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# Impact of Various Iron 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 iron forms, i.e., green iron nanoparticles (Fe-NPs), beside two tradional iron forms, ferrous sulfate ($FeSO_4.7H_2O$), and Fe-chelate (Fe-EDTA), on the leaf nutritional status, productivity, and fruit quality of Washington navel orange trees.". Each iron source was applied, covering the whole foliage of each tree canopy, whereas 5 liters were found to be 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 iron forms induced a remarked promotion in leaf nutritional status. Also iron 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 green Fe-$NPs_2$ (1/40 dilution of the Fe-NPs stock solution) which significantly superior in this concern compared with control (water spray) and other iron treatments ,thus it could be recommended to spray Washington navel orange trees with green Fe-$NPs_2$ (1/40 dilution of the Fe-NPs stock solution) 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, green iron nanoparticles (green Fe-NPs), 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.

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).**

Iron is an essential element for plant growth, chlorophyll synthesis, respiration, and redox processes of tissues of the plant and it is also involved in the synthesis of important cytokines in plants, in addition to the important cycle of photosynthesis **Sheykhbaglou *et al.*, (2010).**

Thus, this study was conducted to investigate the effect of foliar sprays of green iron nanoparticles (green Fe-NPs), ferrous sulfate ($FeSO_4.7H_2O$), and Fe-chelate (Fe-EDTA) as a foliar spray at different levels on 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 | | | |

Iron nanoparticles (Fe-NPs) prepared by green method beside two traditional iron fertilizer forms, ferrous sulfate ($FeSO_4.7H_2O$) product by Star Grace Company and Fe-chelate (Fe- EDTA 13%) produced by Poligono Industrial Primores Company (Espana) were applied as a foliar spray **.**

The present experiment included six treatments as each Fe form were respended 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 green Fe-$NPs_1$ (1/80 dilution) of the Fe-NPs stock solution /5L/tree.

**$T_3$**-Foliar spray with green Fe-$NPs_2$ (1/40 dilution) of the Fe-NPs stock solution /5L/tree.

**$T_4$**-Foliar spray with ferrous sulfate ($FeSO_4.7H_2O$) at 7.5g/5L/tree.

**$T_5$**-Foliar spray with ferrous sulfate ($FeSO_4.7H_2O$) at 15g/5L/tree.

**$T_6$**-Foliar spray with Fe-chelate (Fe- EDTA) 13% at 5 g/5L/tree.

**$T_7$**-Foliar spray with Fe-chelate (Fe- EDTA) 13% at 10g/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 nano of Fe-NPs prepared by green method as following:**

**1. Preparation of Green Fe-NPs**

Extract fresh guava leaves (*Psidium guajava* L.) were collected from the Al-Qanater Horticultural Research Station, Qalubia Govern orate, cleaned and washed with tap water first, then with distilled water, to remove the associated pollutants. The samples were air-dried for two weeks before being ground to a fine powder in the laboratory and used to make the extract. About 150 g of the powder sample was boiled in one liter of distilled water for 20 min and filtered after cooling. The extracts were then kept at 4 ◦C until they were used to make green Fe-NPs.

**2 .Green Synthesis of Fe-NPs**

A solution of 5 mM FeSo4 was set through FeSO4 dissolving in the distilled water. Green synthesis using the *Psidium guajava* L. (guava) leaf extract and Fe ions were reduced and capped using the method was described by (**Patil and Rane (2020)** , with some modifications. These modifications included adding 200 mL of the extract to the aqueous solution of FeSO4 at normal atmospheric pressure, and the pH was adjusted to 9.0. To obtain the stock solution, the mixture was constantly stirred at 70 ◦C–80 ◦C for 8 h, followed by further stirring at room temperature overnight without heating. The prepared Fe-NPs solution was diluted 80 and 40 times to obtain Fe-NPS1 and Fe-$NPS_2$, respectively, for application as a foliar spray with two different concentrations **(El-Gioushy *al.*, 2021).**

**3. Scanning Electron Microscopy** (SEM).

Scanning electron microscopy (SEM) was used to determine the morphology and size of the particles. The shape and size of the iron nanoparticles were revealed by scanning electron microscopy measurements. The results showed that the iron nanoparticles had almost a needle shape, which displays the Fe NP diameter and length. The particle diameter was in the range of 21±9 nm, and the length was 87±1 nm, as shown in **Fig (1).**

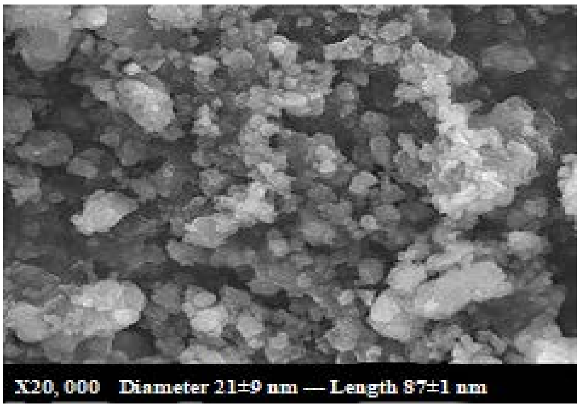


**Fig (1)**- cleared the shape and size of the iron nanoparticles by Scanning Electron Microscopy (SEM)

**4. Transition Electron Microscope** (TEM).

The morphology and size of the particles were determined by a Transmission electron microscope (TEM, JEOL GEM-1010 transmission electron microscope at 70 kV) at the Regional Center for Mycology and Biotechnology, Egypt. A drop containing Fe-NPs was deposited onto carbon-coated copper grids (CCGs) and then exposed to the infra light for 30 min. The micrograph was analyzed by JEOL—JEM 1010—Transmission Electron Microscope at 70 kV in the RCMB, Al-Azhar .

