Effect of Foliar Application with Nano and Other Potassium Sources on Yield and Fruit Quality of Washington Navel Orange.

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ABSTRACT

The present study was carried out on fruitful Washington navel orange trees budded on sour orange rootstock planted on clay loamy soil with flood irrigation in El- Qalyubia governorate, Egypt during two successive seasons 2020 and 2021 in a simple experiment with a complete randomized block design aimed to study using nano-potassium fertilizer compared with two conventional fertilizers potassium sources (Potassium nitrate and potassium humate) as foliar application with two levels each, three times/season on yield and fruit quality of "Washington" navel orange as well as their impact on fruits protein characteristics. Obtained results revealed that yield, fruit quality (physical and chemical) properties, and leaf nutrient contents (N, P, and K) responded differently to varied treatments. Potassium nitrate at 0.2% treatment increased fruit weight, juice weight, fruit total soluble solids, TSS/acid ratio, (lowest juice acidity %) and significantly displayed the reddish-orange fruit rind color. Application of 0.4% potassium nanoparticles (K-NPs) significantly enhanced the average yield, yield efficiency (kg/m3), and juice percentage, nevertheless unfortunately, this also revealed unsuspected variations in the genetic composition of eaten part of the fruit (whole segments) proteins compared to other treatments. Potassium humate treatment at 1% gave the highest V.C juice content.

Keywords: Navel orange- Fruit quality- Protein electrophoreses analysis- Potassium fertilizers.

INTRODUCTION

Statistical data of 2022 firmly establishes that Egypt's leading position in global citrus exportation, as it secured the top spot in citrus exports for the fifth year in a row, exporting a remarkable 1.987 million tons of citrus fruits. In terms of production, Egypt ranks eighth globally with an output of 4.71 million tons of citrus fruits, representing 2.84% of total global citrus production, placing it among the world's top citrus producers. Locally, citrus fruits constitute Egypt's most prominent fruit crop, both in terms of cultivated area (519,788 feddans, representing 29.8% of the total) and total fruit production (4,708,424 tons, representing 36.2%). Navel oranges hold a dominant position within citrus cultivation, occupying 161,631 feddans (31.1% of the citrus area) and contributing 1,531,315 tons of fruits (32.5% of overall citrus production) Agricultural Statistics Bulletin, Egypt, (2022) and FAO. (2022).

Nutrient fertilization is crucial for improving crop quality, and increasing production. Chemical fertilizers precise and management are a global challenge in producing horticulture crops. **(**Zulfiqar et al., 2019). Potassium is one of the necessary minerals for plants and essential to the physiology and growth of plants. In addition to being a structural component of plants, numerous metabolic processes, including protein synthesis, glucose metabolisms, and enzyme activation, are regulated by potassium. It is also necessary for many physiological activities, including stomatal control and photosynthesis. K has been gives plants resistance to abiotic stress; moreover, it is necessary for critical physiological processes like sugars & carbohydrates transportation, and the creation of starch. When compared to other nutrients, potassium is removed in large quantities by citrus fruits; potassium primarily affects the interior and exterior characteristics of citrus fruits (Hasanuzzaman et al., 2018).

Nano fertilizers improve stressed plants yield, both qualitatively and quantitatively by allowing nutrients to be released gradually over an extended length of time due to their small size and large surface areas, nano fertilizers have high reactivation that increases yields and can address the fundamental problem with conventional fertilizers, which is loss of nutrients in the soil. Regarding crop fertilization, nano fertilizers may improve nutrient interaction and uptake efficiency. To minimize environmental pollution, it is crucial to adjustment the use of chemical fertilization for crop nutrient requirements. This can be done by testing alternative fertilization techniques that make use of cutting-edge technologies like nanotechnology (Shalaby, et al., 2022, Seleiman, et al., 2021 and Manjunatha et al., 2016).

Applying plant nanoparticles may alter the treated plants' gene expression, which is linked to genetic pathways and ultimately impacts the plants' ability to grow and develop (Nair et al., 2010).

On Balady mandarin, Ennab and Khedr (2021) showed that foliar spraying with potassium humate (10% K_2O) significantly enhanced the amount of nitrogen, phosphorus, and potassium in leaves as well as fruit weight and yield (kg/tree or ton/feddan). According to research conducted by Vijay et al. (2016 and 2017) on Jaffa orange, fruit weight, number/tree, yield, yield characteristics and fruit colour can be enhanced by using potassium nitrate foliar spray.

Not so long ago, it was observed that the number of studies about the use of nanoparticles in plant fertilization, and many results of these researches confirm the existence of a change in the protein composition of the leaves and do not mention the impact of this on the eaten part of the fruits and the extent of its impact on human and animal health. So, we thought about studying the eaten part of the fruits and the effect of using nanoparticles on it and thus on human health.

Therefore, the purpose of this investigation is to assess the effects of various potassium fertilization sources on production, fruit characteristics, and nutritional leaves contents of navel orange trees, focusing on protein structure differences on the portion of the fruit that has been eaten.

