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MODULATION IN GROWTH, PHOTOSYNTHETIC PIGMENTS, GAS EXCHANGE ATTRIBUTES AND INORGANIC IONS IN SUNFLOWER (*HELIANTHUS ANNUUS* L.) BY STRIGOLACTONES (GR24) ACHENE PRIMING UNDER SALINE CONDITIONS

YASMIN SARWAR AND MUHAMMAD SHAHBAZ*

[1] *Department of Botany, University of Agriculture, Faisalabad 38040, Pakistan*
**Corresponding author's email: shahbazmuaf@yahoo.com*

Abstract

Plants respond to various abiotic stresses in a complex way, depending upon their severity through cellular, morphological and physiological modifications. Phytohormones are signaling molecules which mediate plant growth and development. They modulate plant physiological responses to acclimatize stress like salinity. Phytohormones interact with each other to alleviate abiotic stress. Striglactones are relatively newly discovered phytohormones and are proposed to have their role in stress responses like those of salinity. A synthetic analogue of strigolactones GR24 was used to explore its role to ameliorate adverse effects of salt stress on sunflower plants. Achenes of two sunflower hybrids (FH-593 and FH-596) were primed with four concentrations of GR24 (water (0), 0.001, 0.01 and 0.1 mg L^{-1}) and grown under two salt regimes i.e. non-saline and 120 mM NaCl in pots. Salt stress significantly decreased growth attributes while GR24 showed a positive effect to alleviate salt stress. Pre-sowing achene treatment with GR24 significantly enhanced plant biomass and shoot length. Salinity markedly decreased photosynthetic pigments and net CO_2 assimilation, stomatal conductance and transpiration. Chlorophyll contents and gas exchange attributes of both sunflower hybrids showed a non-significant response to GR24 treatment. However, carotenoids contents increased with GR24 pre-sowing achene treatment. Salinity significantly raised the contents of Na^+ contents but decreased that of Ca^{2+} and K^+ ions in both shoot and root. The GR24 application enhanced the Na^+, K^+ and Ca^{2+} in shoots and roots.

Key words: Salinity; Strigolactones; Sunflower; Growth; Chlorophyll; Gas exchange.

Introduction

Constantly varying environment either naturally or anthropogenically is affecting living organisms including plants. Plants being non-motile in nature have developed various mechanisms and biochemical signaling pathways to cope with the changing environment. One of these components is signaling through phytohormones by sensing and responding to fluctuating environmental conditions (Pandey *et al*., 2016). Phytohormones modulate plant developmental processes according to the nature and intensity of abiotic stress (Zwack & Rashotte, 2015). The recently discovered phytohormones are strigolactones which are putative carotenoid based lactones extracted from plant root exudates (Yoneyama *et al*., 2008). So far, with the help of advanced techniques, 18 SLs have been characterized based on their structural similarities (Xie *et al*., 2010). Strigolactones are considered as destructive plant metabolites because of their role as a stimulator of parasitic weeds germination (Cook *et al*., 1972). One of the advantageous functions of SLs is mycorrhizal symbiotic association between fungi and plants. Hyphal branching within arbuscular mycorrhizae is regulated by SLs and helpful during biotic or abiotic stresses tolerance (Liu *et al*., 2007). SLs as a phytohormone were characterized after discovery of branching mutants of rice, *Arabidopsis*, *Petunia* and pea (Beveridge & Kyozuka, 2010). SLs promote seed germination in many crop plants and also are involved in nodulation by promoting interaction between legume-rhizobium (De Cuyper *et al*., 2015).

Strigolactones regulate the architecture of plant shoot and root by interacting with other hormones (De Cuyper *et al*., 2015). Strigolactones control many physiological processes of plant life like suppression of shoot branching, nodulation, leaf shape, root and shoot architecture, internode elongation, leaf senescence, secondary thickening of stem, shoot gravitropism (Waters *et al*., 2012), regulate photomorphogenesis, programmed cell death, and control plant responses to abiotic stresses (Ueda & Kusaba, 2015). A chemical analogue of strigolactone is GR24 (Tsuchiya & McCourt, 2009). GR24 promotes the elongation of primary root (Ruyter-Spira *et al*., 2011). SLs mutants namely *max1*, *max3* and *max4* showed smaller primary length as compared to wild plants, but they can restore their phenotype on GR24 application (Ruyter-Spira *et al*., 2011). SLs enhance the elongation of root hairs but suppress lateral root development by controlling auxin efflux (Kapulnik *et al*., 2011). GR24 application enhances tolerance in *Arabidopsis* during drought as well as salt stress (Ha *et al*., 2014).

One of the environmental stresses is salinity that reduces the crop productivity by limiting plant growth especially in arid regions (Rozema & Flowers, 2008). Salinity affects more than 50% of irrigated land and 20% of cultivated land of world (Sairam & Tyagi, 2004). Salinity declines the average crops yield by 50% (Bray *et al*., 2000). Several morpho-physiological changes have been observed because of salt induced ionic and osmotic stresses (Jampeetong & Brix, 2009).

