Pak. J. Bot., 55(3): 851-863, 2023. DOI: http://dx.doi.org/10.30848/PJB2023-3(7)

MITIGATION OF DROUGHT INDUCED EFFECTS IN TOMATO (*SOLANUM ESCULENTUM* L.) USING PLANT GROWTH REGULATORS

AMNA SHAHZADI[1], KHALID HUSSAIN[1*], KHALID NAWAZ[1], ZAINAB ABDUL ROUF[1], MEHREEN JAVERIA[1], IQRA IQBAL[1], NOSHIA ARSHAD[1], HUMA RIAZ[1], RIDA AKRAM[1], RIDA ZAINAB[1] AND DURRE NAYAB[2]

[1]Department of Botany, University of Gujrat (UOG), Gujrat-Pakistan
[2]Quaid-i-Azam University, Islamabad, Pakistan
**Corresponding author's email: khalid.hussain@uog.edu.pk*

Abstract

Experiments were performed to mitigate the drought-induced effects in two tomato varieties (Rio Grande and Yaqui) using plant growth regulators i.e. indole-3-acetic acid (IAA) and naphthalene acetic acid (NAA). Drought stress (25 & 50%) reduced the growth, physiological, quality and yield attributes like the length of root and shoot, fresh and dry biomass of root ant shoot, chlorophyll pigments, proteins and carbohydrates contents, photosynthetic assimilation rate, rate of transpiration, intercellular CO_2 and also stomatal conductance and fruit yield. Variety "Yaqui" showed more drastic effects of drought in response to growth and yield. Antioxidant activities of catalases (CAT), peroxidase (POD) and superoxide dismutase (SOD) were increased under drought stress. It was noted that drought levels (50%) showed more adverse effects as compared to 25% drought. Foliar applications of IAA and NAA overcome drought detrimental effect and enhanced the growth, quality and yield attributes that were severely affected by drought. The foliar application of NAA was more effective to overcome the drought effect than the IAA. It was concluded that the levels of drought stress (25 & 50%) markedly decreased the growth parameters, biochemical, physiological and yield attributes in both tomato varieties. Foliar applications of NAA and IAA mitigate the drought effects by increasing the growth, physiological attributes that resulted better yield of tomato under drought stress.

Key words: Drought, Hormones, Tomato, Yield, Physiology, Antioxidants.

Introduction

Tomato (*Solanum esculentum* L.) member of family Solanaceae is one of the most famous vegetable found in the world. Tomato is widely cultivated in different region of the world (Naika *et al*., 2005). Tomatoes are a rich source of vitamins, minerals, sugars, amino acids and potential antioxidants (Naika *et al*., 2005). It contains an excessive amount of lycopene, flavonoids and vitamins that play a vital role in human health (Dorais, 2005). Lycopene is an important pigment in tomato, largely responsible for the red color of a tomato and it has important health properties (Denniss *et al*., 2008; Mirondo & Barringer, 2015). Crucial disease epithelial cancer can be controlled using potential antioxidant lycopene and it also prevents heart issues in humans (Singh & Goyal, 2008). Drought is considered one of the most serious issues for global food production, threatening about 50% of the world's land area with present environmental fluctuations (Zhang *et al*., 2014). Drought stress combines different types of stress and therefore has very complex phenomenon in decreasing the productivity of vegetables (Zlatev & Lidon, 2012). The growth of plant cells is sensitive to desiccation due to low cell turgor pressure. The primary effect of limited water supply is to impede germination rate and seedling growth due to a decrease in the various physiological processes (Harris *et al*., 2002). Tomato crop growing in water stress conditions suffering from various morphological and physiological aspects like reduction in leaf area and size of fruit along with deficiency of mineral because of less absorption which causes several physiological disorders (Kumar *et al*., 2012). Tomato needs 30-35°C temperature and better quality of water for optimum growth and better fruit quality (Dhaliwal, 2017). The prolific root system is good features of resistance to drought. According to Wu and Cosgrove (2000), a massive root system enables the plant for more absorption of water and minerals. In tomato, lycopene is a very good source of metabolites having key role in biosynthesis, where plants complete their life cycle before drought starts (Blum, 2005).

