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Beneficial effect of titanium on plant growth, photosynthesis and nutrient trait of tomato cv. Foria

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ABSTRACT- Titanium is a beneficial element for plant since its promotive effect on plant metabolism has been well documented. However, the physiological role of this trace element in tomato is not clear. This experiment was conducted as a complete randomized design to study two concentrations of titanium (1 and 2 mg/L Ti) and 0 as control on physiological and nutrient properties of tomato cv. Foria with 4 replications. Plant growth (fresh and dry weight, root volume and flower number), greeness Index (SPAD value), photosynthesis and nutrient parameters of tomato were evaluated. The result of nutrient use efficacy (NUE) showed that NUE of K, Ca and Mn improved by Ti supplementation and Zn use efficiency decreased by increasing Ti concentration. The earliest flower induction was observed at 2 mg/L Ti. Root volume increased by both Ti concentration and root fresh weight increased at 2 mg/L Ti. Greeness Index (SPAD value) and PWUE were not influenced by Ti application. Results showed that photosynthesis rate increased by increasing Ti concentration. Transpiration was reduced at the highest Ti concentration. Based on the results, Ti increased plant growth and photosynthesis through increasing nutrient uptake and nutrient use efficiency.

INTRODUCTION

Tomato is one of the most important vegetables grown in the world and in Iran in soil and hydroponic culture. Increasing plant productivity through different ways is considered by agriculturists. One of the most important factors controlling growth and productivity is good plant nutrition (Simon et al., 1988). Plant nutrients are chemical elements required for plant growth and production.

There is a beneficial element stimulating plant growth which included aluminium (Al), cobalt (Co), Si, sodium (Na), vanadium (V) and titanium (Ti). Ti is widely distributed in the earth with the average concentration of 6 g/kg; however, availability of Ti to plant is very limited (Wojcik and Klamkowski, 2007). Ti as the tenth most abundant element in the earth's crust is hardly absorbed by plants (McClendon, 1976).

Ti has an important role in plant metabolism and promotes absorption and activity of some nutrient elements (Lopez Moreno et al., 1996). Kužel et al. (2003) showed that titanium application on oats has beneficial effects on plant growth, yield and chlorophyll content and also application of Ti in soil was more effective than foliar application. Also, the results of Carvajal et al.'s (1994) study showed that titanium increased concentration of other elements in leaves; namely, biomass and growth of plant whether applied to soil or leaf spray, and increase of chlorophyll in tomato (Pais1983). Martínez-Sánchez et al. (1993) showed that Ti application by leaf spray increased ascorbic acid and capsantin of pepper fruit. Also, these authors reported that Ti increased N concentration and resulted in increasing photosynthesis rate and caused improved plant growth (Kužel et al., 2003).

Although the beneficial effects of Ti were found 80 years ago (Kužel et al., 2003), the effects of Ti on plants in different conditions and the physiological role of titanium in higher plants specially in tomato cv Foria is not well known. Therefore, the aim of this experiment was to study the beneficial effects of titanium on plant growth, flower initiation, photosynthesis trait and nutrient uptake of tomato in hydroponic conditions.

MATERIALS AND METHODS

This experiment was conducted in a plastic greenhouse in the Department of Horticulture Science of Isfahan University of Technology, Isfahan, Iran, with mean temperature of 30-35°C and relative humidity of 30-35%.

Production Of Seedling

Tomato (cultivar 'Foria') seeds were germinated in a soilless growing system in peat (Fafard Co., Canada). When the plants had 2-3 leaves, they were transplanted into a hydroculture container system (in-house built) aerated with an air pump every 2 h for 10 min each time. The nutrient solution was renewed almost every 4 days when the nutrient solution level in the container decreased to almost half the original volume. Treatments were 1 and 2 mg/L titanium and 0 as control with 4 replications.

Photosynthesis Trait Assay

After one month, leaf chlorophyll content was measured using a nondestructive dual-wavelength chlorophyll meter (SPAD-502, Minolta Corp., Ramsey, NJ, USA). Five measurements were made for each replicate.

Photosynthesis properties were determined from the youngest fully expanded leaf for 3 replications per treatment by a portable area meter (Li-Cor Li-3000, USA) from 10:00 to 11:00 am on a clear day (without clouds). The measurements were conducted with photo synthetically active radiation (PAR) intensity of 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and reference CO_2 concentration of 350 µmol·mol.

Plant Growth

The time to first flower induction from the start of the treatment application was measured. The number of flowers was counted at the end of the experiment. The shoot diameter was measured with digital caliper (Model 16 ER 0-6).

