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Foliar nutrition of date palm: advances and applications. A review

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Abstract

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Foliar fertilization is one of the crucial ways for continued cultivation of date palm, obtaining the best results of growth and production, in addition to the possibility to reduce damage from abiotic stress. Although subjected date palm to an annual fertilization program, it faces some challenges, including low soil availability for nutrients, dryness of the soil surface, low root activity in the breeding period, soil alkalinity, as well as water scarcity in areas of cultivation, and symptoms of deficiency of some elements. This review attempts to shed light on the importance of using leaf fertilization, demonstrating the successful technique and positive results, and proving the ability of date palm cells to absorb nutrients, similar to other trees, and interact with chemical and biological fertilizers. Besides, the leaflet's possibility of absorbing various nutrients, chelated iron, biostimulants, antioxidants, and nano-fertilization, are presented.

Keywords

date palm, foliar nutrition, leaf morphology, leaf anatomy, *Phoenix dactylifera* L.

Introduction

Plant development and advancement generally rely upon the mix and grouping of mineral supplements accessible in the soil. Plants frequently face critical difficulties in getting sufficient flexibility of these supplements to satisfy the needs of fundamental cell measures because of their relative idleness. Inadequacy of any of them may bring about diminished plant profitability or potential ripeness. Indications of supplement inadequacy may incorporate hindered development, the demise of plant tissue, or yellowing of the leaves brought about by a diminished chlorophyll creation, a pigment required for photosynthesis. Supplement lack can significantly affect agribusiness, bringing about decreased harvest yield or diminished plant quality. Nutrient deficiencies can also reduce overall biodiversity because plants act as producers that support most food webs (Morgan and Connolly, 2013).

Many factors determine how much a plant needs nutrients and how much the soil can provide the plant with nutrients. Three soil properties as most important concerning any plant response-related functions are; soil pH (to regulate nutrient availability), texture (to regulate water transmission properties and fixation and release of nutrients), and organic matter (to realize the cascading effect on the whole range of soil physical as well chemical properties, including the biological properties), and above all, plant traits as well (nutrient efficient and nutrient responsive both) (Comerford, 2005).

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Notwithstanding, the root isn't the main organ that is associated with the absorption of nutrients. The foliage, including leaves, stem, inflorescence, and organic products, can likewise assimilate supplement nutrients (Oosterhuis, 2009). Foliar nutrients are an essential indicator of field farming's evolution, as it is one of the modern methods of high economic efficiency (Alshaal and El-Ramady, 2017).

The efficacy of nutrients is governed by spray formulation's physicochemical properties such as pH, surface tension, polarity, additives (surfactants, humectants, spreader/stickers, etc.), molecular size, ionic charge, and solubility in spray fluid. Characteristics of the species and the environment such as humidity (Schönherr and Schreiber, 2004), temperature (Zhang and Brown, 1999), light (Abadia, 1992; Álvarez-Fernández et al., 2004), and wind in which the plant is grown affect the rate of foliar uptake (Dordas, 2008). Finally, the plant factors like a physical and physiological characteristics (chemical composition of the leaf such as cuticle composition, source/sink status and leaf expansion affect absorption, distribution, and penetration availability of foliar-applied nutrients of a plant), phonological stage (leaf age, leaf homogeneity) (Zhang and Brown, 1999) morphological traits (leaf shape, presence of hairs, presence of discontinuities (lenticels, cracks…), plant architecture (canopy architecture such as new growth, presence of reproductive structures, presence of floral or leaf buds that have a determinative effect on spray retention and penetration), epidermal systems such as stomata, cuticle thickness, stomatal distribution and density, leaf surface architecture, leaf angle, and orientation, canopy surface area, characteristics of the plant surface, leaf surface chemistry and mobility of nutrient within the part system also determine foliar nutrient uptake efficiency (Zhang and Brown, 1999; Bringe et al., 2006; Fernández and Brown, 2013). The leaf's physiological state at the time of spraying and plant metabolic activity can alter demand and source: sink dynamics, availability of substrate and energy for absorption and assimilation, uptake rate, mobilization assimilation, and remobilizations of nutrients.

Foliar nutrition of date palm

Date palm (*Phoenix dactylifera* L.) (2n = 36) is a dioecious perennial tree extensively cultivated in subtropical regions, including the Middle East and North Africa (Ibrahim, 2018). One of the primary essential tools for productive and sustainable management of crops worldwide is foliar fertilization. Target orientation and environmentally friendly properties are the most important reasons for foliar fertilization over soil fertilization. Foliar fertilizer is a vital device for the practical and gainful administration of yields and is of considerable commercial significance around the world (Fageria et al., 2017). Roots retain water and mineral supplements from the soil transported through the xylem to the leaf. In the leaf, these supplement components are absorbed into different natural compounds by biochemical procedures, for example, photosynthesis and related processes. These natural compounds are then transported from the leaf (source) to other plant organs (sink, for example, roots, creating young leaves, blooms, and natural products (Ördög and Molnár, 2011).

Foliar spraying is a new process and not essential in feeding date palm because it helps solve low growth and productivity and environmental issues such as drought, salinity, and high temperatures. Foliar technics used to reduce saltwater damage (Shareef, 2016). Expanding the use of the foliar technic is a modern method for improving date palm culture. Besides, it provides new opportunities for reviving date palm in areas exposed to harsh environmental conditions that hinder date palm cultivation's success. Therefore, this review attempts to shed light on the importance of using leaf fertilization as a successful technique giving positive results and proving the ability of date palm cells to absorb nutrients, similar to other trees, and interact with chemical and biological fertilizers.

Date palm leaf morphology

Date palm leaves, popularly called fronds, are pinnate, compound leaves spirally arranged around the stem's top (meristem). In maturity, leaves are about 4 m in length, with a range of 3–6 m and 0.5 m wide at the focal midrib that limits the two leaves closest (Lobo et al., 2014). The foliage of the date palm is long and broad dark green. The date palm leaf consists of two parts; the blade and the petiole; the leaf blade consists of three parts; pinnae, spines, and rachis; the petiole consists of a rachis base and fiber sheath (Zaid and Arias-Jiménez, 2002) (see Fig. 1). The pinnae (leaflet) represents the target area using a foliar spray, especially their lower surfaces. The number of stomata is more significant on the lower body (see Fig. 2). Besides, the cuticle is thinner, which makes the foliar-spraying process more effective (see Fig. 3). The quantity of leaves created every year differs from 10 to 26 and a mature palm may have from 100 to 125 leaves. Leaves stay appended to the tree following their senescence and must be physically pruned (Al-Yahyai and Manickavasagan, 2012). The morphology of date palm leaves encourages foliar fertilization because it is a large total vegetative area to the plant's size.