**5. Zeta Potential and Dynamic Light Scattering**

The zeta potential (surface charge) is important in determining the stability and shelf life of nanoparticles. A high zeta potential value, either positive or negative, is required to prevent particle aggregation (**Gumustas *et al* ., (2017).** A high zeta potential increased repulsive forces relative to attractive forces, preventing particle agglomeration **Mahbubul *et al.* (2019).**

The zeta potential value of iron nanoparticles was−12.1 mV, indicating good stability of the nanoparticles . The size of Fe-NPs was 20.83 nm on average, with 9.48% of all particles distribution, which was in good agreement with the result obtained using SEM, which was 21±9 , as shown in **Fig (2)**

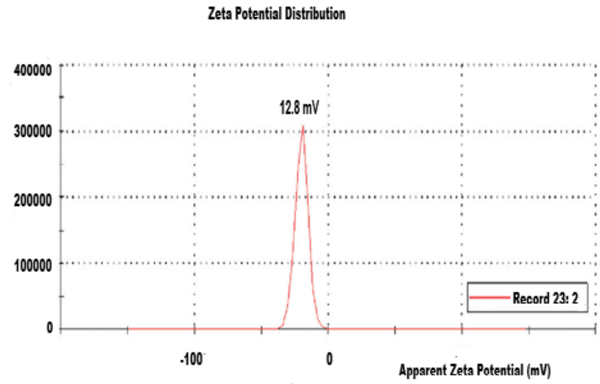


**Fig (2)** - cleared the value of iron nanoparticles by Zeta Potential and Dynamic Light Scattering

## 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 various iron forms on nutritional status of Washington navel orange trees.**

**1.1. Leaf total chlorophyll content (SPAD):**

**Table (1)** displays that foliar application on Washington navel orange trees with all investigated treatments using iron forms significantly increased leaf total chlorophyll content over control, However, the trees that were sprayed with green Fe-$NPs_2$ (1/40 dilution), (3$^{rd}$ treat.,) or Fe-chelate (EDTA) 13% at 10g (7$^{th}$ treat.,) had heist a significant increase in the total chlorophyll content of their leaves, (84.84 & 85.59 SPAD) and (85.25 & 85.42 SPAD) without statistical differences observed between them compared to the other treatments and the control during both seasons, statically followed by spraying with Fe-$NPs_1$ (1/80 dilution), i.e., 2$^{nd}$ treatment, with values (79.06 & 80.36 SPAD), respectively. Moreover, the trees that were sprayed with ferrous sulfate ($FeSO_4$ .7$H_2O$) at 15g (5$^{th}$ one) or Fe-chelate (EDTA) 13% at 5g (6$^{th}$ treat.,) found in their leaves an average content of total chlorophyll during the two seasons, without statistical differences between them, statically followed by ferrous sulfate ($FeSO_4$ .7$H_2O$) at 7.5g (4$^{th}$ one), which is considered the least efficient treatment in this regard compared to other treatments.In general, all iron treatments improved the nutritional status by increasing the total chlorophyll content in the leaves of Washington navel orange trees during both experimental seasons compared to those sprayed with water. The reason for the increased content of the leaves of total chlorophyll may be because iron is directly involved in the formation of the enzyme coproporphyrinogen oxidase, which is an enzyme involved in the sixth step of Porphyrins metabolism and is necessary for the manufacture of α-amino levulinic acid, which is the precursor to the formation of chlorophyll.

The mentioned above results are similar agree with **Qin *et al.* (1993)** on lemon trees (*Citrus limon* L), **Sanz *et al.* (2002)** on peach Cv, **Al-Hamdani (2004)** on olive seedlings, **Hadi (2010)** on grapevine Cv. AL-Kamali, **Al-Temimi *et al.*, (2012)** on guava seedlings Cv Mahally , **Abdul-Wahid *et al.*, (2014)** on local sour orange seedlings (*Citrus aurantium* L), **Hamouda *et al.* (2015),** on pear trees cv. Le Conte (*Pyrus communis*, L.), **Abou El-Nasr, *et al.* (2015)** on pear saplings, **Al-Shammari and Al-Obaidi (2018)** on grape vines, **Al-Zuhairi *et al*. (2021)** on local lemon (*Citrus limon* L.) transplants, **Khazaal (2023),** on old lemon trees.

**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 iron 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:**

Regarding the influence of the iron forms treatments on leaf N% of Washington navel orange trees, the tabulated results in **Table (1)** revealed that all treatments resulted in a significant increase over control (water spray), however, the significant differences were pronounced between the treatments and each other during both seasons. However, the trees were sprayed with green Fe-$NPs_2$ (1/40 dilution) (3$^{rd}$ treatment), and the nitrogen content of its leaves was the highest significantly (2.88 & 2.81%), followed by those sprayed with Fe-chelate (EDTA) 13% at 10 g compared with other treatments and control during both experimental seasons with values (2.77 & 2.68%). On the contrary, the tree leaves that were exposed to water spray (control) showed the least nitrogen content, i.e., (2.29 & 2.32).Furthermore, the remaining iron treatments gave an average effect in this regard between the abovementioned treatments during 2022 and 2023 seasons.