MATERIALS AND METHODS

The present study was carried out during two successive seasons 2020 and 2021 in a private citrus orchard in (El-Qalyubia Governorate, Egypt). 25 years-old Washington navel orange trees (*Citrus sinensis* L., Osbek), budded on Sour orange rootstock (*Citrus aurantium*), grown on clay loamy soil at 5 × 5 m under flood irrigation system, were used to investigate the influence of foliar spray with (potassium nitrate KNO_3 (0.1 and 0.2 %), potassium-nano particles K-NPs (0.2 and 0.4%), potassium humate (0.5 and 1%) alongside water as control, the treatments were as follows:

1- Control (tap water)
2- Potassium nitrate at 0.1%
3- Potassium nitrate at 0.2%
4- Nano-potassium K-NPs at 0.2 %
5- Nano-potassium K-NPs at 0.4%
6- Potassium humate at 0.5%
7- Potassium humate at 1%

Experimental layout:

With the aim of investigate how different potassium sources affect Washington navel orange's productivity and fruit quality, forty-two unvarying as possible fruitful trees (three replicates, each with two trees) in a complete randomized block design were subjected three times/season in mid-May, July and September, respectively to investigate previously mentioned treatments on nutritional status, yield, yield efficiency and fruit quality of Washington navel orange. In particular, studying how potassium sources impact the properties of proteins of the edible portion of fruit (segments). Whereas, throughout the two seasons of study, these trees were subjected to cultural practices following a package of recommended practices from the Ministry of Agriculture.

Samples of fully expanded leaves were taken in mid-September of both seasons, cleaned, oven-dried, crushed, and digested. The percentages of nitrogen (N %) was estimated by using the semi-micro Kjeldahl after the method described by Plummer, (1971), phosphorus (P %) was calorimetrically estimated after Snell and Snell (1967), and potassium (K %) was determined using Flame photometer ″ JENWAY- PFP7″ by going through the procedure described by Jayaraman (1985).

In mid-September of each experimental year measurements of tree height and canopy circumference were taken to calculate the volume of tree canopy in cubic meters according to (Castle, 1983) with the following equation:

Tree canopy volume m^3 (CV) = 0.528 x H x D^2

Where, H = tree height, D = tree diameter

The fruits were harvested on December 20, 2020, and December 30, 2021, for both seasons, respectively. After each tree's fruits were collected, they were counted individually, total yield was expressed as number /tree and kg/tree (by multiplying the numbers of fruits × average fruit weight) then (yield per feddan was calculated) .Yield efficiency (YE) was calculated for the harvests of 2020 and 2021 seasons by dividing the fruit yield (kg/tree) by the canopy volume (m^3/tree) and the result was expressed in kg/m^3 of the tree canopy according to Maria et al. (2019). After that, fruit samples were obtained to the laboratory to determine their physical and chemical characteristics, fruit samples were weighed in grams using a two digital sensitive balance. The height, diameter (cm) and fruit peel thickness (cm) of each fruit were also measured by Digital Vernier's Calipers then fruit shape index was calculated. Fruit rind color components lightness, chroma, and hue angle were determined using (Lch colour model) to quantify fruit rinds color (McGuire, 1992) whereas L (Lightness) parameter indicates the brightness of the peel color. Higher values represent lighter colors, a axis (Green to Red), b axis (Blue to Yellow), and hue angle which represents the dominant color in degrees.

Fruit chemical properties TSS% by handheld refractometer, titratable acidity% (citric acid as g/100 ml juice), TSS/acid ratio, and 2.6-dichlorophenol indophenol methodology to determine vitamin C (ascorbic acid as mg/100 ml juice) were determined according to (A.O.A.C., 2010).

As well as segments (fruits' edible part) protein, for the three forms of potassium utilized in this experiment were examined as follows:

Protein related index:

Sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE) was used to assess electrophoretic proteins in treated fruits (navel orange eaten bulb (segments)) with potassium nitrate 0.2%, potassium humate1%, and potassium nanoparticles 0.4%. Fresh fruits were picked at (December 2021), it was cleaned with tissue paper, then kept in an ice box then directly transported to the laboratory for determine electrophoretic proteins. Samples were weighed then processed using the procedure described by Oresegun et al. (2016). By comparing with a medium molecular weight protein standard marker given by Ferments com., the number of distinct protein bands and its molecular weight were determined.

Potassium nano-fertilizer preparation:

Potassium nano-fertilizer was successfully synthesized by incorporating potassium salts in a chitosan carrier via ionotropic pre-gelation method described by Nido et al. (2019) as follows: Water was used to dissolve potassium sulphate and potassium carbonate powder to a concentration of 30% weight/weight. Chitosan dry powder was dissolved in 0.1% acetic acid solution to make 2% viscous chitosan solution. Then the mixture solution of potassium sulphate and potassium carbonate was added dropwise to chitosan solution, and pre-gelation was significantly finished after 4 hours at ambient temperature. After 4 hours, the obtained nanospheres were dried at 40 ºC for 48 hours.

Potassium nano-fertilizer characterization:

Dynamic Light Scattering (DLS) supplied from Malvern Analytical Instruments model M3-PALS zeta potential analysis determined the particle size distribution. The average diameter of potassium nano-fertilizer was determined using the TEM images J software. JEOL (JEM-100CXII) Ltd. 1-2, Musashino 3-chome Akishima Tokyo, Japan.

Statistical analysis:

Analysis of variance was performed on all data obtained in both seasons at a 5% probability level of significance. Snedecor and Cochran's (1989) methodology was used to identify significant differences between means. According to Duncan`s multiple test range (Duncan, 1955), capital letters were employed to distinguish between the means of all treatments. MSTAT-C (Freed and Scott, 1986) was the program utilized.