Anatomical characteristics of date palm leaflet

A date palm leaflet comprises the accompanying parts in cross-section and includes the cuticle, epidermis, mesophyll, and vascular tissue. The cuticle covering elevated leaf parts is an extra-cellular layer consisting of a biopolymer framework with wax impregnated into (intracuticular) or overlaying (epicuticular wax) the surface (Fernadéz et al., 2015). On the inner side, a waxy substance called cutin is integrated with polysaccharide material from the epidermal cell wall, which is primarily composed of cellulose, hemicellulose, and gelatin (Xu et al., 2012). Subsequently, the cuticle skin itself can be considered as a 'cutinized' cell wall; the heterogeneous

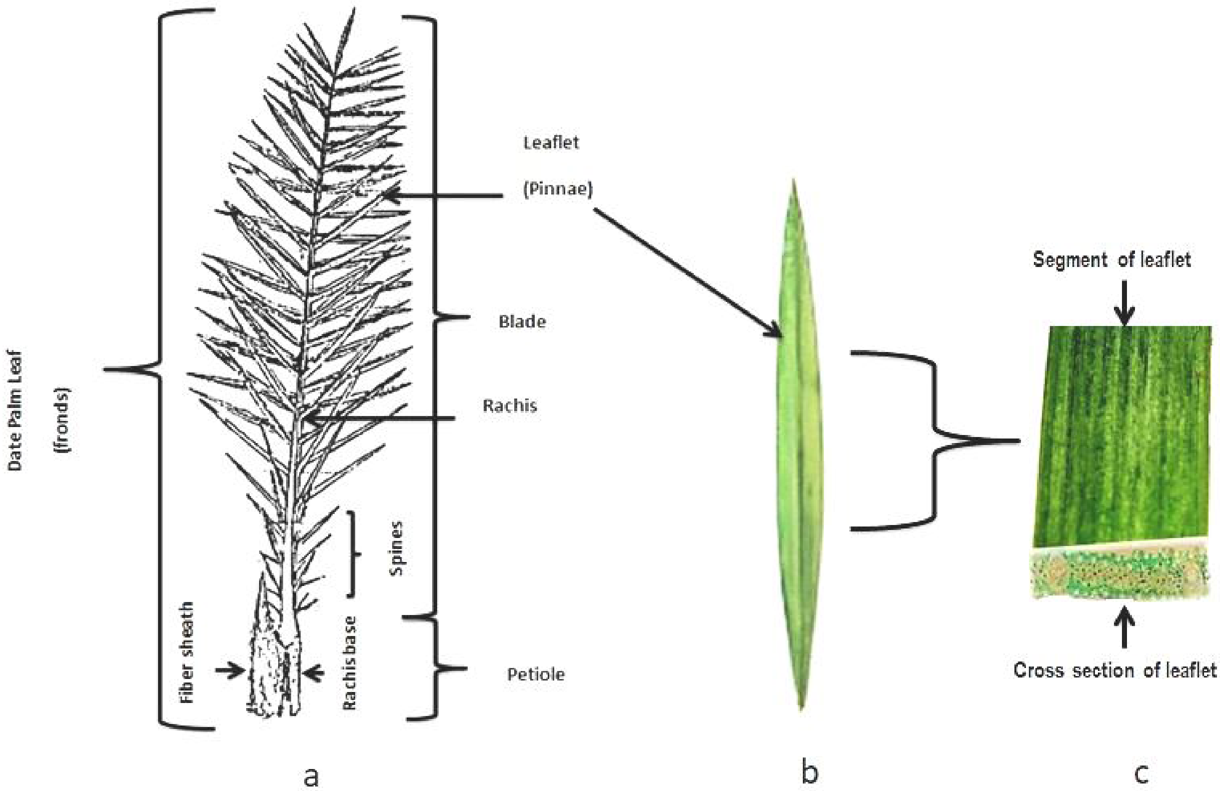

Fig. 1. The morphology of date palm leaf (a) from (Zaid and Arias-Jiménez, 2002), (b) Pinnae (leaflet), (c) cross-section of a leaflet. Photo by authors.

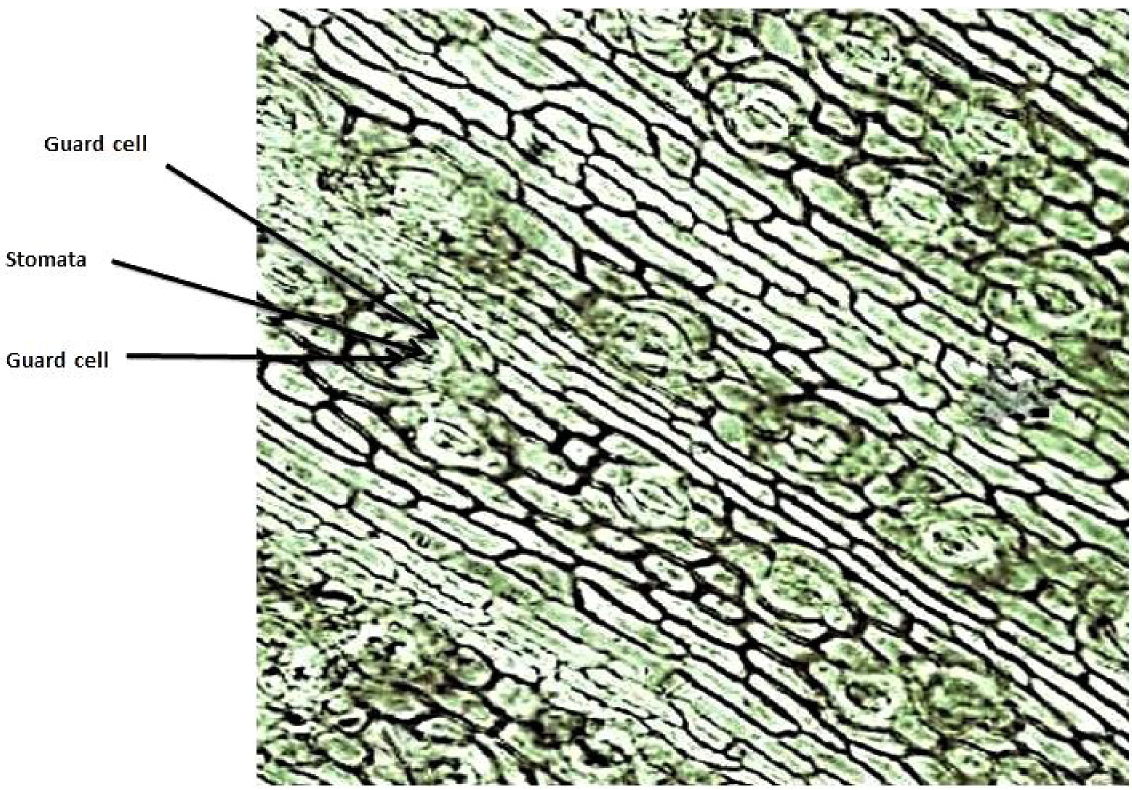

Fig. 2. A lower surface of date palm leaflet (stomata). Photo by authors.

