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Effects of Different Potassium Forms on The Nutritional Status, Productivity, and Fruit Quality of Washington Navel Orange Trees.

Al-Sabbagh[1], M. N; Abd El-Latif[1], F. M; El-Badawy[1], H.E; Baiea[2] , M. H; El-Gioushy[1], S. F.
[1]Horticulture Department, Faculty of Agriculture (Moshtohor), Benha University, Egypt
[2] Horticultural Crops Technology Department, National Research Centre, Dokki, Giza, Egypt.

Corresponding author: mohamed.nabil.ahmed2019@gmail.com

Abstract

This study was carried out during the 2022 and 2023 seasons on 12-year-old Washington navel orange trees budded on Sour orange rootstock planted at 5 x 5 meters apart (168 trees/fed.) under the surface irrigation system of a private orchard at Moshtoher village, Toukh region, Qalubia Governorate, Egypt, to study the effect of foliar spray with different potassium forms, i.e., Nano potassium nitrate (KNO_3 NPs) 20% it's commercial name is Biota (46% K and 13% N) beside two traditional potassium fertilizer forms, potassium citrate ($K_3C_6H_5O_7$) 37.5% K (Citro pro commercial name) and potassium polysulfide (K_2S_x) 45% contain (33% K, 25% S), on the leaf nutritional status, productivity, and fruit quality of Washington navel orange trees. Each potassium source was applied, covering the whole foliage of each tree canopy, whereas 5 liters were sufficient in this regard. Besides, it is periodically applied five times per season at a one-month interval (in the 1st week of March, April, May, June, and July). The obtained results showed that all potassium forms induced a remarked promotion in leaf nutritional status. Also potassium forms enhanced yield , fruit physical and chemical characteristics compared with water sprayed trees (control). The best results with regards to foliar application were obtained by Nano potassium nitrate (KNO_3-NPs) at 20% at 3 cm which significantly superior in this concern compared with control (water spray) and other potassium treatments ,thus it could be recommended to spray Washington navel orange trees with Nano potassium nitrate (KNO_3-NPs) at 20% at 3 cm 5/L/tree ,five times per season at a one-month interval (in the 1st week of March, April, May, June, and July). to improve leaf nutritional status , maximize yield and enhanced fruit quality traits under the same experimental conditions.

Keywords: Navel orange, yield, Nano potassium nitrate, nutritional status, productivity, and fruit quality.

Introduction

Citrus (*Citrus spp*.) is considered one of the most important fruit crops grown in many tropical and subtropical countries. At the moment, there are about 1.5 million hectares of citrus trees cultivated for commercial purposes in the world, yielding nearly 40 million metric tons of oranges, lemons, limes, etc. **(MALR, 2022).** Citrus trees have outstanding economic importance among fruit crops in Egypt. The total production of citrus fruit amounts to 3,765,042 tons **(FAO, 2022).**

It is well known that citrus ranked the second fruit after grapes in the world as fruit production while it ranks first in fruit production in Egypt. According to the **(MAS, 2022),** the total cultivated area occupied by citrus trees reached about (519.788) feddan out of them (451531) feddan are fruitful, producing about 4.780.427 metric tons with an average of (10.428 tons/fed.). Oranges represent the largest cultivated area of all citrus varieties in Egypt. Orange production represents 30 percent of Egypt's total fruit production and 65 percent of total citrus production.

The Washington Navel orange is the favorite and most popular fresh fruit in Egypt due to its seedless, large size, nutritive value, flavor, and aroma characteristics. It is also a valuable source of early-season income for citrus growers in some commercial citrus areas of the world.

There are various factors responsible for quality improvement in citrus. Out of these factors one of the most important factor is nutrition which play an important role in plant metabolism and moreover, citrus is highly responsive to nutrients. It is well known that nutrients sprayed on fruit trees for improvement of vegetative growth, flowering, correction of deficiency symptoms would invariably affect the fruit quality **(Josan *et al*., 1995).**

Foliar fertilization is considered a more targeted and sustainable approach to applying the mineral nutrients needed for crop yield and quality **(Bindraban *et al*., 2018).** Foliar fertilization still needs optimization in terms of the mineral uptake of hydrophilic nutrients through the hydrophobic surface of the leaves **(Fernandez and Brown 2013).**

Potassium is one of the most important nutrients which play a key nutritional role in determining physical and chemical characteristics of citrus fruits **(Vijay *et al.*, 2016)** Where potassium plays a major role in photosynthesis, translocation of photosynthetic compounds, protein synthesis, control of ionic balance, regulation of plant stomata, water use, activation of plant enzymes, and many other processes **(Alva *et al.*,2006** and **Kumar *et al.*, 2006)** In this respect, **Quaggio *et al.*, (2011)** evaluated the effect of two K forms (K_2SO_4 and KCl) at 0, 100, 200, and 300 kg/ha on yield and fruit quality of Pera and Valencia oranges and found that yield increased with increasing K doses and total soluble solids decreased. Also, **Hamza *et al.*, (2015)** evaluated two forms of potassium with different levels (KNO_3 at 0, 5, and 8% and K_2SO_4 at 2.5 and 4%) to verify their effect on fruit characteristics. It was concluded that foliar application of potassium, regardless of the source used, increased fruit weight, size, color, firmness, and rind thickness, as well as a slight increase in acidity percentage and total soluble solids associated with potassium application.

Thus, this study was conducted to investigate the effect of foliar spray with 6 combinations between nano potassium nitrate, potassium citrate and potassium polysulfide in addition to control (water spray) treatment on the nutritional status, yield, and fruit quality of Washington navel orange trees.

Materials and Methods

This study was carried out during the 2022 and 2023 seasons on 12-year-old Washington navel orange trees budded on Sour orange rootstock planted at 5 x 5 meters apart (168 trees/fed.) under the surface irrigation system of a private orchard at Moshtoher village, Toukh region, Qalubia Governorate, Egypt. All trees were subjected to the same horticultural practices (irrigation, fertilization, weed control, and pest control) adopted in the area according to the recommendation of the Ministry of Agriculture. Before starting the 1st season (2022), mechanical and chemical analysis of the orchard soil surface (40cm depth) was determined according to **Black *et al.*, (1982),** as shown in **Table (A).**

Table A: physical and chemical properties of the investigated soil.

