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STUDYING EFFECT OF TITANIUM DIOXIDE NANOPARTICLES ON IMPROVING QUALITY AND QUANTITY OF STRAWBERRY (*FRAGARIA ANANASSA*)

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ABSTRACT

This experiment was conducted to assess the influence of titanium dioxide nanoparticles (anatase TiO_2 NPs) on strawberry (c.v Queen Eliza and Paroos) in a hydroponic condition. Hoagland solution supplemented with TiO_2 NPs at seven concentrations of 0, 1.5, 3.5, 5.5, 7.5, 9.5 and 11.5 mg/l was used. The results indicated that the hydroponically application of anatase TiO_2 NPs in the nutrient solution, compared with the control, increased different characteristics of strawberry plant such as chlorophyll content of leaves, weight and size, ascorbic acid, TSS and TSS/TA ratio of the fruit, pH of the fruit extract and yield (gr/plant). The best results were obtained when using a high concentration (11.5 mg/l) of TiO_2 NPs.

KEYWORDS: Anatase, Titanium dioxide nanoparticle, Photocatalyst, Strawberry.

INTRODUCTION

Strawberry (*Fragaria×ananasa* Duch.), a small fruit crop and a hybrid of two highly variable octoploid species, is adapted to extremely different environmental conditions [1]. Prerequisites for a successful strawberry growing are climate, cultivars, soil and nutrition [2]. Titanium (Ti) which is beneficial at low and toxic at higher concentrations has significant biological effects on plants [3]. Many investigators have demonstrated the promotion of growth by titanium, whether applied as a fertilizer to the soil or as a spray to the leaves [4]. Reverte et al. [5] found that the application of Ti^{4+}-ascorbate significantly improved red paprika yield and fruit quality as well as the photostability of ground peppers during storage. Grenda [6] reported the positive effects of Ti-treatment on rape plant development (an increase in chlorophyll content and photosynthesis intensity), yield and mass of a thousand seeds of winter wheat and yield and sugar contents in sugar beets. Beneficial influence of Ti^{4+}-ascorbate spraying in combination with Ca^{2+} and Mg^{2+} was observed on plum trees [7] and peach tree performance and fruit size [8]. Further, the positive effect of titanium on different fruit trees consisting of apple, grapes, sour cherry, gooseberries, black currents, peaches and apricots has been also reported by researchers [9]. Recently, Choi et al. [10] found that the yield and hardness of strawberry fruit and chlorophyll content in leaves were increased after the spraying of TiO_2. Changes in agricultural technology have been a major factor, which shape modern agriculture [11]. Recently, the rapidly increasing applications of engineered nanoparticles with the sizes of smaller than 100 nm in various areas of the economy, such as textiles, electronics, pharmaceutics, cosmetics and environmental remediation have received great attention and concern [12]. Having a photocatalyzed characteristic, TiO_2 NPs under light could cause an oxidation-reduction reaction [13] and attract considerable attention in many different studies [14]. Effects of TiO_2 NPs on the promotion of seed germination and increased seedling growth have been also reported [15, 16]. Anatase TiO_2 NPs improved light absorbance and promoted the activity of Rubisco activate and also affected the nitrogen photoreduction and improved the growth of spinach plant [17, 18, 19, 20, 21]. Anatase TiO_2 NPs can accelerate light energy to electron energy and increase the photosynthesis [22]. They improve light harvesting complex II (LHC II) on thylakoid membranes of spinach and increase the LHC II content [23]. Raliya et al [24] found that spray of mung bean leaves with nanoTiO_2 increased shoot and root length, root area and nodule, chlorophyll content and total

soluble leaf protein as well as microbial population, activity of acid phosphatase, alkaline phosphatase, phytase and dehydrogenase enzymes in the rhizosphere.
In this study, the effect of anatase nanoparticle on the properties of strawberry fruit was studied in a hydroponic condition.

MATERIALS AND METHODS
The experiment was set up according on a factorial design with three replications. This research was conducted in Faculty of Agriculture, Shahid Chamran University of Ahvaz, Iran (in a place with open environmental conditions and direct exposure to sunlight). Required seedlings from two cultivars of Queen Eliza and Paroos were supplied from Kurdistan in Iran. Cocopeat was used as the medium in the experiment. Strawberry seedlings were planted after disinfection with fungicide benomyl (2 g/l). The plants were irrigated with Hoagland nutrient solution supplemented with TiO_2 NPs concentrations and fed on 1 lit per pot per week. The treatments included concentrations of 0, 1.5, 3.5, 5.5, 7.5, 9.5 and 11.5 mg/l from TiO_2 NPs (nanoanatase). Mineralogical structure of anatase titanium dioxide nanoparticles with sol gel solution was prepared by Department of Physics, Sharif University of Technology, Iran. Transmission electron microscopy (TEM) nano-sized titanium dioxide particles were about 30 nm and spindle-shaped (Fig 1). In order to prevent accumulation and increased salt concentration in the root environment, the pots were washed with water weekly. After 3 months, different characteristics including chlorophyll content [25], weight of fruit, fruit size, soluble solids (TSS), pH of the extract, TSS/TA ratio, ascorbic acid and yield (gr per plant) were measured.
The statistical analysis of the data was performed using SAS 9.1 software and the means were compared using Duncan test at the significance level of 0.01.