nature of this layer has a physiologically-vital association with the underlying cell wall (Domínguez et al., 2011). A cross-section of the date palm leaflet shows no difference from a cross-section of other plant leaves. The thickness of the cuticle layer in the date palm leaflet is close to that of other plants that regularly are given foliar fertilization, such as citrus. The thickness of the cuticle in date palm ranges from 3–7 µm in various varieties (Alnajjar and Alhamd, 2016).

In contrast, the thickness of the cuticle in other plants is 2–10 µm (Lequeu et al., 2003), and the cuticle layer's thickness 4–5 µm in citrus (De Paula et al., 2019). The epidermis consists of a single row of non-specialized monocytes containing a living protoplast. No chloroplasts, but having other plastids with a few grana. The skin surrounding the top, upper epidermis, and lower epidermis surrounded by the cuticle is a single row of cells whose function is to protect the internal tissue. The skin also contains stomata, which consists of thick-walled cells connected to the air chambers. The stomata are abundant in the upper part of the leaf (upper or ventral surface), 182 stomata per mm^2 compared to the lower body (dorsal) 166 stomata per mm^2 (Abbas, 2004) (see Fig. 2). The number of stomata per unit area does not differ from that of other plants. Obiremi and Oladele (2001) found that the number of stomata in a plant of Citrus limon was 188 per mm2.

The mesophyll is the tissue trapped between the upper and lower bodies. It is not distinguished into a palisade and a spongy layer at date palm. The middle tissue contains many green plastids (Davoodi et al., 2002). Vascular tissue consists of a group of vascular bundles spread in leaf veins and is more extensive in the petiole and surrounds each top and bottom. Sclerenchyma tissue consists of fiber cells with thick walls responsible for strengthening the leaf, divided into xylem and phloem (see Fig. 3). Xylem is near the top surface of the leaflet and is composed of parenchyma cells and follicles. Xylem is of two types protoxylem and metaxylem. Protoxylem is found in new leaves and appears in small circles in the leaflet's cross-section, while large rings are known as metaxylem and found in adult leaves (Zaid and Hughes, 1996). Phloem consists of small parenchyma cells and mucous tubes located at the bottom of the leaflet. The leaflet of date palm also contains the bundle sheath consisting of thin-walled parenchyma cells, including green plastids (Doaigey et al., 2013).

The mechanism of foliar absorption of nutrients

The cuticle is composed mainly of the epicuticular wax layer, the cuticular proper (intracuticular waxes and cutin/cutan), and the cuticular layer (polysaccharide material and cutin/cutan). The exposed aerial surface is a complex of the specialized cell of different layers which help plant tolerate unfavorable condition such as herbivory, wind, temperatures, irradiation, vapor pressure deficits, dust, rain, aerial pollutants, drought condition (restrict the loss of nutrients, metabolites, water, and passage of water vapor and gases) physical damage, insect attack, and bacterial and fungal pathogens. Understanding the physiochemical attributes of plant surfaces and the penetration processes of nutrients into the plant can improve foliar fertilization's efficacy and reproducibility.

The nutrient absorption process's success through the leaf surface depends on forming a thin layer of solution wetting the leaf surface (Wójcik, 2004). The presence of substances such as detergent Tween 20 or 80 (surfactant chemicals) is necessary to reduce the solution droplets' surface tension, which increases the adhesion area on the leaf surface (Taiz and Zeiger, 2010). Elements transfer at cell needs the passage of particles through the cuticle layer, which is usually cracked or broken due to the effect of wind on the leaves, allowing the particles to enter the skin that has cytoplasmic channels that help the passage of molecules as well as find spaces between the cells. Also, the presence of stomata, which is the pore, is an important outlet that helps penetrate nutrients into the leaf and the space between the cells. This phenomenon occurs with the property of diffusion (Wójcik, 2004). The foliar absorption mechanism includes Surface absorption, Negative diffusion, and Active uptake by cells.

Surface absorption

The regression concentration is mainly responsible for penetration nutrients from the outside into the cell wall in the free spaces and then reaching into the cells (the cytosol), i.e., from the hydrophobic to the hydrophilic component and from the low to the high charge (Ördög and Molná, 2011).

Negative diffusion

The movement of biochemical and other atoms and molecules across the cell membrane is called *negative diffusion*. Unlike active transport, passive transport does not require the input of chemical energy but is driven by an increase in the system's introspection. The negative transfer rate depends on cell membrane permeability, which depends on the cell membrane's regularity and properties' lipids and proteins. The four main types of passive transport are spread, laxative, filtration, and osmotic (Taiz and Zeiger, 2010). At the time of transpiration, the leaf's central tissue cells lose some water in transpiration, increasing its absorptive strength and withdrawing water from the adjacent cells, which increases the absorption by osmosis and removes moisture from neighboring cells. The stream reaches the vessel's wood absorption by the roots or gaps or skin cells. And then, the leaf's surface and absorption occur through the leaves (Lambers et al., 2008).

Active uptake by cells

Under the cuticle layer (skin cells), as the thickness of the cuticle does not impede the absorption of nutrient ions because of the occurrence of cracks in the layer of cuticle and the presence of cytoplasmic channels extending from skin cells to the area of the cutin, nutrients can enter into the cellular tissue. The process of nutrient absorption through the vegetative parts is similar to absorption across the roots. The elements move between cells and their outer environment based on the water potential difference (Taiz and Zeiger, 2010). The absorption process begins