At the end of the experiment, plants were harvested and washed using tap water. Shoots were excised from the roots using a steel blade, and then oven dried at 70°C for 2 days to a constant weight. The fresh weight (FW) and dry weight (DW) of shoots and roots were measured. Root volume was measured with the method using the changes of water volume.

Nutrient Assay

Dried leaf samples were used for nutrient analysis. The concentration of nutrients (k, Ca, Mn, Fe, Cu, Zn, and Ti) was measured using X-ray fluorescence (Unisantis XMF104, Germany) (Simabuco and Nasciment Filho, 1994). Nutrient uptakes were calculated according to this formula:

Nutrient uptake = nutrient concentration × shoot dry weight

Statistics Analysis

The experiment was conducted based on a completely randomized design (CRD) with four replications. Data were analyzed with Statistics 8 (Tallahassee FL, USA). All data were subjected to a one-way analysis of variance (ANOVA) and the means were compared for significance by the least significant difference (LSD) test at $P < 0.05$.

RESULTS AND DISCUSSION

When the Ti concentration increased, the K, Ca and Mn decreased. The Fe and Zn concentration increased when Ti2 was applied. Cu concentration decreased in Ti2. Ti concentration of leaves did not change with Ti application in nutrient solution (Table 1).

K, Ca, Mn and Ti uptake did not change in Ti1 and Ti2 significantly. Fe uptake decreased with Ti1 and Ti2 application. Cu and Zn uptake decreased in Ti2 (Table 2).

NUE of K increased in Ti2. NUE of Ca increased while Ti concentration increased in nutrient solution. NUE of Mn increased when Ti was applied in Ti1 and Ti2. NUE of Fe, Cu, and Ti of leaves did not change with Ti application. NUE of Zn increased in Ti2 (Table 3)

Root volume increased with Ti1 and Ti2. Flower number and root fresh weight increased in Ti2. Shoot diameter, root dry weight, shoot dry weight and shoot fresh weight did not change by Ti application. Time to first flower induction decreased by increasing Ti concentration in nutrient solution (Table 4).

Table 1. The effect of titanium on nutrient concentration of tomato leaves cv. Foria

Treatment	K(ppm)	Ca(ppm)	Mn(ppm)	Fe(ppm)	Cu(ppm)	Zn(ppm)	Ti(ppm)
Ti0	2.71a	6.86a	1.26a	157.00b	244.00a	118.00ab	--------
Ti1	2.55b	6.60b	0.89b	154.00b	228.00a	82.60b	0.71a
Ti2	2.49 c	6.42c	0.41c	265.00a	109.00b	145.00a	0.69a

Within a column, the means followed by the same letter are not significantly different at $P < 0.05$ according to the LSD test. Ti0, Ti1 and Ti2 included control, 1 and 2 mg/L titanium, respectively.

Table 2. The effect of titanium on nutrient uptake of tomato leaves cv. Foria

Treatment	K(ppm)	Ca(ppm)	Mn(ppm)	Fe(ppm)	Cu(ppm)	Zn(ppm)	Ti(ppm)
Ti0	0.82a	0.49a	0.01a	10.60a	2.60a	92.90a	-------
Ti1	0.80a	0.51a	0.03a	5.70b	2.80a	86.40a	0.27a
Ti2	0.82a	0.44a	0.02ab	6.00b	1.50b	48.85b	0.27a

Within a column, the means followed by the same letter are not significantly different at $P < 0.05$ according to the LSD test. Ti0, Ti1 and Ti2 included control, 1 and 2 mg/L titanium, respectively.

Table 3. The effect of titanium on nutrient use efficiency of tomato leaves cv. Foria

Treatment	K(ppm)	Ca(ppm)	Mn(ppm)	Fe(ppm)	Cu(ppm)	Zn(ppm)	Ti(ppm)
Ti0	0.05b	0.26c	0.09b	0.30a	0.27a	0.27a	-------
Ti1	0.12b	0.41b	0.69a	0.42a	0.37a	0.21ab	0.231a
Ti2	0.35a	0.77a	0.67a	0.29a	0.46a	0.13b	0.212a

Within a column, the means followed by the same letter are not significantly different at $P < 0.05$ according to the LSD test. Ti0, Ti1 and Ti2 included control, 1 and 2 mg/L titanium, respectively.