Sunflower (*Helianthus annus* L.) ranks 3rd among world oilseed crops (Nasim *et al*., 2012) because of its promising oil and forage properties (Armitage & Laushman, 2003). It has a unique value in Pakistan agriculture because of its wide adaptability to various soil and climatic condition, short duration and perfect position in cropping system (Nasim *et al*., 2012). Sunflower has a 4.8 dS m^{-1} threshold level of salinity tolerance (Sadak *et al*., 2010) and one unit rise in salinity than the threshold level, decline 5% yield of sunflower (Flagella *et al*.,

2004). Sunflower showed a significant decline in fresh and dry weights, stomatal conductance, transpiration rate, substomatal CO_2 and net CO_2 assimilation rate under saline stress (Noreen & Ashraf, 2008). Salinity has threatened the productivity of sunflower, so it is dire need to find means to improve plant survival under salinity.

Seed priming is a useful technique that enhances seed emergence and seedling growth (Cantliffe, 2003). Most critical phase of plant life is germination that is adversely affected by salinity (Ghavami & Ramin, 2007). Chiu *et al*., (1995) reported that the hostile influences of abiotic stresses could be minimized by seed priming. Seed priming for oilseed crops, cereals, and vegetables has successfully documented for earlier and more vigorous seedling emergence (Rehman *et al*., 2014). It accelerates number of metabolic processes of early germination phases that improve seed performance, better, faster and harmonized growth as well as more stress tolerant than unprimed seedlings (Farooq *et al*., 2006). Seed priming at subcellular phase protect the cellular proteins (Varier *et al*., 2010), repair the damage DNA of seed embryo (Thornton *et al*., 1993), refine the function of protein synthesis apparatus (Soeda *et al*., 2005) and boost the mitochondrial functioning (Benamar *et al*., 2003). Priming with hormones like salicylic acid, cytokinins, GA3, ascorbic acid, strigolactones etc. is called hormonal priming. Seed priming with phytohormones enhances crop vigour and survival under saline environment (Meriem *et al.,* 2014). Its positive role in seedling emergence, metabolites accumulation, flowering, and overall growth as well as development of plant has made it more successful (Arif *et al.,* 2014). The core objectives of the present study were to find out whether or not GR24 primed achenes could alleviate the salinity induced adverse effects and assess the impact of various concentrations of GR24 on growth, biochemical and physiological characteristics of sunflower hybrids under saline environment.

Materials and Methods

An experiment was conducted in net-house of University of Agriculture, Faisalabad. Achenes of two sunflower hybrids (FH-593 and FH-596) were taken from Oil Seed Department of Ayub Agricultural Research Institute, Faisalabad. The achenes were surface sterilized with 1% solution of sodium hypochlorite, and thereafter the seeds were washed with distilled water. An amount of 1 mg of GR24 was dissolved in half ml of acetone. Then, the final volume of GR24 stock solution was maintained up to 10 with distilled water. The stock solution (100 mg L^{-1}) of GR24 was used to prepare further concentrations of GR24 solution. Achenes of both hybrids were soaked in four concentrations of GR24 solution [0 (water soaking), 0.001, 0.01 and 0.1 mg L^{-1}] for 16 h at room temperature. After 16 h, achenes were kept on blotting paper to eliminate extra moisture. Achenes of sunflower hybrids FH-593 and FH-596, pre-treated with GR24 were propagated in pots holding carefully washed sand. Hoagland's nutrient solution was applied @ 2 liters per pot weekly. Thinning was performed to five plants/pot after thirty days of seeding. There were two salt levels (0 mM NaCl) and 120 mM NaCl]. After an acclimatization period of 4-week, salinity treatment was applied. A plant set treated with distilled water worked as mock. Salinity treatment was applied to 36 days old sunflower plants. To attain the anticipated salinity level (120 mM NaCl) aliquot of 50 mM NaCl in Hoagland's nutrient medium solution/pot was applied every day. After 2 week of treatment, data for morphological, biochemical and physiological attributes were recorded.

Plant biomass: Shoot and root length, fresh and dry weights were documented after 14 days of treatment. Two plants were taken from each of the replicated of the treatment and fresh weight and length were recorded immediately after uprooting. Then plants were oven dried at 70°C till constant weight was achieved.

Gas exchange traits: Gas exchange parameters were analysed with portable infrared gas analyser, LCA-4 ACD (Hoddesdon, UK) on leaves. The rate of net CO_2 assimilation (*A*) and transpiration (*E*), water use efficiency (*A/E*), sub-stomatal conductance (C_i), and stomatal conductance (g_s), and (C_i/C_a) were recorded from 10:00 am to 12:30 pm on top second leaf of sunflower plant. In addition, the attributes adjusted by analyser were: leaf chamber gas flow rate (U) 251 µmol s^{-1}, ambient pressure (P) 98.8 kPa; leaf surface area 6.25 cm^2; leaf chamber water vapor pressure 6.0 to 8.9 mbar; ambient CO_2 concentration 352 µmol mol^{-1}; molar air flow/unit leaf area (Us) 22.06 mol m^{-2} s^{-1}; leaf chamber temperature 28.4 to 32.4°C; *PAR* (Q leaf) 942 µmol m^{-2} s^{-1} and relative humidity of chamber 41.2%.

Photosynthetic pigments: Arnon (1949) protocol was used for quantifying photosynthetic pigments (*a*, *b* and total) and carotenoids. Leaf samples (0.5 g) were extracted in 80% acetone. Supernatant was attained after centrifugation of the extracted material at 12,000 x *g* for 15 minutes. The UV-visible spectrophotometer (IRMECO U-2020) was used to record the absorbance of the supernatant at wavelengths of 645, 663 and 480 nm against a blank (80% acetone).

