight. Additionally, the interaction treatments between the two factors were significantly superior compared to the control treatment in terms of fruit diameter, size, and weight, except for the interaction treatment of spraying with chelated iron at a concentration of zero and organic fertilizer at 4 kg Tree^{-1}. The control treatment recorded the lowest values for fruit length, diameter, size, and weight, amounting to 3.39, 2.50 cm, 8.36 cm^{3}, and 8.05 g, respectively.

Table 4. Effect of spraying with different concentrations of nano-chelated iron, and ground treatment with organic fertilizer potgrond on some physical characteristics including length, diameter, size, and weight of date palm fruits (Khalal stage of "Khalas cultivar).

Nanoparticle iron concentration mg L^{-1}	Potgrond organic fertilizer kg tree^{-1}	fruit length (cm)	fruit diameter (cm)	the size of the fruit (cm^{3})	fruit weight (g)
0	0	3.39^{c*}	2.50^{d}	8.36^{f}	8.05^{e}
	4	3.46^{c}	2.60^{c}	9.92^{e}	9.47^{d}
	8	3.72^{b}	2.68^{c}	10.35^{de}	10.85^{ab}
90	0	3.66^{b}	2.64^{c}	9.89^{e}	10.08^{cd}
	4	3.78^{ab}	2.79^{b}	10.83^{cd}	10.92^{ab}
	8	3.81^{ab}	2.82^{b}	11.21^{bc}	11.11^{ab}
180	0	3.71^{b}	2.67^{c}	10.25^{de}	10.57^{bc}
	4	3.81^{ab}	2.82^{b}	11.78^{ab}	11.26^{a}
	8	3.91^{a}	2.92^{a}	12.11^{a}	11.40^{a}

* Similar letters are not significantly different ($P < 0.05$) according to the Least Significant Difference (LSD) test, mg L^{-1} = milligrams per liter, cm = centimeters, cm^{3} = cubic centimeters.

Table 5 presents the impact of the combined treatments, which involved spraying with chelated iron and ground fertilization with potgrond organic fertilizer on various chemical characteristics of Khalas variety date palm fruits. The results displayed in the table demonstrated that the intervention treatment, specifically spraying with chelated iron at a concentration of 180 mg L^{-1} and ground fertilization with organic fertilizer at 8 kg Tree^{-1} resulted in the highest values for the chemical characteristics under study including dry matter, total dissolved solids, and total sugars, with percentages of 64.77, 62.69, and 59.26% respectively. In contrast, the comparison treatment yielded the lowest values, with percentages of 58.63, 56.42, and 54.59% for the same chemical properties. Notably, the treatment involving spraying with chelated iron at a concentration of 180 mg L^{-1} and organic fertilization at 8 kg tree^{-1} did not exhibit significant differences compared to the treatment involving spraying with chelated iron at a concentration of 180 mg L^{-1} and organic fertilization at 4 kg tree^{-1} for dry matter and total dissolved solids, with recorded values of 63.98 and 61.38% respectively. However, all other treatments were significantly superior to the comparison treatment, except for the treatment involving spraying with chelated iron at a concentration of zero and ground fertilization with organic fertilizer at 4 kg tree^{-1} for total dissolved solids and total sugars, which recorded values of 56.71 and 55.40% respectively, while the comparison treatment yielded values of 56.42 and 54.59% for the same characteristics.

Table 5. Effect of spraying with different concentrations of nano-chelated iron, and ground treatment with organic fertilizer potogrond on some chemical characteristics including dry material, total soluble solids and total sugars of dates palm fruits (Khalal stage of "Khalas" cultivar).

Nanoparticle iron concentration mg L^{-1}	Characteristic %			
	Potgrond organic fertilizer kg $tree^{-1}$	Dry matter	Total soluble solids	Total sugars
0	0	58.63^{e}	56.42^{g}	54.59^{f}
	4	60.86^{d}	56.71^{fg}	55.40^{ef}
	8	61.66^{cd}	58.11d^{ef}	56.56^{d}
90	0	61.30^{d}	57.51^{efg}	56.09^{de}
	4	62.40^{c}	59.46^{cd}	57.05^{bcd}
	8	63.50^{b}	60.28^{bc}	57.78^{b}
180	0	61.37^{d}	58.69^{de}	56.65^{cd}
	4	63.98^{ab}	61.38^{ab}	57.60^{bc}
	8	64.77^{a}	62.69^{a}	59.26^{a}

* Similar letters are not significantly different ($P < 0.05$) according to the Least Significant Difference (LSD) test. mg L^{-1} = milligrams per liter.