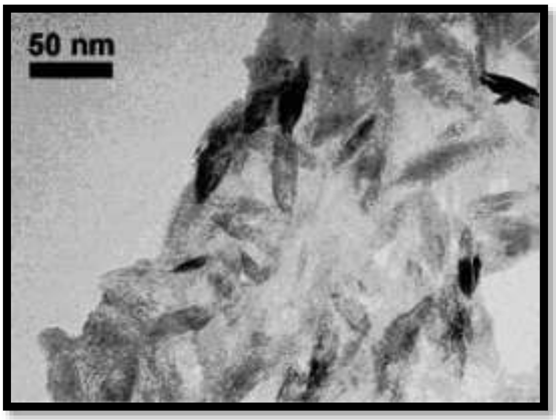

Fig. 1. Image TEM of nano TiO_2

RESULTS AND DISCUSSION
Analysis of variance showed significant differences from nanoanatase TiO_2 treatment in all the characteristics, except TA.

Chlorophyll content
Chlorophyll content increased during the experimental period. The lowest content of chlorophyll (1.23 mg/g) was observed in the control plants, Paroos, and the highest (2.3 mg/g) was in Queen Elisa at the concentration 11.5 mg/l of nanoanatase (Fig 2-A).

Fruit weight and volume
Weight of strawberry fruit and volume increased during the treatment with nanoanatase TiO_2. The results showed that the control plants had the lowest mean weight (16.4 g) and volume (18.6 cm^3) of the fruit in varieties of Queen and Paroos, but the concentration of 11.5 mg/l nanoanatase created the highest fruit weight (42.48g) and volume (43.4 cm3) in the variety of Queen (Fig 2 B, C). In other words, by the application of nanoanatase to the concentration of 11.5 mg/l, the fruit weight was increased by almost 2 times (Fig 3). It was reported that the nanoanatase increased nutrient uptake by the roots [26].

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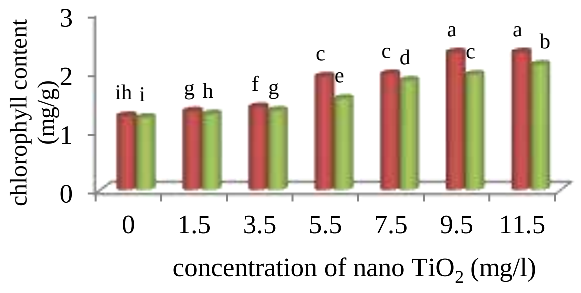
A



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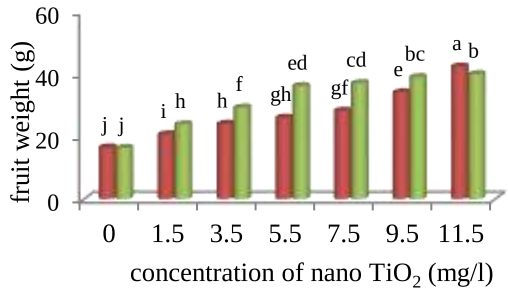

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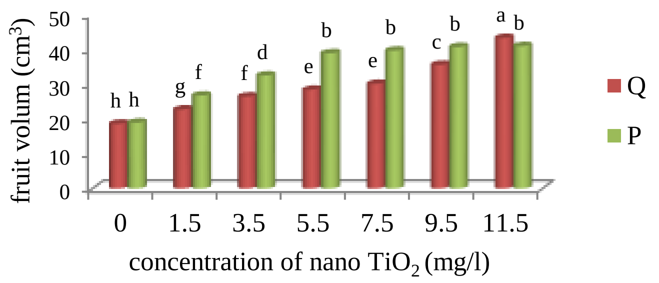


Fig. 2. Effect of anatase TiO_2 NPs on A) chlorophyll content B) fruit weight and C) fruit volume of the strawberry cultivars: Queen Eliza (Q) and Paroos (P).

A

B

Fig. 3. Weight of Queen Eliza fruit in control (A) and under nano-TiO_2 treatment (B).