Mineral nutrients (Na^+ and K^+): Allen *et al*., (1985) method for mineral ions (Na^+ and K^+) estimation in shoot and root was followed. Dried powdered material of shoot and root (100 mg) was digested in H_2SO_4 (2 ml) in a digestion flask. The digested mixture was diluted up to 50 mL with distilled water, filtered and then filtrate was used for estimation of Na^+ and K^+ ions with a flame photometer (Sherwood, 410).

Statistical investigation: The scheme of experiment was completely randomized design (CRD) with four replicates. To analyze the data a three-way analysis of variance (ANOVA) was used for all attributes by computing the package of COSTAT computer (Cohort software Berkeley, California).

Results

Salt stress (120 mM) significantly ($p \leq 0.001$) declined the plant biomass of both sunflower hybrids (FH-593 and FH-596). Achene priming with GR24 significantly enhanced shoot and root biomass under normal and salt stress. GR24 level, 0.01 mg L^{-1} was more effective than other levels. Sunflower hybrid FH-593 showed higher biomass accumulation. A highly significant interaction ($p \leq 0.001$) between GR24 and hybrid for shoot fresh and root dry weight showed that sunflower hybrid FH-596 showed more potent response to GR24 (Table 1; Fig. 1). Shoot and root growth significantly ($p \leq 0.001$) declined under salt stress in both hybrids. Achene treated with GR24 prominently ($p \leq 0.001$) increased the shoot and root length. GR24 level, 0.01 mg L^{-1} performed better than other levels. FH-593 showed more shoot growth under salt-stressed and controlled conditions. A highly significant interaction ($p \leq 0.001$) between GR24 and hybrid for shoot length showed that GR24 response was more significant for sunflower hybrid FH-593. GR24 significantly enhanced the shoot length under saline condition (Table 1; Fig. 1).

Table 1. Data of mean squares from analysis of variance for growth attributes, gas exchange aspects, photosynthetic pigments and mineral nutrients (Na^+ and K^+ ions) of salt stressed and non-stressed sunflower (*Helianthus annuus* L.) plants raised from achene primed with GR24 for 16 h.

Source of variance	df	Shoot fresh weight	Root fresh weight	Shoot dry weight	Root dry weight	Shoot length	Root length
Salinity (S)	1	10900.665***	39.974***	79.745***	0.25***	15557.885***	217.009***
GR24	3	2292.869***	10.684***	26.729***	0.765***	1064.591***	24.387***
Hybrids (HB)	1	3263.979***	0.138ns	8.41***	0.397***	721.929***	2.121ns
S x GR24	3	110.567*	3.539**	2.118*	0.002ns	357.534***	4.233ns
S x HB	1	1.207ns	0.270ns	0.018ns	0.102***	73.638ns	2.954ns
GR24 x HB	3	772.939***	1.098ns	1.825*	0.155***	932.686***	1.046ns
S x GR24 x HB	3	611.623***	1.0489ns	2.183*	0.005ns	161.805**	2.244ns
Error	48	33.484	0.780	0.641	0.007	33.038	3.457
Source of variance	**df**	***A***	***E***	g_s	C_i	C_i/C_a	***A/E***
Salinity (S)	1	663.642***	2.500***	14101.563***	941.723ns	0.008ns	0.126ns
GR24	3	16.171ns	0.444ns	255.729ns	318.176ns	0.003ns	74.771***
Hybrids (HB)	1	148.322***	0.095ns	826.562ns	941.723ns	0.007ns	0.126ns
S x GR24	3	8.061ns	0.0733ns	551.562ns	845.175ns	0.007ns	7.738*
S x HB	1	85.586**	1.059*	264.062ns	2839.599**	0.023**	1.606ns
GR24 x HB	3	25.994ns	0.109ns	868.229ns	1222.376ns	0.010ns	6.603ns
S x GR24 x HB	3	14.740ns	0.134ns	822.396ns	342.541ns	0.003ns	0.881ns
Error	48	9.886	0.178	628.646	657.544	0.005	2.374
Source of variance	**df**	**Chl. *a***	**Chl. *b***	**Chl *a/b***	**Total Chl.**	**Carotenoids**	**Shoot Na^+**
Salinity (S)	1	0.323*	3.874***	12.033***	6.652***	0.184***	1560.25***
GR24	3	0.081ns	0.005ns	0.703ns	0.082ns	0.081***	6.792***
Hybrids (HB)	1	0.002ns	2.003***	6.144***	1.079*	0.268***	0.563ns
S x GR24	3	0.029ns	0.06ns	1.268**	0.241ns	0.019ns	4.542**
S x HB	1	0.804***	0.210ns	1.179*	1.538**	0.006ns	0.562ns
GR24 x HB	3	0.315**	0.133ns	0.885*	0.716**	0.011ns	2.354ns
S x GR24 x HB	3	0.187*	0.049ns	0.494ns	0.180ns	0.072***	1.854ns
Error	48	0.064	0.0638	0.253	0.155	0.009	0.875
Source of variance	**df**	**Root Na^+**	**Shoot K^+**	**Root K^+**	**Shoot Ca^{2+}**	**Root Ca^{2+}**	
Salinity (S)	1	2835.563***	473.063***	83.266***	78.766***	147.016***	
GR24	3	5.958*	29.688***	0.974ns	1.807*	3.682**	
Hybrids (HB)	1	189.063***	68.0623***	0.766ns	5.641**	28.891***	
S x GR24	3	103.854***	4.938ns	4.974***	2.557**	5.932***	
S x HB	1	6.25ns	10.563*	6.891***	0.766ns	43.891***	
GR24 x HB	3	35.604***	74.104***	2.307**	5.932***	1.641ns	
S x GR24 x HB	3	21.792***	5.854ns	1.849*	3.391**	3.891**	
Error	48	1.656	2.260	0.516	0.547	0.661	

