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# INFLUENCE OF FOLIAR APPLICATION OF TRIACONTANOL ON GROWTH ATTRIBUTES, GAS EXCHANGE AND CHLOROPHYLL FLUORESCENCE IN SUNFLOWER (*HELIANTHUS ANNUUS* L.) UNDER SALINE STRESS

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## Abstract

To appraise the effect the foliar application of triacontanol (TRIA) on sunflower (*Helianthus annuus* L.) under saline stress, a pot experiment was conducted under natural conditions. Two sunflower cultivars (SMH-907 and SMH-917) were grown in sand culture medium supplemented with full strength Hoagland's nutrient solution for 25 days, after which time, two saline regimes [control (0 mM) and saline (150 mM)] were applied. Three TRIA levels [0 (water spray), 50 and 100 µM] were applied as foliar spray on 44-day old plants. Plants were harvested after 4 weeks of TRIA application. The root growing medium saline stress significantly reduced shoot and root fresh weights and their lengths, net $CO_2$ assimilation rate (*A*), transpiration rate (*E*), water use efficiency (WUE), co-efficient of non-photochemical quenching ($q_N$) and non-photochemical quenching (*NPQ*) in both sunflower cultivars. Foliar-applied TRIA markedly increased shoot and root fresh weights and lengths, *A*, *E*, stomatal conductance and WUE in both cultivars under both saline and non-saline regimes. TRIA did not show prominent effect on chlorophyll fluorescence attributes such as electron transport rate and photochemical quenching of sunflower plants. The TRIA level 100 µM was more effective as compared to the others and sunflower cultivar SMH-917 showed better performance than those of cv. SMH-907 in terms of different attributes measured in this study.

## Introduction

Triacontanol is a potential plant growth regulator which has been reported to significantly affect plant growth and development (Verma *et al*., 2009; Shahbaz *et al*., 2013). For example, exogenously applied triacontanol (TRIA) has been shown to enhance growth of many crops including wheat, maize, rice (Naeem *et al*., 2009; Perveen *et al*., 2010, 2011). TRIA application not only can enhance yield but also quality characteristics of crops as observed in wheat, tomato, cotton, etc. (Ries, 1985; Naeem *et al.,* 2009). Foliar application of TRIA has been reported to enhance chlorophyll contents, total soluble sugars, protein, nucleic acids, photosynthetic rate and chlorophyll fluorescence in wheat parameters (Perveen *et al.,* 2010) and soybean (Krishnan & Kumari, 2008). TRIA generally can influence the enzymes which regulate growth (Chen *et al.,* 2002) and metabolic processes in plants (Morre *et al*., 1991). TRIA not only improves crop growth and yield under non-stress conditions, but it also can up-regulate crop growth under stressful environments. For example, exogenously applied TRIA has been reported to play a positive role in enhancing the plant growth in *Erythrina variegata* (Muthuchelian *et al*., 1996), *Ocimum bacillicum* (Borowski & Blamowski, 2009), and common duck weed (Kilic *et al*., 2010).

Like in most mesophytes, growth and yield of sunflower (*Helianthus annuus* L.) is adversely affected by salt stress. For example, gas exchange characteristics, proline contents and carbohydrates have been found to be reduced in sunflower under saline conditions (Hassnein *et al*., 2009). However, from the literature no report was found regarding the role of TRIA in sunflower under saline stress. Thus, the main objective of present study was to assess whether or not foliar application of TRIA could enhance growth, chlorophyll contents and gas exchange characteristics in sunflower under saline stress.

## Materials and Methods

An experiment was performed in a net-house of the Botanical Garden, University of Agriculture Faisalabad, Pakistan, (altitude 213 m, latitude 31° 30'N and longitude 73° 10'E), to examine the effect of foliar application of TRIA on sunflower (*Helianthus annuus* L.) subjected to saline stress. The climatic conditions were: mean day and night temperature 29°C and 15°C, 9 h and 15 h was light and dark period, respectively. Two sunflower cultivar achenes namely SMH-907 and SMH-917 were obtained from NARC (National Agricultural Research Centre) Islamabad, Pakistan. The experiment was laid out in a completely randomized design with four replications. Twelve achenes were sown in each pot filled with thoroughly washed river sand and allowed them to germinate. In each pot plants were thinned to maintain 6 plants per pot after 21 d of germination. Full strength Hoagland's nutrient solution was applied every week @ two liter per pot to fulfill the nutritional requirement. After 25 d of sowing, two salinity levels [(0 mM (Control) and 150 mM NaCl] prepared in full strength Hoagland's nutrient solution were applied. Salinity level was gradually enhanced as an aliquot of 50 mM per day up to the desired level. Then 150 mM was applied in Hoagland's nutrient solution (full strength) every week @ two liter per pot till the end of the experiment. Three levels of TRIA (0 µM (control), 50 µM, and 100 µM) were applied to 44-d old plants. The TRIA levels were prepared following the method described in Perveen *et al*. (2010). Plants were harvested 72 d after sowing. Two plants per pot were harvested to record shoot and root fresh biomass. The plants were washed with distilled water before recording the biomass. In addition, following attributes were also determined.