Table 4. The effect of titanium on plant growth and flower number of tomato cv. Foria

Treatment	First flower induction	Flower number	Root volume (mL)	Shoot diameter (mm)	Root dry weight (g)	Shoot dry weight (g)	Root fresh weight(g)	Shoot fresh weight(g)
Ti0	13.25a	5.75ab	25.33b	0.55a	0.66a	3.28a	13.55b	38.71a
Ti1	10.00b	4.50b	32.00a	0.61a	0.66a	3.45a	12.60b	37.58a
Ti2	6.50c	8.00a	35.33a	0.50a	0.56a	3.38a	16.36a	40.10a

Within a column, the means followed by the same letter are not significantly different at $P < 0.05$ according to the LSD test. Ti0, Ti1 and Ti2 included control, 1 and 2 mg/L titanium, respectively.

SPAD and PWUE did not change with Ti. Photosynthesis increased and transpiration decreased with Ti application (Table 5).

Table 5. The effect of titanium on photosynthesis trait and SPAD value of tomato cv. Foria

Treatment	Greeness Index (SPAD value)	Photosynthesis (μmol m^{-2} s^{-1})	Transpiration (mmol/$m^{-2}s^{-1}$)	PWUE
Ti0	23.32a	10.24c	0.17a	1.43a
Ti1	20.79a	10.30b	0.19a	1.60a
Ti2	23.42a	10.37a	0.15b	1.58a

Within a column, the means followed by the same letter are not significantly different at $P < 0.05$ according to the LSD test. Ti0, Ti1 and Ti2 included control, 1 and 2 mg/L titanium, respectively.

In the present study, root volume increased along with Ti concentration. In line with the present study, Inman et al. (1935) reported that Ti increased root growth through reducing the toxic effect of some other elements.

Kiss et al. (1985) reported that the beneficial effect of Ti on plant growth may be due to enhanced nutrient requirement of plants induced by an increase in photosynthetic activity. Klamkowski et al. (1999) showed that foliar application of Ti increased nutrient uptake and plant biomass apple tree grown in semi hydroponic culture. Martínez Sánchez et al. (1993) found that Ti increased plant growth and nutrient concentration of *Capsicum annuum*. The yield of apple tree (*Malus domestica*), corn (*Zea mays*), and sugar beet (*Beta vulgaris* subsp. vulgaris) increased by as much as 30 % and the content of chl by 15−65 % when Tytanit was used (Prusiński and Kaszkowiak, 2005)

In our study, we observed that root fresh weight increased at the highest Ti concentration and other plant growth parameter such as shoot diameter, shoot fresh weight, dry weight of shoot and root had not been affected by Ti supplementation. It seems that more studies are needed to examine the varying ranges of Ti on physiological traits of tomato in hydroponic and soil culture.

In the present study, photosynthesis rate increased by increasing Ti application. Carvajal and Alcaraz (1995) found that Ti improved photosynthetic activity of paprika pepper through increasing chlorophyll level and activity of some enzyme. Nano-TiO2 improved photosynthesis and growth of spinach (*S. oleracea*) (Yang et al., 2007).

Ti applied in oats (*Avena sativa*), as a nutrient solution, was more effective than spraying it on the leaves, benefiting various plant physiological parameters such as biomass yield, chlorophyll (chl) content, and growth (Kužel et al., 2003).

Ti application increased photosynthesis through promotion of the synthesis of multimetal cofactors and of some metal-binding storage protein as phytoferritins or to increase the activity of Fe, Cu, and Zn in leaf cell chloroplasts and cytoplasm (Wojcik and Klamkowski, 2004). Carvajal et al. (1994) proposed that Ti increased iron activity in cell chloroplast and cytoplasm and resulted in increasing plant photosynthesis activity. In the present study, we observed that Ti increased Fe concentration in tomato leaves and may cause a significant increment of photosynthesis rate of tomato leaves.

In the present study, Ti supplementation increased Fe concentration and reduced Mn, Ca and K concentration in tomato leaves and this may be due to increasing Fe concentration in the plant and also, antagonistic effect between Mn and two other elements (Kužel et al., 2003). Also, hormesis theory indicates that Ti shows macro and micronutrient deficiency symptoms and in this way, active immune plant system results in increasing essential elements (Kužel et al., 2003). Pais (1983) indicated that Ti enhanced photosynthesis, thereby increasing enzyme activity that requires metal ion and finally stimulated ion uptake. Ti promoted the better utilization of Fe due to an increase in intracellular Fe^{2+} (Simon et al., 1988). This influence of Ti on Fe uptake and its effect on metabolism, including an increase in the content of photosynthetic pigments, are based on the premise that the low redox potential of the Ti (IV)/Ti(III) couple can influence the activity of metals in the chloroplast and in the cytoplasm (Larbi et al., 2006). Since Fe is an essential component of photosystem II (PSII), any influence of Ti on Fe uptake and subsequent Fe deficiency would influence the biochemical and physiological balance of the photosynthetic apparatus in general, weakening it, for example, by lowering PSII efficiency (Cigler et al., 2010).