Physical analysis	Value	Chemical analysis			
		Cations meq/1		Anions meq/1	
Coarse sand	11%	Ca	8.8	CO_3^{--}	Zero
Fine sand	18.2%	Mg^{++}	3.25	HCO_3^-	4.5
Silt	18.2%	Na^+	4.30	Cl^-	6.45
Clay	51.4%	K^+	1.08	SO_4^{--}	6.48
Texture class	Clay loam	Available N: 24.5 mg/kg			
Soil pH	7.2	Available P: 11.94 mg/kg			
E.C, ds/m	1.74	Available K: 170.5 mg/kg			

Nano potassium nitrate (KNO3 NPs) 20% it's commercial name is Biota product by Biota Egypt Company which contain (46% K and 13% N) beside two traditional potassium fertilizer forms, potassium citrate (K3C6H5O7) 37.5% K (Citro pro commercial name) and potassium polysulfide (K2Sx) 45% contain (33% K, 25% S) which commercial known with same name , Produced by Misr El-Dawliya Egypt Company. Were applied as a foliar spray. The present experiment included six treatments as each K form were respented by thus concentrations in addition to control treatment (water spray). Thus, the following seven treatments were included in this experiment:

T_1-Control (water spray)

T_2 -Foliar spray with Nano potassium nitrate (KNO3 NPs) at 2 cm /5L/ tree.

T_3-Foliar spray with Nano potassium nitrate (KNO3 NPs) at 3 cm /5L/ tree.

T_4-Foliar spray with potassium citrate (K3C6H5O7) at 5 cm /5L/ tree.

T_5-Foliar spray with potassium citrate (K3C6H5O7) at 10 cm /5L/ tree.

T_6-Foliar spray with potassium polysulfide (K2Sx) at 5 cm /5L/ tree.

T_7-Foliar spray with potassium polysulfide (K2Sx) at 10 cm /5L/ tree.

Experiments layout:

The complete randomized block design with three replications was employed for arranging the seven investigated spraying treatments in both experimental seasons, whereas a single tree represented each replicate. Consequently, 21 healthy, fruitful Washington navel orange trees were carefully selected as being healthy, and disease-free. Chosen trees were divided according to their growth vigor into three categories (blocks), which each included seven similar trees for receiving the investigated seven treatments (a single tree was randomly subjected to one treatment).

Application time:

Taking into consideration that sprays treatments were applied covering the whole foliage of each tree canopy, whereas 5 liters were found to be sufficient in this concern. Besides, periodically applied 5 times / season at the one-month interval in the 1st week of March, April, May, June and July.

The following data was recorded:

1. Nutritional status:

In the second week of August, twenty mature leaves were sampled from each replicate to determine total chlorophylls and leaf NPK content as follows: Total chlorophylls in fresh leaf samples were determined by using the chlorophyll meter model **SPAD 502**, according to **Netto *et al*., (2005).** The remaining leaf samples were dried at 70 °C to a constant weight. Dried leaves were grounded and digested with H_2SO_4 and H_2O_2, according to **Evenhuis and Dewaard (1980).** In digested solution samples, nitrogen, phosphorus, and potassium were determined as follows: nitrogen was determined by the micro-Kjeldahl method **(A.O.A.C. 1990),** phosphorus was determined calorimetrically as described by **Murphy and Riley (1962)** and potassium was estimated by using a flame photometer as described by **Brown and Lillelland (1974).**

2. Productivity (yield):

In 15/9/2022 and 18/9/2023 fruits of each individual tree were separately harvested, then counted and weighed. Tree productivity (yield) was estimated either as a number or weight (kg) of harvested fruits per each tree. Besides, yield per each tree (Kg) as well as yield per feddan (ton).

3. Fruit quality traits:

To determine fruit quality, 20 healthy fruits were taken at random from each tree at the harvest time of both seasons and prepared for the determination of physical and chemical fruit quality assessment according to **A.O.A.C. (1990).**

3-A- Fruit physical properties :

The average values of fruit dimensions, fruit shape index (L/D), fruit peel thickness (mm), average fruit volume (cm3), fruit juice volume (cm3), fruit juice percentage (%),were the investigated physical properties.

3-B-Fruit chemical characteristics:

The following fruit juice chemical properties were determined according to **(A.O.A.C, 2005).**

-Total soluble solids percentage (TSS %) was determined by using Zeiss hand refractometer .

-Total titratable acidity percentage was determined in fruit juice as percentage of anhydrous citric acid by titration with 0.1 N Sodium hydroxide using phenol phthalein as an indictor.

- Total soluble solids/total acidity (TSS/acid ratio) was calculated by dividing the total soluble solids percentage over total acidity percentage .

-Total sugars (%) in fruit juice was determined after the method described by **Smith *et al*., (1956).**

-Fruit juice ascorbic acid (Vitamin C) content as mg/100 ml juice was determined using 2,6 dichlorophenol indol phenol dye as indicator .

Statistical analysis:

The obtained data were subjected to an analysis of variance according to **Snedecor and Cochran (1990)**. Duncan's multiple range test (**Duncan, 1955)** at the 5% level was used to compare the mean values.

Results and Discussion

1. Effect of different potassium forms on nutritional status of Washington navel orange trees:

1.1. Leaf total chlorophyll content (SPAD.):

The results presented in **Table (1)** showed the effect of foliar sprays with different potassium forms on the leaf total chlorophyll content of Washington navel orange trees that all treatments used under study significantly increased its content as compared with control during both 2022 and 2023 experimental. However, the trees were subjected to foliar spray with Nano potassium nitrate (KNO_3-NPs) at 3cm (3^{rd} treatment) was significantly superior and showed the highest leaf total chlorophyll content (82.86 &83.46 SPAD unit) during both seasons, respectively, statistically followed by in second rank that exposed to either Nano potassium nitrate (KNO_3-NPs) at 2cm (2nd treatment) or potassium polysulfide (K_2S_x) at 10 cm (7^{th} treatment) which both showed same significant values in both seasons of study. Moreover, the leaf contents of trees that were sprayed with potassium polysulfide (K_2S_x) at 5cm (6^{th} treatment) had medium total chlorophyll content, compared with other treatments and control. Furthermore, the foliar spray with potassium citrate ($K_3C_6H_5O_7$) form at both concentrations (5^{th} and 6^{th} treatments) was the least effective form in this respect, whereas both treatments came just before the control (water spray) during both the 2022 and 2023 experimental seasons. The increased total chlorophyll content in leaves may be due to the importance of potassium in delaying the aging of leaves due to its role in delaying protein catabolism and raising the efficiency of photosynthesis. Deficiency in potassium leads to a decrease in the energy complex of ATP and a decrease in the transport system inside the plant, which leads to the accumulation of products of the photosynthesis process in the leaves in addition to a decrease in the rate of this process that affects the manufacture and production of chlorophyll **(Krans (1993)** and **Matts (2015).** The results are in agreement with the findings of **Sharaf (1990)** on Balady orange trees, **Abd El-Moneim (1999)** on Valencia orange. They found that all potassium treatments enhanced total chlorophyll content as compared with the control. In addition, **Al-Bamarny *et al.*, (2010)** on peach trees (*Prunus persica* L.) Cv. However, increased pigment content with the K-NPs application form on date palms Cv. Zaghloul has also been reported **(Shalan and El-Boray, 2019).**