**Shoot and root lengths (cm):** Shoot and root lengths were recorded using a measuring scale.

**Gas exchange characteristics:** A portable infra-red gas analyzer (ACD LCA-4 Analytical Development, Hoddesdon, UK) was used to measure the gas exchange characteristics. The second intact leaf from top of each plant was used. The gas exchange parameters were measured from 10:30 to 1:00 h using the following specific settings: leaf surface area 6.25 $cm^2$, leaf chamber gas flow rate into the leaf chamber (U) 251 µmol $s^{-1}$; water vapor pressure ranged from 6.0 to 8.9 mbar, leaf chamber temperature range was 28.4 to 32.4°C; ambient pressure 98.8 kPa; concentration of ambient $CO_2$ was 350 µmol $mol^{-1}$; molar flow of air per unit leaf area (Us) 22.06 mol $m^{-2}$ $s^{-1}$; *PAR* (Qleaf) at the leaf surface was up to 942 µmol $m^{-2}$ $s^{-1}$.

**Photosystem II activity:** Chlorophyll fluorescence attributes were determined using multi-mode chlorophyll fluorometer (model, $OS_5P$ Opti-Sciences, Inc. Winn Avenue Huolson, USA) and determined the coefficient of nonphotochemical quenching ($q_N$), nonphotochemical quenching (*NPQ*), photochemical quenching ($q_P$), efficiency of photosystem-II (*Fv/Fm*), and electron transport rate (*ETR*). The measurements were determined by polyphasic rise in fluorescence transients according to Strasser *et al*., (1995).

**Statistical analysis of data:** A COSTAT computer software (Cohort Software, Berkeley, CA) was used to analyze the data. Least significance difference test was used according to Snedecor & Cochran (1980) to compare the mean values.

## Results

Imposition of saline stress (150 mM NaCl) to the root growing medium caused a significant reduction in shoot fresh weight of two sunflower cultivars, SMH-907 and SHM-917. Foliar-applied various levels of triacontanol (TRIA) (0, 50 and 100 µM) markedly enhanced shoot fresh weight of both sunflower cultivars under both saline and non-saline conditions (Table 1; Fig. 1). Both sunflower cultivars did not differ significantly in this attribute.

Root fresh weight of both sunflower cultivars decreased significantly under saline regimes (Table 1; Fig. 1). The foliar application of different TRIA levels has a varying effect on the root fresh weight of the two cultivars. For example, 50 µM TRIA level was effective for cv. SMH-917 in enhancing root fresh weight under non-saline conditions, while the other TRIA levels remained non-effective to both cultivars under both saline and non-saline conditions.

Saline regimes adversely affected the shoot and root lengths of both sunflower cultivars (Table 1; Fig. 1). Foliar-applied TRIA markedly improved shoot length but it did not have any prominent effect on root length. Although 50 µM TRIA significantly increased root length in cv. SMH-917 under non-saline regimes, the other TRIA levels did not show any prominent effect on this growth trait. Of both sunflower cultivars, cv. SMH-907 showed better performance in shoot length as compared to cv. SMH-917 (Table 1; Fig. 1).

Saline stress significantly decreased net $CO_2$ assimilation rate (*A*) in both sunflower cultivars. However, the cultivar difference was not prominent with respect to this gas exchange attribute (Table 1; Fig. 1). Foliar application of TRIA caused a substantial increase in photosynthetic rate of both sunflower cultivars under both saline and non-saline conditions, but effect was not prominent on cv. SMH-917 under saline conditions. The increase in photosynthetic rate was significantly high when TRIA was applied @100 µM under both saline regimes.

Transpiration rate (*E*) of the two sunflower cultivars decreased significantly under various saline regimes. Although 50 µM TRIA caused a significant increase in transpiration rate in cv. SMH-917 under non-saline regimes, the other TRIA levels did not show any prominent effect on this attribute. Both sunflower cultivars showed a uniform performance in transpiration rate (Table 1; Fig. 1).

