EFFECT OF TiO$_2$ NANOPARTICLES SPRAYING ON FENNEL PLANT
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ABSTRACT

The present investigation was carried out to investigate effects of TiO$_2$ nanoparticles on growth and chemical composition of fennel plants.

Previous work showed that TiO$_2$ nanoparticles could significantly raise photosynthesis and greatly improve growth of fennel (Foeniculum vulgare Mill) plants. The plants were sprayed with different concentrations of TiO$_2$ nanoparticles 2, 4 and 6 ppm. The results showed that, TiO$_2$ nanoparticles at treatment 6 ppm could obviously get the highest number of branches, the tallest plants, the highest fruit yield per plant and the highest values of Pigments, Carbohydrates, phosphorus, Sugars nitrogen, potassium. sprayed fennel plant with concentrations of TiO$_2$ nanoparticles 0, 2, 4 and 6 ppm is safe for human.

Keywords: Titanium nanoparticles, yield, biochemical constituents, growth, Foeniculum vulgare.

INTRODUCTION

Fennel (Foeniculum vulgare Mill) belongs to family Apiaceae. The Florence fennel is a variety group with inflated leaf bases which form a bulb-like structure (Chiej, 1984). Fennel is used as a condiment due to volatile oil compounds isolated from its fruits (Bhati et al., 1988; Brenness and Herbs, 1997; Philips and Rix, 1998). The fennel essential oil is used to flavor different food preparations and in perfumery industries (Masada, 1976; Abdallah et al., 1978; Simon et al., 1984). Fennel have a medical effects such as: to ease flatulence, relax the intestines and many other medicinal uses (Chiej, 1984; Leung and Foster, 1996; Bown, 1995). It is still used in traditional medicine as digestive, diuretic and appetizer (Karnick, 1994).

Nanoparticles (NP) are particles with size between 1-1000 nm. Nanotechnology has many applications in different areas such as industry medicine, agriculture etc. TiO$_2$ nanoparticles can stimulate antioxidant system, enhance absorbing of utilizing water abilities, hasten germination and growth in Glycine max (Lin and Xing, 2007). This nanoparticle generally be in crystal shape with three titles: Anatase, rutile, and brukite, and there are also noncrystallines. TiO$_2$ nanoparticles is applied in optical module, coated surfaces, dipole electron tubes, sporting goods, disinfectant sprays, etc. TiO$_2$ nanoparticles has effects on redox oxygen preparations (ROS) in the presence of Ultraviolet (UV) light (Kim et al., 2010). TiO$_2$ nanoparticles enhanced seed germination, plant growth of spinach and fennel (Feizi et al., 2013; Zheng et al., 2005) and enhance light absorbance and promoted the activity of Rubisco thus accelerated growth of spinach plant (Zheng et al., 2005; Lei et al., 2008). The important effects of TiO$_2$ compounds on plants are enhancement the yield of different crops, increase the activity of peroxidase catalase, improve some essential element contents, enhance nitrate reductase activities in plant tissues, improve plant growth by enhancing nitrogen metabolism and promote plant photosynthesis by promoting the absorption of nitrate (Yang et al., 2006; Lei et al., 2007).

The ability of TiO$_2$ nanoparticles to enhance the light harvesting complex content of plants is highly comparable with the use of Titanium dioxide (Anusorn et al., 2008).

The present work is conducted to investigate effects of TiO$_2$ nanoparticles on growth yield and chemical composition of fennel plants.

MATERIALS AND METHODS

The field research was carried out during two successive seasons, 2011/2012 and 2012/2013 at a Farm in Sakara, Giza, Egypt.

Seeds were obtained from the National Research Centre, Doki, Giza, Egypt. The fennel plants were sprayed by TiO$_2$ nanoparticles at the concentrations of 0, 2, 4 and 6 ppm. The seeds were sown on 1 November of both years, the plot area was 2m x 4m. The distance between lines was 75 cm and 30 cm between plants.

The layout of the experiment is a complete randomized block design, comprising 4 treatments and each of them is replicated three times and the replicate consisted of approximately 30 plants.