1.2. Leaf mineral composition.

In this regard, leaf N, P, and K contents of Washington navel orange trees as influenced by the differential investigated different potassium forms treatments were the concerned leaf mineral composition as an indicator for nutritional status of trees under study. Data obtained during both the 2022 & 2023 seasons are presented in **Table (1)**

1.2.1. Leaf nitrogen content:

As for the leaf N% in Washington navel orange trees, **Table (1)** shows that all tested treatments considerably increased its content significantly as compared to control (water spray) in both seasons except spraying with potassium citrate ($K_3C_6H_5O_7$) at 10 cm during the second season (5^{th} treatment). The content of the leaves of the trees that were subjected to this treatment didn't reach a level of significance. Anyhow, it could have been said that the response to the investigated treatments was not only significant but also followed to a great extent the same trend previously discussed with chlorophyll content. Hence, spraying with Nano potassium nitrate (KNO_3-NPs) at 3 cm (3^{rd} treatment) statistically was superior treatment and resulted significantly in the highest leaf N content (2.74 and 2.78 %) during both seasons, respectively, which ranked statistically 1^{st}, followed by in second position either spraying with Nano potassium nitrate (KNO_3-NPs) at 2 cm (2^{nd} treatment) or potassium polysulfide (K_2S_x) at 10 cm (7^{th} treatment) during 2022 and 2023 seasons.

1.2.2. Leaf phosphorus content:

Results in **Table (1)** showed the effect of foliar spraying with different forms of potassium on the leaf P% content of Washington navel orange trees. Where the superior treatments have followed approximately the opposite trend detected with the former parameter, despite exceeding statistically the water spray trees (control).Generally, all potassium treatments used under study significantly increased the leaf content of phosphorus in both seasons. However, the treated trees with potassium citrate ($K_3C_6H_5O_7$) at 10 cm (5^{th} treatment) showed the highest significant values in this respect, statistically followed by those subjected to low concentration from the same potassium form (4^{th} treatment) during both seasons, and potassium polysulfide (K_2S_x) at 5 cm (6^{th} one) in the second season.In addition, the Nano potassium nitrate (KNO_3-NPs) treatments at both concentrations were in the intermediate categories of treatments and showed the same significant values during both seasons compared with other treatments used in the study.

1.2.3. Leaf potassium content:

Regarding the influence of the investigated potassium treatments on leaf K% of Washington navel orange trees, results in **Table (1)** revealed that three potassium forms resulted in a significant increase in its content over water-sprayed trees (control)).

Table 1. Effect of different potassium forms on leaf total chlorophyll (SPAD), N, P, and K contents of Washington navel orange trees during the 2022 and 2023 experimental seasons.

Parameters / Treatments	Total chlorophyll (SPAD)		N%		P%		K%	
	2022	2023	2022	2023	2022	2023	2022	2023
T_1-Control (water spray).	66.26 D	67.80 D	2.28 F	2.31 D	0.150 C	0.151 C	1.19 E	1.28 D
T_2-Nano potassium nitrate at 2cm.	81.70 AB	82.03 AB	2.60 B	2.64 B	0.153 BC	0.152 BC	1.57 C	1.60 BC
T_3-Nano potassium nitrate at 3cm.	82.86 A	83.46 A	2.74 A	2.78 A	0.152 BC	0.153 BC	1.78 A	1.81 A
T_4- potassium citrate at 5 cm.	71.46 C	73.96 C	2.45 D	2.50 C	0.159 AB	0.161 AB	1.57 C	1.55 BC
T_5- potassium citrate at 10 cm.	71.70 C	73.30 C	2.38 E	2.37 D	0.168 A	0.166 A	1.63 B	1.64 B
T_6-potassium polysulfide at 5 cm.	79.10 B	79.73 B	2.50 C	2.57 BC	0.158 BC	0.160 AB	1.47 D	1.51 C
T_7-potassium polysulfide at 10 cm.	81.80 AB	82.53 AB	2.59 B	2.59 B	0.158 BC	0.158 ABC	1.76 A	1.74 A

The means followed by the same letters within each column are not significantly different from each other at the 0.5 level.

Hence, the greatest significant leaf potassium percentage in a closed relationship with trees that were subjected to spraying with Nano potassium nitrate (KNO_3-NPs) at 3 cm (3rd treatment) or potassium polysulfide (K_2S_x) at 10 cm (7th treatment), where both showed the same leaf K level, without significant differences observed between them, followed by in 2nd rank, the trees were sprayed with potassium citrate ($K_3C_6H_5O_7$) at 10 cm (5th treatment). In addition, other investigated treatments were in between the aforesaid extremes during both the 2022 and 2023 experimental seasons.

2. Effect of different potassium forms on average fruit weight (g), number of fruits/tree, yield/tree (kg), and yield / feddan (tons) of Washington navel orange trees.