Plant growth regulators may influence budding, flowering, fruiting and fruit production, abscission of leaves or fruits, control of certain metabolic processes and resistance of plants to water stress and are normally active in a cell of the plant at the lower level (Abebie *et al*., 2010). Plant hormones are commonly used to promote plant growth, seed count, fruit collection, fruit size and horticultural yield (Batlang, 2008). At the time of flowering, the application of IAA and NAA resulted in lessened fruit fall and enhanced the size of fruit in tomato (Choudhury *et al*., 2013). IAA affects many physiological and morphological processes, accelerates ripeness and improves fruit quality in many plants (Rout, 2006). Plant growth is controlled by IAA, for instance, it regulates cellular elongation and development, apical dominance and horizontal root formation (Wang *et al*., 2003). It is noted where the application of plant growth regulators including IAA and NAA promote the size of fruit and fruit set in tomato. The use of plant growth regulator can fulfill the demand of natural growth hormone that is needed for development and also promote fruit

setting in tomato (Denniss *et al*., 2008). Gemici *et al*., (2006) stated that the use of synthetic auxin and gibberellin has been successful in improving the yield and quality of tomato. Gibberellic acid and naphthalene acetic acid combined present in the plant cell growth promoters in increasing plant production and yield also (Golldack *et al*., 2014). NAA influences physiological processes, accelerates growth, and increases fruit quality in tomato (Pundir & Yadav, 2001). Flower and fruit formation are also under the control of IBA and NAA and metabolic change during the storage of tomato plants (Bhosle *et al*., 2002; Meena, 2008).

Foliar application of IAA and NAA applied to tomato growth media had a stimulating effect on growth and development (Zhang *et al*., 2014). By foliar application of NAA and IAA fruit set of tomato has been developed successfully (Llanes *et al*., 2016). IAA promotes cell enlargement which is a critical step towards cell growth. The use of IAA on plants encourages vegetative and reproductive development (Singh & Rathore, 1998).

In the light of above mentioned literature, this study was designed to find out the effects of drought in tomato and the strategy to cope the adverse effects of drought using IAA and NAA.

Materials and Methods

Experiments were performed in the research area, University of Gujrat, Gujrat-Pakistan during 2019-2020. Five plants of ten days old seedling of two tomato varieties (Rio Grande and Yaqui) were transplanted in 10 inch earthen pots having 7 kg sandy loam soil. Drought treatments (0, 25 and 50%) were applied after 10 days of plants transplantation in pots.

Hormones (IAA and NAA) were applied as foliar spray after 10 days of drought treatments in one single dose application separately as well as in combination. The treatments were; IAA (25ppm), NAA (25ppm), drought + IAA (25%+25ppm), drought + IAA (50% + 25ppm), drought + NAA (25% + 25ppm), drought + NAA (50%+25ppm). Experiment was laid down in Completely Randomized Design (CRD) with three replicates. Data for root and shoot lengths; root and shoot dry weights; numbers of leaves; leaf area; stomatal conductance; transpiration rate; photosynthetic rate; intercellular CO_2 concentration; contents of chlorophyll, antioxidants proteins and carbohydrates, and activities of catalase, superoxide dismutase and peroxidase were collected at vegetative and fruiting stages. The number of fruit and fruit weight were calculated at fruiting stage and maturity.

Chlorophyll a and b were estimated using the method of Arnon (1949). Total carbohydrates were estimated with the Anthrone method. Soluble protein was estimated following Bradford (1976). Catalase, superoxide dismutase and peroxidase activities were determined using the method of Chance & Maehly (1955). Data were subjected to analysis of variance in COSTAT computer software. The comparison of mean was made using Duncan's New Multiple Range Test (DMRT) at a probability level of 5% by the method of Steel & Torrie (1986).