RESULTS

Nutritional status:

Figure (1) presents the effect of various concentrations of potassium sources treatments on Washington navel orange dried leaves' nutritional status (N%, P% and K %) over two experimental seasons (2020 and 2021). Each treatment has different effects on N, P and K leaves content, there were significant differences among treatments for each nutrient. For N%, the treatment "potassium nitrate 0.2%" has the highest nitrogen values (2.70 and 2.71%) meanwhile, the lowest N% resulted from the control treatment (2.42 and 2.43 %) in the first and second seasons respectively which states that leaves nitrogen contents were significantly influenced by all treatments (except the control treatment) in both seasons. For P% no treatment resulted in a significant increase in phosphorus leaves content compared to the control for both two seasons of study. As for leaves potassium (K %) content, there was a significant response to treatment with all forms of potassium, leaves potassium percentage in all treatments were increased above its percentage in control leaves. The highest leaves K % resulted from treatment with nano-potassium at a concentration of 0.4% in both seasons of the study (2020 and 2021), where it was recorded 1.86% and 2.20 % respectively, followed by potassium nitrate 0.2% treatment which ranked second after nano-potassium K-NPs treatment with 1.73 and 2.07 % of potassium in leaves, while the lowest percentage was the control treatment with 1.26% and 1.34% in both seasons respectively, and the rest of potassium percentages in leaves for the rest of treatments varied between that, i.e. (Nano potassium K-NPs at 0.4% led to highest significant increase in potassium content).

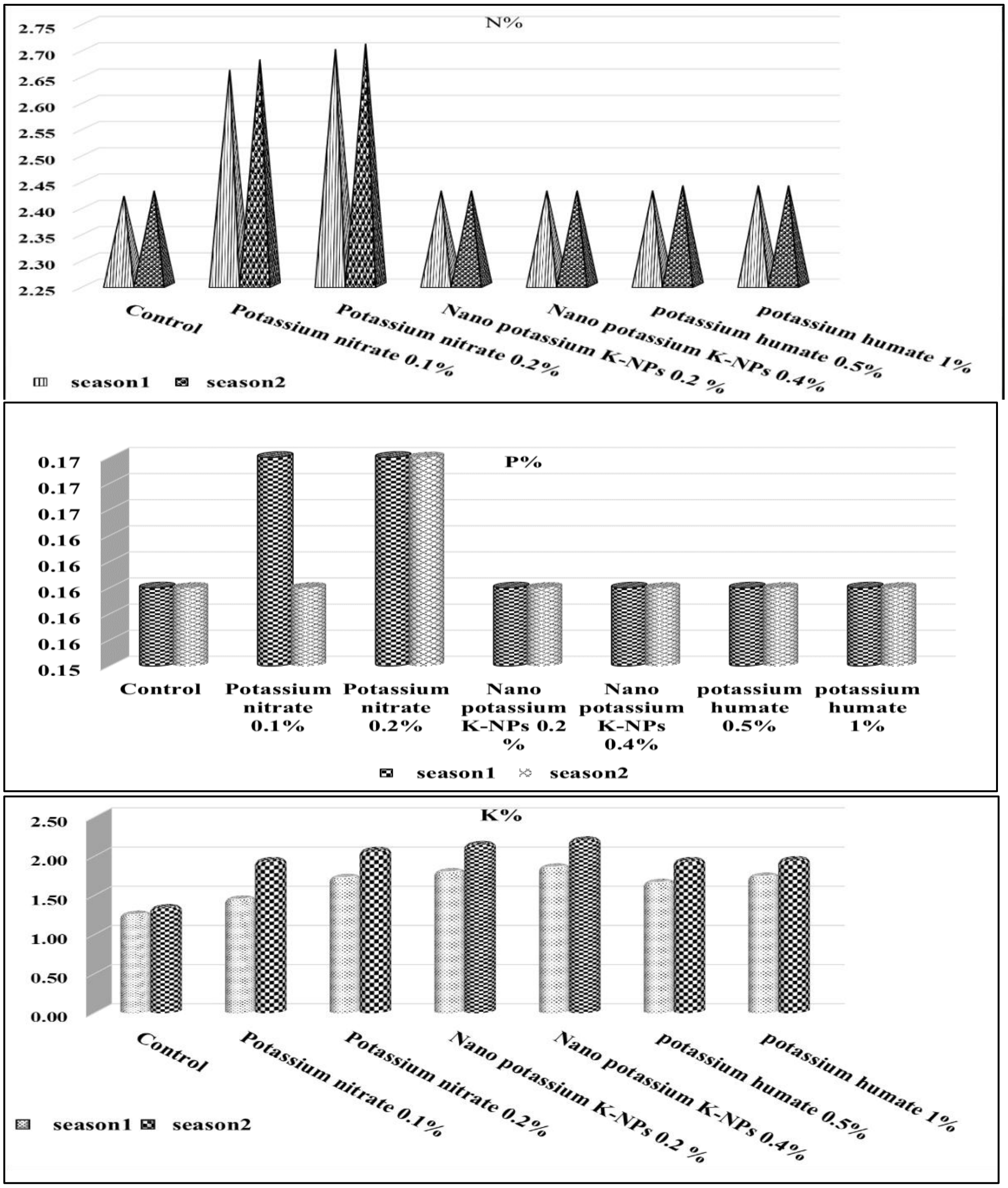

Fig. (1). Effect of potassium sources and concentrations on Washington navel orange leaves nutrient contents over 2020 and 2021 experimental seasons.

