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Enhancing yield and fruit quality of date palm (*Phoenix dactyllifera* L., *cv.* Zaghloul) using nitrogen and potassium nano-fertilizer

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Abstract

The present investigation was carried out during two successive seasons of 2018 / 2019 and 2019/ 2020 on 15-year-old date palm trees of Zaghloul cv. grown in sandy soil in a private orchard in El-Behira governorate, Egypt. The research aimed to investigate the effect of nitrogen and potassium nano-fertilizers on yield and fruit quality compared with conventional mineral fertilizers. Four doses of nitrogen and potassium nano-fertilizer (75, 150, 300 and 600g/ palm/ year) were applied compared to the conventional nitrogen and potassium mineral fertilizers as a control. Different fertilization treatments significantly affected palm yield and fruit quality during both seasons. Treatment of 600g of nano N and K fertilizers produced higher values of tree yield and bunch weight, fruit volume, and fruit length in both seasons. Meanwhile, 600g of nano-fertilizer and control treatments gave the highest fruit and flesh weight. The obtained results also showed fruit content of total soluble solids, total and reducing sugars was significantly increased by nano-fertilizer treatment at 600 and 300g per palm and improved significantly N, P, and K content. Whereas treatment with 75 and 150g nano-fertilizer gave higher values of total tannins and phenol contents in Zaghloul fruits in both seasons. In the presnet study, nano-fertilizers have demonstrated their remarkable ability to enhance date palm yields, elevate fruit quality, and improve nutritional richness.

Key words: Date palm, nano-fertilizer, yield, fruit quality

Introduction

Date palm (*Phoenix dactyllifera* L., family: Palmaceae) is one of the oldest fruit tree crops in the world. It is known as "Tree of life" because of its resilience, long-term productivity and multiple-purpose qualities (Chao and Krueger, 2007). Dates are considered an ideal food that provides many essential nutrients and health benefits. The fruit of dates are a good source of sugars, vitamins, minerals and fiber (Al-Farsi *et al.,* 2007; Elleuch *et al.,* 2008; El-Shibli and Korelainen, 2009). About 100 million date palm trees are growing globally, and about 60% are grown around Arabian countries, the Middle East, and North Africa (Chao and Krueger, 2007; Wakil *et al.,* 2015). Egypt is the leading date palm producer in the world, followed successively by Iran and Saudi Arabia (Bekheet and El-Sharabasy, 2015). In Egypt, dates are important traditional crops; many cultivars, such as Barhi, Zaghloul, Samany, and Hayany, are grown in different regions (Kassem, 2012; Bekheet and El-Sharabasy, 2015). Economically, Zaghloul date is one of Egypt's most important local soft cultivars (El-boray *et al.,* 2012). Date palm yield and fruit quality depend on various factors, including cultivar, climate, soil condition and cultural practices (Mohamed *et al.,* 2004; Al-Rawahi *et al.,* 2005; Al-Farsi *et al.,* 2007). There is a general agreement that nutrition is one of the most important factors affecting tree growth, yield, and fruit quality (Kassem and Marzouk, 2010; Kassem., 2012). Fertilization is one of the most important practices in the orchard management system; it represents approximately 20% of the total production costs, of which more than 80% is devoted to nitrogen fertilizers. Nitrogen, phosphorus and potassium are the primary nutrients in commercial fertilizers; each of these nutrients plays a key role in plant nutrition. When applying fertilizers to the palms, we aim to maximize nutrient uptake to achieve the optimum growth, yield and fruit quality (Tung *et al.,* 2009). However, the low use efficiency and high cost of mineral fertilization is a big problem for fruit tree growers (Raliya *et al.,* 2017). Zulfiqar *et al.* (2019) reported that the estimated losses of nitrogen and potassium fertilizers are approximately 40-70% and 50-90%, respectively. In addition, recent research revealed that mineral fertilizers have a role in health problems and environmental pollution (Kabeel *et al.,* 2005). Recently, nanotechnology has received much attention. It is expected to support various applications in chemistry, physics, biology and medicine (Mansoori and Soelaiman, 2005). Nanotechnology is the manipulation of the self-assembly of individual atoms or molecules to create ultra-small particles with vastly different properties (Joodaki, 2012). The unique properties of the nanoparticles enable applications in a wide range of agriculture fields, *e.g.*, enhancing plant growth, yield, and production of secondary metabolites (Babu *et al.,* 2021). Moreover, nanotechnology aims to develop a new delivery system of nutrients and pesticides, thereby reducing waste and environmental pollution (Tarafdar *et al.,* 2013; Nuruzzaman *et al.,* 2016; Wang *et al.,* 2016; Ismail *et al.,* 2017). Such systems are designed to deliver mineral nutrients in a regulated pattern corresponding to the plant requirements (Manikandan and Subramanian, 2015). Nano-fertilizers are nanomaterials that provide one or more types of nutrients to the growing plants, supporting their growth and improving production (Liu and Lal, 2015). Nano-fertilizer with a slow releasing ability is a suitable alternative to conventional fertilizer to increase crop productivity, enhance nutrient use efficiency, and increase soil fertility; moreover, the application can be made in smaller amounts, which in turn minimizes nutrient losses and reduces the risk of environmental pollution (Liu *et al.,* 2006; Barrios *et al.,* 2016; Raliya *et al.,* 2017).