The chemical properties of the soil in this study were determined and illustrated in (Table 1) according to (Jackson, 1997; Cottenie et al., 1982).
Preparation of TiO$_2$ Nanoparticles

Titanium nanoparticles (TiO$_2$) were prepared by laser ablation of a Titanium(TiO$_2$) plate (99.9% in purity) in 10 ml deionized water. Q-switched Nd:YAG (Quantel) pulse laser at the wavelength of 1064 nm and 8 ns pulses with the repetition rate of 10 Hz and the energy density was 400 mJ cm$^{-2}$, was focused using a 100 mm focal length lens on the Titanium(TiO$_2$) plate immersed in water according to (Siuzdak et al., 2014).

Characterization of TiO$_2$ Nanoparticles

Physicochemical properties of TiO$_2$ nanoparticles were characterized via TEM imaging (Fig. 1) illustrating a spherical shape and an average particle size of 19.5 to 20 nm.

Figure 1: TEM imaging of the prepared TiO$_2$ nanoparticles revealed a spherical shape of the particles, with an average size of 20 ±2.0 nm.

Chemical analysis

The following determinations had been measured:
- Total soluble Sugars (TSS) content was measured according to Thomas and (Ductcher, 1924).
- Phosphorus content was determined according to (Jackson, 1958).
- Insoluble Carbohydrates content was measured according to (A.O.A.C., 1985).
- Potassium content was determined according to (Brown and Liljelund, 1946).
- Nitrogen content was determined according to (Pregl, 1945).
- Chlorophyll a (Chla), Chlorophyll b (Chlb) and Carotenoids content were determined according to the method (Wettstein, 1957).

Determination of heavy elements

Fe, Mn, Ni, B, Pb, Zn, Ti and Cu concentrations were determined by atomic absorption spectrophotometer (Thermo Jarrell Ash Model AA SCAN1) according to the method of (Reuter, 1980).

Statistical Analyses

Data were statistically analyzed using SAS software version 9. R- Squared values ($R^2$) are considered significant at (p-values <0.05), least significant difference (LSD) at 5 % was used to compare the deference between the means of treatment values by analysis of variance test (ANOVA) as described by (Snedecor and Cochran., 1990).

RESULTS AND DISCUSSION

Plant growth

There was interaction between plant height and foliar spray with TiO$_2$ Nanoparticles (Table 2). The highest plants were recorded for the plants treated with 6 ppm of TiO$_2$ Nanoparticles giving (116.3 and 118.7 cm) as compared with untreated plants (83.3 and 85.8 cm) for first and second season respectively. These results agreed with that reported by (Zheng et al., 2005; Yang et al., 2006).

Number of branches / plants

Data in (Table 2) revealed that spraying fennel plants with TiO$_2$ at 2.4 and 6 ppm increased significantly the number of branches/plant. The highest number of branches/plant (7.1 and 7.8) had been found for the plants treated with 6 ppm TiO$_2$ Nanoparticles as compared with (4.6 and 5.3) branches for the untreated plants in first and second season respectively. These results are in harmony with that found by (Zheng et al., 2005; Yang et al., 2006; Lei et al., 2008).

Fruit yield

Foliar treatment of fennel with TiO$_2$ Nanoparticles at 2, 4 and 6 ppm had significantly increased Fruit yield/plant (Table 2) treating the plants with the highest concentration (6 ppm) recorded the highest fruit yield (50.9 and 51.7 g/plant) as compared with the untreated plants (32.6 and 33.8 g/plant) for first and second season respectively. Our finding agreed with that found by (Yang et al., 2006).
These results showed that carbohydrates content increased with the development of nitrogen. They agreed with those of (Lei et al., 2008; Zheng et al., 2005). These results were in agreement with those of (Lei et al., 2008; Zheng et al., 2005).

Photosynthetic Pigments Analysis

In (Table 3) the foliar treatment of fennel with TiO$_2$ Nanoparticles at 2, 4 and 6 ppm increased the chlorophyll content in the leaves of the treated plants as compared with untreated plants. These results are in agreement with those of (Lei et al., 2008; Zheng et al., 2005).

Soluble sugars content (TSS)

Data in (Table 4) showed that soluble sugars content was increased by spraying the plants with TiO$_2$ Nanoparticles giving the highest content 1.07 and 1.17 mg/g$^{-1}$ Dw for plants treated with 6 ppm TiO$_2$ Nanoparticles as compared with 0.583 and 0.642 mg/g$^{-1}$ Dw for control plants in the seasons 2011/2012 and 2012/2013, respectively. These results agreed with (Rutskaya et al., 1974) who found that the development of sugar-beet was enhanced by inserting ammonium titanium sulfate to the soil. According to their results the chlorophyll content of the leaves became higher and the sugar content of the beet root increased.