Potassium nitrate (KNO_3) application at 0.1% and 0.2% concentrations significantly increased both nitrogen (N) and potassium (K) levels in Washington navel orange leaves across two seasons. This suggests that KNO_3 may enhance N and K uptake and utilization, potentially improving overall plant health. No significant changes in phosphorus (P) content were observed, indicating potential dependence on environmental factors or plant developmental stages. The positive effects of nano-potassium (K-NPs) treatments at 0.2% and 0.4% on leaf K contents may be explained by the plant's enhanced capacity to absorb nano potassium (K-NPs) as a result of the particles' tiny size and ease of absorption, which raised the concentration of the K% in the leaves.

Yield and yield efficiency:

Data in **Table (1)** shows that control treatment had the lowest yield in terms of number of fruits per tree (221, 211), kg per tree (56.9 , 60.5), and tons per feddan (9.6, 10.2) for first and second season respectively. The highest yield was observed with the nano-potassium K-NPs 0.4% treatment, which had 265, 274 fruits per tree, 79.1, 87.1 kg per tree, and 13.3, 14.6 tons per feddan. The largest increase in yield compared to the control was observed with the nano-potassium K-NPs 0.4% treatment, with a change of (+3.7 and +4.4 tons per feddan) for both seasons 2020 and 2021 respectively. Potassium nitrate 0.2% also had significant yield increases in first season; with changes of +2.6 tons per feddan, meanwhile, nano-potassium K-NPs 0.2% treatments in two seasons of study had significant increases in yield, with changes of +3.3 and +3.6 tons per feddan, respectively.

Table (1). Effect of foliar application with potassium nitrate, nano-potassium and potassium humate on yield (number of fruits /tree, kg/tree and ton /feddan) and change (tons) in yield of Washington navel orange during 2020 and 2021 experimental seasons.

Treatments	Yield number of fruits/tree	Yield (kg/tree)	Yield (ton/feddan)	Change (tons) in yield
First season				
Control	221 E	56.9 D	9.6 D	-
Potassium nitrate 0.1%	214 F	67.4 C	11.3 C	+ 1.7
Potassium nitrate 0.2%	219 E	72.5 B	12.2 BC	+ 2.6
Nano-potassium K-NPs 0.2 %	259 B	76.9 A	12.9 AB	+ 3.3
Nano-potassium K-NPs 0.4%	265 A	79.1 A	13.3 A	+ 3.7
Potassium humate 0.5%	229 D	70.0 BC	11.8 BC	+ 2.2
Potassium humate 1%	237 C	72.0 B	12.1 BC	+ 2.5
Second season				
Control	211 C	60.5 F	10.2 F	-
Potassium nitrate 0.1%	225 B	71.3 CD	12.0 CD	+ 1.8
Potassium nitrate 0.2%	228 B	74.3 C	12.5 C	+ 2.3
Nano-potassium K-NPs 0.2 %	279 A	81.9 B	13.8 B	+ 3.6
Nano-potassium K-NPs 0.4%	274 A	87.1 A	14.6 A	+ 4.4
Potassium humate 0.5%	223 B	66.3 E	11.1 E	+ 0.9
Potassium humate 1%	225 B	68.9 DE	11.6 DE	+ 1.4

Means followed by the same letter in a column do not differ statistically according to Duncan's test at $P<0.05$.

In summary, the foliar application of Nano potassium, especially at the higher concentration of 0.4%, resulted in the highest yields and the greatest increase in yield compared to the control and other treatments during both experimental seasons. This suggests that all of the treatments were effective in improving the productivity of the Washington navel orange trees and indicates that nano-potassium K-NPs at 0.4% may be the most effective for boosting productivity. Our results are in harmony with findings of Vijay et al. (2016 and 2017), Adel et al. (2023) who reported that 0.02% K NPs have improved the yield and fruit quality of date palms.

The results in **Table (2)** showed that, the application of nano-potassium K-NPs at a concentration of 0.4% had the most significant positive impact on both tree canopy volume (m^3) and yield efficiency (kg/m^3) of Washington navel orange trees. The nano-potassium treatments outperformed the potassium nitrate and potassium humate treatments in both seasons.

Table (2). Effect of foliar application with potassium nitrate, nano-potassium and potassium humate on tree canopy volume (m^3) and yield efficiency (kg/m^3) of Washington navel orange trees during 2020 and 2021 experimental seasons.

Treatments	Tree canopy volume (m^3)	Yield efficiency (yield Kg)/m^3 of canopy volume (kg/m^3)
First season		
Control	17.8 E	3.2 C
Potassium nitrate 0.1%	21.2 D	3.2 C
Potassium nitrate 0.2%	22.8 A	3.2 C
Nano-potassium K-NPs 0.2 %	22.1 B	3.5 A
Nano-potassium K-NPs 0.4%	22.8 A	3.5 A
Potassium humate 0.5%	21.6 C	3.2 C
Potassium humate 1%	21.8 C	3.3 B
Second season		
Control	17.2 C	3.5 C
Potassium nitrate 0.1%	19.1 B	3.7 B
Potassium nitrate 0.2%	22.7 A	3.3 D
Nano-potassium K-NPs 0.2 %	21.6 A	3.8 B
Nano-potassium K-NPs 0.4%	21.9 A	4.0 A
Potassium humate 0.5%	22.2 A	3.0 E
Potassium humate 1%	22.4 A	3.1 E

Means followed by the same letter in a column do not differ statistically according to Duncan's test at $P<0.05$.