Root medium applied saline stress did not affect stomatal conductance ($g_s$) of the two sunflower cultivars i.e. SMH-907 and SMH-917 (Table 1; Fig. 1). Foliar applied TRIA slightly enhanced $g_s$ in cv. SMH-907 under both saline and non-saline conditions, while 100 µM TRIA caused a substantial reduction in cv. SMH-917. Overall, the difference between both cultivars was non-significant with respect to $g_s$.

Sub-stomatal $CO_2$ concentration ($C_i$) and relative intercellular $CO_2$ ($C_i/C_a$) in both sunflower cultivars showed almost uniform values under saline regimes (Table 1; Fig. 1). Exogenous application of TRIA as foliar spray did not alter both $C_i$ and $C_i/C_a$ in the sunflower plants. Of both cultivars, cv. SMH-917 was higher than cv. SMH-907 in both gas exchange attributes.

Root growing medium salinity adversely affected water use efficiency (WUE) in sunflower cultivars SMH-917, while the effect was not prominent in cv. SMH-917 (Table 1; Fig. 1). Foliar application of TRIA significantly enhanced WUE of both sunflower cultivars under non-stress and salt stress conditions. Of various TRIA levels, 100 µM TRIA caused a marked increase in WUE of the sunflower plants under both saline regimes.

Maximum quantum yield of PSII (*Fv/Fm*) in both sunflower cultivars increased significantly under saline stress (Table 1; Fig. 2). Although TRIA had a significant effect, the effect was not uniform in both sunflower cultivars under saline regimes. Of both cultivars, SMH-907 was slightly higher as compared to cv. SMH-917 in *Fv/Fm*.

Root growing medium saline stress slightly increased electron transport rate (*ETR*) in cv. SMH-917 while the effect was not prominent in cv. SMH-907. Of both cultivars, cv. SMH-907 was superior to cv. SMH-917 under non-saline conditions, however, both cultivars responded uniformly under saline stress. The foliar application of TRIA did not affect this attribute under either saline or non-saline environment (Table 1; Fig. 2). Foliar-applied TRIA as well as root growing medium saline stress had non-significant effect on photochemical quenching ($q_P$) of the sunflower cultivars (Table 1; Fig. 2). The cultivars showed a significant difference as cv. SMH-917 showed higher value of $q_P$ than that in cv. SMH-907.