Results

Morphological attributes: From the results of our experiment, it was found that drought stress affects morphological attributes of tomato plants. Mean squares from analysis of variance (ANOVA) indicated that the effect of plant growth hormones was highly significant on shoot length of all varieties of Tomato at both vegetative and maturity stages. However, the interaction between treatments, varieties and drought stress showed non-significant outcomes (Table 1). From (Fig. 1A), it was clearly observed that shoot length of plants was improved after NAA treatment at maturity stage in V2 (Yaqui) as compare to V1 (Rio Grande). Overall results showed that drought reduced the length of shoot at both varieties. The hormonal effect was highly significant on fresh and dry biomass of shoot. While the interaction between drought as well as treatments showed non-significant results (Table 1). Maximum fresh weight of shoot was recorded at T4 on V2 (Yaqui) as compare to other variety. Results also indicated that foliar application of 25 ppm NAA gave the best results to maintain biomass of shoot in drought stress conditions (Fig. 1B). Highest dry weight of shoot was obtained at maturity stage at both varieties of tomato. However, foliar application of NAA gave beneficial outcomes as compare to other treatments (Fig. 1C). Means squares from (ANOVA) demonstrated that effect of PGRs and drought on root length of tomato was highly significant at vegetative stage on the other hand non-significant outcomes were obtained at maturity stage also with interactions (Table 2). Largest length of root was noted at fruiting stage as compare to vegetative stage at all treatments. T8 showed best results to suppress the effect of drought on tomato varieties (Fig. 1D). On the base of comparison between 2 varieties, the fresh and dry weight of the root of V1 (Rio Grande) was more affected by drought stress as compare to V2 (Yaqui). Foliar application of NAA and IAA proved useful in drought stress conditions on fresh and dry biomass of root (Figs. 2A, B). Means square from Table 2) elaborated that effect of plants growth hormones on fresh and dry weight of root were highly significant. ANOVA results had demonstrated that interaction between treatments and droughts were also highly significant (Table 2). After analysis of data, results had showed that the drought decreased the number of leaves in tomato plants as compare to control. Foliar spray of IAA gave maximum numbers of leaves at both stages (Fig. 2C). ANOVA related to the effect of growth regulators and drought on number of leaves were highly significant. While their interaction showed non-significant results (Table 1).

Gaseous exchange attributes: Means results from (ANOVA) indicated that hormonal effect under drought condition on tomato plants were highly significant. However the interaction between varieties and phytohormones were also highly significant with drought stress (Table 3). It was observed that after the application of phytohormones on drought stressed plants, the photosynthetic rate become equal to control

treatment. On the other hand, foliar application of IAA and NAA improved rate of photosynthesis of normal plants at both varieties (Fig. 3A). Drought stress showed a remarkable reduction in the transpiration rate of tomato plants. ANOVA results demonstrated that the effect of treatment on transpiration rate was non-significant while drought effect was significant with its interaction (Table 3). From (Fig. 3B) it was clearly observed that application of IAA and NAA (25ppm) under drought stress gave best results of transpiration rate at maturity stages. Results also showed that foliar spray of phytohormes gave best results at both stages. Drought application declined the value of the stomatal conductance highly significant at vegetative as well as maturity stage on both tomato varieties. The interaction between phytohormone and drought was significant at vegetative as well as the maturity stage. Phytohormone x variety interaction was non-significant at the fruiting stage (Table 3). The maximum value of stomatal conductance was observed in the Rio Grande with the application of phytohormone (IAA 25ppm) at the vegetative stage (Fig 3C). From the results of ANOVA, it was concluded that the effect of hormones on intercellular CO_2 Concentrations was highly significant while the interplay of Variety X Phytohormies X Drought was also highly significant (Table 3). After the drought stress on both tomato varieties, it was noticed that the Intercellular CO_2 concentration of leaves was decreased as compare to phytohormones treated plants. Best results Intercellular CO_2 concentration were recorded in that plants which were treated with 25ppm NAA under drought stress (Fig. 3D).

Biochemical attributes: Means data from ANOVA showed that the value of chlorophyll 'a' content was significantly reduced at the vegetative and maturity stage under water deficit (Table 4). Foliar application of IAA and NAA alleviate the drought-induced inhibitory effect and enhanced the value of chlorophyll a. Drought level 50% had more adverse effects as compared to 25% on chlorophyll 'a' content on both growth stages. NAA showed better results as compared to IAA on Yaqui variety at the maturity stage. It is also noted that phytohormones enhanced the value of chlorophyll 'a' content on the control plant as compared to drought treated plants (Fig. 4A). Cultivation of tomato on drought area markedly reduced the value of chlorophyll b content at both stages. ANOVA table 4 showed that the interaction between drought and phytohormone was highly significant at the vegetative stage while it was non-significant at the maturity stage. Foliar spray of phytohormone (IAA and NAA) enhanced the chlorophyll b content at vegetative as well as the maturity stage. NAA had a more positive effect than IAA on Yaqui variety at vegetative as well as maturity stage under drought (25% and 50%) treated plants (Fig. 4B). It was also observed that the effect of drought and phytohormone was highly significant at the vegetative and maturity stage. Interaction between phytohormone x drought was significant at the vegetative stage. Drought and phytohormone interaction was non-significant at the maturity stage (Table 4). Exogenously applied IAA and NAA significantly enhanced the protein content of tomato. NAA applied to drought showed a better result as compared to IAA to reduce the drought-induced effect on tomato. Maximum protein content was noted in the variety Rio Grande at the fruiting stage (Fig. 4C). Drought and phytohormone interaction was significant at the vegetative stage. Carbohydrate content was reduced with the applications of drought. The interaction between drought and phytohormone was non-significant at the fruiting stage (Table 4). Maximum reduction was noted with a 50% drought. Variety Yaqui showed the maximum reduction during both growth stages. The effect of hormones (IAA and NAA) showed an increase in the carbohydrate content of tomato at vegetative and fruit harvesting stages (Fig. 4D).