**1.2.2. Leaf Phosphorus content:**

As for the leaf P % of Washington navel orange trees, **Table (1)** displays, as found before, that all investigated treatments increased its content significantly as compared to the control (water spray), however, the response to treatments followed an opposite trend to previously discussed with leaf nitrogen content, whereas the richest leaves in their phosphorus content were significantly in close relationship to sprayed trees with low concentrations from iron treatments without significant difference appearing with them during both seasons of study. Moreover, the high concentrations from those treatments were close to each other from a statistical point of view, taking into consideration that the green Fe-NPs$_2$ (1/40 dilution) treatment (3$^{rd}$ one) was the best in this respect during the 2022 and 2023 seasons.

### 1.2.3.Leaf potassium content:

Regarding leaf K%, data in **Table (1)** revealed that spraying trees with different iron forms increased its content as compared with the control (water spray). Hence, the trees that were sprayed with green Fe-NPs$_2$ (1/40 dilution), i.e., 3$^{rd}$ treatment, gave the highest values, followed by those who were sprayed with Fe-chelate (EDTA) 13% at 10 g (7$^{th}$ treatment) in the second rank, then spraying with either ferrous sulfate ($FeSO_4.7H_2O$) at 15 or Fe-chelate (EDTA) 13% at 5 g (5$^{th}$ and 6$^{th}$ treatments), which both ranked statistically 3$^{rd}$ without significant difference between them during two seasons of study.On the contrary, the green Fe-NPs$_1$ (1/80 dilution), i.e., 2$^{nd}$ one, was the least effective treatment, which came just before the control in this respect during both experimental seasons.

The increment of mineral nutrients content in the Washington navel orange tree may also be attributed to the important role of iron in the photosynthesis process through its formation role of different cytochromes as well as its role in the cell division process, which leads to an increment in photosynthesis productions and increase in the root's absorption which reflected on plant nutrients, and increase the leaf content of nitrogen and phosphorous, potassium (**Tylor, 1995).**

The obtained results are in harmony with those reported by **Al-Hamdani (2004)** on olive seedlings, **Tsipouridis *et al.* (2006)** on peach trees, **Abou El-Nasr *et al.* (2015)** on pear saplings Cv (Le-Conte), **Hamouda *et al.*, (2016)** found that the foliar sprays of Fe at concentrations of 500 and 1000 ppm on 'Manfalouty' pomegranate trees had significant effects on leaf concentrations of N, P, K, Ca, Fe, Mn, Zn and Cu. Furthermore, **Davarpanah *et al.* (2017)** on pomegranate, **El-Dahshouri *et al.* (2017)** on le-conte pear trees, **Singh *et al.* (2018)** on peach, **Alalaf *et al.* (2020)** on seedlings of Citrus grandis, **Shakur and Muhammad (2020)** on Jujube trees, *Ziziphus mauritiana Lam*, **Rahemi *et al.* (2020)** on quince trees, **Abd-El-Latif *et al.* (2020)** on pear trees and **Davarpanah *et al.* (2020)** on pomegranate trees.

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

| Parameters Treatments | Chlorophylls (SPAD) | | N% | | P% | | K% | |
|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2022 | 2023 | 2022 | 2023 | 2022 | 2023 |
| $T_1$-Control (water spray). | 66.39 E | 68.06 E | 2.29 F | 2.32 F | 0.150 C | 0.151 B | 1.20 F | 1.29 E |
| $T_2$- green Fe-NPs$_1$ (1/80 dilution). | 79.06 B | 80.36 B | 2.53 D | 2.42 E | 0.163 A | 0.164 A | 1.47 E | 1.51 D |
| $T_3$- green Fe-NPs$_2$ (1/40 dilution) | 84.84 A | 85.59 A | 2.88 A | 2.81 A | 0.161 AB | 0.158 AB | 1.80 A | 1.83 A |
| $T_4$- ferrous sulfate at 7.5. | 70.30 D | 71.56 D | 2.49 E | 2.59 CD | 0.164 A | 0.165 A | 1.59 D | 1.62 C |
| $T_5$- ferrous sulfate at 15 g. | 73.22 C | 74.33 C | 2.62 C | 2.62 BC | 0.152 BC | 0.155 AB | 1.67 C | 1.65 BC |
| $T_6$- Fe-chelate (EDTA) 13% at 5g. | 73.76 C | 75.69 C | 2.63 C | 2.54 D | 0.163 A | 0.165 A | 1.65 C | 1.66 BC |
| $T_7$- Fe-chelate (EDTA) 13% at 10g. | 85.25 A | 85.42 A | 2.77 B | 2.68 B | 0.155 ABC | 0.152 B | 1.75 B | 1.73 AB |

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

### 2. Effect of various iron 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 either as average fruit weight (g), number of fruit per tree, yielded per tree of harvested, and yield per feddan (tons) were the investigated four productivity parameters regarding the response to differential evaluated iron forms, data obtained during 2022 and 2023 experimental seasons are presented in **Table (2).** All measurements of the productivity of Washington navel orange trees responded positively and significantly to various investigated treatments. Herein, four measurements were increased by all investigated iron form treatments as compared to the water-sprayed trees (control). Meanwhile, four cropping parameters of tree productivity followed the same trend, whereas the foliar sprayed trees associated with $T_3$-Fe-NPs$_2$

(1/40 dilution) surpassed statistically other treatments during both seasons. However, the 7th treatment (Fe-chelate (EDTA) 13% at 10g) came in the second rank, followed by the 5th treatment (ferrous sulfate ($FeSO_4.7H_2O$) at 15g) in the third rank. On the other hand the lowest yield parameter was dominant with water-sprayed trees; furthermore rest iron treatments showed medium efficiency in this respect, and such a trend was true during both experimental seasons. Taking into consideration, the productivity parameters vary from one treatment to another and from season to season compared with control.