Nano-fertilizers provide high-efficiency nutrients and low waste due to their higher absorption and translocation within plant tissue (Subramanian and Rahale, 2009; Rico *et al.,* 2011). Controlled-release kinetics of nanoparticles make them "a smart delivery system" of mineral nutrients (Naderi and Danesh-Shahraki, 2013; Solanki *et al.,* 2015; León-Silva *et al.,* 2018). Previous research showed that nano-fertilizers improve plant growth, flowering, increase crop yield, fruit quality and decrease fruit waste (Zahedi *et al.,* 2020); macro and micro-scale nano-fertilizers significantly improve vegetative and reproductive growth of fruit trees such as pomegranate (Zahedi *et al.,* 2019), mango (Saied *et al.,* 2018), date palm (Refaai, 2014), and grape (Sabir *et al.,* 2014). However, research on the effect of nano-fertilizers on the fruiting behavior of date palm trees is limited, and more research is needed on these topics. As a result, the current study compares the effects of nano- and conventional nitrogen and potassium fertilizers on date palm yield and fruit quality in the Zaghloul date palm cultivar.

Materials and methods

The current study was conducted during two successive seasons (2018/2019 and 2019/2020) on 15-year-old Zaghloul date palm trees. Date palm trees were grown in a private orchard at Cairo, Alex. desert road, El-Behara governorate, Egypt. The experiment was conducted on 15 healthy, vigor and uniform date palm trees. The date palm trees were planted in sandy soil at 10 x 10m under a drip irrigation system. Soil and water samples were analyzed according to AOAC (Cunniff, 1997) at the Soil and Water Laboratory, Water and Environmental Research Institute, Agricultural Research Centre, Giza, Egypt. The soil sample was collected randomly at 30, 60 and 90 cm depth. Chemical analysis of water and soil samples in the experimental orchard are illustrated in Tables (1 and 2). The standard horticultural management practices (irrigation, pruning, pollination and pest) were carried out as usual in a commercial production system.

Fertilization treatments: The nano-fertilizer of NPK (15:0:9) was obtained from Zongcheng Guolian Biotechnology Co. Ltd, China. The nano fertilizer was applied at four doses (75, 150, 300 and 600g /palm /year of the powder nano-fertilizer). Each dose was applied in three equal batches in April, June and October. All palms that were treated with nano-fertilizer didn't receive any chemical fertilization. Nano-fertilizer dose was dissolved in 5 litter water and applied to each palm tree separately. The control treatment was applied using the chemical form of nitrogen and potassium; ammonium sulfate (20.6% N) was used as a nitrogen source, and potassium sulfate (Ever sol; 50% K_2O) was used as a potassium source. The palm of control treatment received 1500g (N) and 1000g (K) / palm/year as recommended previously (Ezz *et al.,* 2010; Marzouk, and Kassem, 2011) and was added as soil application with irrigation water from February to October. Phosphorus was added to all palms at 750 g P_2O_5 in the form of calcium superphosphate (12.5% P_2O_5) and phosphoric acid (85% P_2O_5), and micronutrients mix was applied at 100g/ palm divided into two doses in February and July. The fruits were harvested at khalal stage in the first half of September in each season, and the following measurements were determined:

Table 1. Chemical analysis of experimental orchard soil samples

Parameter		Sample		
		30 cm	60 cm	90 cm
pH		7.3	7.4	7.6
Cation (mel^{-1})	K+	23.23	0.61	0.42
	Na+	42.08	27.2	32.83
	Mg++	80.66	12.07	17.96
	Ca++	98.68	36.84	34.21
Anion (mel^{-1})	SO4--	159.42	48.94	53.41
	Cl-	122.88	25.24	29.66
	HCO3-	2.36	2.36	2.36
	CO3-	-	-	-

Table 2. Chemical analysis of experimental orchard irrigation water sample

Parameter		Value
pH		7.42
E.C		1.46
Cation mel^{-1}	K^+	0.3
	Na^+	7.5
	Mg^{++}	1.8
	Ca^{++}	3.9
Anion mel^{-1}	$SO4^{--}$	1,89
	Cl^-	11.1
	HCO^{3-}	0.51
	CO^{3-}	-

Yield and fruit physical characteristics: Each bunch was weighted at harvest to calculate the average bunch weight (kg) and yield per palm. Then, a sample of 10 fruits was randomly collected from each replicate to estimate fruit weight (g)**,** flesh weight (g), fruit volume (cm³) and fruit length (cm)

Fruit chemical characteristics

Total soluble solids %: Total soluble solids was determined in date palm fruit juice using a Carl Zeiss hand refractometer.

Total sugars (g.100g^{-1} FW): In ethanol extract, total sugars was determined by the phenol-sulphuric acids methods according to Dubois *et al.* (1956). One mL of ethanol extract was mixed with 1mL of 5% phenol, followed by the addition of 5mL of concentrated sulfuric acid. The mixture was shaken gently and left to cool. The absorbance of the developed yellow-orange colour was measured at 490 nm using a spectrophotometer. The total sugar amount was calculated from a standard curve using pure glucose.

Total phenols (g.100g^{-1} FW): Total phenols content was determined according to Velioglu *et al.* (1998), 0.5 mL of Folin-Ciocalteu reagent was added to 1 mL of ethanol extract followed by addition of 4 mL of 2.5% sodium carbonate. The tubes were shacked and left 30 min. in the dark at room temperature; the absorbance was measured at the wave length of 725 nm. The amount of total phenols was calculated from a standard curve using gallic acid.

Total soluble tannins ($g.100g^{-1}$ FW): Total soluble tannins was measured according to Taira (1996). 1 mL of ethanol extract was mixed with 6 mL distilled water and 0.5 mL 10% Folin-Ciocalteu reagent and shaken well. After 3 min, 1 mL of saturated sodium carbonate was added and mixed well. Then, 1.5mL distilled water was added, mixed well, and left for one h at room temperature before measuring absorbance at 750 nm. Soluble tannins were quantified from a calibration curve using gallic acid.

Fruit nutrient content: 10g of fresh fruit samples were dried in an oven at 70°C for 72 hours; 0.5 of the fruit dry weight was digested with sulfuric acid and hydrogen peroxide (Evanhuis and De Waard, 1980). Fruits content of nitrogen was determined with the Micro-kjeldahl method (Cunniff, 1997). The phosphorus content was determined with atomic absorption spectrophotometer (Model 305B) and the content of potassium was determined with the Flame photometer method (Temminghoff and Houba, 2004).

Statistical analysis: The experimental treatments were arranged in a completely randomized block design. Analysis of variance was performed using the SPSS software (version 25). The mean and standard error were calculated from three replicates per treatment and the significant differences within and between treatments were assessed using a multiple-range test at a significance level of 0.05 (Duncan, 1955).