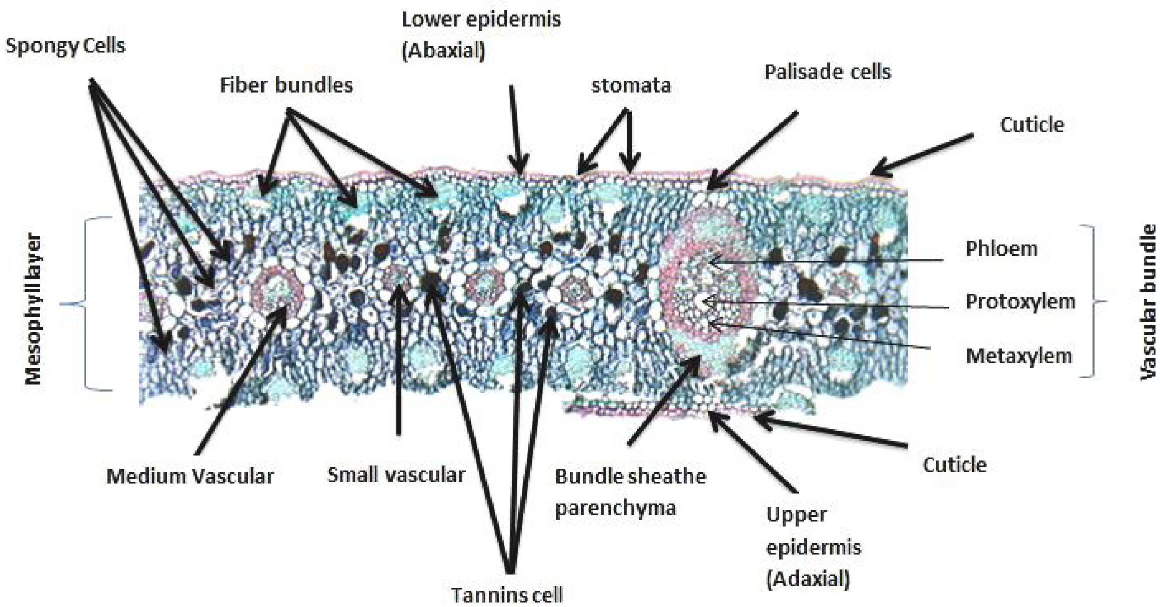

Fig. 3. Typical structure of cross-section to date palm leaflet. Photo by authors.

with the start of the spraying of nutrient solutions. When the leaves are wet, the guard cells' turgor pressure in the leaf increases with the nutrient solutions, leading to the stomata's opening. The permeability of the cuticle increased for nutrients. It penetrates by the pores present inside the cuticle and through small water channels that are also pathways for absorbing the nutrients (Jones and Jeff Jacobsen, 2001).

Essential aspects for spraying technique

There are two essential aspects when using the spraying method on date palm: surfactants and the availability of chelating material.

Surfactants

Surfactants are usually utilized in pesticide definitions to improve a droplet arrangement (Holloway and Stock, 1990). Surfactants have a place with the dynamic surface operators having both hydrophilic and lipophilic gatherings. Such a structure can make "spans" between the fluid arrangement and lipophilic waxes (see Fig. 4) (Schőnherr, 2001). In this way, surfactants decrease the leaf's surface tension, prompting an expansion in leaf wetting. Surfactants likewise bridge the gap between the air layer and the fluid and leaf surfaces, incrementally infiltrate solutes through the stomata, cuticular films, cell dividers, and the point of confinement the drying of beads (see Fig. 4, B) (Wójcik, 2004).

Chelates

Chelates are intricate mixes comprised of a focal metal particle connected by a couple of organizing bonds with a ligand. Metal capacity to make chelates declines with the diminishing electric charge proportion to particle range (Tuteja and Singh Gill, 2013). Chelation encourages

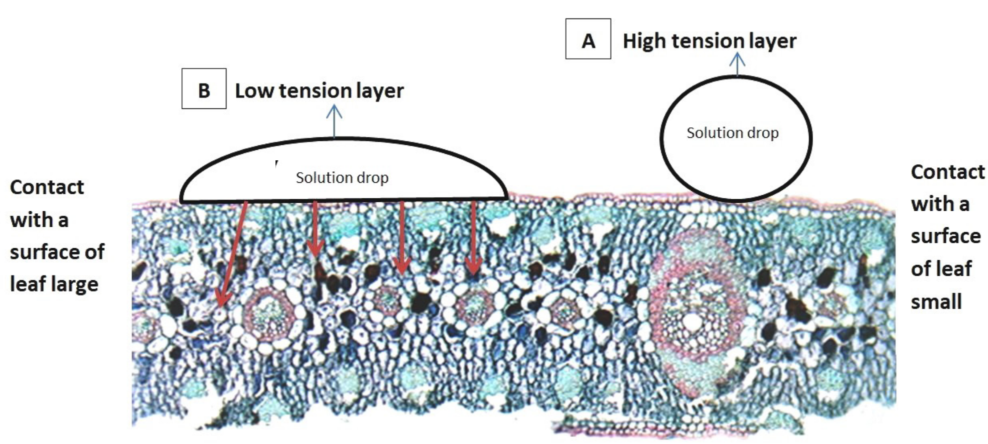

Fig. 4. Effect of surfactant on date palm leaflet surface (A) solution drop without surfactant, (B) solution drop with surfactant. Photo by authors.

the versatility of molecular inside a plant. The utilization of chelated supplement frames, as a rule, does not build retention in connection to inorganic salts (Torabi et al., 2012). Thus, it appears that the impact of chelates on leaf capacity to take up nutrients identified with a few properties of a chelate, for example, a sub-atomic load of the mind-boggling, separation consistent, and steadiness of the complex at different arrangement pH (Keller, 2004). The chelating substances are original mixes with low atomic loads that can shape complex components. Citric acid is one of the most important and widely available types of chelate (Shareef et al., 2017). Chelates are easily absorbed by the plant's roots and veins as organic matter, removing the positive charge of the nutrients and solves the negative charge and enter through the pores of the roots and leaves (Goli et al., 2012). The pores' charge is negative (micro-positive charge) and will be established naturally within the pores and challenging to enter the plant. Easy to move inside the plant, simple to install, and assimilation inside the plant as organic matter. Under alkaline conditions, iron, zinc, magnesium, and copper are the best ways to supply micro-nutrients to the plant, compatible with a wide range of pesticides and liquid fertilizers as they do not interact with their constituents (mixed with dry and liquid substances) (Bharathiraja et al., 2016). Chelate cannot be lost from the soil because it is firmly bonded to soil particles' surfaces, and the natural chelate is better than an industrial chelate (Sekhon, 2003). One of the most important of these chelating materials is organic acids. The best way to use chelate to facilitate foliar fertilization is to mix it with the substance to be sprayed on the date palm in a correct proportion.