Antioxidants activities: Drought application significantly enhanced the catalase activity (CAT) at both growth stages. The effect of drought, phytohormone and variety were highly significant for catalase activity at vegetative as well as a maturity stage. The interaction between drought x phytohormone x variety was highly significant at the maturity stage but the interaction between phytohormone and variety was non-significant at the vegetative stage (Table 5). Maximum catalase activity was observed in Yaqui variety at the maturity stage under 50% drought. Foliar spray of plant growth promoter (IAA and NAA) showed variable response on drought treated and non-treated plants at vegetative and fruiting stage (Fig. 5A). The values of SOD content increased significantly under drought stress. Interaction between drought and phytohormone was significant at both stages. Phytohormone and variety interaction was non-significant at both vegetative and fruiting stages (Table 5). The maximum value of SOD content was shown under drought (50%) in variety Yaqui at the vegetative stage. Application of phytohormone IAA and NAA decreased the SOD value in variety Yaqui at the maturity stage (Fig. 5B).

Yield attributes: There was a highly significant effect of drought and phytohormone on number of fruits of tomato. However the interaction between drought, phytohormones and variety were non-significant (Table 5). The number of fruits was reduced with the application of drought. Maximum reduction was noted with a 50% drought. Variety Yaqui showed maximum reduction as compared to other varieties. The effect of hormones (IAA and NAA) showed an increase in the number of tomatoes at fruit harvesting stages. Phytohormone was useful to increase the number of fruits under drought stress. Maximum number of fruits was observed with the foliar spray of NAA (25%) (Fig. 5C). There were highly significant effects of drought, phytohormone and its interactions on yield of tomato. The application of IAA and NAA helped to reduce the effect of drought from tomato. Total yield was improved by phytohormone when applied under drought stress. Minimum yield was noted in Yaqui and the maximum was in variety Rio Grande (Fig. 4.20).

Table 1. Means squares (MS) from the analysis of variance (ANOVA) for various morphological attributes of tomato (*Solanum esculentum* L.) under the effect of IAA, NAA.

Source	df	Shoot length (vegetative stage)	Shoot length (fruiting)	Shoot fresh weight (vegetative stage)	Shoot fresh weight (fruiting)	Shoot dry weight (vegetative stage)	Shoot dry weight (fruiting)	Number of leaves (vegetative stage)	Number of leaves (fruiting)
Drought (D)	2	79.644*	414.636***	2.480*	5.003***	0.838***	0.844*	39.796***	10.888**
Phytohormone (P)	2	176.242***	516.222***	5.254**	17.028***	0.342***	3.439***	4.018 ns	6.222 **
Variety (V)	1	67.943*	391.664***	1.212ns	67.571***	4.331***	25.839***	18.962**	37.5 ***
D x P	4	18.241ns	29.193 ns	6.223ns	0.745 ns	0.087*	0.269ns	1.407 ns	2.777 ns
D x V	2	335.078***	111.392*	0.182ns	3.560**	0.285***	1.098*	11.462**	4.666 ns
P x V	2	33.610ns	29.521 ns	4.291**	2.795**	0.212***	0.529ns	2.907 ns	2.666 ns
D x P x V	4	32.277ns	63.505 ns	4.834***	1.254ns	0.072*	0.176ns	2.074 ns	0.666 ns
Error	36	16.121	28.295	0.669	0.494	0.024	0.209	1.629	1.648
Total	53								

ns = Non-significant, *** = Significant at $p \leq 0.001$ probability levels

Table 2. Means squares (MS) from the analysis of variance (ANOVA) for various morphological attributes of tomato (*Solanum esculentum* L.) under the effect of IAA, NAA.