PH of the fruit extract

The pH of the fruit extract increased with increasing the concentration of the nanoanatase TiO_2. The lowest pH (3.53) belonged to the control plants in Paroos cultivar and the highest pH (4.07) was read in the case of the highest concentration treatment (11.5 mg/l) in Queen Elisa cultivar. However, it should be noted that the concentrations of 7.5, 9.5 and 11.5 mg/l were not significantly different (Fig 4 A).

Total soluble solid (TSS)

TSS is an indicator that directly related to quality of the edible fruit. The lowest total soluble solid was obtained in the control plants (9.26%) in Paroos and Queen Elisa cultivars and the highest TSS (11.65%) was observed at the highest concentration of nanoanatase (11.5 mg/l) in Queen Elisa cultivar (Fig 4 B). Changes in starch, acid and sugar during the fruit ripening process, increase the amount of total soluble solid. Therefore, treatment by TiO_2 NPs (nanoanatase) improved the fruit quality.

Ratio of TSS/TA

Total soluble solids (TSS) and titratable acidity (TA) are generally used to evaluate the flavor and ripening stages of the fruit. The highest quality fruit is dependent on the mount of increase in sugar to acid ratio [35]. The ratio of TSS/TA of the strawberry fruit over a period of treatment with nanoanatase TiO_2 was increased. The results showed that the control plants had the lowest proportion (11.05) and the nanoanatase concentration of 11.5 mg/l created the highest TSS/TA (14.74) in Queen Elisa cultivar (Fig 4 C).

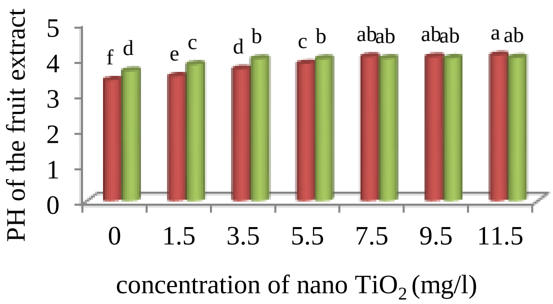
Content of ascorbic acid

Ascorbic acid of the fruit juice was significantly increased by increasing nanoanatase TiO_2 concentration in both cultivars of Queen Eliza and Paroos. The lowest amount of ascorbic acid (54.08 mg/100g) was observed in the control plants and the highest amount (64.53 mg/100g) was recorded at the concentration of 11.5 mg/l (Fig 4 D).

Yield

Yield of the plants treated with nanoanatase TiO_2 was higher than that of the control. The highest yield (150.88 g per plant) was obtained in the plants treated with the concentration of 11.5 mg/l nanoanatase and the lowest yield was recorded in the control plant (72.92 g per plant). The application of nanoanatase at the concentration of 11.5 mg/l increased strawberry yield by almost 2 times (Fig 4 E).

A



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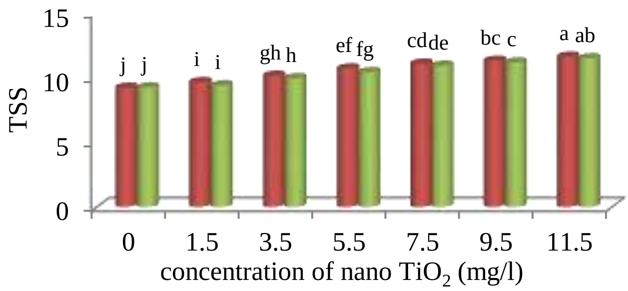

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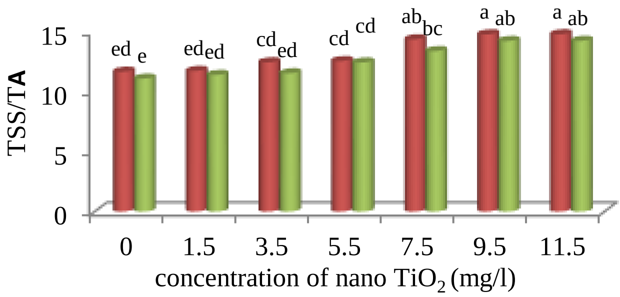

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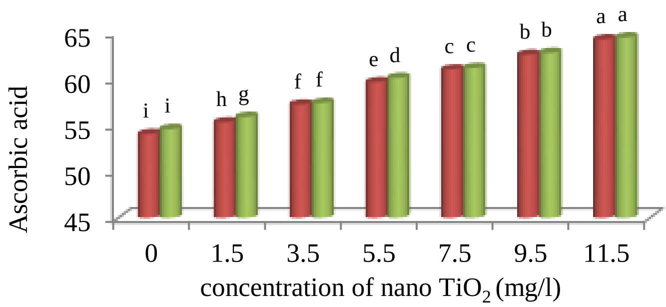