Date palm responses to foliar fertilization

The first attempt to use foliar spraying on date palm was during the 1989–1990 growing season in Egypt (Ahmed et al., 1991). The researchers used magnesium sulfate as a fertilizer to overcome the shortage of magnesium in the sandy lands of the Bint Aisha fruit-bearing variety. In the growing season, 1994–1995, the same researcher Ahmed and Abdel Hamid (1997) experimented to identify the behavior of the date palm cultivar of Bint Aisha, which was grown in sandy soils under the influence of boric acid spray. The positive results obtained from both studies contributed to the launching of many experiments on the extent of date palm response to foliar spraying. The earliest attempt in Iraq was by Abass et al. (2007), who used urea and iron application on Hillawi cultivar's productivity. Studies conducted during the past 30 years, either on adult date palm trees or on offshoots, especially those subjected to environmental stresses such as salinity and drought.

Date palm responses to spray foliar of mineral nutrients

Researchers have obtained many positive and clear indications that the date palm does not differ from other plants in response to foliar spraying. All these experiments recommended using their results and conducting other operations to develop the reality of date palm cultivation in the world (Table 1). Most of the nutrients used in feeding date palms are urea, phosphorus, potassium sulfate, potassium silicate, sodium silicate, and boric acid. As well as used whether NPK (20-20-20-1% MgO) or NPK (20-20-20 + Fe-Mn-B-Zn-Mo-Cu) as indicated in Table 1, studies showed positive results in leaf area, fruit weight, and dates production.

Date palm responses to spray foliar of chelated iron

Chelated iron is widely used in feeding date palms in various ways, including foliar spraying. Iron is essential in regulating many enzymes, including peroxidase, catalase, and cytochrome oxidase (De Paula et al., 2019). Iron in these compounds is of particular importance in oxidation reactions, the transfer of electrons in oxidation and reduction reactions, confirming its role in cell metabolism processes. And iron is essential in maintaining green matter inside the plant and the representation of nucleic acids and chloroplasts (De Paula et al., 2019). Several experiments were conducted, including iron, to improve the growth and production of dates are provided in Table 2 (Abass et al., 2012; Faisal et al., 2017; Faisal et al., 2018).

Date palm responses to spray foliar of bio-stimulants

Agricultural biostimulants (ABs) incorporate differing definitions of compounds, substances, and other products, for example, microorganisms, trace elements, enzymes, plant growth regulators, and macroalgal separates that are applied to plants or soils to direct and upgrade the yield's physiological procedures, accordingly making them progressively proficient. "Agricultural biostimulants act on the physiology of the plant through different pathways to improve yields, quality, and post-harvest shelf-life/conservation," according to Sharma et al. (2014). Macroalgal ABs appear to impact respiration, photosynthesis, nucleic acid synthesis, and ion uptake (Du Jardin, 2015). Several studies have used biostimulants to either reduce environmental impacts (Attah et al., 2016; Shareef et al., 2017; Taha and Abood, 2018; Shareef, 2020) or to improve the growth and production of date palm (Altememe and Al-Sirdah, 2012; Al-Wasfy, 2013; Attaha and Al-Mubark, 2014; Al-Haiaj et al., 2020). These studies showed positive results in using biostimulants on date palms and rapid response by plants (see Table 3).

Date palm responses to spray foliar of antioxidants

Antioxidants participate in plant development flowering and organic product improvement through their positive activity on upgrading the biosynthesis of natural hormones, nutrient uptake, photosynthesis, biosynthesis of plant

Table 1. Effect of spray foliar of minerals nutrients on date palm.

Nutrients	Concentrations	Treatment date	Cultivar	Details	References
Urea (N 46%)	1%	Two times: before the opening of the cluster and after the fruit set	Hellawi	• Increased yield and nitrogen content in leaf • Decreasing the percentage of dropping fruits	ABBAS et al. (2007)
	0.5, 1%	At the Khalal stage	Shahany	• Increased pulp weight, pulp/seed ratio, fruit length and diameter • Increased total soluble solids • Increased yield and quality of fruits	KHAYYAT et al. (2007)
	1%	Two times first before opening the cluster and the second at the beginning of the Kimmri stage	Khidrawi	• Decreased of fruits drop • Increased the total yield • Increased nitrogen content in leaf	SHAREEF (2011a)
	1%	Two times: first before opening the cluster and the second at the beginning of the Kimmri stage	Khidrawi	• Increased total soluble solids, total sugars, and reducing sugars • Increased dry matter and percentage of fruit ripening	SHAREEF (2011b)
Zinc sulfate	300, 600 ppm	At the Khalal stage	Shahany	• The more significant part of pulp weight, pulp/seed ratio, fruit length and diameter, Increased Total soluble solids • Increased yield and quality of fruits	KHAYYAT et al. (2007)
Boron H_3BO_3	1,500, 2,500 ppm	At Khalal stage	Shahany	• The more significant part of pulp weight, pulp/seed ratio, fruit length, and diameter • Increased Total soluble solids • Increased boron, increased yield and quality of fruits	KHAYYAT et al. (2007)
	15, 30 mg l^{-1}	Two times on March 15 and April 15	Zehdi and Khestawi	• Increased boron concentration in fruits, seed weight, fruit flesh, the weight of cluster, and total yield	AL-DULAIMY and AL-KRAIDI (2017)
	400, 800, 1,200, 1,600 ppm	In May, June, and July	Medjool	• Increased yield, bunch weight, fruit set, physical fruit characters, and fruit quality	AL-HAJJAJ and AYAD (2018)
Ca rexon (calcium chelate)	1,000, 2,000 ppm	March 1	Berhi and Sayer	• Increased plant height, leaf area, number of new leaves, and girth of the offshoot	JASIM et al. (2016)
Phosphorus	0,125, 250 mg l^{-1}	Two times first in March and the second was after 45 from the first treatment	Shukar	• fruit length, weight, diameters, and volume • percentage of total soluble solids, total sugar, and sucrose • Increased productivity	FASAL et al. (2014)
Sodium selenite	0.01, 0.02%	Four times at growth start, after fruit setting and at one-month intervals	Zaghloul	• Improved growth, nutritional status • Increased yield, bunch weight, and improved quality of the fruits	GAD EL-KAREEM et al. (2014)