*, **, *** Significant at 0.05, 0.01 and 0.001 levels respectively; ns = non-significant; Chl. *a* = Chlorophyll a; Chl. *b* = Chlorophyll b; Chl. Total Chl = Total Chlorophyll; *a*/*b* =Chlorophyll *a*/*b* ratio; WUE (A/E) = Water use efficiency; *A* = net CO_2 assimilation rate; *E* = Transpiration rate; g_s = Stomatal conductance; C_i = Substomatal CO_2 concentration; C_i/C_a = Relative internal CO_2 concentration

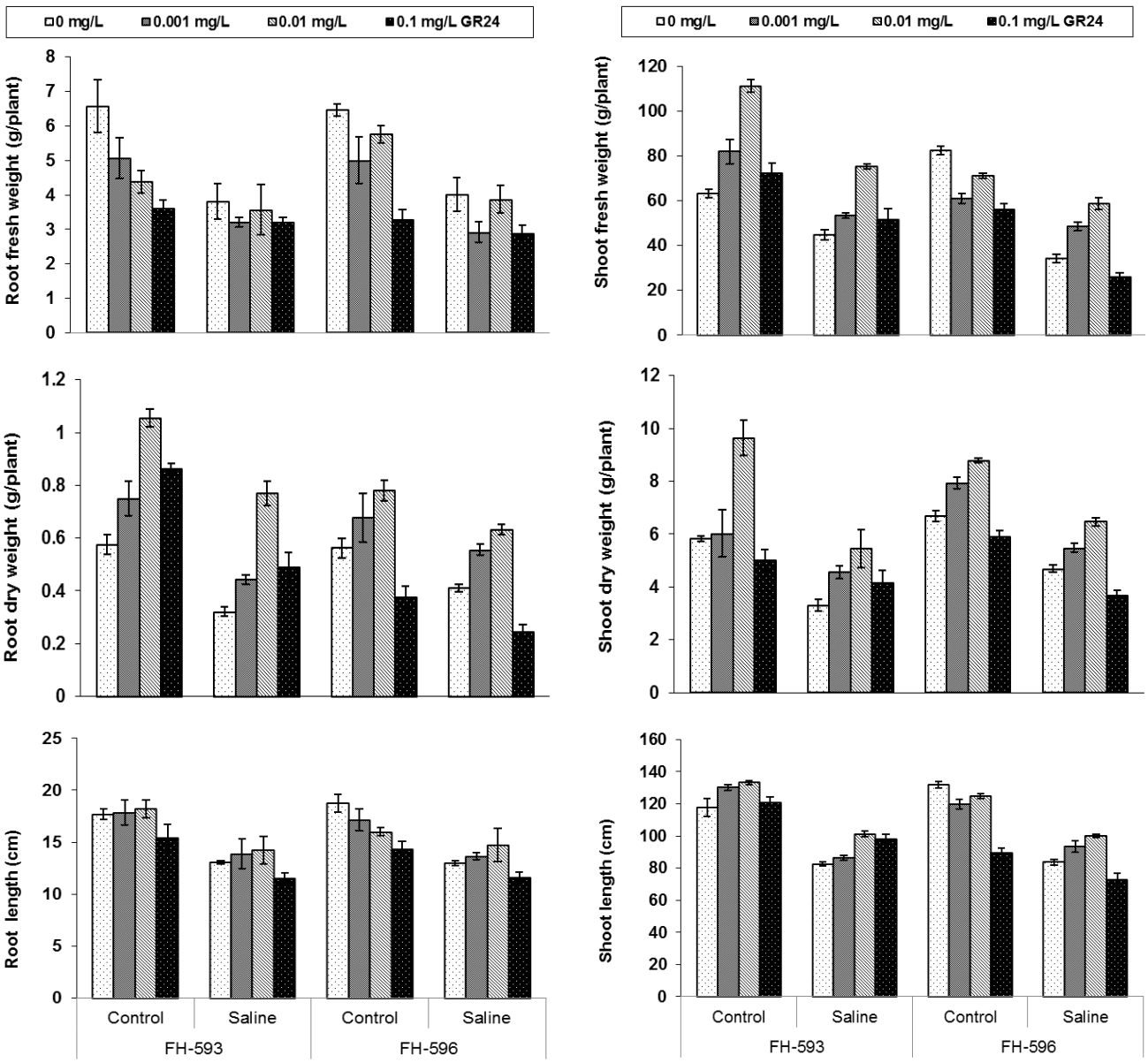

Fig. 1. Growth attributes of salt stressed and non-stressed sunflower (*Helianthus annuus* L.) plants raised from achene treated with GR24 for 16 h.