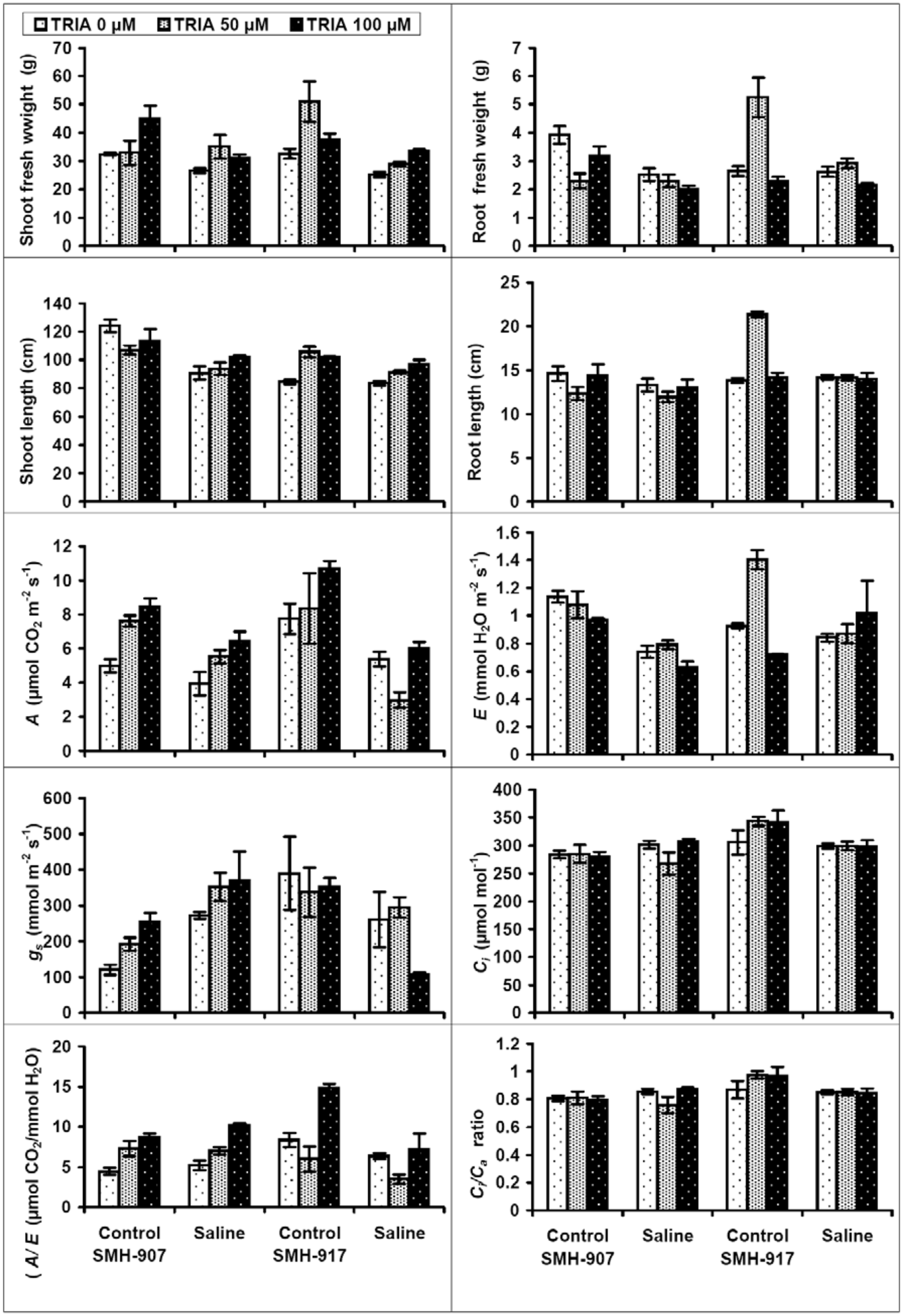

Fig. 1. Growth and gas exchange attributes of sunflower (*Helianthus annuus* L.) when plants were foliary applied with triacontanol under saline or non-saline conditions.

**Table 1. Mean squares from analyses of variance of data for growth attributes, gas exchange and chlorophyll fluorescence of sunflower (*Helianthus annuus* L.) when plants were foliary applied with triacontanol under saline or non-saline conditions.**

| Source of variations | df | Shoot fresh weight | Root fresh weight | Shoot length | Root length | $A$ |
|---|---|---|---|---|---|---|
| Cultivars (Cvs) | 1 | 10.97ns | 0.923ns | 1476.7*** | 48.70*** | 5.689ns |
| Salinity (S) | 1 | 868.1*** | 8.739*** | 2019.9*** | 34.49*** | 103.0*** |
| Triacontanol (TRIA) | 2 | 316.8** | 2.587** | 241.9* | 5.261ns | 24.57*** |
| Cvs × S | 1 | 85.94ns | 0.001ns | 491.7** | 5.063ns | 17.66* |
| Cvs × TRIA | 2 | 79.36ns | 6.873*** | 482.1** | 39.16*** | 9.134* |
| S × TRIA | 2 | 12.28ns | 0.306ns | 85.05ns | 13.16** | 4.584ns |
| Cvs × S × TRIA | 2 | 302.6** | 4.169*** | 300.0* | 22.77*** | 1.005ns |
| Error | 36 | 39.52 | 0.334 | 59.93 | 1.940 | 2.39 |
| **Source of variations** | **df** | $E$ | $g_s$ | $C_i$ | $A/E$ | $C_i/C_a$ |
| Cultivars (Cvs) | 1 | 0.061ns | 10740.0ns | 8957.1*** | 3.834ns | 0.072*** |
| Salinity (S) | 1 | 0.603*** | 24.08ns | 1558.3ns | 33.90** | 0.012ns |
| Triacontanol (TRIA) | 2 | 0.167** | 4743.5ns | 402.0ns | 95.71*** | 0.003ns |
| Cvs × S | 1 | 0.168* | 238290.0*** | 5008.2* | 66.04*** | 0.040* |
| Cvs × TRIA | 2 | 0.066ns | 45433.0* | 1257.8ns | 27.36*** | 0.010ns |
| S × TRIA | 2 | 0.150** | 15666.0ns | 1331.0ns | 6.183ns | 0.010ns |
| Cvs × S × TRIA | 2 | 0.196** | 6320.5ns | 740.7ns | 14.53* | 0.006ns |
| Error | 36 | 0.028 | 10789.7 | 679.8 | 3.185 | 0.005 |
| **Source of variations** | **df** | ***Fv/Fm*** | ***ETR*** | $q_P$ | $q_N$ | ***NPQ*** |
| Cultivars (Cvs) | 1 | 0.120*** | 15.84** | 0.328*** | 0.044*** | 0.034** |
| Salinity (S) | 1 | 0.238*** | 52.71*** | 0.002ns | 0.07*** | 0.146*** |
| Triacontanol (TRIA) | 2 | 0.051*** | 3.12ns | 0.006ns | 0.016** | 0.015* |
| Cvs × S | 1 | 0.029*** | 102.0*** | 0.014* | 8.585ns | 0.014* |
| Cvs × TRIA | 2 | 0.050*** | 2.689ns | 0.007* | 0.009* | 5.825ns |
| S × TRIA | 2 | 0.051*** | 3.719ns | 0.001ns | 0.002ns | 0.023** |
| Cvs × S × TRIA | 2 | 0.112*** | 60.57*** | 0.001ns | 0.003ns | 0.018** |
| Error | 36 | 0.002 | 1.658 | 0.002 | 0.002 | 0.003 |