Generally, it could be safely said that all investigated iron forms treatments significantly increased yield over control during both seasons of study. The Positive effect of Fe forms on Washington navel orange tree fruit yield might be attributed to its important roles in different processes in plants including biosynthesis of chlorophyll, proteins like cytochrome and ferredoxin, nitrogen fixation, Fe-S complexes, electron transport chain complex, and structure of enzymes involved in nitrate absorption **(Marschner, 2012; Al-Bamarny *et al.*, 2010** and **Hamouda *et al.*, 2016).** As the crucial roles of Fe in photosynthesis increase, trees with a higher rate of photosynthesis can retain more fruits. The aforementioned functions of Fe in plants and also its availability in sufficient quantities provided through foliar spray can be possible reasons for yield increase (**Abdi and Hedayat, 2010).**

The results agree with those obtained by **Alvarez-Fernandez *et al.*, (2006)** indicating that Iron increased threefold in the lemons yield 30% of this is due to the increase in fruit size and the rest was due to an increase in the number of fruit per tree, **Al-Aareji *et al.* (2010)** found that application of Fe-EDDHA (6% Fe) as a source of Fe on the Apple Fruits Cv. Starking Delicious led to a significant increase in the fruit number per tree, fruit weight, and tree yield, **Hadi (2010)** on grapevine, **Aboutalebi and Hassanzadeh (2013)** on sweet lime trees, **Davarpanah *et al.* (2013)** on pomegranate, **Hamouda *et al.* (2015) and El-Dahshouri *et al.*, (2017)** on Pear trees, **Lateef *et al.* (2018),** and **Davarpanah *et al.* (2020)** on pomegranate trees and **Khazaal (2023)** on lemon trees .

**Table 2.** Effect of various iron 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 fruits /tree | | Yield/tree (Kg) | | Yield / Feddan (Tons) | |
|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2022 | 2023 | 2022 | 2023 | 2022 | 2023 |
| $T_1$-Control (water spray). | 216.23 C | 221.56 C | 155.67 E | 176.33 E | 33.66 E | 39.06 E | 5.65 E | 6.56 E |
| $T_2$- green Fe-$NPs_1$ (1/80 dilution). | 227.14 B | 230.32 ABC | 178.19 C | 187.43 BC | 40.48 C | 43.17 BC | 6.80 C | 7.25 BC |
| $T_3$- green Fe-$NPs_2$ (1/40 dilution) | 233.78 A | 238.11 A | 185.35 A | 191.07 A | 43.33 A | 45.50 A | 7.27 A | 7.64 A |
| $T_4$- ferrous sulfate at 7.5. | 224.26 B | 225.77 BC | 172.79 D | 181.06 D | 38.75 D | 40.88 DE | 6.51 D | 6.86 DE |
| $T_5$- ferrous sulfate at 15 g. | 234.92 A | 233.51 AB | 180.76 BC | 185.97 C | 42.47 AB | 43.42 BC | 7.13 AB | 7.29 BC |
| $T_6$- Fe-chelate (EDTA) 13% at 5g. | 228.24 B | 228.60 ABC | 183.16 AB | 185.46 C | 41.81 B | 42.40 CD | 7.02 B | 7.12 CD |
| $T_7$- Fe-chelate (EDTA) 13% at 10g. | 234.31 A | 235.94 A | 181.78 ABC | 188.97 AB | 42.59 AB | 44.59 AB | 7.15 AB | 7.49 AB |

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

**3. Effect of various iron forms on fruit quality measurements 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), average fruit volume ($cm^3$), fruit juice volume ($cm^3$), and fruit juice percentage (%) were the evaluated fruit physical characteristics of Washington Navel orange in response to different applied treatments iron forms. 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 iron forms. **Table (3)** shows obviously that both parameters responded significantly to all iron treatments compared with the control, However, sprayed trees with green Fe-$NPs_2$ (1/40 dilution) i.e., 3rd treatment resulted in the tallest polar fruit diameter during both seasons(8.18 &8.30 cm), while the trees were exposed to 5th treatment (ferrous sulfate ($FeSO_4.7H_2O$) at 15g) during both season (7.68&7.93cm) and green Fe-$NPs_2$ (1/40 dilution) i.e., 3rd treatment in the first seasons (7.69 cm) gave widest fruit diameter, statically followed by 7th treatment (Fe-chelate (EDTA) 13% at 10g) for two fruit dimensions i.e., length 8.03 & 8.11 cm and width 7.54 &7.73 cm, respectively, during both seasons of study. On the contrary, the water-sprayed trees (control) induced significantly the lowest fruits in their dimensions during the 2022 and 2023 seasons. Moreover, other investigated treatments were in between the aforesaid extremes, such a trend was true during both experimental seasons for both polar and equatorial fruit diameters.