Net CO_2 assimilation (*A*) and transpiration rate (*E*), stomatal conductance (g_s) were significantly reduced ($p \leq 0.001$) but sub-stomatal CO_2 concentration (C_i), C_i/C_a ratio and water use efficiency of sunflower hybrids did not alter under both saline regimes. The salinity × hybrid interaction was significant ($p \leq 0.01$) for C_i and C_i/C_a ratio which meant hybrid FH-593 performed better under salinity (Table 1; Fig. 2). GR24 application as pre-achene treatment did not modulate gas exchange attributes except water use efficiency. Application of GR24 considerably ($p \leq 0.001$) decreased water use efficiency under both salt levels. Both sunflower hybrids showed uniform response toward GR24 pre-sowing achene treatment (Table 1; Fig. 2). Achene priming with GR24 did not affect the gas exchange characteristics. Salt-induced reduction was noted considerably in chlorophyll *a* and *b* contents of FH 596 as compared to FH-593. Both sunflower hybrids respond uniformly under salinity (Table 1; Fig. 3). Salt stress significantly ($p \leq 0.001$) decreased the total chlorophyll but increased chlorophyll *a/b* ratio in both sunflower hybrids. GR24 treatment did not modulate chlorophyll pigments (*a* & *b*) of both hybrids under two salt levels. Although, significant ($p \leq 0.01$) interaction among GR24 and hybrid for chlorophyll *a* indicated that hybrid FH-593 responded well to GR24 (Table 1; Fig. 3). FH-596 response was remarkable ($p \leq 0.001$) regarding chlorophyll *a/b* ratio. Moreover, remarkable interaction ($p \leq 0.01$) among GR24 and salinity showed that chlorophyll *a/b* ratio of both hybrids was increased by GR24 treatment under salt stress (Table 1; Fig. 3). FH-593 response was substantial ($p \leq 0.05$) in rising total chlorophyll contents. Imposition of salinity at rooting medium lessened the carotenoids contents extensively ($p \leq 0.001$). Achene priming with GR24 raised carotenoids contents expressively ($p \leq 0.001$) under both salt regimes. GR24 @ 0.01 mg L^{-1} was most operational than others. The hybrid FH-593 gave more outcome than FH-596 regarding carotenoids (Table 1; Fig. 3). Salt application at rooting medium amplified the sodium ions of sunflower root and shoot. However, GR24 priming treatment reduced sodium contents of root and shoot in FH-596 and FH-593 hybrids

under both salt stress levels. Salt stress meaningfully declined the K^+ ions of shoot and root of both hybrids. GR24 Pre-sowing treatment improved the K^+ contents of shoot (Table 1; Fig. 3). Ca^{2+} accumulation in shoot and root was declined significantly ($p \leq 0.001$) in both sunflower hybrids under salt stress (Table 1; Fig. 4). GR24 treated achenes showed high ($p \leq 0.05$) accumulation of calcium contents in shoot and root of FH-596 under normal and stressed conditions. The interaction between salinity and GR24 was significant which showed that GR24 increased shoot and root calcium under salt stress (Table 1; Fig. 4).

Discussion

Environmental changes are perceived by plants and are coordinated with plant developmental programs to respond (Stepanova *et al*., 2005). A significant adverse impact of salinity is growth inhibition (Vu *et al*., 2015). However, seed primed with GR24 lightened the deterring impacts of salt stress by increasing shoot length as reported by Boyer *et al.,* (2014). Our results suggested an increase in root length which was also demonstrated by Ruyter-Spira *et al*., (2011) and Koren *et al*., (2013). In our experiment, strigolactones analogue GR24 pre-sowing seed treatment significantly enhanced shoot and root biomass that was analogous to the outcomes of Daws *et al*., (2008), Kotze (2010) and Ma *et al*., (2017). Salinity first affects the plant roots then restricts the shoot growth by accumulating ions (Hu *et al*., 2016). Present results clear the fact that salinity significantly declined the shoot and root biomass. GR24 application as pre-achene treatment significantly enhanced the root and shoot biomass under salinity which showed its positive response under saline stress (Boyer *et al*., 2014). Strigolactones regulate the development of above and below ground structure of plant (Ruyter-Spira *et al*., 2011) and also enhance stem elongation (Boyer *et al*., 2014). Nutrient acquisition is directly dependent on root hairs number and length (Sanchez-Calderon *et al*., 2005). Strigolactones amplified the elongation of root hairs (Kapulnik *et al*., 2011) and length of primary root by increasing meristematic cells in *max2* mutant plants (Koren *et al*., 2013). This can be an adaptive response of plant to unfavorable growth conditions. Kotze (2010) reported GR24 treatment enhanced the seedling growth. Steenkamp (2011) observed that GR24 application increased the mass and length of *Nicotiana benthamiana*, of seedlings under controlled conditions. But under saline conditions, leaf number, lateral root number and fresh mass were increased significantly.