*, **, *** = Significant at 0.05, 0.01, and 0.001 levels, respectively
ns = Non-significant

Salt stress markedly reduced co-efficient of non-photochemical quenching ($q_N$) and non-photochemical quenching (*NPQ*) in both sunflower cultivars (Table 1; Fig. 2). Foliar applied TRIA caused a slight decrease in both attributes in both sunflower cultivars under both saline and non-saline conditions except in cv. SMH-917 under saline conditions where TRIA treatment slightly increased both the above-mentioned attributes.

## Discussion

Triacontanol (TRIA) is an effective plant growth regulator which can significantly enhance plant growth (Khan *et al*., 2009; Naeem *et al.,* 2009; Perveen *et al*., 2010, 2011, 2012b; Shahbaz *et al*., 2013). In the present study, the foliar application of TRIA (50 µM and 100 µM) enhanced growth, measured as shoot fresh and dry weights, in both sunflower cultivars (SMH-907 and SMH-917) under both saline and non-saline conditions. Foliar-applied TRIA-induced enhancement in growth has already been observed in several crops like ginger (Singh *et al*., 2012), hyacinth beans (Naeem *et al*., 2009), tomato (Khan *et al*., 2009), mungbean (Reddy *et al*., 2002), rice (Pandey *et al*., 2001), etc. TRIA-induced improvement in growth of sunflower as observed in the present study might be due to one of the many reasons such as up-regulation of many genes related to photosynthesis (Singh *et al*., 2012), modulation in activities of antioxidants (Perveen *et al*., 2011) by triggering a secondary messenger or a metabolite which is responsible for activity of those enzymes involved in carbohydrate metabolism and many physiological responses (Naeem *et al*., 2009). In our current study, saline stress markedly reduced the growth of sunflower plants which might be due to hormonal imbalance (Babu *et al*., 2012), osmotic stress (Shabala *et al*., 2012), and toxicity of specific ions e.g. $Na^+$ and $Cl^-$ (Shahbaz & Zia, 2011; Shahbaz *et al*., 2011; Babu *et al*., 2012).

Saline stress adversely affected gas exchange attributes in both sunflower cultivars. Salinity-induced reduction in gas exchange attributes has already been observed in many crops such as canola (Shahbaz *et al*., 2013), sunflower (Akram *et al*., 2009, 2012), radish (Noreen *et al*., 2012), wheat (Kanwal *et al*., 2011; Perveen *et al*., 2012a; Kausar & Shahbaz, 2013, Shahbaz & Ashraf, 2013), etc. The decreased photosynthetic rate may be due to closure of leaf stomata which is caused by toxic $Na^+$ and $Cl^-$ ions (Tavakkoli *et al*., 2011) and the reduced leaf expansion may cause build-up of undesired photosynthates in young tissues which act as signals in the process of down-regulating photosynthesis (Munns & Tester, 2008). In the present study, the foliar application of TRIA enhanced net $CO_2$ assimilation rate (*A*), water use efficiency (*A/E*) and transpiration rate (*E*) in both sunflower cultivars under both saline and non-saline conditions. TRIA application is effective in enhancing net $CO_2$ assimilation rate. However, the underlying mechanism by which TRIA accelerates rate of photosynthesis is not clear yet. One of the possible reasons is the role of TRIA in up-regulating Rubisco activity (Houtz *et al*., 1985). For example, Chen *et al*. (2002) observed the up-regulation of *rbc* gene by TRIA application in rice seedlings which was ascribed to enhanced rate of photosynthesis. Increase in photosynthetic rate by exogenous application of TRIA has also been observed in opium poppy (Srivastava & Sharma, 1990), wheat (Perveen *et al*., 2010), and canola (Shahbaz *et al*., 2013).