### 3.1.2. Fruit shape index:

Regarding the response of the fruit shape index (polar diameter: equatorial diameter) of Washington Navel orange Cv to iron forms treatments, **Table (3)** shows a considerable variation in this respect whereas a variable degree of response varied from one season to another when comparing each other or with the control. However, a significant difference was observed in the average of the concerned. Taking into consideration from a statically point the variation in fruit shape index indices due to the differential investigated treatment could be logically explained by the unparalleled response of two fruit dimensions to a given treatment. Generally, results cleared that the most treatment which affected the fruit shape index of Washington Navel orange trees, the spraying treatment with green Fe-$NPs_2$ (1/40 dilution) in both seasons and Fe-chelate (EDTA) 13% at both levels ($6^{th}$ or $7^{th}$ treatment) in the first season. On the other hand, data showed that the shape index values of harvested fruits from sprayed trees with green Fe-$NPs_1$ (1/80 dilution) and ferrous sulfate ($FeSO_4 .7H_2O$) at 15 g ($5^{th}$ treatment) during both seasons or 5g concentration ($4^{th}$ treatment) in the first season, didn't reach a level of significance in comparison to control, rather recorded lower statistical values in this regard.

**Table 3.** Effect of various iron forms on fruit dimensions (cm) 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). | 7.08 E | 7.17 F | 6.78 F | 6.92 F | 1.04 B | 1.03 CD |
| **$T_2$**-green Fe-$NPs_1$ (1/80 dilution) | 7.43 D | 7.58 E | 7.25 D | 7.36 D | 1.02 C | 1.02 D |
| **$T_3$**-green Fe-$NPs_2$ (1/40 dilution) | 8.18 A | 8.30 A | 7.69 A | 7.72 B | 1.06 A | 1.07 A |
| **$T_4$**-ferrous sulfate at7.5g. | 7.32 D | 7.52 E | 7.12 E | 7.19 E | 1.02 BC | 1.046 BC |
| **$T_5$**-ferrous sulfate at 15g. | 7.95 B | 8.05 C | 7.68 A | 7.93 A | 1.03 BC | 1.01 E |
| **$T_6$**-Fe-chelate (EDTA)13% at 5 g. | 7.80 C | 7.90 D | 7.32 C | 7.54 C | 1.06 A | 1.048 BC |
| **$T_7$**-Fe-chelate (EDTA) 13% at10g. | 8.03 B | 8.11 B | 7.54 B | 7.73 B | 1.06 A | 1.049 B |

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

### 3.1.3. Fruit peel thickness (mm):

Concerning the response of fruit peel thickness of Washington navel orange trees to the various investigated iron forms treatments, it is quite evident from **Table (4),** that during 2022 and 2023 experimental seasons, the peel thickness of fruits harvested from the trees that sprayed with green Fe-$NPs_2$ (1/40 dilution) was significantly higher (2.83 & 2.84 mm), statically followed by the fruits resulting from the spraying treatment with Fe-chelate (EDTA) 13% at 10g ($7^{th}$ treat) during both seasons, and ferrous sulfate ($FeSO_4.7H_2O$) at 15g ($5^{th}$ treat) in second season of study. On the contrary, the lowest fruit peel thickness found with water-sprayed trees (control) during both seasons. In addition, other investigated iron forms treatments showed a moderate effect on fruit peel thickness, where intermediate values were recorded between the aforesaid extremes i.e., $3^{rd}$ one (superior treatment) and control (inferior), however, some treatments showed statistical homogeneity values in this regard compared to each other during both experimental seasons.

### 3.1.4. Average fruit volume ($cm^3$):

Data presented in **Table (4)** indicated that, during both seasons, the sprayed Washington navel orange trees with green Fe-$NPs_2$ (1/40 dilution) i.e., $3^{rd}$ treat) gave significantly highest fruit volume (248.9 & 253.4 $cm^3$)**,** statistically followed by the sprayed trees with the following treatments i.e., green Fe-Fe-$NPs_1$ (1/80 dilution) i.e., $2^{nd}$ treat, Fe-chelate (EDTA)13% at 5 g and 10g ($6^{th}$ and $7^{th}$ treat) were significantly similar treatments as their efficiency in this concern. Furthermore, the foliar spray with ferrous sulfate ($FeSO_4.7H_2O$) treatments at both concentrations used, were the least effective treatments without significant difference between both levels despite they exceeded statistically the water sprayed trees (control) during the first season only, while it did not reach the level of significance in the second season compared to the control.

### 3.1.5. Fruit juice volume ($cm^3$)

The data in **Table (4)** showed obviously that the best response of fruit volume juice followed nearly approximately the same trend detected with the previous parameter (fruit volume), where is the increase in fruit juice volume significantly have been associated with any of three iron forms under study compared with control treatment (water spray) which induced significantly the poorest fruit juice volume during both seasons. However, the greatest increase in juice volume was markedly coupled with the sprayed trees with Fe-$NPs_2$ (1/40 dilution) during both seasons. In addition, the foliar spray with Fe-chelate (EDTA) form at 10g and 5g cons, ranked statistically 2nd and 3rd respectively, during both seasons. In the same context, other investigated treatments, i.e., green Fe-$NPs_1$ (1/80 dilution) and ferrous sulfate ($FeSO_4.7H_2O$) treatments at both concentrations used were in between the aforesaid two extremes with noticeable degrees of efficiency despite their statistical variations between abovementioned superior and inferior treatments during both experimental seasons.