The yield of the Washington navel orange Cv expressed as average fruit weight (g), number of fruits/tree, yield/tree (kg), and yield / feddan (tons) were the investigated tree productivity parameters regarding the response to differentially evaluated potassium forms. Data obtained during both the 2022 and 2023 experimental seasons are presented in **Table (2),** whereas all measurements of Washington navel orange trees yield responded positively and significantly to various investigated treatments. Herein, the four measurements were increased by all investigated potassium forms treatments as compared with untreated trees (control), where the parameters of tree productivity followed the same trend. As found, the sprayed trees with Nano potassium nitrate (KNO_3-NPs) at 3 cm (3rd treatment) statistically outperformed in this concern during both experimental seasons. However, the 7th treatment (potassium polysulfide (K_2S_x) at 10 cm) ranked statistically second after the superior one (3rd treatment), in addition, the foliar spray with the other four potassium treatments, i.e., Nano potassium nitrate (KNO_3-NPs) at 2 cm (2nd treat.), potassium citrate ($K_3C_6H_5O_7$) at 10 cm (5th treat.), potassium polysulfide (K_2S_x) at 5 cm (6th treat.) and potassium citrate ($K_3C_6H_5O_7$) at 5 cm (4th treat.) in descending order, were the less effective treatments on yield parameter, however, 2nd treatment was significantly more effective than the three other ones of such group, taking into consideration, that the yield rate compared to water sprayed trees (control) varied from one treatment to another and from season to season. In other words, the tree yield of those subjected to foliar spray with 3rd treatment (Nano potassium nitrate (KNO_3-NPs) at 3 cm) yielded approximately an increase of half higher fruits than control when estimated as the weight of harvested fruits per tree or average (ton/fed), respectively. Generally, it could be safely said that all investigated potassium forms treatments increased significantly yield over control at both seasons of study. The increase in yield parameters may be due to photosynthesis productions that are transferred by potassium which contributes to transferring the outputs from the source (leaves) to the sink (vegetative growth, flowers, fruits), as well as the activation of potassium for many enzymes which responsible for the activities of vegetative growth may contribute to increasing the cellular activity and transfer of nutrients to the fruits and thus reflected on the yield **(Patrick *et al.*, 2001) .**Another probable cause could be the greater mobility of assimilates by potassium to the developing fruits which acted as a strong metabolic sink**,** resulting in increased fruit weight and number, which reflect on final productivity**.**

Table 2. Effect of different potassium forms on average fruit weight (g), number of fruits/tree, yield/tree (kg), and yield / feddan (tons) of Washington navel orange trees during the 2022 and 2023 experimental seasons.

Treatments \ Parameters	Average fruit weight (g)		No. of fruit/tree		Yield/tree (Kg)		Yield / Feddan (Tons)	
	2022	2023	2022	2023	2022	2023	2022	2023
T_1-Control (water spray).	216.31 E	221.69 F	155.74 E	176.46 E	33.68 E	39.11 F	5.65 E	6.57 F
T_2- Nano potassium nitrate at 2 cm.	257.31 B	255.47 C	190.67 AB	194.00 BC	49.06 A	49.56 C	8.24 A	8.32 C
T_3- Nano potassium nitrate at 3 cm.	259.61 A	262.74 A	193.33 A	200.00 A	50.19 A	52.55 A	8.43 A	8.82 A
T_4- potassium citrate at 5 cm.	249.07 D	239.11 E	183.00 D	187.33 D	45.58 D	44.79 E	7.65 D	7.52 E
T_5- potassium citrate at 10 cm.	252.24 C	252.91 C	187.67 BCD	192.00 C	47.34 BC	48.55 C	7.95 BC	8.15 C
T_6- potassium polysulfide at 5 cm.	251.97 C	244.64 D	185.00 CD	190.33 CD	46.61 CD	46.56 D	7.83 CD	7.82 D
T_7- potassium polysulfide at 10 cm.	258.81 AB	259.94 B	188.33 ABC	196.33 AB	48.74 AB	51.03 B	8.18 AB	8.57 B

The means followed by the same letters within each column are not significantly different from each other at the 0.5 level.

The present results are in general accordance with those previously found by **Achilea *et al.* (2001)** found that foliar sprays of potassium nitrate increased the yield of citrus trees, **Saleh and Eman (2003)** found that spraying potassium citrate positively affected the enhanced fruit set number, decreased the fruit drop, and increased fruit retention of mango trees, **Khattab *et al* (2005)** on mango (Cv. Ewais and Sidik), **Mostafa and Saleh (2006)** on Balady mandarin trees. They found that foliar application of potassium from several sources enhanced fruit sets, **Dutta *et al.* (2011)** on mango **Yasin *et al* (2012)** mentioned that the application of K was effective in improving fruit set, fruit retention, and yield on Kinnow, **Vijay *et al.* (2017)** on Jaffa sweet orange, **Al-Sultan and Al-Tufaili (2020)** on eggplant,**Gad *et al.*, (2021)** on Ewais Mango Cv, **Al-Saif *et al* ., (2023)** on date palm Cv. Samani. **Randa-Habasy and Huda-Ismaiel (2023)** and **El-Shereif *et al.*, (2023)** on Valencia Orange .

3. Effect of different potassium forms on fruit quality of Washington navel orange trees.

3.1. Fruit physical properties.

In this regard, fruit dimensions (equatorial and fruit polar diameters), fruit shape index (L/D), fruit peel thickness (mm), fruit volume (cm^3), fruit juice volume (cm^3), and fruit juice percentage (%) were the evaluated fruit physical properties of Washington Navel orange in response to different applied treatments potassium forms treatments. Data obtained during both the 2022 and 2023 experimental seasons are presented in **Tables (3)** and **(4).**

3.1.1. Fruit dimensions:

The polar and equatorial fruit diameters of Washington navel orange Cv. were investigated as two fruit dimensions regarding their response to the differential potassium forms treatments. **Table (3)** shows obviously that both parameters responded significantly to all treatments. Herein, the trees sprayed with Nano potassium nitrate (KNO_3-NPs) at 3 cm (3rd treat.) were superior and resulted significantly in the tallest polar and equatorial diameters, statistically followed by spraying with potassium polysulfide (K_2S_x) at 10 cm (7th treat). Moreover, the reverse was true with the control treatment (water spray), which significantly induced the shortest polar and equatorial diameters during both experimental seasons. On the other hand, other treatments, recorded averagely significant values in fruit dimensions between the abovementioned treatments during both experimental seasons, taken into consideration from the statistical point of view, the effect of 2nd treatment was significantly nearly to the 7th one. Potassium (K) plays an active role in the swelling and expansion of cells and has a close relationship with water.. In addition, potassium plays an important role in maintaining the pH of the soil, osmotic regulation, and synthesis of protein, the movement of stomata, the process of photosynthesis, and the extension of cells.

3.1.2. Fruit shape index:

Concerning the fruit shape index (polar diameter: equatorial diameter) of Washington Navel orange Cv. in response to different potassium form treatments, **Table (3)** shows clearly that the variances were relatively few to be taken into consideration from the statistical point of view.