Chlorophyll fluorescence is also considered as one of the potential indicators of stress tolerance including salt tolerance (Mehta *et al*., 2010). In our experiment, saline stress significantly reduced the co-efficient of non-photochemical quenching ($q_N$) and non-photochemical quenching (*NPQ*) and increased maximum quantum yield of PSII and electron transport ratio (*ETR*). Although TRIA induced improvement in different chlorophyll fluorescence attributes has been reported in different plant species like *Erythrina variegata* (Muthuchelian *et al*., 2003), mangrove seedlings (Moorthy & Kathiresan, 1993), and *Ocimum basilicum* (Borowski & Blamowski 2009). In our study, exogenous application of TRIA as foliar spray either did not affect chlorophyll fluorescence attributes or if affected, the effect being inconsistent in the two sunflower cultivars. Similar findings were also observed by Shahbaz *et al*., (2013) in canola when TRIA was applied as pre-seed treatment under saline conditions. They observe slight increase in $q_P$ and *ETR* under saline conditions, and non-significant effect of TRIA on *Fv/Fm* and $q_N$ in canola.

In conclusion, saline stress reduced growth attributes, gas exchange characteristics and efficiency of photosystem-II. However, exogenous application of TRIA as foliar spray significantly enhanced growth, net $CO_2$ assimilation rate, stomatal conductance and water use efficiency in both sunflower cultivars. TRIA slightly enhanced efficiency of photosystem-II. Of all TRIA levels used, 100 µM was the most effective in regulating all the earlier mentioned attributes. Overall, cultivar SMH-917 showed better performance than cv. SMH-907 in response to TRIA application and salt stress.

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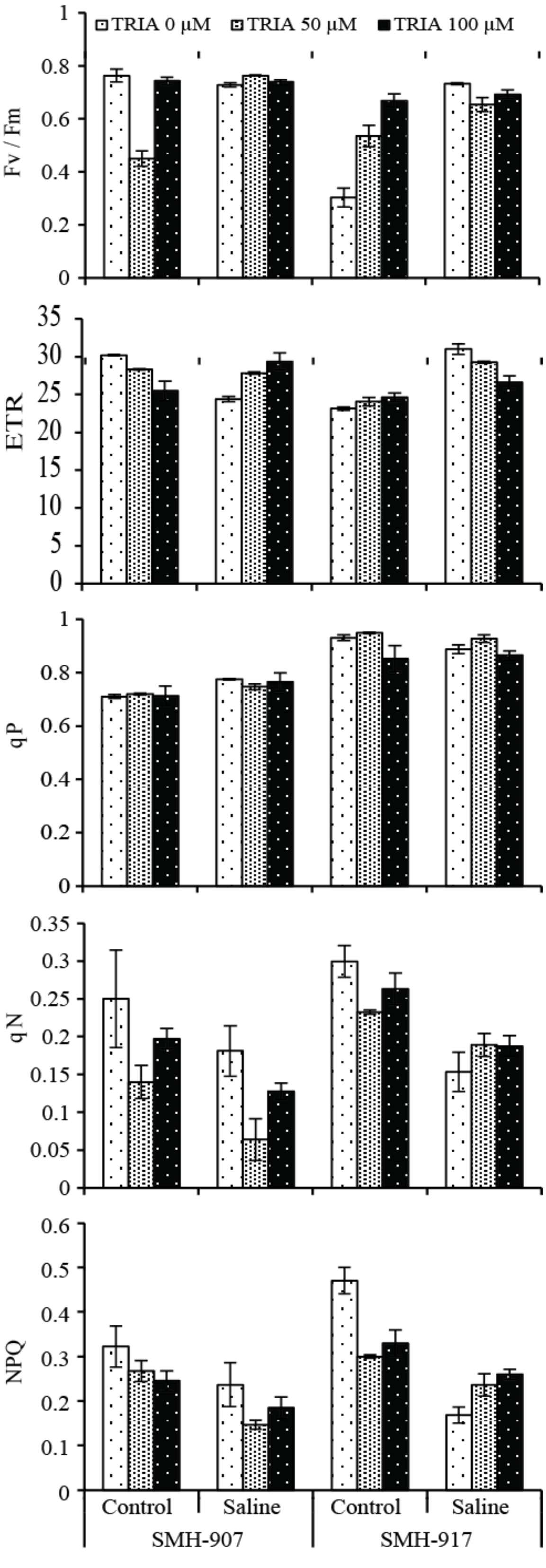

Fig. 2. Leaf chlorophyll fluorescence of sunflower (*Helianthus annuus* L.) when plants were foliary applied with triacontanol under saline or non-saline conditions.

## References

Akram, M.S., M. Ashraf, M. Shahbaz and N.A. Akram. 2009. Growth and photosynthesis of salt-stressed sunflower (*Helianthus annuus* L.) plants as affected by foliar-applied different potassium salts. *J. Plant Nutr. Soil Sci*., 172: 884-893.