Discussion

Nanofertilizers are believed to provide essential nutrients and trace elements that are not readily absorbed from the soil by plants. These nutrients, primarily micronutrients, promote accelerated growth and encourage early plant maturity. Moreover, plants require these elements to maximize benefits such as enhanced resistance to environmental stress, improved physicochemical properties, and optimized metabolism (Ahmad and Akhtar, 2019). The results of this study demonstrated that spraying nano-chelated iron on palm leaves significantly increased various biochemical values, such as higher total chlorophyll content (Table 2). Iron plays a critical role in numerous plant processes, particularly in the formation of coproporphyrinogen oxidase, an enzyme that governs the sixth step of physiological activity. Iron is also essential for Warfarin metabolism and the production of α-amino levulinic acid, a precursor in chlorophyll biosynthesis (Barker and Stratton, 2015). Furthermore, iron acts as a catalyst and activator in the reaction chain leading to chlorophyll formation. The observed increases in nitrogen, phosphorus, potassium, and iron concentrations in the leaves can be attributed to the nano-chelated iron fertilizer, which strengthens roots and enhances mineral absorption from the soil (Table 3). Sekhon (2014) emphasized that the high absorption capacity of nano-chelated iron, due to its increased surface area, facilitates the uptake of elements essential for photosynthesis.

Additionally, the application of organic fertilizer improved several leaf characteristics, likely due to its role in increasing chlorophyll and carbohydrate levels (Table 2). Nitrogen from organic fertilizers had a notable impact on total chlorophyll content, as nitrogen is essential for the formation of the porphyrin ring, a critical component of chlorophyll synthesis. Nitrogen is also a key nutrient that enhances the photosynthesis of amino acids, the building blocks of proteins, and promotes carbohydrate accumulation in plant branches. Phosphorus, another essential element, is crucial for the synthesis of chloroplast proteins and amino acids. The elevated chlorophyll content may also be linked to higher potassium levels, which enhance the activity of several enzymes necessary for chlorophyll production (Medan, 2021). The increased concentration of elements in the leaves, resulting from the rich supply of macro- and micronutrients in Potgrond fertilizer, contributed to the growth and development of palm trees (Table 3). This fertilizer provides optimal quantities of nutrients, and its organic matter content further contributes to nutrient absorption.

The physical characteristics of the fruits also improved with nano-chelated iron treatment (Table 4), which can be attributed to iron's role in enhancing the absorption efficiency of other nutrients, including nitrogen. Nitrogen is critical for amino acid formation, especially tryptophan, which plays a key role in cell division and elongation. This leads to increases in fruit length, diameter, volume, and weight (Yadegari, 2013). The higher sugar content in the fruit, as indicated by elevated levels of total soluble solids and dry matter (Table 5), was likely due to the increased production of organic compounds. Organic fertilizer treatments also enhanced the physical and chemical characteristics of the fruits (Tables 4 and 5), likely due to the provision of macro-nutrients, such as nitrogen, phosphorus, and potassium. Nitrogen, in particular, contributes to porphyrin production, which is vital for chlorophyll synthesis (Ohkouchi and Takano, 2014). Chlorophyll, as a key indicator of plant health, facilitates carbohydrate production in the leaves, which is then transferred to the fruits.

The application of foliar nano-fertilizers, even at low concentrations, accelerates growth by boosting metabolic activity in the fruits, thus hastening the ripening process. Early ripening is advantageous for farmers, as it allows them to obtain premium prices for their dates (Hussein et al., 2020). Nano-fertilizers, either alone or in combination with traditional fertilizers, increased fruit weight due to the enhanced nutrient absorption by the leaves, which positively influenced growth and yield. This process likely involved increased photoassimilate production and improved transportation and storage of these compounds in the fruits. The use of nano-chelated iron and organic fertilizer (Potgrond) had a beneficial impact on various physical, chemical, and physiological traits of date palms, leading to improved growth characteristics under specific environmental conditions.

Conclusions

Comprehensive plans to apply fertilizers and various fertilizer techniques can foster new possibilities in palm orchard management. This opportunity is particularly evident with fertilizer blends containing combinations of organic substances and nano-materials, leading to cost-effective practices and eco-friendly agricultural activities. Date palm trees showed a favorable response to spraying with nano-chelated iron, especially at a concentration of 180 mg L^{-1}, thus significantly improving most of the physical, chemical, and physiological characteristics. Adding the organic fertilizer Potgrond (8 kg $tree^{-1}$) to the soil notably enhanced the studied variables. Moreover, the interaction between 180 mg L^{-1} nano-chelated iron and 8 kg $tree^{-1}$ organic fertilizer had significant superiority in enhancing most of the studied variables, particularly fruit characteristics, thus resulting in increased yields.

Conflict of Interest

The authors indicate no conflict of interest in this work.

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