Table 3. Effect of different potassium forms on fruit dimensions (mm) and fruit shape index of Washington navel orange trees during the 2022 and 2023 experimental seasons.

Parameters / Treatments	Polar diameter (cm)		Equatorial diameter (cm)		Fruit shape index	
	2022	2023	2022	2023	2022	2023
T_1-Control (water spray).	70.95 E	71.83 F	67.97 D	69.32 F	1.043 DE	1.03 D
T_2-Nano potassium nitrate at 2 cm.	83.23 B	85.53 B	74.30 BC	78.10 B	1.120 AB	1.095 A
T_3-Nano potassium nitrate at 3 cm.	85.40 A	87.63 A	78.63 A	79.33 A	1.086 BC	1.104 A
T_4- potassium citrate at 5 cm.	73.26 D	75.86 E	71.83 C	71.83 E	1.020 E	1.056 C
T_5- potassium citrate at 10 cm.	80.50 C	83.03 B	75.56 B	77.20 C	1.065 CD	1.075 B
T_6-potassium polysulfide at 5 cm.	80.46 C	81.63 D	74.100 BC	74.10 D	.1.086 BC	1.101 A
T_7-potassium polysulfide at 10 cm.	83.99 AB	85.46 B	74.36 AB	78.03 B	1.198 A	1.095 A

The means followed by the same letters within each column are not significantly different from each other at the 0.5 level.

Herein, variations in fruit shape indices due to the differentially investigated potassium forms could be logically explained by the unparalleled response of two fruit dimensions (polar and equatorial diameters) to a given treatment. Since, in most cases, the increase in fruit length (polar diameter) was relatively higher than those that resulted in fruit width (equatorial diameter), the response to each treatment was individually (separately) taken into consideration. Anyhow, it could be declared that harvested fruits from sprayed trees with potassium polysulfide at 10 cm (7^{th} treatment) during both seasons, were statistically superior in fruit shape index, as well as 2^{nd}, 3^{rd}, and 6^{th} treatments showed the same significant superiority during second season only in this respect, as well as results showing that all the harvested fruits affected by the different treatments tended to be relatively rounded, during both experimental seasons.

These results agreed with the findings of of **El-Saiada (1996)** on Washington navel orange trees, **Hegab (2003)** on Valencia orange trees, and **Alva *et al.*,(2006)** on citrus trees. They found that fruit quality is quite sensitive to different levels of K availability.

3.1.3. Fruit peel thickness (mm):

Data obtained during 2022 and 2023 experimental seasons are presented in **Table (4)** most potassium treatments increased fruit peel thickness, except foliar spray with Nano potassium nitrate (KNO_3-NPs) form (2^{nd} or 3^{rd} treatments) didn't significantly differ as compared to each other and didn't reach the level of significance in this regard compared to the control (water spray) in the first season only under study. Furthermore, fruits harvested from trees exposed to 5^{th} treatment (potassium citrate ($K_3C_6H_5O_7$) at 10 cm), it is peel was thicker compared with other treatments, statistically followed by fruits induced from sprayed with potassium citrate ($K_3C_6H_5O_7$) at 5cm (4^{th} treatment) or potassium polysulfide (K_2S_x) at 5cm (6^{th} one) during both seasons study. However, other investigated treatments had a moderate effect on peel thickness.

IV.1.D.1.4. Average fruit volume (cm^3):

The data presented in **Table (4)** reveals that all treatments under study succeeded in increasing fruit volume in both seasons in comparison to the control. However, the greatest fruit volume was significantly coupled with harvested fruits from trees which subjected to spraying with Nano potassium nitrate (KNO_3-NPs) at 3 cm (3^{rd} treatment) during both seasons and Nano potassium nitrate (KNO_3-NPs) at 2 cm (2^{nd} treatment) in the second season, statistically followed by either sprayed with potassium citrate ($K_3C_6H_5O_7$) at 10 cm (5^{th} treatment) or potassium polysulfide (K_2S_x) at 5 cm (6^{th} one) during both seasons, respectively, which both showed same static values of fruit volume in comparison to water sprayed trees (control) and other potassium treatments. On the other hand, the foliar sprayed trees with potassium citrate ($K_3C_6H_5O_7$) at 5 cm (4^{th} treatment) were significantly the least effective in increasing fruit volume compared to other investigated potassium treatments during both seasons of study.

The increase in fruit volume with potassium forms application can be associated with the vital roles of K in plants, in particular the role it plays in cell expansion that leads to the formation of a large central vacuole in fruit cells (**Talaie, 2008**). In addition, the roles of K in promoting photosynthesis and transporting assimilates to developing fruits can be another possible reason for the increase in fruit volume under the influence of K application (**Kumar, 2006; Baiea *et al.*, 2015).**

IV.1.D.1.5. fruit juice volume (cm^3):

Regarding the effect of different potassium treatments on average fruit juice volume (cm^3) of Washington navel orange trees. **Table (4)** reveals that differences in most cases were relatively pronounced from one season to another to be taken into consideration from the statistical standpoint. However, the trees that were subjected to spraying with Nano potassium nitrate (KNO_3-NPs) at 3 cm (3^{rd} treatment) during both seasons, as well as Nano potassium nitrate (KNO_3-NPs) at 2 cm (2^{nd} treatment) or potassium citrate ($K_3C_6H_5O_7$) at 10 cm (5^{th} one) treatments gave the highest fruit juice volume without significant difference between them in the first season, statistically followed by the foliar spray with potassium polysulfide (K_2S_x) form at both concentrations used (6^{th} & 7^{th} treatments) with equal significant values in first season. Such a trend was the opposite during the second season. Hence, the trees that were subjected to Nano potassium nitrate (KNO_3-NPs) at 2 cm (2^{nd} treatment.) ranked second compared with the previous season, as well as the foliar spray with potassium polysulfide (K_2S_x) at 10 cm (7^{th} treatment) was least effective during the second season compared with the first season; it came just before the control.