E

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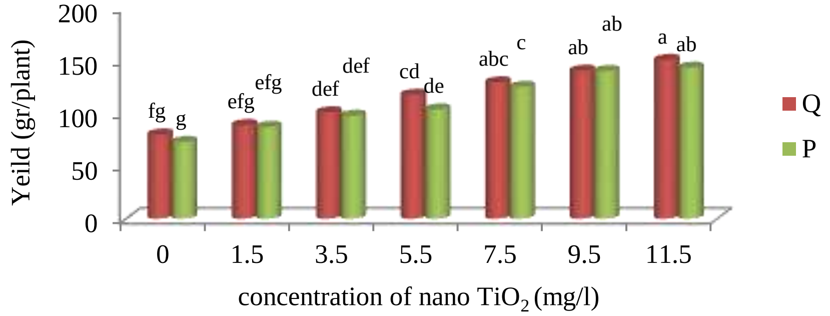

Fig. 4. Effect of anatase TiO_2 NPs on A) pH of the fruit extract B) TSS C) TSS/TA D) Vitamin C and E) Yield of the strawberry cultivars: Queen Eliza (Q) and Paroos (P).

The results clearly indicated that all the measured traits in this experiment were positively affected by nanoanatase TiO_2 compared with the control and the effects of nanoanatase were increased by increasing their concentration so that the best results were obtained at the highest concentration of nanoanatase (11.5 mg/l). Yang et al. [20] reported that the nanoanatase TiO_2 improved plant growth by enhanced nitrogen metabolism that promoted the absorption of nitrate and, accelerated the conversion of inorganic nitrogen into organic nitrogen and, thereby, increased the fresh and dry weights. Anatase TiO_2 NPs can also be involved in photophysical and photochemical processes. They photogenerate electron by absorbed light photons and excite the energized electrons from the valence band to the conduction band [14]. Nanoanatase promotes energy transfer and oxygen evolution in photosystem II (PS II) and photophosphorylation activity in chloroplast under visible and ultraviolet light [17, 18, 27]. For this reason, applying TiO_2 solution to strawberry plants in greenhouse, when insufficient solar radiation happens during the winter season, could promote the growth and increase both yield and quality [10].

It seems that anatase TiO_2 NPs absorb light, convert light energy into chemical energy and protect the chloroplasts against aging [28]. Nanoanatase can enter the chloroplast and increase chlorophyll in plants [23]. Increase in the accumulation of total chlorophyll content in cucumber after treatment with TiO_2 NPs was also reported [29]. Skupien and Oszmianski [9] showed that spray the strawberry plants with titanium, increased ascorbic acid in five cultivars except one cultivar. Increasing ascorbic acid may be due to better availability of carbohydrate reserves for the growth and development of the fruit [30]. Further, Servin et al. [29] found that the catalase activity in the leaves of cucumber treated with TiO_2 NPs was increased and the treated plants had 35% more potassium and 34% more phosphorus. It was also found that nano-packing strawberry with anatase TiO_2 NPs inhibited decreasing TSS, TA and ascorbic acid during the storage [31]. Moreover, nanoanatase TiO_2 could decrease the oxidative stress to spinach chloroplast caused by UV-B radiation through decreasing the accumulation of superoxide radicals, hydrogen peroxide and malonyl dialdehyde content, and enhancing the activities of superoxide dismutase, catalase, ascorbate peroxidase and guaiacol peroxidase [13]. Mohammadi et al. [32] demonstrated that reduction damage on chickpea cell membrane under cold stress at low TiO_2 NPs concentrations through decreased levels of electrolyte leakage index and malondialdehyde could probably decrease the ROS. Moreover, TiO_2 NPs may have less toxicity effects on plants and soil microbes [33] and exhibit low mobility from soil to leachates and limited uptake into the plant [34]. Furthermore, biosynthesis of TiO_2 NPs may be achieved through biological systems which will cheap in cost and also safe to environment [24].

On the other hand, our results showed that Queen Eliza cultivar, compared with Paroos cultivar, was more affected by the nanoanatase concentrations. Similarly, Skupien and Oszmianski [9] reported that the influence of titanium spray on strawberry plants was cultivar-dependent so that the total polyphenol content was increased only in one cultivar and L-ascorbic acid increased almost in all the tested cultivars, while the total anthocyanin content was increased only in three out of all the six cultivars. Cultivar-dependent influence of titanium in strawberry is due to their genetic characteristics. We finally recommend performing more research, especially to investigate the existence and durability of TiO_2 NPs in strawberry fruit.

CONCLUSION

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The results obtained in this study demonstrated that adding anatase TiO_2 NPs to hydroponic nutrient solution at the concentration of 11.5 mg/l could increase strawberry growth and improve fruit quality, but we finally recommend performing more research, especially to investigate the existence and durability of TiO_2 NPs in strawberry fruit.

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