Akram, N.A., M. Ashraf and F. Al-Qurainy. 2012. Aminolevulinic acid-induced regulation in some key physiological attributes and activities of antioxidant enzymes in sunflower (*Helianthus annuus* L.) under saline regimes. *Sci. Hortic*., 142: 143-148.

Babu, M.A., D. Singh and K.M. Gothandam. 2012. The effect of salinity on growth, hormones and mineral elements in leaf and fruit of tomato cultivar PKM 1. *J. Anim. Plant Sci*., 22: 159-164.

Borowski, E. and Z.K. Blamowski. 2009. The effect of triacontanol 'TRIA' and Asahi-SL on the development and metabolic activity of sweet basil (*Ocimum basilicum* L.) plants treated with chilling. *Folia Hortic*., 21(1): 39-48.

Chen, X., H. Yuan, R. Chen, L. Zhu, B. Du, Q. Weng and G. He. 2002. Isolation and characterization of triacontanol regulated genes in rice (*Oryza sativa* L.): possible role of triacontanol as plant growth stimulator. *Plant Cell Physiol*., 43: 869-876.

Hassanein, R.A., F.M. Bassony, D.M. Barakat and R.R. Khalil. 2009. Physiological effects of nicotinamide and ascorbic acid on *Zea mays* plant grown under salinity stress. 1- Changes in growth, some relevant metabolic activities and oxidative defense systems. *Res. J. Agric. Biol. Sci*., 5: 72-81.

Houtz, R.L., S.K. Ries and N.E. Tolbert. 1985. Effect of triacontanol on Chlamydomonas. I. Stimulation of growth and photosynthetic $CO_2$ assimilation. *Plant Physiol*., 79: 357-64.

Kanwal, H., M. Ashraf and M. Shahbaz. 2011. Assessment of salt tolerance of some newly developed and candidate wheat (*Triticum aestivum* L.) cultivars using gas exchange and chlorophyll fluorescence attributes. *Pak. J. Bot*., 43: 2693-2699.

Kausar, F. and M. Shahbaz. 2013. Interactive effect of foliar application of nitric oxide (NO) and salinity on wheat (*Triticum aestivum* L.). *Pak. J. Bot*., 45(SI): 67-73.

Khan, M.M.A., G. Bhardwaj, M. Naeem, Moinuddin, F. Mohammad, M. Singh, S. Nasir and M. Idrees. 2009. Response of tomato (*Solanum lycopersicum* L.) to application of potassium and triacontanol. *Acta Hortic*., 823: 199-208.

Kilic, N.K., E. Duygu and G. Donmez. 2010. Triacontanol hormone stimulates population, growth and Brilliant Blue R dye removal by common duckweed from culture media. *J. Hazard. Materi*., 182: 525-530.

Krishnan, R.R. and B.D.R. Kumari. 2008. Effect of n-triacontanol on the growth of salt stressed soybean plants. *J. BioSci*., 19(2): 53-62.

Mehta, P., A. Jajoo, S. Mathur and S. Bharti. 2010. Chlorophyll a fluorescence study revealing effects of high salt stress on PSII in wheat leaves. *Plant Physiol. Biochem*., 48: 16-20.

Moorthy, P. and K. Kathiresan. 1993. Physiological responses of a mangroove seedling to triacontanol. *Biol Plant*., 35: 577-81.

Morre, D.J., G. Sellden, X.Z. Zhu and A. Brightman. 1991. Triacontanol stimulates NADH oxidase of soybean hypocotyl plasma membrane. *Plant Sci*., 79: 31-36.

Munns, R. and M. Tester. 2008. Mechanisms of salinity tolerance. *Annu. Rev. Plant Biol*., 59: 651-681.

Muthuchelian, K., C. Murugan, R. Harigovindan, N. Nedunchezhian and G. Kulandaivelu. 1996. Ameliorating effect of triacontanol on salt stressed *Erythrina variegata* seedlings. Changes in growth, biomass, pigments and solute accumulation. *Biol. Plant*., 38: 133-136.

Muthuchelian, K., M. Velayutham and N. Nedunchezhian. 2003. Ameliorating effect of triacontanol on acidic mist-treated *Erythrina variegata* seedlings. Changes in growth and photosynthetic activities. *Plant Sci*., 165: 1253-1257.

Naeem, M., M.M.A. Khan, Moinuddin and M.H. Siddiqui. 2009. Triacontanol stimulates nitrogen-fixation, enzyme activities, photosynthesis, crop productivity and quality of hyacinth bean (*Lablab purpureus* L.). *Sci. Hortic*., 121: 389-396.