Source	df	Root length (vegetative stage)	Root length (fruiting)	Root fresh weight (vegetative stage)	Root fresh weight (fruiting)	Root dry weight (vegetative stage)	Root dry weight (fruiting)
Drought (D)	2	0.124ns	27.615ns	1.344**	0.973ns	0.107***	0.137*
Phytohormone (P)	2	35.192***	23.282ns	0.888*	8.948***	0.144***	1.951***
Variety (V)	1	100.887***	311.520***	3.705***	3.586 **	2.4675ns	4.126***
D x P	4	10.062**	30.971ns	0.280ns	0.667ns	0.066***	0.094ns
D x V	2	10.265**	2.867ns	1.831***	0.793ns	0.191***	0.324***
P x V	2	9.895*	3.711ns	0.145ns	0.050ns	0.020ns	0.235**
D x P x V	4	14.277***	23.884ns	0.433ns	0.699ns	0.018ns	0.226***
Error	36	1.946	20.666	0.194	0.403	0.009	0.036
Total	53						

ns = Non-significant, *** = Significant at $p \leq 0.001$ probability levels

Table 3. Means squares (MS) from the analysis of variance (ANOVA) for various gaseous attributes of tomato (*Solanum esculentum* L.) under the effect of IAA, NAA.

Source	df	Photosynthetic rate (vegetative stage)	Photosynthetic rate (fruiting)	Transpiration rate (vegetative stage)	Transpiration rate (fruiting)	Intercellular CO_2 concentrations (vegetative stage)	Intercellular CO_2 concentrations (fruiting)	Stomatal conductance (vegetative stage)	Stomatal conductance (fruiting)
Drought (D)	2	1332.092***	2289.762***	3773.907***	93.986**	1083.526***	3917.467***	403.462***	440.460**
Phytohormone (P)	2	178.733**	1018.555***	360.240 ns	10039.144***	2705.661***	7273.193***	123.685*	369.507*
Variety (V)	1	12531.244***	455.992***	704.166*	12.494 ns	9509.520***	74.727 ns	1057.796***	1506.088***
D x P	4	164.625***	191.581**	123.685 ns	1118.896 ***	769.251***	2970.615***	348.268***	452.757**
D x V	2	497.064***	114.251 ns	948.722 **	769.542*	1020.903***	1850.606***	20.685 ns	687.334***
P x V	2	182.227**	108.390 ns	193.5 ns	233.014 ns	805.854***	2076.568***	159.129**	63.566ns
D x P x V	4	32.628 ns	157.667**	106.388 ns	2017.551***	446.255***	1902.261***	136.768 **	305.955*
Error	36	27.340	38.231	115.666	159.097	28.007	144.884	26.333	80.952
Total	53								

ns = Non-significant, *** = Significant at $p \leq 0.001$ probability levels

Table 4. Means squares (MS) from the analysis of variance (ANOVA) for various biochemical attributes of tomato (*Solanum esculentum* L.) under the effect of IAA, NAA.

Source	df	Chl a (vegetative stage)	Chl a (fruiting)	Chl b (vegetative stage)	Chl b (fruiting)	Protein (vegetative stage)	Protein (fruiting)	Carbohydrate (vegetative stage)	Carbohydrate (fruiting)
Drought (D)	2	0.064***	0.101 ***	0.064***	0.101***	0.449***	1.152***	288.115***	70.224***
Phytohormone (P)	2	0.025**	0.082 ***	0.025**	0.082***	0.456***	2.754***	36.637**	254.764***
Variety (V)	1	0.529***	0.032 **	0.529***	0.032*	9.233***	0.203 ns	1357.099***	98.496***
D x P	4	0.044***	0.009 ns	0.044***	0.009 ns	0.142***	0.195 ns	21.742**	3.092ns
D x V	2	0.026**	0.003 ns	0.026**	0.003 ns	0.010ns	1.774***	40.658**	2.413ns
P x V	2	0.052***	0.021*	0.052***	0.021*	0.110***	0.129 ns	5.903 ns	8.903ns
D x P x V	4	0.006 ns	0.030**	0.006 ns	0.030**	0.050**	0.141 ns	10.548 ns	5.227ns
Error	36	0.004	0.005	0.004	0.005	0.012	0.085	5.547	3.484
Total	53								

ns = Non-significant, *** = Significant at $p \leq 0.001$ probability levels

Table 5. Means squares (MS) from the analysis of variance (ANOVA) for various antioxidants activities and yield attributes of tomato (*Solanum esculentum* L.) under the effect of IAA, NAA.