Results and discussion

Palm yield and bunch weight (kg): Data in Table 3 show that applying nano-fertilizers at 300 & 600g / palm/ year significantly improved tree yield and bunch weight compared to the conventional form of N and K. The best fertilization treatment *via* nano fertilizers was 600g, followed by 300g, and the conventional form of N and K (control). The obtained results agreed with Soliman and Osman (2003) who found that the date palm yield was significantly increased by nitrogen and potassium fertilization; N and K are essential mineral in photosynthesis and plant growth (Hou *et al.,* 2019). Nitrogen and potassium increases yield by increasing the number, weight, and size of fruits (Kassem, 2012; Muhammad *et al.,* 2018). The positive effect of nano-fertilizer application may be attributed to nanoparticles' unique properties, *e.g.*, small surface area with high absorption (Sekhon, 2014). These nano-fertilizers increase nutrient use efficiency, reduce soil toxicity, minimize the potential negative effects associated with overdosage, and reduce the application frequency (Qureshi *et al.,* 2018). Nano-fertilizers mainly delay the release of nutrients and extend the fertilizer effect period. There is an opportunity for nanotechnology to significantly influence the economy and the environment by improving fertilizer use efficiency (Ditta, 2012). The nano-fertilizer application's effect on yield was reported previously in different crop species, including potato, corn and rice (Wang *et al.,* 2011; Khaveh *et al.,* 2015; Zareabyanel *et al.,* 2015).

Fruit physical properties

Fruit and flesh weight (g): Regarding the effect of fertilization treatments on fruit weight, the obtained results indicated that, fertilization with the conventional nitrogen and potassium fertilizers form (1500 g N, and 1000 g K) and 600 g nano-fertilizer

Table 3. Effect of nano and conventional fertilizers on yield and bunch weight of Zaghloul date palm

Fertilization treatments	Yield (kg)	Bunch weight (kg)
First season (2018/2019)		
Control	116.30 c	14.00 b
75 g nano-fertilizer	101.30 d	12.66 b
150 g nano-fertilizer	104.00 d	13.00 b
300 g nano-fertilizer	131.67 b	15.75 a
600 g nano-fertilizer	147.67 a	17.06 a
Second season(2019/2020)		
Control	126.33 c	15.16 ab
75 g nano-fertilizer	106.00 e	13.88 b
150 g nano-fertilizer	117.41 d	14.67 b
300 g nano-fertilizer	134.00 b	16.12 ab
600 g nano-fertilizer	149.50 a	17.31 a

Mean values followed by different letters are significantly differed at $P < 0.05$; each value represent mean of three replicate± standard error (SE)

gave the highest fruit weight, without significant differences between them, followed by 300g nano-fertilizer per palm as compared with other treatments in the first and second seasons (Table 4). Regarding the effect of fertilization treatments on the flesh weight of date palm fruits, 600 g nano fertilizer and conventional fertilizers form (1500 g N and 1000 g K) gave the highest flesh weight without significant differences between them, followed by 300 g nano fertilizer per palm.

Fruit length (cm): According to the data illustrated in Table 4, fruit length was significantly affected by the different fertilization treatments. The obtained data indicated that nano-fertilizer at (600g and 300g) per palm recorded the highest fruit length, followed by conventional fertilizer form (1500g N and 1000g K). The data indicated that treatment with nano-fertilizer at 75 and 150g per palm recorded the lowest fruit length.

Table 4. Effect of nano and conventional fertilizers on fruit weight (g), flesh weight, fruit length and fruit volume of Zaghloul date palm

Treatment	Fruit weight (g)	Flesh weight (g)	Fruit length (cm)	Fruit volume (cm)
First season (2018/2019)				
Control	23.20± 0.00 a	21.20±0.16a	5.68±0.23 b	26±1.15 ab
75 g NF	18.90 ±2.05b	16.87±2.03b	5.05±0.05 c	23.33±0.66 b
150 g NF	19.87±1.32 b	18.03±1.37b	5.23±0.03 c	24.00±0.57 b
300 g NF	21.00±0.82 ab	18.77± 0.05ab	5.81±0.08 ab	27.67±0.66 a
600 g NF	23.00±0.00 a	21.40± 0.00a	6.11±0.06 a	28.00±1.15 a
Second season (2019/2020)				
Control	23.700.16± a	21.47± 0.21ab	5.72±0.19 b	26.5±1.18 ab
75 g NF	19.20±2.05c	17.17±2.03c	5.14±0.06 c	23.53±0.66 c
150 g NF	20.00±0.82bc	19.37± 0.90bc	5.19±0.04 c	24.2±0.63cb
300 g NF	22.50±0.41ab	20.80± 0.16ab	5.98±0.13 b	28.16±0.71 a
600 g NF	24.00 ±0.82a	22.30 ±0.24a	6.40±0.04 a	28.6±1.21 a