Total carbohydrates

Total carbohydrates content increased with TiO$_2$ Nanoparticles (Table 4). The highest total carbohydrates content 40.03 and 41.15 mg/g$^{-1}$ Dw resulted from 6 ppm of TiO$_2$ Nanoparticles compared with untreated plant 28.3 and 29.6 mg/g$^{-1}$ Dw.

Nitrogen Content

It is clear that spraying 6 ppm of TiO$_2$ Nanoparticles on fennel plant exhibited the highest content of nitrogen 2.1 and 2.2% compared with 1.4 and 1.6 % for untreated plants, in the first and second season, respectively (Table 5). These findings are agreement with (Yang et al., 2006) who reported that Nano-TiO$_2$ (anatase) improved plant growth by increase the nitrogen metabolism that enhance the absorption of nitrate in spinach and accelerating the transforming of inorganic into organic nitrogen. They added that nitrogen photoreduction was reflected on the improved growth of treated spinach plants.

Phosphorus Content

Data on phosphorus (%) in fennel plants found in (Table 5) showed that, the highest content of phosphorus resulted from spraying the plants with 6 ppm TiO$_2$ Nanoparticles (0.87 and 0.95 %, as compared with untreated plants 0.34 and 0.43 % in the two seasons, respectively). These results were in agreement

<p>| Table 2: Effect of different concentrations of TiO$_2$ NPs foliar spray on Plant height, Number of branches and yield (g/pl.) of Fennel during 2012 and 2013 |
|------------------------------------|--------------------|--------------------|--------------------|</p>
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant height (cm)</th>
<th>Number of branches (Branch/Plant)</th>
<th>Fruit yield (g/pl.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>83.325</td>
<td>4.646</td>
<td>32.623</td>
</tr>
<tr>
<td>2 ppm</td>
<td>96.354</td>
<td>5.353</td>
<td>42.925</td>
</tr>
<tr>
<td>4 ppm</td>
<td>105.040</td>
<td>6.161</td>
<td>47.066</td>
</tr>
<tr>
<td>6 ppm</td>
<td>116.352</td>
<td>7.171</td>
<td>50.904</td>
</tr>
</tbody>
</table>

| R$^2$   | 0.99             | 0.99                        | 0.93             |

| LSD     | 1.1              | 0.32                        | 0.6              |

<p>| Table 3: Effect of different concentrations of TiO$_2$ NPs on chl.a, chl.b and carotenoids of Fennel plants during 2012 and 2013 |
|-------------------------------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Chlorophyll a (mg/g$^{-1}$ fw)</th>
<th>Chlorophyll b (mg/g$^{-1}$ fw)</th>
<th>Carotenoids (mg/g$^{-1}$ fw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.059</td>
<td>1.294</td>
<td>0.382</td>
</tr>
<tr>
<td>2 ppm</td>
<td>2.313</td>
<td>1.444</td>
<td>0.453</td>
</tr>
<tr>
<td>4 ppm</td>
<td>2.725</td>
<td>1.783</td>
<td>0.553</td>
</tr>
<tr>
<td>6 ppm</td>
<td>2.730</td>
<td>2.151</td>
<td>0.693</td>
</tr>
</tbody>
</table>

| R$^2$   | 0.90                           | 0.96            | 0.97            |

| LSD     | NS                             | NS              | 0.33            |

NS = not significant

<p>| Table 4: Effect of different concentrations of TiO$_2$ NPs on sugars contents and total carbohydrates contents of Fennel plants during 2012 and 2013 |
|---------------------------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sugars (mg/g$^{-1}$ Dw)</th>
<th>Carbohydrates (mg/g$^{-1}$ Dw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.583</td>
<td>0.642</td>
</tr>
<tr>
<td>2 ppm</td>
<td>0.863</td>
<td>0.963</td>
</tr>
<tr>
<td>4 ppm</td>
<td>0.983</td>
<td>0.988</td>
</tr>
<tr>
<td>6 ppm</td>
<td>1.073</td>
<td>1.177</td>
</tr>
</tbody>
</table>

| R$^2$   | 0.92     | 0.89     | 0.93      | 0.96      |

| LSD     | 0.25     | 1.6      |

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with (Bielecki et al., 1983), who reported that treated plants with titanium contained higher concentrations of P in leaves as compared to the control. As well as, the enhancement of biomass, growth and fruit quality obtained from many plant species treated with titanium (TiO_2), increased the concentrations of some essential elements such as phosphorus (P), magnesium (Mg) and nitrogen (N) (Pais, 1983; Carvajal et al., 1998).