Source	df	CAT (vegetative stage)	CAT (fruiting)	POD (vegetative stage)	POD (fruiting)	SOD (vegetative stage)	SOD (fruiting)	Number fruit/plant	Total fruit yield
Drought (D)	2	0.007 ***	0.080***	6.288 ***	29.406***	0.127*	0.203**	55.129 ***	163088.222***
Phytohormone (P)	2	0.003 **	0.028***	5.839 ***	2.316 ns	0.134*	0.139*	16.462 **	32042.888***
Variety (V)	1	0.172***	0.089***	203.222***	11.146*	6.074***	4.178***	9.796 *	8816.666 *
D x P	4	0.004***	0.012**	1.276 *	3.811 ns	0.216***	0.491***	0.268 ns	549.444 ns
D x V	2	1.756ns	0.107***	0.706ns	39.229***	0.125*	0.436***	4.462 ns	5769.555*
P x V	2	0.001ns	0.062***	3.424 **	0.493 ns	0.052 ns	0.043 ns	0.240 ns	640.666 ns
D x P x V	4	8.719ns	0.009*	1.347 *	3.563 ns	0.169 **	0.019 ns	1.824 ns	1392.222 ns
Error	36	6.868	0.002	0.436	1.534	0.036	0.027	2.185	1502.759
Total	53								

ns = Non-significant, *** = Significant at $p \leq 0.001$ probability levels
CAT = Catalases, POD = Peroxidase, SOD = Superoxide dismutase