Means values followed by different letters significantly differ at $P < 0.05$; each value represents a mean of three replicate± standard error (SE).

Fruit volume (cm^3): It is obvious from the data presented in Table 4 that in both seasons, nano fertilizer at 600 g per palm gave the highest fruit volume, followed by treatment with nano-fertilizer at 300 g per palm compared with conventional fertilizer form. The results showed that the physical fruits properties were significantly affected by nitrogen and potassium fertilization treatment in both seasons. These results are in harmony with those obtained by Baruah and Dutta (2009) and Sabir *et al.* (2014). Soliman and Osman (2003) found that date palm fruit length and diameter were significantly affected by fertilizer treatments. Nitrogen fertilization increased the fruit weight of pear (Sete *et al.,* 2019) and peach (Ferreira *et al.,* 2018). Kassem (2012) reported that potassium fertilization increased the fruit weight, volume, and dimensions as potassium plays an important role in cell expansion. Nano-fertilizers positively affected the number and weight of mango and pomegranate fruits (Davarpanah *et al.,* 2016; Zagzog and Gad, 2017).

Table 5. Effect of nano fertilizers on fruit content of phenols, tannins reducing sugars, total sugars and total soluble solids of Zaghloul date palm

Treatments	Total phenols (mg/g)	Total tannins (mg/g)	Reducing sugar (mg/g)	Total sugars mg/g)f.w	TSS (%)
		First season (2018-2019)			
Control	3.29b	0.53b	18.75ab	22.75ab	28.10ab
75g NF	3.38a	0.69a	15.39b	19.36b	27.23b
150g NF	3.36a	0.64a	17.68ab	22.25ab	27.5ab
300g NF	3.25c	0.47bc	19.58ab	24.77ab	28.3ab
600g NF	3.21d	0.44c	19.99a	25.32a	28.6a
		Second season (2020-2021)			
Control	3.28b	0.46b	21.13ab	25.55ab	28.33ab
75 NF	3.37a	0.58a	18.04b	21.64b	27.33b
150g NF	3.35a	0.55a	20.08ab	24.44ab	27.62ab
300g NF	3.23c	0.41bc	22.58a	27.37ab	28.45ab
600g NF	3.17d	0.37c	23.72a	28.56a	28.83a

Means values followed by different letters significantly differ at $P < 0.05$; each value represents a mean of three replicate± standard error (SE).

Fruits chemical properties: Zaghloul date palms with fertilizer *via* nano source effectively improved fruits chemical properties in terms of increasing fruit T.S.S%, total and reducing sugars (Table 5). The maximum values of TSS were recorded with 600g nano-fertilizer in the first and second seasons, followed by 300g nano-fertilizer and control. Results show that the amount of total and reducing sugars in date palm fruits increased significantly with increasing the dose of nano-fertilizer (Table 5). The highest content of total sugars was recorded in date palm trees treated with 600g nano-fertilizer in both seasons. In contrast, the lowest one was observed for the 75g of nano-fertilizers. Fertilization treatments significantly changed date palm fruits' total phenols and tannins content. The lowest concentration of total phenolic and tannins was recorded with the treatment of 600g nano-fertilizer followed by 300g and control in both seasons, whereas the highest was recorded in fruits of trees treated with 75 and 150g of nano-fertilizers. These results align with those obtained by Ekinci *et al.* (2014) and Refaai (2014). The observed increase in fruit TSS content may be due to an increase in the chlorophyll content and photosynthesis efficiency, as potassium has a main role in sugar accumulation in fruit tissues (Shen *et al.,* 2018; 2019), which leads to an increase in TSS and sugars content (Lester *et al.,* 2010). The highest dry matter in plants treated by nano-fertilizer is associated highly with increased leaf photosynthetic pigments and photosynthesis rates that increase total carbohydrate accumulation (Mahmoud *et al.,* 2019). Davarpanah *et al.* (2016) reported that spraying pomegranate trees with nano-fertilizer improved fruit quality and increased TSS content and total sugars. TSS, sugars, and anthocyanin content of date palm fruits increased, whereas fruit acidity and tannins decreased with appropriate nitrogen fertilization treatment. Furthermore, the potassium and fertilization enhanced the physico-chemical characteristics of the fruit (Kassem, 2012). K nutrition has been associated with increased soluble solids and improved fruit color of many horticultural crops (Al-Moshileh and Al-Rayes, 2004; Nava *et al.,* 2007; Kumar *et al.,*2006; Harhash and Abdel-Nasser 2010; Hend, 2011; Ibrahim *et al.,* 2013). Lacombe *et al.* (2000) suggest that potassium has a specific channel linked to sugar metabolism. Potassium also regulates the expression of genes involved in sorbitol metabolism, sugar accumulation, which leads to improved fruit quality (Shen *et al.,* 2018).