Table 1. Continued

Nutrients	Conc.	Treatment date	Cultivar	Details	References
NPK (20-20-20-1% MgO)	2 , 2.5%	Before opening the cluster and at the beginning of the Kammri stage	Khidrawi	• Decreased of fruits drop, increased the total yield • Increased nitrogen content in leaf	SHAREEF (2011a)
	2 , 2.5%	Before opening the cluster and at the beginning of the Kammri stage	Khidrawi	• Increased total soluble solids, total sugars, and reducing sugars • Increased dry matter and percentage of fruit ripening	SHAREEF (2011b)
NPK (20-20-20+Fe-Mn-B-Zn-Mo-Cu)	4, 8 g	Before opening cluster, at the appearance of fluorescences and during the phase of Hababok and the period of Kammri	Barhi	• Improved total chlorophyll content and total soluble carbohydrates • Increased nitrogen, phosphorus, and potassium and total protein in leaf, fruit ripening percentage at Khalal stage and fruit dry weight and yield	ATTAHA AND AL-MUBARK (2014)
	9, 18 g l^{-1}	On March 10, May 10, and April 10	Mak-toom	• Increased the chlorophyll a • Increasing nitrogen, phosphorus, potassium, and total protein.	ALTEMEME et al. (2017)
	2, 1, 4 g l^{-1}	March 1	Khastawi	• Increased weight of fruit pulp and bunch • Increase of fruit N and P content and protein content and K	JUBEIR and AHMED (2019a)
Potassium sulfate	1, 2%	At Khalal stage	Shahany	• Increased pulp weight, pulp/seed ratio, fruit length, and diameter, Increased TSS, increased yield and quality of fruits	KHAYYAT et al. (2007)
	2%	Ten days after pollination	Kabkab	• Increased mineral nutrients • yield and quality of fruits	ABDI and HEDAYAT (2010)
	1, 2, 3% K_2SO_4	In June		• The highest vegetative growth, yield, and fruit quality • Potassium increased	ELSAYD et al. (2018)
Potassium silicate	0.01, 0.02%	Each palm received four sprays at growth start, just after fruit setting, and at one-month intervals	Zaghloul	• Enhancing the leaf area, increased total chlorophylls • Increased percentages of N, P, and K in the leaves • Increased yield, bunch weight, improved quality of the fruits	GAD EL-KAREEM et al. (2014)
	0.05, 0.2 %	Four times at growth start, just after fruit setting and at one-month intervals	Sakkoti	• leaf content of N, P, K, and Mg, increased yield, bunch weight • Improved quality of the fruits	AL-WASFY (2013)
	200, 300, 400 mg l^{-1}	Two times in March and April	Barhi	• Increased chlorophyll a, b, total chlorophyll, carotenoid, • soluble protein, and carbohydrates	FASIL et al. (2019)
Potassium nitrate	1,500 ppm	October 1	Sayer	• Increased the number of clusters, the number of new leaves • Increased the content of carbohydrates, ascorbic acid • Increased indoleacetic acid, zeatin, gibberellin, and abscisic acid • Showed five and six protein bands, respectively, that differed in the molecular mass of one polypeptide	SHAREEF (2019)
Potassium silicate	0.01, 0.02%	Each palm received four sprays at growth start, just after fruit setting and at one-month intervals	Zaghloul	• Enhancing the leaf area, increased total chlorophylls • Increased percentages of N, P, and K in the leaves, increased yield, bunch weight, improved quality of the fruits	GAD EL-KAREEM et al. (2014)

pigments, and sugars. Protecting the plant from biotic and abiotic stress increases antioxidant defense systems and reduces reactive oxygen species (Merwad et al., 2015). Antioxidants such as organic acids, amino acids, and vitamins may assume a straightforward job in solving the problem of low yield through enhancing growth, nutritional status (Dorria et al., 2012) such as date palm (Fasal et al., 2014; Shareef, 2016; Al-Dulaimy and Al Kraidi, 2017; Shareef, 2019) (see Table 4).

Date palm responses to spray foliar of nano-fertilization

The use of nano-fertilizers in agriculture to increase crop yield increases interest due to their unique physicochemical properties. Nanotechnology is utilized as spray-based delivery systems in fruit crop nutrition (Nasrollahzadeh et al., 2019). Nano-fertilizers (NFs) assume significant roles in expanding vegetative development, improving regenerative growth and flowering, and efficiency, item quality, and the time frame of realistic usability (Zahedi et al., 2020)which play very important roles in increasing vegetative growth, improving reproductive growth and flowering, thereby increasing productivity, product quality and ultimately increasing shelf-life and decreasing fruit waste. These nanomaterials, which are generally sprayed at low concentrations on trees at different time intervals and in frequent sessions, are also considered as growth stimulants. Macro- and micro-scale NFs such as zinc, boron, chitosan, and fertilizer nanocomposites such as ZnFeMnB (zinc, iron, manganese, boron). Nanomaterials generally sprayed at low concentrations at various time intervals, are additionally considered as development energizers for date palm, for example, nano-boron, (Super Fifty) seaweed extract, Optimus-Plus (5% nitrogen, 30% amino acids, and 3% organic nitrogen), Super-micro plus (Mn 0.7%, Mg 6%, Ca 6%, Fe 4.5%, Zn 8%, K 3%, P 3%, N 5%, Mo 0.1%, B 0.65%, and Cu 0.65%) (Refaai, 2014; Jubeir and Ahmed, 2019a; Jubeir and Ahmed, 2019b; Ressan and Al-Tememi, 2019; Shareef et al., 2020) (see Table 5).

Advantages and disadvantages of foliar fertilization to date palm

Foliar fertilization has certain potential benefits; for example, the provision of fertilizers where the use of small amounts of fertilizer is appropriate compared to soil fertilization. Foliar fertilization can overcome the problems of soil factors that lead to the low utilization rate of manure, whether these factors lead to loss of fertilizer in the form of gas, or with irrigation water such as nitrogen, or determine the movement of sediment or fixing, such as phosphorus and microelements. The plant's rapid supply needs for elements during certain stages of growth, such as flowering or the beginning of the development of seeds and fruits, where root absorption of nutrients has often ceased. The earth's elements' interactions make absorption by the roots small, and boron and manganese

Table 2. Spray foliar of chelated iron on date palm

Nutrients	Concentrations	Treatment date	Cultivar	Details	References
Iron sulfate	250 ppm	Two times before the opening of the cluster and after the fruit set	Hellawi	● Increase in yield ● Decrease the dropping fruit percentage	Abbas et al. (2007)
	20, 40 ppm	First 14 weeks of pollination and the second after 16 weeks of pollination at the end of the Kammri stage	Hellawi	● Increased carbohydrate and chlorophyll in the leaf ● fruit weight, flesh weight ● fruit volume, length, and diameter ● Percentage ripening	Abass et al. (2012)
Chelated Iron	25, 50 mg l^{-1}	After 8 and 12 weeks of pollination	Sayer	● Increased TSS, total sugar, reducing sugar and dry material	Faisal et al. (2017)
	25, 50 mg l^{-1}	One time on 1 April	Sayer	● fruit weight ● fruit diameters	Faisal et al. (2018)