### 3.1.6. Fruit juice percentage (%):

The data in **Table (4)** shows that there were no statistical differences between investigated iron forms which didn't reach a level of significance when compared with control in fruit juice % of Washington Navel oranges, especially during the first season study. On the contrary, during the second season, there were significant differences were relatively pronounced, whereas the highest fruit juice percentage was significantly in closed relationship to sprayed trees with Fe-chelate (EDTA) 13% at 10g (7th treatment), statistically followed by that sprayed with green Fe-$NPs_2$, 1/40 dilution (3rd treat) or Fe-chelate (EDTA) 13% at 5g (6th treat) with same significant values. Moreover, other investigated treatments were less pronounced and didn't reach a level of significance with comparison to the control (water spray). The increase in nutrients leads to an increase in carbon metabolism and some produced metabolic compounds such as saccharides in the fruits, which is positively reflected in some quantitative properties of the fruits **(Al-Jubouri, 2006).** Our finding is in keeping with the reports on Valencia orange varieties **(Pestana *et al.*, 2001),** lemon **(Alvarez -Fernandez, 2006)**, and Darabi Orange varieties **(Amri *et al.*, 2009).** Iron increases photosynthesis and carbohydrate synthesis and the reproductive growth of fruit in organs of the plant acts as a strong sink.

**Table 4.** Effect of various iron forms **on fruit peel thickness (mm), fruit volume ($cm^3$), juice fruit 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). | 2.51 F | 2.55 C | 234.4 C | 236.8 B | 90.84 D | 91.92 C | 38.74 A | 38.80 B |
| $T_2$-green Fe-$NPs_1$ (1/80 dilution). | 2.63 D | 2.63 BC | 244.1 AB | 247.6 AB | 95.86 BCD | 96.97 B | 39.27 A | 39.15 B |
| $T_3$-green Fe-$NPs_2$ (1/40 dilution). | 2.83 A | 2.84 A | 248.9 A | 253.4 A | 102.0 A | 102.7 A | 41.00 A | 40.51 AB |
| $T_4$-ferrous sulfate at 7.5g. | 2.61 E | 2.65 BC | 239.2 BC | 240.1 B | 95.1 BCD | 95.5 BC | 39.77 A | 39.76 B |
| $T_5$-ferrous sulfate at 15g. | 2.68 C | 2.78 AB | 237.6 BC | 240.1 B | 93.7 CD | 95.0 BC | 39.45 A | 39.57 B |
| $T_6$-Fe-chelate (EDTA)13% at 5 g. | 2.68 C | 2.66 ABC | 243.1 AB | 242.1 AB | 97.4 ABC | 99.2 AB | 40.06 A | 41.00 AB |
| $T_7$-Fe-chelate (EDTA) 13% at 10g . | 2.74 B | 2.79 AB | 245.1 AB | 242.7 AB | 100.3 AB | 102.3 A | 40.94 A | 42.15 A |

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 iron 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) (%):**

**Table (5)** displays obviously that all iron forms treatments increased the fruit juice TSS % of Washington navel orange Cv during 2022 & 2023 experimental seasons. However, the highest fruit juice TSS percentage was markedly associated with fruits harvested from trees that were sprayed with green Fe-$NPs_2$ (1/40 dilution), whereas it was the richest in TSS content ( 11.91 & 12.19%) , followed by in decreeing order: Fe-chelate (EDTA) 13% at 10g ($7^{th}$ treatment), ferrous sulfate ($FeSO_4.7H_2O$) at 15g ($5^{th}$ treatment) and green Fe-$NPs_1$ (1/80 dilution) i.e., ($2^{nd}$ one), which occupied the statistical ranks $2^{nd}$,$3^{rd}$ and $4^{th}$ respectively. On the other hand, the fruit juice of water-sprayed trees (control) significantly was the poorest in their TSS % content during both experimental seasons. In addition, the other two investigated treatments were in between the aforementioned extremes with a relative tendency of variance pointing out the least effective treatments, where they came before the control. The increase in TSS after Fe applications may be related to adequate Fe provided by foliar spraying, which consequently led to an increase in the rate of photosynthesis. Since the main products of photosynthesis are sugars, the increased TSS can be a result of increased photosynthesis **(Abdi and Hedayat, 2010).**

**3.2.2. Fruit juice total acidity percentage (%):**

About the fruit juice acidity percentage of Washington navel orange trees as influenced by the differential iron forms treatments, data obtained during 2022 and 2023 experimental seasons are presented in **Table (5),** and it is clear that an opposite trend was found to TSS% previously detected in this respect. Hence, the fruit juice acidity percentage was significantly increased by water-sprayed trees (control) during both experimental seasons, while the opposite was true with exposed trees to green Fe-$NPs_2$ (1/40 dilution), which gave the lowest significant values of acidity, followed by from the static point with either spray with ferrous sulfate ($FeSO_4.7H_2O$) at 7.5 g or Fe-chelate (EDTA) 13% at 10 g without significant difference between them as compared with the other treatments and the control at both seasons. On the other hand, the foliar spray with ferrous sulfate ($FeSO_4.7H_2O$) at 15g and green Fe-$NPs_1$ (1/80 dilution) both differed in their static position from one season to another, which they recorded height acidity % as compared with other iron treatments, wearer both came just before the control. Moreover, the median total acidity percentage (%) coupled with a tree subjected to Fe-chelate (EDTA) was 13% at 5g during both seasons of the study.