Noreen, Z., M. Ashraf and N.A. Akram. 2012. Salt-induced regulation of photosynthetic capacity and ion accumulation in some genetically diverse cultivars of radish (*Raphanus sativus* L.). *J. Appl. Bot. Food Qual*., 85: 91-96

Pandey, S., D. Behura, R. Villano and D. Naik. 2001. Drought risk, farmer's coping mechanisms and poverty: a study of the rainfed rice system in eastern India. In: Rice research for food security and poverty alleviation. (Eds.): S. Peng, B. Hardy IRRI, Los Banos, Philippines, pp. 267-275.

Perveen, S., M. Shahbaz and M. Ashraf. 2010. Regulation in gas exchange and quantum yield of photosystem II (PSII) in salt-stressed and non-stressed wheat plants raised from seed treated with triacontanol. *Pak. J. Bot*., 42(5): 3073-3081.

Perveen, S., M. Shahbaz and M. Ashraf. 2011. Modulation in activities of antioxidant enzymes in salt stressed and non-stressed wheat (*Triticum aestivum* L.) plants raised from seed treated with triacontanol. *Pak. J. Bot*., 43(5): 2463-2468.

Perveen, S., M. Shahbaz and M. Ashraf. 2012a. Changes in mineral composition, uptake and use efficiency of salt stressed wheat (*Triticum aestivum* L.) plants raised from seed treated with triacontanol. *Pak. J. Bot*., 44: 27-35.

Perveen, S., M. Shahbaz and M. Ashraf. 2012b. Is pre-sowing seed treatment with triacontanol effective in improving some physiological and biochemical attributes of wheat (*Triticum aestivum* L.) under salt stress? *J. Appl. Bot. Food Qual*., 85: 41-48.

Reddy, B.O., P. Giridhar and G.A. Ravishankar. 2002. The effect of triacontanol on micropropagation of Capsicum frutescens and *Decalepis hamiltonii* W & A. *Plant Cell Tissue Organ Cult*., 71: 253-8.

Ries, S.K. 1985. Regulation of plant growth with triacontanol. CRC. *Crit. Rev. Plant Sci*., 2: 239-285.

Shabala, L., A. Mackaya, Y. Tianb, S.E. Jacobsenc, D. Zhoud and S. Shabala. 2012. Oxidative stress protection and stomatal patterning as components of salinity tolerance mechanism in quinoa (*Chenopodium quinoa*). *Physiol. Plant.,* 146(1): 26-38.

Shahbaz, M. and B. Zia. 2011. Does exogenous application of glycinebetaine through rooting medium alter rice (*Oryza sativa* L.) mineral nutrient status under saline conditions? *J. Appl. Bot. Food Qual*., 84: 54-60.

Shahbaz, M. and M. Ashraf. 2013. Improving salinity tolerance in cereals. *Crit. Rev. Plant Sci*., 32: 237-249.

Shahbaz, M., M. Ashraf, N.A. Akram, A. Hanif, S. Hameed, S. Joham and R. Rehman. 2011. Salt-induced modulation in growth, photosynthetic capacity, proline content and ion accumulation in sunflower (*Helianthus annuus* L.). *Acta Physiol. Plant*. 33: 1113-1122.

Shahbaz, M., N. Noreen and S. Perveen. 2013. Triacontanol modulates photosynthesis and osmoprotectants in canola (*Brassica napus* L.) under saline stress. *J. Plant Interact*. DOI: 10.1080/17429145-2013-764469.

Singh M., M.M.A. Khan, Moinuddin and M. Naeem. 2012. Augmentation of nutraceuticals, productivity and quality of ginger (*Zingiber officinale* Rosc.) through triacontanolapplication. *Plant Biosystems*, 146(1): 106-113.

Snedecor, G.W. and G.W. Cochran. 1980. Statistical Methods. 7th edition. The Lowa State University Press. Ames, Lowa.

Srivastava, N.K. and S. Sharma. 1990. Effect of triacontanol on photosynthesis, alkaloid content and growth in opium poppy (*Papaver somniferum* L). *Plant Growth Regul*., 9: 65-71.

Strasser, R.J., A. Srivastava and Govindjee. 1995. Polyphasic chlorophyll '*a*' fluorescence transients in plants and cyanobacteria. *Photochem. Photobiol*., 61: 32-42.

Tavakkoli, E., F. Fatehi, S. Coventry, P. Rengasamy and G.K. Mcdonald. 2011. Additive effects of $Na^+$ and $Cl^-$ ions on barley growth under salinity stress. *J. Exp. Bot*., 62(6): 2189-2203.

Verma A., C.P. Malik, V.K. Gupta and Y.K. Sinsinwar. 2009. Response of groundnut varieties to plant growth regulator (BAP) to induce direct organogenesis. *World J. Agric. Sci*., 5(3): 313-317.

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