Alcaraz Lopez et al. (2003) found that 2 mg/L Ti increased Ca concentration in plum plant and improved plat growth, fruit quality and postharvest through increasing Ca concentration. In the present study, Ca concentration was reduced by the application of Ti.

In agreement with the present study, Bedrosian and Hanna (1966) reported that by increasing Ti concentration, Fe and Mn concentration of *Pieris japonica* decreased. Results of the present study showed that Ti supplementation increased Fe on tomato leaves.

Wojcik (2002) found that $TiCl_2$ had no influence on nutrient status of apple leaves. Another study by Wojcik et al. (2010) showed that foliar application of Ti had no influence on N, Fe, Mn, Zn and Mg leaves. The result of our study showed that Mn concentration in tomato leaves was reduced by Ti application.

Wojcik and Klamkowski (2007) indicated that concentration of macro and micronutrient in leaf and fruit was not affected by foliar application of Ti. Kužel et al. (2003) found that Ti induced Zn transport by the apparent deficiency of Zn in oats. Also, these authors showed that Ti increased Mg at Mg deficit soil which was not significant at higher Mg concentration in soil.

In the present study, titanium had no effect on Ti concentration in tomato leaves. In contrast with the present study, Ti application of growth media increased titanium concentration in cabbage leaves (Hara et al., 1976). A similar result was also found by Ram et al. (1983) and Pais (1983) which showed that Ti concentration of bean and maize increased by the application of Ti onto media, respectively.

CONCLUSIONS

Titanium through increasing photosynthesis rate and ion uptake (by increasing root volume) involved in chlorophyll and photosynthesis (Fe) led to increasing plant growth. We suggest that this experiment be repeated with varying Ti concentrations. Moreover, the effect of Ti on fruit productivity and quality can also be investigated.

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تاثیر مثبت تیتانیوم در رشد، فتوسنتز و صفات تغذیه‌ای گوجه-فرنگی رقم Foria

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رشدگیاه

چکیده- تیتانیوم عنصری سودمند برای گیاهان است اما نقش فیزیولوژیکی این عنصر کمیاب در گوجه‌فرنگی هنوز مشخص نیست. این آزمایش در قالب طرح کاملا تصادفی برای مطالعه دو غلظت تیتانیوم(1 and 2 mg/L) و غلظت صفر به عنوان شاهد بر خواص تغذیه‌ای و فیزیولوژیکی گوجه فرنگی رقم Foria با ۴ تکرار انجام شد. شاخص‌های رشد گیاه (وزن تر و خشک، حجم ریشه و تعداد گل)، شاخص سبزینگی، فتوسنتز و تغذیه‌ای گوجه‌فرنگی ارزیابی شد. نتایج نشان داد که کاربرد تیتانیوم غلظت K, Cs, Mn, Cu را کاهش و غلظت آهن را افزایش داد و تاثیر معنی‌داری بر میزان تیتانیوم گیاه نداشت. جذب کلسیم، پتاسیم و تیتانیوم تحت تاثیر تیتانیوم قرار نگرفت در حالیکه جذب آهن، مس و روی در برگ تحت تاثیر تیتانیوم کاهش یافت. نتایج کارایی استفاده از عناصر نشان داد که کارایی استفاده از عناصر پتاسیم، کلسیم و منگنز با کاربرد تیتانیوم بهبود یافت و کارایی استفاده روی با افزایش غلظت تیتانیوم کاهش یافت. سریعترین گل‌آغازی در غلظت ۲ میلی‌گرم در لیتر تیتانیوم مشاهده شد. حجم ریشه با هردو غلظت تیتانیوم افزایش یافت و وزن تر ریشه با غلظت ۲ میلی‌گرم در لیتر تیتانیوم افزایش یافت. شاخص سبزینگی و کارایی مصرف آب فتوسنتزی تحت تاثیر کاربرد تیتانیوم قرار نگرفت. نتایج نشان داد که نرخ فتوسنتز با افزایش غلظت تیتانیوم افزایش یافت. میزان تعرق در بالاترین غلظت تیتانیوم کاهش داشت. براساس نتایج ما، تیتانیوم رشد و فتوسنتز گیاه را از طریق افزایش جذب عناصر و کارایی استفاده از عناصر افزایش داد.