In the first season, the nano-potassium K-NPs 0.4% and potassium nitrate 0.2% treatments resulted in the biggest tree canopy volumes of 22.8 m^3, while the nano-potassium K-NPs 0.2% and 0.4% treatments had the highest yield efficiencies of 3.5 kg/m^3. In the second season, the nano-potassium K-NPs 0.2%, 0.4%, and the potassium humate 0.5% and 1% treatments had the largest tree canopy volumes, ranging from 21.6 to 22.4 m^3. Nano potassium K-NPs 0.4% treatment had the highest yield efficiency of 4.0 kg/m^3, outperforming all other treatments. These results suggest that the application of nano-potassium K-NPs, particularly at the higher concentration of 0.4%, can significantly improve both the tree canopy volume and yield efficiency of Washington navel orange trees compared to the other potassium-based treatments tested; this indicates that this treatment may be the most effective for boosting productivity relative to canopy size.

Fruit quality (physical and chemical characteristics):

Data in **Table (3)** shows the effects of different treatments on the physical characteristics of Washington navel orange fruits over two experimental seasons (2020 and 2021). Treatments included potassium nitrate at two concentrations (0.1% and 0.2%), nano-potassium at two concentrations (0.2% and 0.4%), and potassium humate at two concentrations (0.5% and 1%). In the first season, the highest fruit weight (331.7 g), fruit height (8.69 cm), fruit diameter (8.44 cm), and fruit juice weight (183.3 g) were observed with 0.2% potassium nitrate treatment. This indicates that the higher concentration of potassium nitrate was more effective in improving these physical characteristics of fruits. Fruit shape index, which is a measure of the ratio of fruit height to fruit diameter, remained relatively consistent across all treatments, suggesting that the different treatments did not significantly affect the shape of the fruits. Fruit peel thickness was highest with 0.2% potassium nitrate treatment, (0.57 cm) indicating that this treatment resulted in thicker fruit peels. The fruit juice weight-to-weight ratio (fruit juice w/w) was highest with 0.5% potassium humate treatment (58.46 %), suggesting that this treatment enhanced the juice content of the fruits.

Second season results, were generally similar to the first season, 0.2% potassium nitrate treatment shows the highest values for most physical characteristics. Fruit shape index and fruit juice w/w were less affected by the treatments in the second season compared to the first season. Overall, the results suggest that the application of potassium nitrate, nano-potassium, and potassium humate can improve physical characteristics of Washington navel orange fruits, with the higher concentrations of potassium nitrate and potassium humate being more effective in enhancing certain characteristics.

Table (3). Effect of foliar application with potassium nitrate, nano-potassium and potassium humate on physical characteristics of Washington navel orange fruits.

Treatments	Fruit weight (g)	Fruit height (cm)	Fruit diameter (cm)	Fruit shape index	Fruit peel thickness (cm)	Fruit juice weight (g)	Fruit juice w/w (%)
First season 2020							
Control	258.70 C	7.77 B	7.73 C	1.003 A	0.41 C	132.7 C	51.41 B
Potassium nitrate 0.1%	315.00 AB	8.50 A	8.30 A	1.027 A	0.50 AB	171.3 AB	54.33 AB
Potassium nitrate 0.2%	331.70 A	8.69 A	8.44 A	1.030 A	0.57 A	183.3 A	55.32 AB
Nano-potassium K-NPs 0.2 %	298.00 B	8.39 A	8.02 B	1.043 A	0.48 BC	161.0 B	54.02 AB
Nano-potassium K-NPs 0.4%	301.70 AB	8.29 A	8.19 AB	1.010 A	0.48 BC	166.3 AB	55.05 AB
Potassium humate 0.5%	305.70 AB	8.47 A	8.31 A	1.020 A	0.51 AB	178.3 AB	58.46 A
Potassium humate 1%	308.70 AB	8.50 A	8.31 A	1.023 A	0.45 BC	172.7 AB	55.81 AB
Second season 2021							
Control	286.70 C	8.45 B	8.18 B	1.033 A	0.52 C	153.3 B	53.4 A
Potassium nitrate 0.1%	317.30 AB	8.73 AB	8.45 AB	1.037 A	0.54 BC	170.3 A	53.8 A
Potassium nitrate 0.2%	326.70 A	9.12 A	8.48 A	1.077 A	0.64 A	173.7 A	53.2 A
Nano-potassium K-NPs 0.2 %	293.30 C	8.69 AB	8.23 AB	1.057 A	0.52 C	157.0 B	53.5 A
Nano-potassium K-NPs 0.4%	317.30 AB	9.01 A	8.44 AB	1.070 A	0.59 AB	163.3 AB	51.5 A
Potassium humate 0.5%	296.00 C	8.49 B	8.26 AB	1.030 A	0.56 BC	156.7 B	52.9 A
Potassium humate 1%	306.70 B	8.67 AB	8.40 AB	1.033 A	0.51 C	157.7 B	51.4 A

Means followed by the same letter in a column do not differ statistically according to Duncan's test at P<0.05.

Table (4) and Figure (2) provide insights into the fruit peel color characteristics of the treatments. It appears that treatments vary in terms of lightness, hue°, and dominance of specific colors (red, green, or yellow). Which, L (Lightness) parameter indicates brightness of peel color, higher values represent lighter colors. Treatments 1, 7 and 6 have the highest lightness values, indicating lighter peel color (greener yellowish hue°). Meanwhile, treatment 3, (Potassium nitrate 0.2%) has the lowest value suggesting a more reddish orange hue°. The Hue angle represents the dominant color in degrees, which it ranging from 0° (red) through 90° (yellow), 180° (green). Treatments 3, 2 (KNO_3 in 0.2% and 0.1% concentration, respectively) have relatively lower hue° values, suggesting a dominance of deep orange rind colors, while control and potassium humate 1% treatments have higher hue angle values, indicating a dominance of pale yellow color.