**Table 5.** Effect **of various iron forms on** some fruit juice chemical characteristics (TSS, total acidity, TSS/ acid ratio) of Washington navel orange trees during the 2022 and 2023 experimental seasons.

| Treatments / Parameters | TSS % | | Total acidity % | | TSS/ acid ratio | |
|---|---|---|---|---|---|---|
| | **2022** | **2023** | **2022** | **2023** | **2022** | **2023** |
| **$T_1$**-Control (water spray). | 10.11 G | 10.43 F | 1.08 A | 1.07 A | 9.32 G | 9.76 F |
| **$T_2$**- green Fe-$NPs_1$ (1/80 dilution). | 11.02 D | 11.37 D | 1.03 BC | 1.03 B | 10.68 E | 11.06 DE |
| **$T_3$**-green Fe-$NPs_2$ (1/40 dilution). | 11.91 A | 12.19 A | 0.92 E | 0.92 E | 12.93 A | 13.28 A |
| **$T_4$**-ferrous sulfate at 7.5 g. | 10.92 E | 11.37 D | 0.97 D | 0.96 D | 11.19 C | 11.83 C |
| **$T_5$**-ferrous sulfate at 15g. | 11.32 C | 11.48 C | 1.04 B | 1.02 BC | 10.88 D | 11.31 D |
| **$T_6$**-Fe-chelate (EDTA)13% at 5 g. | 10.51 F | 10.90 E | 1.03 C | 1.01 C | 10.21 F | 10.80 E |
| **$T_7$**-Fe-chelate (EDTA) 13% at 10g. | 11.68 B | 11.88 B | 0.97 D | 0.97 D | 12.04 B | 12.23 B |

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

**3.2.3. Fruit juice TSS/acid ratio (%):**

Referring to the influence of different iron forms treatments on fruit juice total soluble solids/acid ratio, **Table (5)** displays obviously that the response was pronounced. Hence, all investigated iron treatments resulted in increasing fruit juice TSS/acid ratio as compared to control (water spray). Such a trend was true during both experimental seasons. However, the effect of spraying with green Fe-$NPs_2$ (1/40 dilution) was statistically superior, whereas it resulted in the highest percentage (12.93 & 13.28%). Meanwhile, the reverse was true with control, where the lowest (9.32 & 9.76 %) resulted during both seasons, respectively. On the other hand, other investigated treatments could be significantly arranged into the following descending order, i.e.,$T_7$-

(Fe-chelate (EDTA) 13% at 10 g), $T_4$-ferrous sulfate (FeSO4.7H2O) at 7.5 g, $T_5$-ferrous sulfate (FeSO4.7H2O) at 15 g, $T_2$-(green Fe-NPs1 (1/80 dilution), and $T_6$-(Fe-chelate (EDTA) 13% at 5 g), taking into consideration that the rate of response to different iron treatments effect on trees could be logically explained depending upon the paralleled rates of changes exhibited in both fruit juice TSS and total acidity parameters during both seasons.

### 3.2.4. Fruit juice total sugar percentage (%):

Regarding the response of total sugar% to the differential investigated iron forms treatments, data in **Table (6)** shows clearly that the variances were relatively too few to be taken into consideration from the statistical point of view, whereas most treatments didn't significantly differ as compared to each other in their effect and didn't reach a level of significance with comparison to control during both experimental seasons, except foliar spray with green Fe-$NPs_2$ (1/40 dilution), i.e., 3rd treatment during second season was statistically superior treatment and showed the highest rate of response in this respect compared with all investigated treatments. On the contrary, the lowest total sugar% in fruit juice was markedly coupled with sprayed trees with Fe-chelate (EDTA) 13 % at 5 g (6th treatment), which was less than the control at the same season aforenoted. The effect of iron on the amount of total sugar percentage may be due to its availability in foliar feeding of plants and the role of iron in photosynthesis that causes a higher photosynthetic rate. Given that the main product of photosynthesis, increasing photosynthesis, leads to an increase in the sugar compounds in fruit juice

### 3.2.5. Fruit juice ascorbic acid (VC) content:

Data obtained during both experimental seasons, as shown in **Table (6)**, displayed that all investigated iron form treatments increased fruit juice V.C (ascorbic acid) content of Washington navel orange trees compared with control. However, sprayed trees with green Fe-$NPs_2$ (1/40 dilution) treatment were significantly superior and showed the greatest vitamin C content, i.e., 39.66 and 39.70 mg V.C /100 mL of fruit juice during 2022 and 2023 experimental seasons. Moreover, the trees that were sprayed with Fe-chelate (EDTA) 13% at 10 g and green Fe-$NPs_1$ (1/80 dilution), respectively, had an increase in the vitamin C content of their fruit juice after the impact of the superior treatment mentioned above, as these treatments occupied 2nd statistical ranking in this regard during both seasons. On the contrary, the least fruit juice ascorbic acid (VC) content was associated with water-sprayed trees (control) which ranked statistically last (35.73 and 37.03 mg/100 mL) during both seasons, respectively. In addition, other investigated treatments were intermediate between the aforementioned extremes, i.e., green Fe-$NPs_1$ (1/80 dilution) i.e., 2nd treatment and control (water spray) during 2022 and 2023 experimental seasons. Our results in harmony with those obtained by **Al-Aareji *et al.* (2010)** on the apple fruits Cv. Starking Delicious. Who found that Fe application led to a significant increase in fruit weight and volume, TSS, carbohydrate concentration, fruit juice content, and a significant decrease in fruit acidity, **Aboutalebi, and Hassanzadeh (2013)** on sweet lime fruit, **Davarpanah *et al.* (2013)** on pomegranate, **Hamouda *et al.* (2015**) on pear trees , **Hamouda *et al.* (2016** on pomegranate trees, **El-Dahshouri *et al.* (2017)** on le-conte pear trees, **Lateef *et al.*,(2018)** on pomegranate trees, **Davarpanah *et al.*, (2020)** on pomegranate trees, **Rahemi *et al.*, (2020)** on quince trees, **Al-Akaishy and Al-Hamidawi (2020**) on the lemon.