Table 3. Spray foliar of bio-stimulants on date palm

Nutrients	Concentrations	Treatment date	Cultivar	Details	References
Seaweed (Kelpak)	8, 16 $cm^3\ l^{-1}$	Before the opening cluster, at the appearance of the fluorescences, and during the Hababok and Kimri stages	Barhi	• Improved total chlorophyll content • Increased total soluble carbohydrates • Increased phosphorus and potassium in leaf • Increased fruit ripening percentage at Khalal stage, Increased fruit dry weight, and total yield	ATTAHA and AL-MUBARK (2014)
	4 and 8 ml l^{-1}	March 1	Barhi	• Increased K, Mn, dry weight of fruit, amino acid	TAHA and ABOOD (2018)
	4 ml l^{-1}	On March 1 and repeated on May 1	Hillawi	• Increased chlorophyll content, organic solutes, • Increased included indole-3-acetic acid, zeatin, and gibberellin • Increased amino acids and ascorbic acid • Increased K+/Na+ ratio	SHAREEF (2020)
Dry yeast (*Saccharomyces cerevisiae*)	4 g l^{-1}	On March 1 and repeated on May 1	Hillawi	• Increased chlorophyll content, organic solutes, • Increased included indole-3-acetic acid, zeatin, and gibberellin • Increased amino acids and ascorbic acid • Increased K+/Na+ ratio	SHAREEF (2020)
Folrtail (Potassium chelate)	10 ml^{-1}	March 1	Berhi and Sayer	• Increased plant height, leaf area, number of new leaves, and girth of the offshoot • Increased total chlorophyll content, total soluble carbohydrates, and soluble protein • Increase peroxidase activity and reduced catalase activity • Increased endogenous IAA and decreased endogenous ABA	SHAREEF et al. (2017)
Royal jelly	0.025 to 0.1 %,	Four times at growth start, just after fruit setting and at one-month intervals	Sakkoti	• Enhancing growth, nutrients namely N, P, K and Mg in the leaves • yield and fruit quality	AL-WASFY (2013)
Wheat seed sprout	0.5 to 2.0 %	Four times at growth start (1st week of Mar.), just after fruit setting (last week of Apr.), and at three-week intervals	Zaghloul	• Enhanced all growth characters, plant pigments, total carbohydrates, nutrients, bunch weight, yield as well as both physical and chemical characteristics of the fruits	REFAAI (2014)
Fetrilon Combi 2	0.025, 0.050, 0.075, 0.100%	Two days before pollination and four weeks after pollination	Hallawi	• Increase in ripening percentage and Total yield and increase in water content • Invertase activity, and the ionic concentration of the fruit and sucrose	ALTEMEME and AL-SIRDAH (2012)
Drin	(2 and 4) ml l^{-1}	Two times on March 15 and June 13	Hillawi	• Increased the dry fruit matter, total soluble solids, free amino acids, soluble protein of fruit, carbohydrates • Increased total chlorophyll concentration of fruit, catalase activity of foliage and fruit	ATTAHA et al. (2016)

Table 3. Continued

Nutrients	Concentrations	Treatment date	Cultivar	Details	References
Vegeamino	(2 and 4) ml l^{-1}	Two times on March 15 and June 13	Hillawi	• Increased seed weight • Increased auxins and abscisic acid concentration • Increased vitamin C of fruit	Attaha et al. (2016)
Humic acid	4 and 8 ml l^{-1}	March 10, May 10, and April 10	Maktoom	• Increased the chlorophyll a • Increasing nitrogen, phosphorus, potassium, and total protein in the leaves.	Altememe et al. (2017)
Chitosan	5 ml l^{-1} and 10 ml l^{-1}	March 1	Barhi	• Increased K, Mn, dry weight of fruit, and amino acid	Taha and Abood (2018)
Biocont - T	1.5 g l^{-1}	Four times from Feb to Abril	Sayer	• Increased the fruit weight, the percentage of the fruit set, the percentage fruit ripening, the bunch weight, and the total yield of fruits	Ressan and Al-Tememi (2019)
Alqawafel K-fertilizer	800, 1,600, 3,200 and 4,000 mg l^{-1}	Three times on May 20, June 20, and July 20	Medjool	• Increased total yield, fruit size, fresh weight, total reduced sugar, fructose content, and glucose content	Al-Hajaj et al. (2020)

deficiency symptoms, iron, zinc, copper, and molybdenum will be apparent. While the use of foliar spray quickly compensates for the shortage of these elements. Ground fertilization is limited to roots only and needs time to reach the other organs, while foliar fertilization can get all parts of the plant for ease (Mikkelsen, 2007)

Foliar fertilization is 8–20 times more efficient than ground fertilization, especially in the delivery of micronutrients. This nutrition has a high elasticity in the addition of fertilizers during the different growth stages, thus meeting the plant's nutrient requirements during different growth periods (Fernández and Brown, 2013). The addition of nutrients to plants through spray-application ensures the nutrient is inputted directly into the plant and enhances plant tissue metabolism, reducing energy consumption. The foliar technique increases the potential for mixing nutrients with growth regulators, saving much effort and time (Salvagiotti et al., 2008).

Due to an inadequate understanding of the involved principles, foliar fertilization technology's full potential is not realized completely. According to the literature, knowledge gaps for developing and improving foliar fertilization strategies are apparent. However, valuable information about plant physiology, uptake mechanisms, fertilizer formulation, etc., are available. The use of foliar feeding is not without problems, and most of them depend on farmers through the use of chemicals fertilizer, especially urea, with higher concentrations than recommended. Seedlings or offshoots whose root group did not develop are still more at risk of higher levels of the elements because the plant metabolism cycle cannot get rid of excess metabolism by the roots, which leads to the toxicity of the plant. Researchers and those interested in date palm should not spray young palm trees (offshoots), especially in the first two years of cultivation, in addition to conducting soil and plant tests to determine the plant's needs for foliar fertilization. High temperature disrupts the plant's metabolism, and therefore the response may be malicious or harmful to the plant, and so on for the phenomena required for foliar fertilization. Not all symptoms of chlorosis leaves are due to a lack of nitrogen; it may be the opposite because yellowing also occurs to increase the concentration of ammonia in the plant or infection with a slight insect like a palm stalk borer. In total, foliar fertilization has great adaptive potential in modern date palm management.