Overall, fruits peel color could be important for aesthetic appeal and consumer preference, So, we can institute that potassium nitrate treatments help promote a redder, darker orange peel color, as opposed to the dull yellow color that arise from control or potassium humate treatments.

Table (4). Effect of foliar application with potassium nitrate, nano-potassium and potassium humate on fruit rind color of Washington navel orange.

No.	Treatments	L (lightness)	A axis (green to red)	B axis (blue to yellow)	Hue°
1	**Control**	74	11	55	37
2	**Potassium nitrate 0.1%**	57	38	48	20
3	**Potassium nitrate 0.2%**	49	51	54	16
4	**Nano-potassium K-NPs 0.2 %**	55	39	55	23
5	**Nano-potassium K-NPs 0.4%**	57	40	58	24
6	**Potassium humate 0.5%**	62	23	63	30
7	**Potassium humate 1%**	64	27	58	35

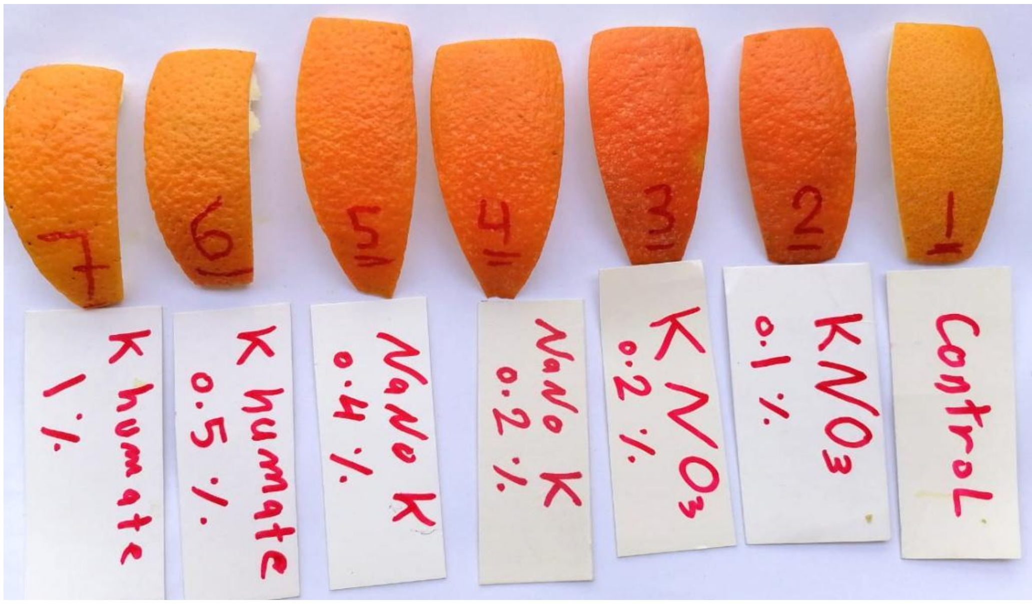

Fig. (2). Fruit peel color of Washington navel orange fruit as affected by varies potassium sources and concentrations.

Data in **Table (5)** revealed that V.C. (mg/100ml juice) content varies across treatments and seasons. Generally, treatments with nano-potassium and potassium humate exhibit higher vitamin C content compared to the control, especially notable in the second season. TSS % (Total soluble solids percentage) shows variability across treatments. In the first season, treatments with nano-potassium K-NPs at both concentrations and potassium nitrate 0.2% demonstrate higher TSS % compared to the control, while in the second season, potassium nitrate treatments show similar trends. The acidity % levels vary among treatments and seasons. Notably, potassium nitrate treatments tend to reduce acidity, particularly in the second season. The ratio of total soluble solids to acidity (TSS/ acid ratio) indicates fruit maturity and flavor balance, which treatments with nano-potassium K-NPs and potassium nitrate, especially at higher concentrations, tend to enhance this ratio, suggesting improved fruit quality. Overall, the Table 5 suggests that different treatments influence the quality of Washington navel orange fruits differently, with nano-potassium and potassium nitrate treatments often leading to favorable outcomes, especially in terms of vitamin C content, total soluble solids, and the T.S.S/ acid ratio.

Table (5). Effect of foliar application with potassium nitrate, nano-potassium and potassium humate on chemical characteristics (V.C, TSS, acidity % and T.S.S/acid ratio) of Washington navel orange fruits.

Treatments	V.C (mg/100ml juice)	T.S.S (%)	Acidity (%)	T.SS/ acid ratio
First season 2020				
Control	52.25 AB	12.33 AB	0.48 AB	25.33 B
Potassium nitrate 0.1%	52.25 AB	12.33 AB	0.49 A	25.03 B
Potassium nitrate 0.2%	49.13 B	13.00 A	0.44 AB	29.17 A
Nano-potassium K-NPs 0.2 %	55.00 A	13.00 A	0.42 B	30.00 A
Nano-potassium K-NPs 0.4%	53.72 A	12.67 AB	0.47 AB	26.40 B
Potassium humate 0.5%	55.00 A	12.67 AB	0.48 AB	25.93 B
Potassium humate 1%	49.50 B	11.67 B	0.48 AB	24.47 B
Second season 2021				
Control	59.58 CD	13.00 B	0.63 A	20.1 C
Potassium nitrate 0.1%	63.25 BC	13.00 B	0.54 B	24.2 B
Potassium nitrate 0.2%	57.75 D	14.00 A	0.48 C	28.7 A
Nano-potassium K-NPs 0.2 %	66.92 B	13.30 AB	0.59 AB	22.4 BC
Nano-potassium K-NPs 0.4%	60.50 CD	13.30 AB	0.59 AB	22.1 BC
Potassium humate 0.5%	66.00 B	13.70 AB	0.55 B	24.4 B
Potassium humate 1%	78.83 A	13.30 AB	0.58 AB	23.0 B

Means followed by the same letter in a column do not differ statistically according to Duncan's test at $P<0.05$.