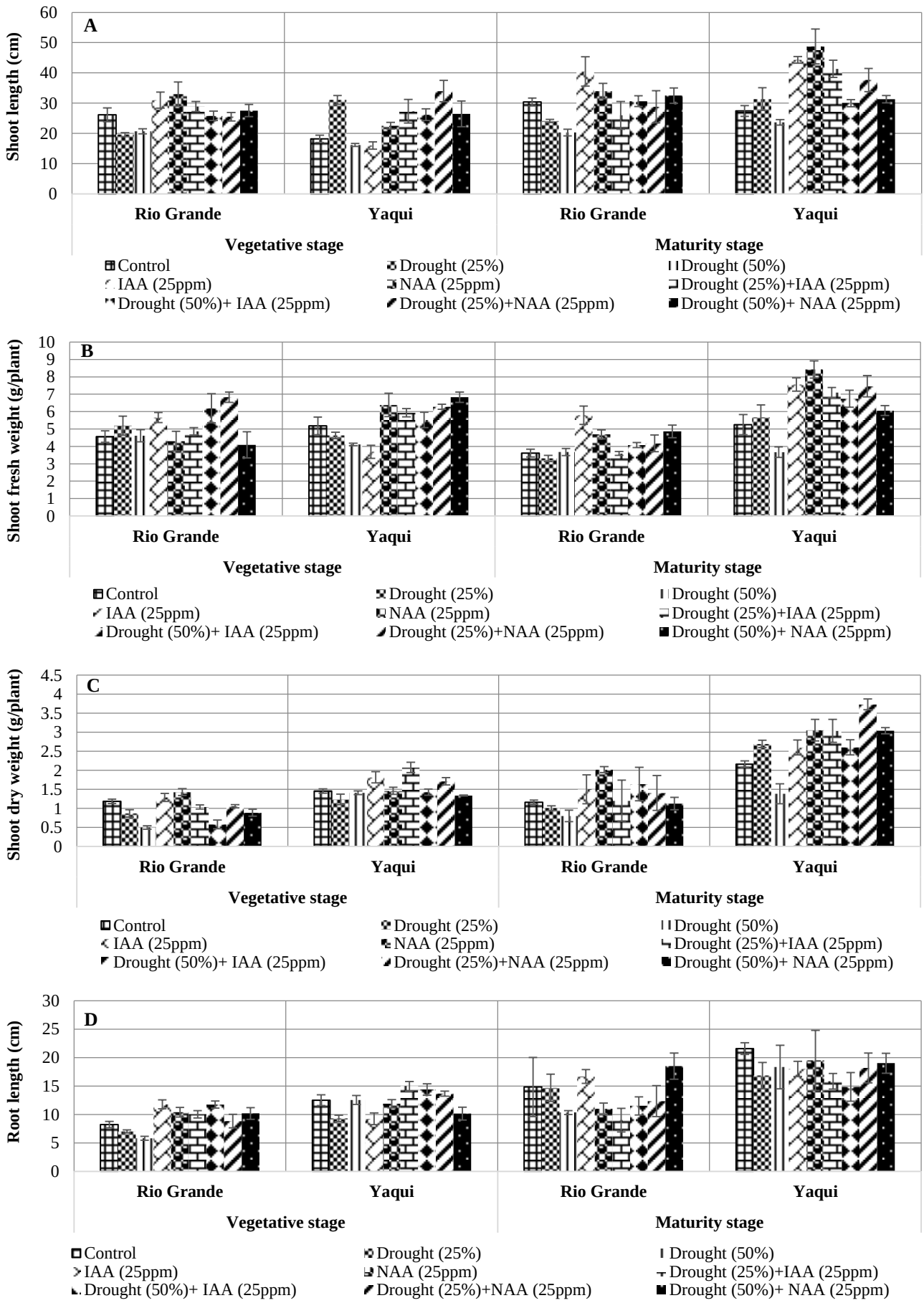

Fig. 1. Effect of IAA and NAA on various morphological parameters of two tomato varieties under drought stress at vegetative and maturity stages.

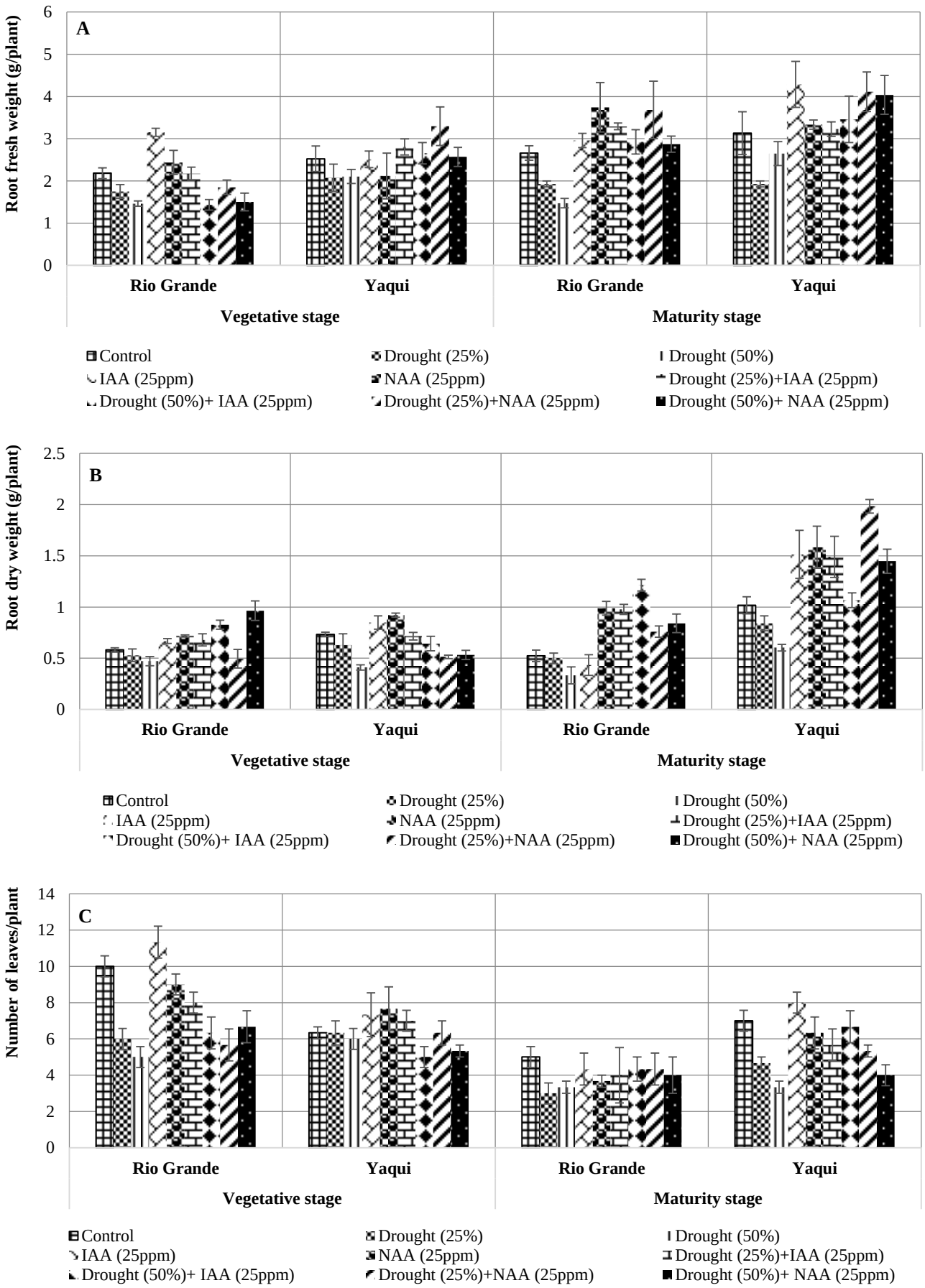

Fig. 2. Effect of IAA and NAA on various morphological parameters of two tomato varieties under drought stress at vegetative and maturity stages.