Photosynthesis is the basic source of energy for all organisms and easily targeted by abiotic stress like salinity (Munns *et al*., 2006). Salinity affects chloroplast which is the primary location for many photosynthetic reactions (Nusrat *et al*., 2014). Salinity induced stomatal closure cause reduction in photosynthesis (Steduto *et al*., 2000). Our results, decline in photosynthetic activity under salinity are reinforced by earlier studies of Ashraf *et al*., 2010 and Nusrat *et al*., 2014. In contrast to our results; the previous findings of Mayzlish-Gati *et al*., (2010), Mashiguchi *et al*., (2009) and Koltai *et al*., (2011) support the positive role of strigolactones in photosynthesis. Ma *et al*., (2017) also reported that seed priming with GR24 enhanced chlorophyll contents and all attributes of photosynthesis in *Brassica napus*. One of the possible explanations might be higher sucrose synthase 2 (SUS2) and reduced adenosine kinase activity. SUS2 enzyme is involved in sucrose degradation. GR24 treatment on strigolactone mutants in rice seedlings increased the expression of SUS2 enzymes (Chen *et al*., 2014). The other reason might be the down regulation of adenosine kinase (ADK) level by GR24 application that involved in formation of adenosine monophosphate (AMP) mandatory for photosynthesis. Reduced expression of genes related to Rubisco and chlorophyll *a/b* binding protein in SL mutant *sl-ort1* suggests a starring role of strigolactones in photosynthesis (Mayzlish-Gati *et al*., 2010). Waldie *et al*., (2014) reported that SLs induced expression of genes are involved in photosynthetic related protein and light harvesting complex. Mashiguchi *et al*., (2009) advocated positive regulatory role of SLs in light-associated processes by the exposure of GR24 within 90 minutes in *Arabidopsis* seedlings. Koltai *et al*., (2011) demonstrated positive association between light responses and SLs levels in roots of tomato. Previous findings support the role of SLs in improving photosynthetic efficiency.

In our investigations, salinity decreased photosynthetic pigments significantly which were similar to previous results. During salinity, structural and functional damage of photosynthetic pigments (Srinieng *et al*., 2015), enhance activity of chlorophyllase enzyme and ion cytotoxicity (Ashraf *et al*., 2010), are major elements that cause decline in green pigments. According to Siddiqi *et al*., (2009), reduction in net photosynthetic rate is due to reduced photosynthetic pigments. This result has been extensively demonstrated in numerous crops e.g. maize (Perveen *et al.*, 2017), pepper (Abbas *et al*., 2013), wheat (Kausar & Shahbaz, 2017), rice (Jamil *et al*., 2012), sunflower (Akram & Ashraf, 2011) and safflower (Siddiqi *et al*., 2009). Achene treated with GR24 did not affect green pigments but pre-sowing application enhanced the carotenoid contents of both sunflower hybrids. Our findings are in contrast to the outcomes of former studies of Mayzlish-Gati *et al*., (2010) and Mashiguchi *et al*., (2009). According to studies carried out by Mazlish-Gati *et al*., (2010), leaf chlorophyll production was linked to strigolactones. The mutant *sl-ort1* showed reduced light related genes expression and chlorophyll (Mayzlish-Gati *et al*., 2010). SLs control *HY5* genes by regulating ubiquitin ligase COP1 localization within nucleus stimulated the light adapted response in *Arabidopsis* (Tsuchiya *et al*., 2010). Light of certain intensity above threshold level caused accumulation of strigolactones in specific time (Mayzlish-Gati *et al*., 2010). Involment of SLs in light related pathways (Mayzlish-Gati *et al*., 2010) or light amended phenomena (Tsuchiya *et al*., 2010) raised many questions how light modified SLs levels or SLs modified light responses. Increased sodium contents of root and shoot but decreased potassium and calcium contents under salinity which are evidenced by Perveen *et al*., (2017) and Shahbaz *et al*., (2011) reports. Achene-priming with GR24 modulated Na^+ contents of shoot and root of two hybrids under controlled and saline conditions but K^+ and Ca^{2+} contents of shoot were increased by GR24 application which is an evidence that GR24 ameliorate the adverse impacts of salinity. According to Aroca *et al*., (2013), quantity of strigolactones at 80 mM salt stress was increased up to five folds which suggested a relationship between strigolactones and salt stress via process of nutrient remobilization.