IV.1.D.1.6. Fruit juice percentage (%):

Referring to the influence of different potassium forms on fruit juice percentage. **Table (4)** displays that the response was pronounced; whereas all investigated potassium treatments resulted in an increasing average juice percentage as compared to the control treatment (water spray). However, the response trend was different for investigated treatments from one season to another, concerning significant differences between them. Anyway, the highest juice percentage was found with the fruits of trees that were exposed to spraying with Nano potassium nitrate (KNO_3-NPs) at 3 cm (3^{rd} treat) during both seasons and Nano potassium nitrate (KNO_3-NPs) at 2 cm (2^{nd} treat.), without significant differences observed between their juice percentage in the first season of study, as well as the most effective treatments (superior) from a static standpoint, followed by in second rank that sprayed with potassium citrate ($K_3C_6H_5O_7$) at 10 cm (5th one) or potassium polysulfide (K_2S_x) at 10 cm (7th treatment), then potassium citrate ($K_3C_6H_5O_7$) at 5 cm (4th treat) during first season of study. Moreover, the results showed that during the second season, there were no significant differences observed between all potassium treatments except the aforenoted treatment (3rd one), which exceeded all treatments and control. Potassium is easily transported through citrus trees and can be involved in the transport of carbohydrates and metabolism. Potassium is used as an osmosis agent in opening and closing stomata, an important mechanism of water uptake.

Table 4. Effect of different potassium forms on fruit peel thickness (mm), fruit volume. (cm^3), fruit juice volume (cm^3) and fruit juice percentage (%) of Washington navel orange trees during the 2022 and 2023 experimental seasons.

Treatments / Parameters	Peel thickness (mm)		Fruit volume (cm^3)		Fruit juice volume (cm^3)		Fruit juice percentage (%)	
	2022	2023	2022	2023	2022	2023	2022	2023
T_1-Control (water spray).	2.530 C	2.560 D	235.50 E	237.01 E	91.91 D	91.96 F	39.02 D	38.80 C
T_2-Nano potassium nitrate at 2 cm.	2.596 C	2.660 CD	260.3 B	263.6 A	112.0 A	112.3 B	43.05 A	42.61 B
T_3-Nano potassium nitrate at 3 cm.	2.643 C	2.780 BC	262.5 A	264.1 A	113.5 A	117.0 A	43.23 A	44.32 A
T_4-potassium citrate at 5 cm.	2.846 AB	2.896 AB	248.3 D	240.2 D	105.1 C	100.6 E	42.35 B	41.88 B
T_5-potassium citrate at 10 cm.	2.983 A	3.006 A	259.8 B	259.4 B	111.4 A	108.0 C	42.90 AB	41.64 B
T_6-potassium polysulfide at 5 cm.	2.886 AB	2.893 AB	260.1 B	257.0 B	107.7 B	109.0 C	41.40 C	42.43 B
T_7-potassium polysulfide at 10 cm.	2.800 B	2.780 BC	250.8 C	246.5 C	107.4 B	104.2 D	42.83 AB	42.29 B

The means followed by the same letters within each column are not significantly different from each other at the 0.5 level.

3.2. Fruit chemical properties.

In this regard, fruit juice content, i.e., total soluble solids (TSS) %, total acidity %, TSS/Acid ratio, total sugar %, and ascorbic acid (VC) contents, were evaluated as fruit chemical characteristics of Washington Navel orange in response to different potassium forms treatments. Data obtained during both the 2022 and 2023 experimental seasons are presented in **Tables (5)** and **(6).**

3.2. 1.Fruit juice TSS (total soluble solids) (%):

Concerning the fruit juice TSS% of Washington navel orange trees as influenced by the various potassium forms treatments, data obtained during 2022 and 2023 experimental seasons is presented in **Table (5)**, it is quite evident that all potassium treatments under study increased fruit juice TSS% in both seasons as compared with fruits of trees sprayed with water (control). However, the highest fruit juice TSS content was markedly coupled with sprayed trees with Nano potassium nitrate (KNO_3-NPs) at 3 cm (3rd treatment), which gave the richest TSS percentages (113.12 and 3.40%) during both seasons, respectively. Moreover, sprayed with either, 2nd treatment (Nano potassium nitrate (KNO_3-NPs) at 2 cm) or 7th treatment (potassium polysulfide (K_2S_x) at 10 cm) in the first season, both ranked statistically second as the influence on fruit juice TSS% was concerned. The reverse was true with the fruit juice of water-sprayed trees (control), which induced significantly poorer fruits in their TSS% content during both experimental seasons. In addition, there were no significant differences between the aforementioned potassium treatments in the second season. Furthermore, the other investigated treatments, i.e., (4th, 5th, and 6th treatments), were between the abovementioned treatments (superior) and lowest treatment (control) during both experimental seasons.

The increase in TSS content with foliar application of K is related to the role of potassium in the synthesis of more carbohydrates and its translocation from leaves to fruits **Havlin *et al.*, (2007).**

3.2. 2.Fruit juice total acidity (%):

About the fruit juice acidity percentage of Washington navel orange trees as influenced by the potassium forms treatments, data obtained during 2022 and 2023 experimental seasons are presented in **Table (5),** an opposite trend was found to what was previously with TSS% in this respect. Hence, the fruit juice acidity percentage was significantly increased by the control during both seasons.

Meanwhile, the reverse was true with subjected trees to Nano potassium nitrate (KNO_3-NPs) at 3 cm (3rd treatment) during both seasons, as well as Nano potassium nitrate (KNO_3-NPs) at 2 cm (2nd treatment) and potassium polysulfide (K_2S_x) at 10 cm (7th treatment) in the second season, where they were poorest in acidity content, with the same statistical ranks. On the other hand, other investigated potassium forms treatments recorded medium acidity percentages with non-significant differences between them compared to the control treatment; this trend has been prevalent throughout both seasons. Potassium also neutralizes organic acids and plays a role in controlling the acidity and pH of fruit juice **(Mullins *et al.*, 1992).**

IV.1.D.2.3. Fruit juice TSS/acid ratio (%):

The data in **Table (5)** showed that all potassium forms treatments increased the fruit juice total soluble solids/acid ratio of Washington navel orange trees during both experimental seasons as compared with the control. However, the trees exposed to Nano potassium nitrate (KNO_3-NPs) at 3 cm (3rd treatment) in both seasons produced fruit with the highest TSS/acid ratio in juice, followed by the results of the five potassium treatments with equal significant values between them in the first season only. On the contrary, the trees that were sprayed with Nano potassium nitrate (KNO_3-NPs) at 2cm (2nd treatment) or potassium polysulfide (K_2S_x) at 10 cm (7th treatment) resulted from an increase in fruit juice TSS/acid ratio during second season compared with the first season, statistically, followed by the spray effect with potassium citrate ($K_3C_6H_5O_7$) at10cm (5th treatment) or potassium polysulfide (K_2S_x) at 5cm (6th treatment). In addition to that, the potassium citrate ($K_3C_6H_5O_7$) at 5cm (4th treatment) effect in this respect was the least, which came just before the control in the second season. Such a trend of response could be logically explained depending upon the paralleled rates of changes exhibited in both fruit juice TSS and total acidity parameters to a given investigated treatment from seasons depending upon the efficiency of investigated potassium forms treatments themselves and, in some cases, from one season to another.