Table (6) and **Fig. (3)** Presents the results of protein electrophoreses analysis conducted on edible portions of fruits (navel orange fruit segments) which identifying the genes present and quantifying the abundance of specific proteins within the fruit samples. No visible morphological or phenotypic differences were observed in the fruits, suggesting no apparent changes in their overall structure. The genetic structure of potassium nitrate and potassium humate treatments treated fruits exhibited no significant differences compared to the control. This indicates that these treatments did not induce any substantial alterations in the fruit's genetic profile. In contrast to the control and other potassium treatments, the nano-potassium treatment revealed distinct changes in the genetic structure of the fruits. Specifically, some genes disappeared (bands 1, 2 and 10), while new genes emerged (bands 3, 9, 15 and 16), this treatment also enhanced the expression of certain genes, leading to increased protein concentration. This was evident for bands 5 and 11. These findings suggest that the nano-potassium treatment induced genetic modifications, potentially activating or silencing certain genes. Additionally, the number of visible genes in the nano-potassium treated fruits was 13, compared to 12 in the control and other potassium treatments. The remaining treatments exhibited varying effects on gene expression, with some influencing specific genes and others leading to overall increases in gene expression. Notably, the nano-potassium treatment demonstrated the most significant impact on gene expression.

Our findings reinforce what Nair et al. (2010) found that, since the size of nanoparticles are smaller than cell wall pores size, they can penetrate and move readily through cell wall and plasma membrane. They are also taken up by plant cells by binding to carrier proteins through ion channels, and endocytosis (Nair et al., 2010).

Explanation of results

Among many essential physiological functions, potassium is needed for protein and carbohydrate synthesis, fine cells division and growth, generation of organic acids, and fruit quality enhancement in terms of size, flavor, and color. There are a few key factors that likely contributed to the superior performance of the nano-potassium treatments compared to the other treatments:

Nano-sized potassium particles have a higher surface area-to-volume ratio compared to larger potassium particles. This increased surface area allows enhanced availability of nutrients and uptake for better dissolution and assimilation of the potassium by the plant, leading to more efficient nutrient uptake. The tiny size of the nano-potassium particles enables them to more easily penetrate the leaf cuticle and be transported within the plant so this may improve nutrients mobility and translocation.

SDS-Protein electrophoresis

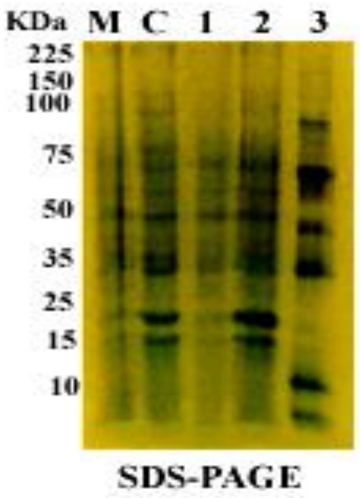

Fig. (3): SDS- segments protein banding patterns of the of navel orange fruit

Table (6): Densitometric analysis for SDS segments proteins of the navel orange fruit

Band No	M.W bp	Treatments			
		Control	0.2% KNO_3	1% potassium humate	0.4 % K-NPs
1	131	1	1	1	0
2	115	1	1	1	0
3	102	0	0	0	1
4	86	1	1	1	1
5	74	1	1	1	1
6	66	1	1	1	1
7	59	1	1	1	1
8	47	1	1	1	1
9	43	0	0	0	1
10	38	1	1	1	0
11	34	1	1	1	1
12	31	1	1	1	1
13	20	1	1	1	1
14	16	1	1	1	1
15	11	0	0	0	1
16	9	0	0	0	1
Total		**12**	**12**	**12**	**13**

This enhanced mobility and translocation of potassium throughout the plant likely resulted in better distribution and utilization of the nutrient. The nano-potassium particles may have another synergistic effect such interacted with other nutrients or plant growth factors in a way that amplified the positive effects on plant growth and yield. Nano-potassium could have improved the availability or uptake of other essential nutrients, leading to a more balanced and optimal nutrient status for the plant. Potassium is known to play a crucial role in plant stress tolerance, helping to regulate osmotic balance, enzyme activation, and other physiological processes.

The enhanced potassium availability from the nano-potassium treatments may have better equipped the plants to withstand environmental stresses, leading to improved overall performance. The nano-potassium particles' tiny size and large surface area may have allowed for more targeted and efficient delivery of the nutrient to the specific plant tissues and locations where it was needed most. In contrast, the larger particle sizes and potentially lower bioavailability of the potassium nitrate and potassium humate treatments may have limited their ability to match the performance of the nano potassium treatments. Thus the positive effects of the treatments on yield are likely due to the increased availability of nutrients, particularly potassium (K), to the trees. Potassium is a crucial nutrient for plants' growth and development and it plays a key role in fruit quality. The nano-potassium K-NPs treatments may have been particularly effective due to the smaller size of the potassium particles, which may have made them easier for the trees to absorb. Additionally, Potassium humate is often added as a ground additive; however, in this case, it was sprayed as a potassium source rather than humate, so potassium humate treatments may have been beneficial due to the chelating properties of humic acid, which can help to make nutrients more available to plants.