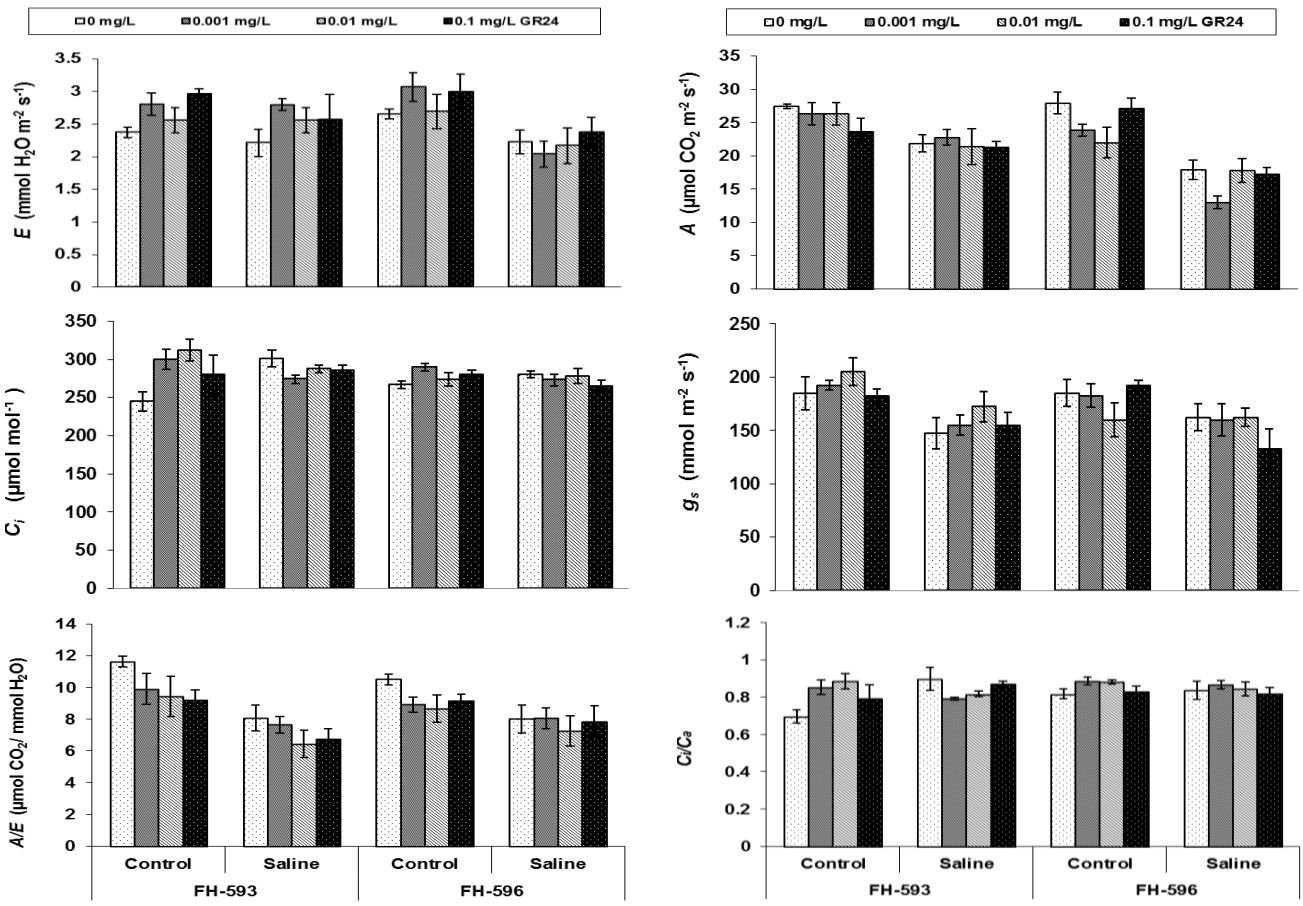

Fig. 2. Gas exchange attributes of salt stressed and non-stressed sunflower (*Helianthus annuus* L.) plants raised from achene treated with GR24 for 16 h.

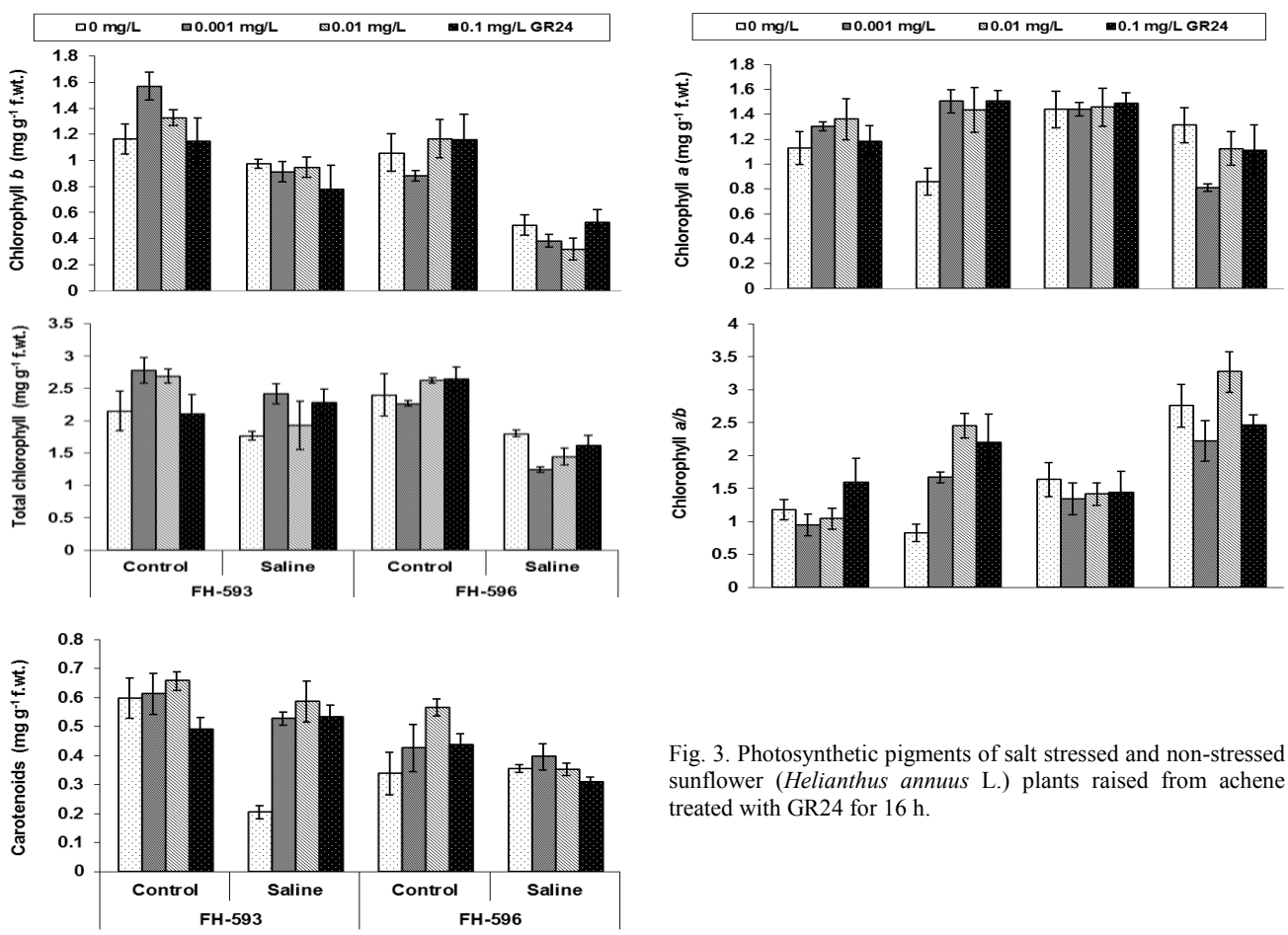

Fig. 3. Photosynthetic pigments of salt stressed and non-stressed sunflower (*Helianthus annuus* L.) plants raised from achene treated with GR24 for 16 h.