Table 5. Effect of different potassium forms on fruit juice TSS %, total acidity %, and TSS/acid ratio of Washington navel orange trees during the 2022 and 2023 experimental seasons.

Parameters / Treatments	Fruit juice TSS (%)		Fruit juice acidity (%)		TSS /Acid ratio	
	2022	2023	2022	2023	2022	2023
T_1-Control (water spray).	10.15 F	10.49 E	1.091 A	1.081 A	9.32 C	9.76 D
T_2-Nano potassium nitrate at 2 cm.	12.90 B	13.21 A	1.026 AB	0.963 B	12.60 B	13.80 AB
T_3-Nano potassium nitrate at 3 cm.	13.12 A	13.40 A	0.930 B	0.916 B	14.12 A	14.64 A
T_4- potassium citrate at 5 cm.	11.85 E	12.11 D	1.016 AB	1.013 AB	11.71 B	12.00 C
T_5- potassium citrate at 10 cm.	12.48 D	12.63 C	1.003 AB	1.000 AB	12.47 B	12.66 BC
T_6-potassium polysulfide at 5 cm.	12.69 C	12.97 B	1.006 AB	0.996 AB	12.64 B	13.04 BC
T_7-potassium polysulfide at 10cm.	12.89 B	13.21 A	1.030 AB	0.966 B	12.55 B	13.75 AB

The means followed by the same letters within each column are not significantly different from each other at the 0.5 level.

3.2.4. Fruit juice total sugar percentage (%):

It is clear from **Table (6)** that spraying with all potassium forms treatments used under study significantly increased the total sugar percentage as compared with the control in both seasons. However, spraying with Nano potassium nitrate (KNO_3-NPs) at 3cm (3rd treatment) in both experimental seasons significantly gave fruits with a higher total sugar percentage, (10.18 and 12.03), respectively, as well as spraying with Nano potassium nitrate (KNO_3-NPs) at 2 cm (2nd treatment) in the first season, which gave an equal statistical value (10.20%) in this respect compared to other treatments and control. On the contrary, the fruit juice harvested from sprayed trees with potassium citrate ($K_3C_6H_5O_7$) at 5cm (4th treat) recorded significantly lowest increased values of total sugar percentage(8.68 and 10.70) respectively compared with other used treatments during both seasons, with taking into consideration the results showed the same total sugar percentage from the statistical point of view between fruit juice induced from sprayed trees with either Nano potassium nitrate (KNO_3-NPs) at 2 cm (2nd treat), potassium citrate ($K_3C_6H_5O_7$) at 10cm (5th treat) and potassium polysulfide (K_2S_x) at 10 cm (7th one), without significant differences observed between them, particularly during the second season, Moreover, the rest treatments under study were between the highest and lowest values during both seasons. The increase in the total sugar percentage happened because potassium is implicated in preserving sugars into phloem which authorizes sugar translocation from source tissues to provide the requirements of growing organs like fruits and roots **(Taiz and Zeiger, 2004).**

3.2.5. Fruit juice ascorbic acid (VC) content:

It is clear, from data in **Table (6)** that all investigated potassium forms treatments increased fruit juice vitamin C (ascorbic acid) content over control treatment during 2022 & 2023 seasons except spraying with potassium citrate ($K_3C_6H_5O_7$) at 5 cm (4th treatment) and potassium polysulfide (K_2S_x) at 5 cm (6th treat), both didn't reach the level of significance compared to the control (water spray), particularly during the first season under study; however, the opposite was found during the second season. Moreover, the sprayed trees with Nano potassium nitrate (KNO_3-NPs) at 3 cm (3rd treatment) were statistically superior and showed the highest juice VC content, i.e., 44.80 and 47.88 mg V/100 mL of fruit juice during both seasons, respectively. Also, the foliar spray with Nano potassium nitrate (KNO_3-NPs) at 2 cm (2nd treatment) and potassium polysulfide (K_2S_x) at 10 cm (7th treatment) solely ranked statistically 2nd in its effect after the aforesaid superior treatment during the first experimental season; in addition to that, those recorded height significant values without significant difference between them and aforenoted 3rd treatment (superiority) in the second season. The increased juice ascorbic acid (VC) content with foliar application of potassium might be related to improved sugar metabolism **Mengal (1997)**. Another probable reason might be the role of potassium in activating the synthesis of ascorbic acid somewhere between D-Glucose to L-Ascorbate **Harold and George (1966).** Similar findings have also been observed by **Sangwan *et al.*, (2008)** they found maximum ascorbic acid with KNO_3 @ 2% in Kinnow mandarin. Similar results have been earlier reported by **Josan *et al.*, (1995)** in lemon and **Sarrwy *et al.*, (2012)** in Balady mandarin.

The obtained of foliar spray with potassium forms on fruit quality (physical and chemical properties) of Washington navel orange trees are in harmony with earlier reports of **, Abd El-Kader *et al. (*2010)** reported that foliar sprays of potassium at a recommended rate increased fruit juice, TSS%, total acidity, and physical properties of Clementine mandarin in a Mediterranean climate, **Dutta *et al.* (2011)** found that foliar sprays from the different K sources showed significant differences in the physical and chemical characteristics of the mango fruit, **Sandhu and Bal (2012)** reported that a foliar spray of K_2SO_4 at 8% proved to be most effective in improving the fruit quality of lemon Cv. Baramasi, **Babul and Rahim (2013)** on mango (*Mangifera indica* L.*)* Cv. Amrapali plants in Bangladesh , **Dalal *et al.* (2017)** on sweet orange, **Roshdy and Refaai (2016)** on date palm ,**Omaima-Hafez *et al.*, (2018)** found that the fruit's vitamin C and TSS content was enhanced in Washington Navel orange trees due to Nano-potassium foliar application, **Al-Sultan and Al-Tufaili (2020)** on eggplant , **Mseer *et al.*, (2020)** on Fig trees , **Gad *et al.*,(2021)** on Ewais Mango Cv , **Al-Saif *et al* ., (2023) on** date palm Cv. Samani,and **Randa-Habasy and Huda-Ismaiel (2023)** on Valencia orange trees .