**Potassium Content**

Results presented in (Table 5) found that, among different exposure treatments with TiO_2 Nanoparticles on fennel, 6ppm of TiO_2 Nanoparticles gave the highest content of potassium 1.65 and 1.74 %, as compared to control plants, in which potassium content was 1.32 and 1.34 % for the first and second seasons, respectively.

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.414</td>
<td>1.616</td>
<td>0.349</td>
<td>0.438</td>
<td>1.323</td>
<td>1.343</td>
</tr>
<tr>
<td>2 ppm</td>
<td>1.838</td>
<td>1.869</td>
<td>0.509</td>
<td>0.630</td>
<td>1.485</td>
<td>1.545</td>
</tr>
<tr>
<td>4 ppm</td>
<td>1.980</td>
<td>2.121</td>
<td>0.566</td>
<td>0.664</td>
<td>1.535</td>
<td>1.586</td>
</tr>
<tr>
<td>6 ppm</td>
<td>2.121</td>
<td>2.262</td>
<td>0.876</td>
<td>0.956</td>
<td>1.656</td>
<td>1.747</td>
</tr>
<tr>
<td>LSD</td>
<td>0.14</td>
<td></td>
<td>0.98</td>
<td></td>
<td>0.96</td>
<td>0.94</td>
</tr>
</tbody>
</table>

**Heavy metals content**

The data in (Table 6A and 6B) showed that the application of TiO_2 Nanoparticles resulted in lower concentrations of Zn, Cu, Fe, Mn, Ni, Pb, Ti and B but higher than the control treatment as compared with the allowable concentrations for each of them.

These results confirmed that concentration 2, 4 and 6 ppm of TiO_2 Nanoparticles are safe when sprayed on fennel plants. Our results agreed with (Larry et al., 1979; Gupta, 1975; Radojevic and Vladimir, 1999; Haider et al., 2004).

**Anatomical structure of fennel leaf**

As shown in (Figure 2a) the epidermis cells of the control were similar in size and shape, while the epidermal cells of the NP-treated leaves became larger in size and reached a maximum size at treatment 6 ppm of TiO_2 Nanoparticles foliar spray (Figure 2b). In addition, the thickness of mesophyll tissue, which is specialized photosynthetic tissue that contains chloroplasts in palisade and spongy parenchyma tissue, was a great compared to control leaves. This finding was based on the chlorophyll concentration, which was higher in 6 ppm of TiO2 Nanoparticles foliar spray treatment compared to control (Figure 2c). This confirms that TiO_2 Nanoparticles enhanced chlorophyll synthesis, photosynthesis and plant growth.
CONCLUSION

TiO$_2$ NPs foliar spray had a significant enhancement on the chlorophyll a, b, carotenoids, phosphorus, nitrogen, potassium, total carbohydrates, and sugars content as well plant growth characteristics and which will increase the total yield of fennel plant. The results show strong evidence for the high efficiency of this new nanofertilizer on enhanced plant growth. These inexpensive nanofertilizers could replace traditional methods of plant growth enhancement. Furthermore TiO$_2$ nanofertilizers development could have large scale, economic implications and multiple benefits for farmers, consumers, producers. This work confirmed that TiO$_2$ nanofertilizers using is eco-friendly, safe and produce healthier products.

REFERENCES


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Washington D.C., U.S.A.


تاثير الرش بالنانوتيتانيوم على نبات الشمر
محمد سليمان خاطر
المعهد القومي لعلوم الليزر- جامعة القاهرة

الدراسة تشير إلى أن الرش بالنانوتيتانيوم يحسن بشكل كبير التمثيل الضوئي والنمو لنباتات الشمر حيث تم رش نباتات الشمر بتركيزات مختلفة من النانو تيتانيوم (0.01 حبة في المليون)- واظهرت النتائج ان الرش بتركيز 0.01 حبة في المليون تم الحصول على اعلى محصول واعلى نمو لنباتات وكذلك اعلى عدد في افروع النباتات واصابات ومزایع والكربوهيدرات والفيتامينات والفيتامينات.

كما ان رش نباتات الشمر بتركيزات 0.01 حبة في المليون من النانو تيتانيوم يكون امن على الإنسان.

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