Fruit NPK content: Results illustrated in Table 6 indicate that varying fertilizer sources significantly affected the fruit content of macronutrients (nitrogen, phosphorus and potassium). The highest values of macronutrient contents were recorded on the fruits of palm trees fertilized with 600g nano-fertilizer treatment in the first and second seasons, respectively, followed by 300g nano-fertilizer and control treatments. In comparison, 75 and 150g of nano-fertilizer were recorded as the lowest values of macronutrient contents on the fruits in both seasons. These results are in harmony with those obtained by Sheykhbaglou *et al.* (2010); Mousavi and Rezaei (2011) and Bozary (2012). Neilsen *et al.* (2004) observed that K fertilization increased leaf and fruit K concentrations. Applying nano-fertilizer increases nutrient use efficiency and reduces nutrient toxicity in the soil-pant and environmental pollution (Omara *et al.,* 2019). Application of nano-fertilizers, even at small doses, can improve nutritional status, increase crop yields and minimize nutrient losses and ecosystem pollution (Kundu *et al.,* 2016; Mukherjee *et al.,* 2016).

Table 6. Effect of nano fertilizers on NPK content of Zaghloul date palm fruits

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)
		First Season (2018/2019)	
Control	1.621c	0.18 c	1.20 c
75 g NF	1.40 e	0.12 d	1.073 d
150 g NF	1.50 d	0.12 d	1.08 d
300 g NF	1.71 b	0.27 b	1.27 b
600 g NF	1.79 a	0.34 a	1.35 a
		Second season (2019/2020)	
Control	1.65 c	0.23 c	1.23 c
75 g NF	1.42 e	0.14 d	1.10 d
150 g NF	1.53 d	0.16 d	1.14 d
300 g NF	1.74 b	0.32 b	1.30 b
600 g NF	1.84 a	0.38 a	1.38 a

Means values followed by different letters significantly differ at $P < 0.05$; each value represents a mean of three replicate± standard error (SE).

Despite the multitude of benefits of nano-fertilizers application on yield and fruit quality of date palm, their effects on the ecosystem and human health should be considered to determine their toxicity and biocompatibility (Dreher, 2004; Biswas and Wu, 2005; Wiesner *et al.,* 2006; Oberdorster *et al.,* 2007). Environmental and health issues can limit the use of this technology in food production (Zulfiqar *et al.,* 2019).

Crop production highly depends on applying mineral fertilizers; however, the massive use of mineral fertilizers results in ecosystem pollution and economic costs. According to the obtained results, fertilization of Zaghloul date palm trees with 600 or 300g/palm /yr. of the nano-fertilizers was comparable and even had a better effect than the application of the conventional form of nitrogen and potassium in terms of yield, fruit quality and nutrients content. The unique properties of nanoparticles compared with traditional mineral fertilizers will enhance crop productivity and nutrient use efficiency; the application can be done in smaller amounts, which minimizes nutrient losses and reduces production costs and the risk of environmental pollution.

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