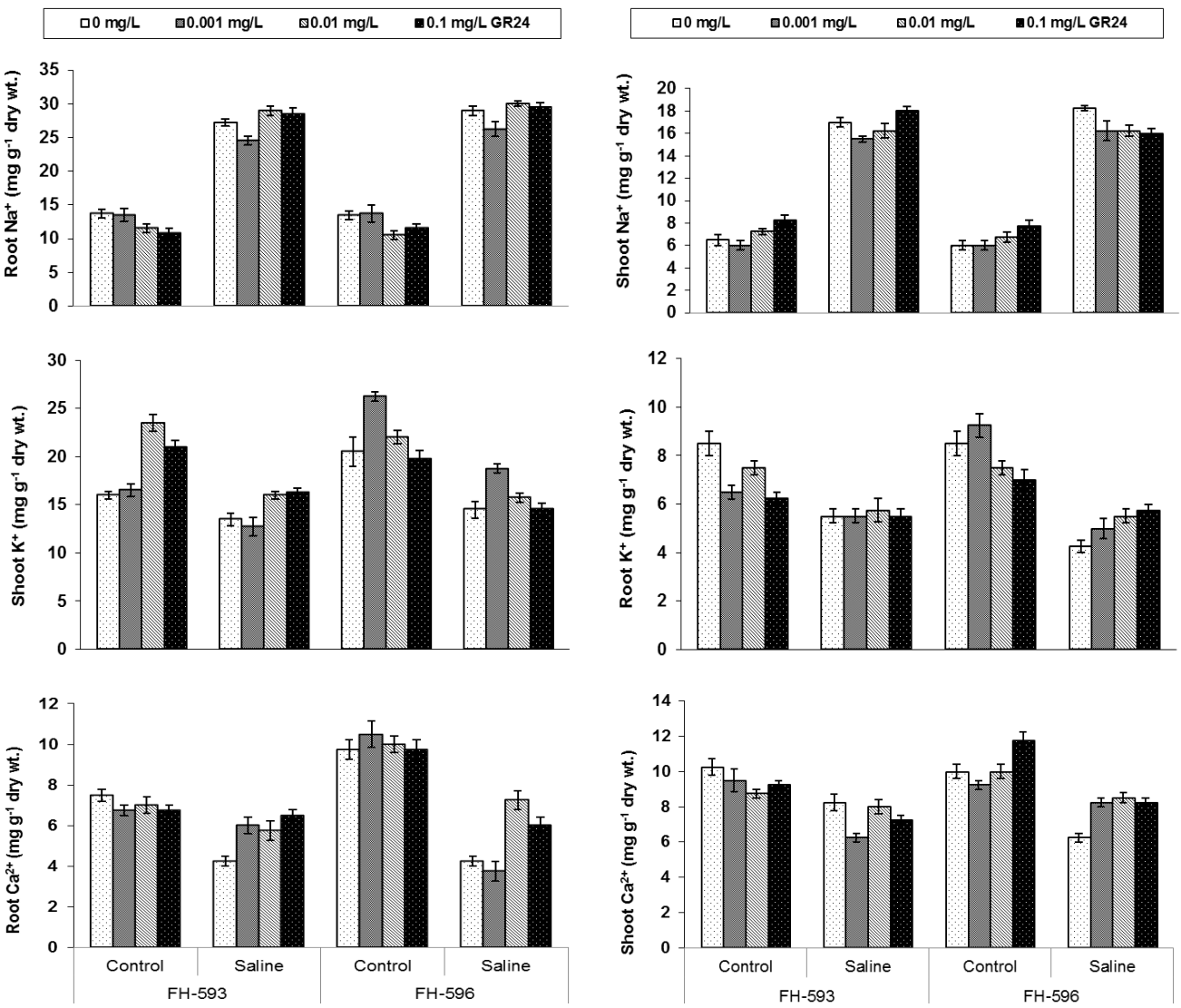

Fig. 4. Mineral nutrients of salt stressed and non-stressed sunflower (*Helianthus annuus* L.) plants raised from achene treated with GR24 for 16 h.

Conclusion

Salinity adversely affected biomass and growth of both sunflower hybrids. Gas exchange attributes and photosynthetic pigments were reduced significantly under salt stress. GR24 pre-sowing treatment ameliorated the inhibiting effect of salt stress by improving shoot and root lengths along with plant biomass. Achene priming with GR24 markedly enhanced the carotenoids but did not modulate chlorophyll pigments. GR24 did not affect gas exchange attributes. Salinity considerably increased shoot and root Na^+ ions but declined the K^+ and Ca^{2+} contents of both sunflower hybrids. Root and shoot Na^+, K^+ and Ca^{2+}, contents were increased by achene-priming with GR24.

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