Conclusions

Ultimately, the decision to use foliar fertilizers requires considerations of relative costs versus supply and demand factors. In general, when the farming system, soil type, or environmental factor is a severe obstacle to providing the required nutrients through the soil. In terms of efficacy and economics, the application of foliar fertilization can be a critical potential practice factor. Currently, after 30 years of applying foliar nutrients to date palms, this nutritional technique has proven suitable for date palms not only to fill deficiencies in some elements but to improve plant

Table 4. Spray foliar of antioxidants on date palm

Nutrients	Concentrations	Treatment date	Cultivar	Details	References
Citric acid	500 and 1,000 ppm	March 1	Berhi and Sayer	• Increased plant height, leaf area, number of new leaves and girth of the offshoot • Increased total chlorophyll content, total soluble carbohydrates, proline concentration, and soluble protein, increase peroxidase activity and reduced in catalase activity, increased endogenous IAA and decreased endogenous ABA	SHAREEF et al. (2017)
	800 ppm	In the first week of March	Kabkab and Ghannami Ahmer	• Decreasing leaf Na+ and Cl- and increasing leaf K+ and K+/Na+ ratio	SHAREEF (2016)
	500, 1,000 ppm	March 1	Berhi and Sayer	• Increased plant height, leaf area • Increased total chlorophyll content, total soluble carbohydrates, proline concentration, and soluble protein • Increase peroxidase activity and reduced catalase activity • Increased endogenous IAA and decreased ABA	SHAREEF et al. (2017)
Salicylic acid	50, 100 mg l^{-1}	One time on April 1	Sayer	• Increased fruit weight and fruit diameters • Increased TSS, Total sugar, reducing sugar • Increased and dry matter • Decreased sucrose and acidity percentage	FAISAL et al. (2017)
	100, 150 mg l^{-1}	Two times on March 15 and April 15	Zehdi and Khestawi	• Increased fruit length • Increased seed weight, fruit flesh, the weight of cluster, and total yield	AL-DULAIMY and AL-KRAIDI (2017)
	500 ppm	October 1	Sayer	• Increased the number of clusters, the number of new leaves, • the content of carbohydrates, ascorbic acid, • indoleacetic acid, zeatin, gibberellin, and abscisic acid • Showed five and six protein bands, respectively, that differed in the molecular mass of one polypeptide	SHAREEF (2019)

Table 4. Continued

Nutrients	Concentrations	Treatment date	Cultivar	Details	References
Proline	125, 250 mg l^{-1}	Two times (at March and the second was after 45 from the first treatment)	Shukar	• Fruit length, weight, diameters, and volume • Percentage of total soluble solids, total sugar, and sucrose • Increased productivity	Fasal et al. (2014)
	50, 75 and 100 mg l^{-1}	Every ten days	date palm seedling	• The increased diameter of bundle sheath cells, fibrous bundles, the length and width of the vascular bundles, the distance between the vascular bundles • Increased the epidermis and cortex, the vascular cylinder's diameter, primary and secondary xylem, and the root's phloem	Alnajjar et al. (2020)
Amino acids	0.05 %	Twice times (after fruit setting), thrice (at the same previous two dates and one month later)	El- Saidy	• Increased all nutrients • Increased plant pigments • Increased total carbohydrates • Increased yield and fruit quality	Ahmed et al. (2014a)
	3, 6 ml l^{-1}	March 1	Barhi	• N content, P content leaves, Fe content, and dry weight of fruit	Taha and Abood (2018)
	600 ppm	During the first week of March	Kabkab and Ghannami Ahmer	• Decreasing leaf Na+ and Cl- and increasing leaf K+ and K+/Na+ ratio	Shareef (2016)
Ascorbic Acid	150, 300, 400 mg l^{-1}	Two times in March and April	Barhi	• chlorophyll a, b, total chlorophyll, carotenoids, soluble protein, and Total soluble carbohydrates	Fasil et al. (2019)
	500, 1,000 mg l^{-1}	Two times on March 15 and June 13	Hillawi	• Increased total chlorophyll and carotene pigments concentration of leaf • Increased proline of leaf • Increased peroxidase activity • Increased bunch weight and total yield	Attaha et al. (2016)
Glutathione	0.2, 0.05 %	Four times at growth start (last week of April), just after fruit setting (last week of March), and at one-month intervals (last week of April and May)	Zaghloul	• Promotion on the leaf area • Total chlorophylls, • Leaf content of N, P, K • Yield, bunch • Weight and fruit quality	Ahmed et al. (2014b)
Vitamin B	Vitamins B (B1 at 250 ppm + B6 at 100 ppm and B12 at 250 ppm)	Four times at growth start, just after fruit setting and at one-month intervals	Sakkoti	• Enhanced growth, nutrients namely N, P, K and Mg in the leaves • Enhanced yield and fruit quality	Al-Wasfy (2013)
Tocopherol	150, 300, and 400 mg l^{-1}	Two times in March and April	Barhi	• Reduction in the concentration of the amino acid proline in the leaves	Fasil et al. (2019)

Table 5. Spray foliar of nano-fertilization on date palm

Nutrients	Concentrations	Treatment date	Cultivar	Details	References
Nano- boron	0.25 to 0.1%	Four times at growth start (1st week of Mar.), just after fruit setting (last week of Apr.), and at three weeks intervals	Zaghloul	• Enhanced all growth characters, plant pigments, total carbohydrates, nutrients, bunch weight, yield as well as both physical and chemical characteristics of the fruits	REFAAI (2014)
(Super Fifty) seaweed extract	2, 1, 4 ml l^{-1}	March 1	Khastawi	• Increased weight of fruit pulp and bunch • Increase of fruit nitrogen and phosphor content and protein content and potassium	JUBEIR and AHMED (2019a)
	2, 1, 4 ml l^{-1}	March 1	Khastawi	• Increased dry matter in leaves, chlorophyll content, and yield of fruit	JUBEIR and AHMED (2019b)
Optimus-Plus	1, 2 ml l^{-1}	March 1	Khastawi	• Increased weight of fruit pulp and bunch • Increase of fruit nitrogen and phosphor content and protein content and potassium	JUBEIR and AHMED (2019a)
	1, 2 ml l^{-1}	March 1	Khastawi	• Increased dry matter in leaves, chlorophyll content, and yield of fruit	JUBEIR and AHMED (2019b)
	1.5 ml l^{-1}	Four times from Feb. to April	Sayer	• Increased the fruit weight, the percentage of the fruit set, the percentage fruit ripening, the bunch weight, and the total yield of fruits	RESSAN and AL-TEMEMI (2019)
Super micro plus	1, 2 g $^{l-1}$	April 1 and May	Hillawi	• Increased in fruit ripening rate, dry mass, and total soluble solids • Increased the enzymes peroxidase, and superoxide dismutase activity, and abscisic acid content	SHAREEF et al. (2020)

growth and increase production. Foliar nutrients do not mean relying primarily on foliar nutrition rather than soil fertilizing. Earth compost is essential for basic plant nutrition and an irreplaceable option in improving soil fertility and plant supply on the planet.

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