**Table 6.** Effect of various iron forms on fruit juice (total sugar and vitamin C) content of Washington navel orange trees during the 2022 and 2023 experimental seasons.

| Treatments / Parameters | Fruit juice total sugar % | | Vitamin C (mg/100ml) fruit juice | |
|---|---|---|---|---|
| | **2022** | **2023** | **2022** | **2023** |
| **$T_1$-**Control (water spray). | 8.106 A | 8.467 AB | 35.73 F | 37.03 D |
| **$T_2$-**green Fe-$NPs_1$ (1/80 dilution). | 8.387 A | 9.1395 AB | 37.99 BC | 38.95 BC |
| **$T_3$-** green Fe-$NPs_2$ (1/40 dilution). | 8.544 A | 9.287 A | 39.66 A | 39.70 A |
| **$T_4$-**ferrous sulfate at 7.5g. | 8.361 A | 8.368 AB | 36.66 DE | 38.52 C |
| **$T_5$-**ferrous sulfate at 15g. | 8.072 A | 8.870 AB | 37.33 CD | 38.51 C |
| **$T_6$-**Fe-chelate (EDTA)13% at 5 g. | 8.702 A | 8.213 B | 36.00 EF | 38.72 BC |
| **$T_7$-**Fe-chelate (EDTA) 13% at 10g. | 8.637 A | 8.802 AB | 38.52 B | 39.31 AB |

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

**Discussion**

It is evident from the results are achieved by applying iron forms in the foliar application; especially in form green Fe-$NPs_2$. It suggested that the iron is considered one of the most important of these elements due to its role in the formation and activation of the chlorophyll pigment by means of its entry into the Porphyrin compounds that make up chlorophyll. It is also included in the composition of the stochrome responsible for the respiration process in the plant in addition to it participates in the synthesis of chloroplast and chloroplasts and the formation of plant proteins **[Gyana and Sunita (2015)],** in addition to the entry of iron in the synthesis of many enzymes such as Catalase, Peroxidase and Cytochrome oxidase, which activate many vital processes within the plant, especially oxidative reactions, as its importance lies in the transfer of electrons in oxidation reactions. Reduction is one of the important roles in cell metabolism **[Havlin *et al.* (2005)].**

The use of nano form an effective alternative to traditional forms, as its use achieves many advantages due to its use in small quantities and its high stability under different growing conditions, which achieves many benefits to the plant, as nanoforms have unique characteristics due to their smallness. Its size and large surface area that leads to an increase in the absorption surface, which leads to an increase in the efficiency of the absorption of nutrients and thus enhances plant growth. The increased surface area in Nanomaterial's can lead to increased reactivity and faster dissolution kinetics **(De Rosa *et al.*, 2010 Mastronardi *et al.*, 2015**).There are various advantages to nano materials, the most important of which is to regulate nutrient release according to plant requirements, reduce nutrient losses and protect the environment from excessive use of traditional fertilizers, maintaining agricultural production, managing soil fertility, reducing soil toxicity, preserving the environment and reducing soil degradation under climate change conditions **[Abobatta (2019)].**

## Conclusion

It can be concluded from the above results that iron forms sprays, especially green Fe-NPs$_2$ (1/40 dilution of the Fe-NPs stock solution) 5L/tree /dose had a positive effect on nitrogen, phosphorus, potassium percentages, total chlorophyll contents in the leaves, which reflected on enhanced yield and fruit physical and chemical characteristics compared with control and other iron forms. Therefore, it could be recommended that spraying Washington navel orange trees grown under similar environmental conditions and horticulture practices adopted in present experiment with green Fe-NPs$_2$ (1/40 dilution of the Fe-NPs stock solution) five times per season at a one-month interval (in the 1st week of march, April, may, June, and July), which is considered the best treatment used to improve leaf nutritional status and get high yield with best fruit quality (physical and chemical properties).

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## تأثير صور الحديد 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 لأشكال الحديد المختلفة مثل ( جزيئات الحديد النانوية ، كبريتات الحديديوز، ، الحديد المخلبى ) على الحالة الغذائية والإنتاجية وجودة الثمار حيث أن معاملة الرش من صور الحديد، تغطى الشجرة بالكامل ، حيث وجد أن 5 لترات كافية في هذا الصدد، بالإضافة إلى أنه تم الرش بشكل دوري خمسة مرات خلال الموسم التجريبي بمعدل مره شهرياً فى الأسبوع الأول من مارس وأبريل ومايو ويونيو ويوليو.

أظهرت النتائج المتحصل عليها أن جميع معاملات الرش بإستخدام صور الحديد 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 نانو الحديد المحضر ة بالطريقة الخضراء بتخفيف 40/1 من المحلول المركز ، 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 الحديد الأخرى ، لذلك يمكن التوصية برش أشجار البرتقال أبو سرة بنانو الحديد المحضر ة بالطريقة الخضراء بتخفيف 40/1 من المحلول المركز 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 ، جزيئات الحديد النانونية ، الحالة الغذائية ، الإنتاجية ، جودة الثمار .