DISCUSSIONS

Our results are in harmony with findings of Shalaby et al. (2022), Vijay and Saini (2016) and Vijay et al., (2016, 2017) on Jaffa sweet orange, Feungchan and Sharma (1974) on two sweet orange cultivars (Hamlin and Valencia orange), and Magda et al. (2022) on Grapevines, which demonstrated that nano-K fertilizer treatments significantly increased N and K leaf compared to control treatment. Concerning to tree canopy volume, yield and yield efficiency, our results in are in synchronization with findings of Vijay et. al. (2016 and 2017) on Jaffa sweet orange” foliar application of potassium enhanced fruit weight, diameter, number of fruits/tree and yield El-Shereif et al. (2023) on Valencia orange “nano-fertilizer treatments increased tree canopy volume, nutrient contents, yield, and fruit quality”. And Rico et al. (2014) whom found improved growth and better yields of plants after application of nanoparticles. Upon entering a cell, nanoparticles can proceed via both apoplastic and symplastic pathways, ultimately impacting several physiological and metabolic processes in plants. Schwab et al. (2015) Because of the difficulties in conducting analyses and the complexity of plant structures, little is known about the uptake, transport, and toxicity of engineered nanomaterials (ENMs) in plants. Although there has been evidence of ENMs migration in plant tissues, particularly the apoplast, the underlying mechanisms are unknown Achilea (1999), Boman (1995), Rabber (1997) these findings align with our observations regarding the enhancement of both tree canopy, yield, yield efficiency and fruit quality attributes (weight, TSS to acidity ratio, juice weight).

Conclusion:

The results of this study suggest that all of the tested treatments can be effective for improving productivity and fruit quality of Washington navel oranges. However, nano-potassium K-NPs at 0.4% concentration appears to be the most effective treatment overall but further research is needed to confirm these findings and to optimize the use of this treatment in commercial orange production.

Recommendations

Despite the good results of nano-potassium treatment in terms of yield and fruit quality, its potential to alter the genetic expression of the treated fruit's DNA is a somewhat worrying result, because this could lead to appearance of mutations in the treated plants, this effect is not a concern as citrus fruits are well-known for carrying a large number of naturally occurring mutations. Rather, the danger here lies in the remaining nanoparticles in the fruits in the form of nano-potassium, and when a person eats these fruits, they may cause the same effect that they caused in the fruits on human DNA, or they may affect the human immune system. Therefore, we do not recommend nanoparticles treatment until extensive biosafety studies have been conducted when utilizing it. In light of the research results and despite the increase in yield from the 0.4% nano-potassium treatment over the other treatments studied, we recommend spraying Washington navel orange trees with a 0.2% potassium nitrate solution (1200 grams per 600 liters of water) at mid-May, June, and September to increase yield and fruit quality. Finally, it should not be overlooked that there is a need for further research in the field of nanotechnology applications in food. We can confidently say that nanotechnology can be used to conduct studies on ornamental plant seedlings and woody trees used in breeding programs to develop new varieties considering all safety and security measures when utilizing.

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الملخص العربى

تأثير الرش الورقى بالنانو و مصادر أخرى من البوتاسيوم على محصول وجودة ثمار البرتقال أبو سرة واشنجطن

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أجريت هذه الدراسة على أشجار برتقال بسرة واشنجطن مثمرة ومطعومه على أصل النارنج، منزرعة فى تربة طينية وتروى بالغمر في محافظة القليوبية - مصر خلال موسمين متتاليين 2020 و2021 في تجربة بسيطة ذات تصميم قطاعات كاملة العشوائية بهدف دراسة أثرالرش الورقى بسماد النانو بوتاسيوم مقارنة مع مصدرين من أسمدة البوتاسيوم التقليدية هما (نترات البوتاسيوم وهيومات البوتاسيوم) بمستويين لكل منهما ثلاث مرات في كل موسم على المحصول، وجودة ثمار البرتقال أبو سرة "واشنجطن"، وكذلك التأثير على خصائص بروتين الثمار.

كشفت النتائج التي تم الحصول عليها أن خصائص المحصول وجودة الثمار (الفيزيائية والكيميائية) ومحتوي الأوراق من العناصر الغذائية (النيتروجين والفسفور والبوتاسيوم) أظهرت استجابات مختلفه لمختلف المعاملات. حيث أدت المعاملة بنترات البوتاسيوم بتركيز 0.2 % إلى زيادة وزن الثمار، ووزن العصير والمواد الصلبة الذائبة الكلية، ونسبة المواد الصلبة الذائبة إلى الحموضة (أقل نسبة حموضة بالعصير)، وأعطت اللون البرتقالي المحمر لقشرة الثمرة. وأدى استخدام تركيز 0.4% من سماد النانو بوتاسيوم (K-NPs) إلى تحسين قراءات كل من متوسط المحصول، وكفاءة المحصول (كجم/م^3)، ونسبة العصير بشكل ملحوظ، ولكن لسوء الحظ، أدت هذه المعاملة أيضًا لوجود اختلافات غير متوقعة في التركيب الوراثي لبروتين الجزء المأكول من الثمرة (الفصوص) مقارنة بالمعاملات الأخرى. وأعطت معاملة هيومات البوتاسيوم بنسبة 1% أعلى محتوى لعصير الثمار من فيتامين ج.