Table 6. Effect of different potassium forms on fruit juice (total sugar % and vitamin C (mg/100ml)) content of Washington navel orange trees during the 2022 and 2023 experimental seasons.

Parameters / Treatments	Fruit juice total sugar %		Vitamin C (mg/100ml) fruit juice	
	2022	2023	2022	2023
T_1-Control (water spray).	8.11 D	8.51 D	35.81 C	37.11 C
T_2-Nano potassium nitrate at 2 cm.	10.20 A	11.88 AB	43.00 AB	48.35 A
T_3-Nano potassium nitrate at 3 cm.	10.18 A	12.03 A	44.80 A	47.88 A
T_4- potassium citrate at 5 cm.	8.68 CD	10.70 C	31.40 D	38.38 BC
T_5- potassium citrate at 10 cm.	9.07 BC	11.53 AB	41.06 B	40.48 B
T_6-potassium polysulfide at 5 cm.	9.38 B	11.18 BC	36.56 C	46.58 A
T_7-potassium polysulfide at 10 cm.	9.27 BC	11.82 AB	43.53 AB	48.15 A

The means followed by the same letters within each column are not significantly different from each other at the 0.5 level.

Discussions

That the obtained results in this study by using different forms of potassium, especially in form K-NPs. It suggested that K activates about 60 enzymes which are involved directly/indirectly in many different physiological processes such as CO^2 assimilation, ATP- synthesis, and photosynthesis **(Lester *et al.*, 2010)**. Also, potassium treatment (K-NPs) promotes the translocation of carbohydrates which is related to nucleic acid, protein, and vitamins, and improves water uptake and root permeability (**Bisson *et al.*, 1994; Oosterhuis *et al.*, 1993).** Furthermore, it enhances tree growth development, and nutritional status, and improves tree yield, and fruit quality **(Marschner, 2012).** Also, the design and development of nano potassium could be more soluble or more reactive than their bulk counterparts. The large surface area and small size of nanomaterials could allow enhancing interaction and efficient uptake of nutrients for crop fertilization. The increased surface area in Nanomaterials can lead to increased reactivity and faster dissolution kinetics **(De Rosa *et al.*, 2010 and Mastronardi *et al.*, 2015).**

Conclusion

It can be concluded from the above results that potassium sprays, especially Nano potassium nitrate (KNO_3-NPs) at 3cm/5L/tree, had a positive effect on nitrogen, phosphorus, potassium percentages, and total chlorophyll contents in the leaves, which reflected on enhanced yield and fruit physical and chemical characteristics compared to control and other treatments. Therefore, it could be recommended that spraying Washington navel orange trees under similar environmental conditions and horticulture practices adopted in a present experiment with Nano potassium nitrate (KNO_3-NPs) at 3cm/5L/tree five times per season at a one-month interval (in the 1st week of March, April, May, June, and July), which are considered the best treatments used to improve tree nutritional status and get high yield with best fruit quality.

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تأثير صور البوتاسيوم المختلفة على الحالة الغذائية والإنتاجية وجودة الثمار لأشجار البرتقال أبوسرة .

محمد نبيل أحمد الصباغ[1]– أ.د. فؤاد محمد عبد اللطيف [1]– أ.د. حامد الزعبلاوى البدوى[1]– أ.د. محمد حمدان بعيه[2] – أ.د. شريف فتحى الجيوشى[1]

1- قسم البساتين . كلية الزراعة . جامعة بنها

2- قسم تكنولوجيا الحاصلات البستانية .المركز القومى للبحوث (الدقى).الجيزه

أجريت هذه الدراسة خلال موسمي 2022 و 2023 على أشجار البرتقال أبوسرة بعمر 12 سنة مطعومة على أصل النارنج والمزروعة على مسافة 5 × 5 م (168 شجرة/فدان) تحت نظام الري السطحي فى بستان خاص بقرية مشتهر، منطقة طوخ، محافظة القليوبية، مصر، لدراسة تأثير الرش الورقي بصور البوتاسيوم المختلفة مثل (نترات البوتاسيوم النانونية ، سترات البوتاسيوم، بوتاسيوم بولى سولفايد) على الحالة الغذائية والإنتاجية وجودة الثمار حيث أن معاملة الرش من صور البوتاسيوم، تغطي الشجرة بالكامل ، حيث وجد أن 5 لترات كافية في هذا الصدد، بالإضافة وتم الرش بشكل دوري خمسة مرات خلال الموسم التجريبي بمعدل مره شهرياً فى الأسبوع الأول من مارس وأبريل ومايو ويونيو ويوليو.

وقد أظهرت النتائج المتحصل عليها أن جميع معاملات الرش بإستخدام صور البوتاسيوم المختلفة أدت إلى تحسن ملحوظ فى الحالة الغذائية للاوراق , وزيادة المحصول وتحسين الخصائص الطبيعية والكيميائية للثمار لاشجار البرتقال ابو سرة مقارنة بالاشجار المرشوشة بالماء (الكنترول) ، كما وجد ان معاملة الرش بإستخدام البوتاسيوم النانونية بمعدل 3سم/5لتر/شجرة ، ، كان له أعلى تأثير معنوى على محتوى الأوراق من الكلوروفيل الكلى ونسبة كلاً من (النتروجين والفوسفور البوتاسيوم) ، مما أنعكس على تحسين الإنتاجية والصفات الفيزيائية والكيماوية للثمرة مقارنة بالكنترول (الرش بالماء) ومعاملات البوتاسيوم الاخري ، لذلك يمكن التوصية برش أشجار البرتقال أبو سرة بنترات البوتاسيوم النانونية بمعدل 3سم/ 5لتر/شجره خمس مرات في الموسم (مره شهريا) في الأسبوع الأول من مارس، أبريل، مايو، يونيو ، يوليو لتحسين الحالة الغذائية للأوراق وزيادة المحصول وتحسين صفات الجودة للثمار تحت نفس الظروف التجريبية .

الكلمات الإسترشادية:

البرتقال أبوسره ، المحصول ، نترات البوتاسيوم النانونية ، الحالة الغذائية ، الإنتاجية ،جودة الثمار .