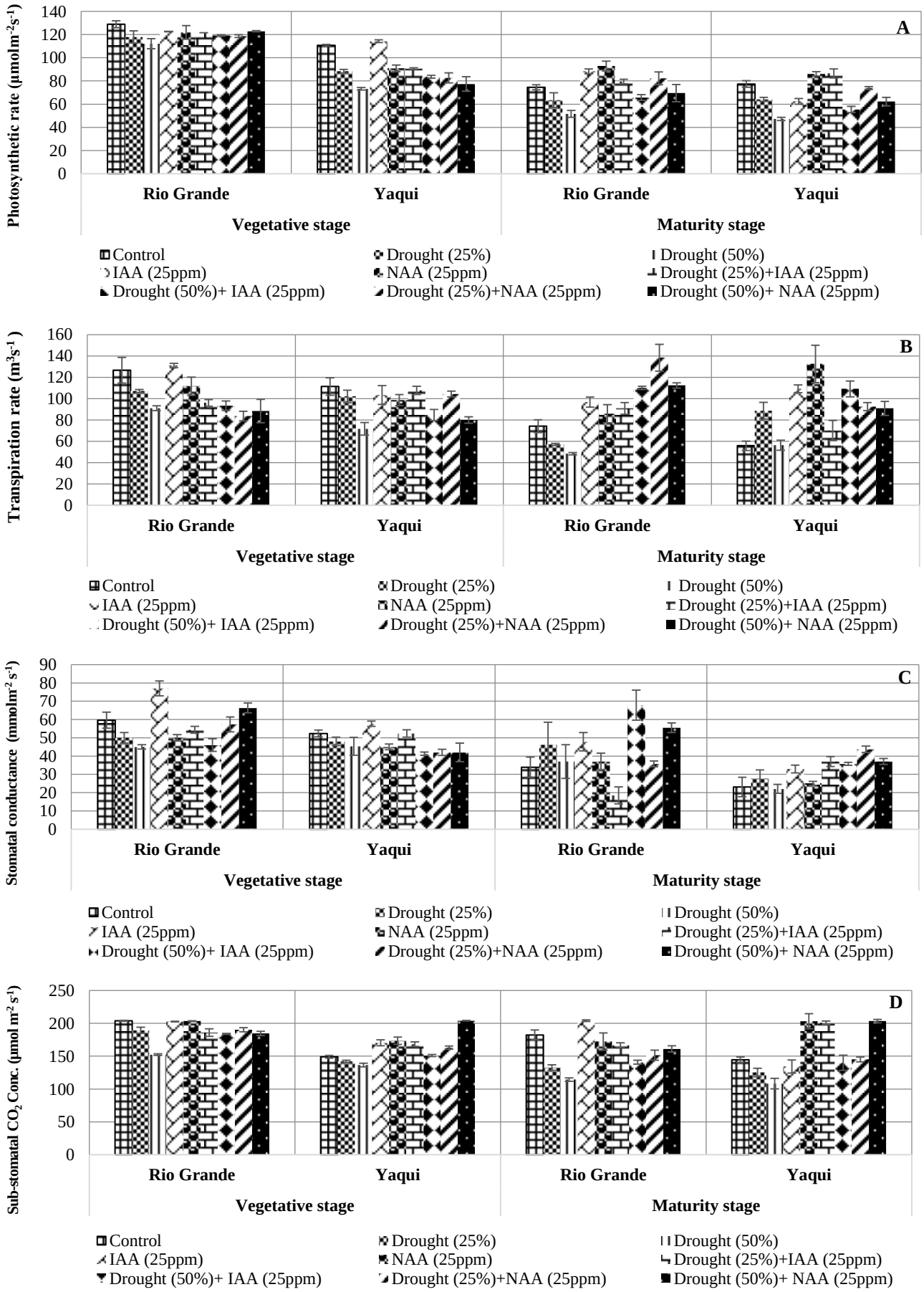

Fig. 3. Effect of IAA and NAA on Various Gaseous Exchange Parameters of Two Tomato Varieties under Drought Stress at Vegetative and Maturity Stages.

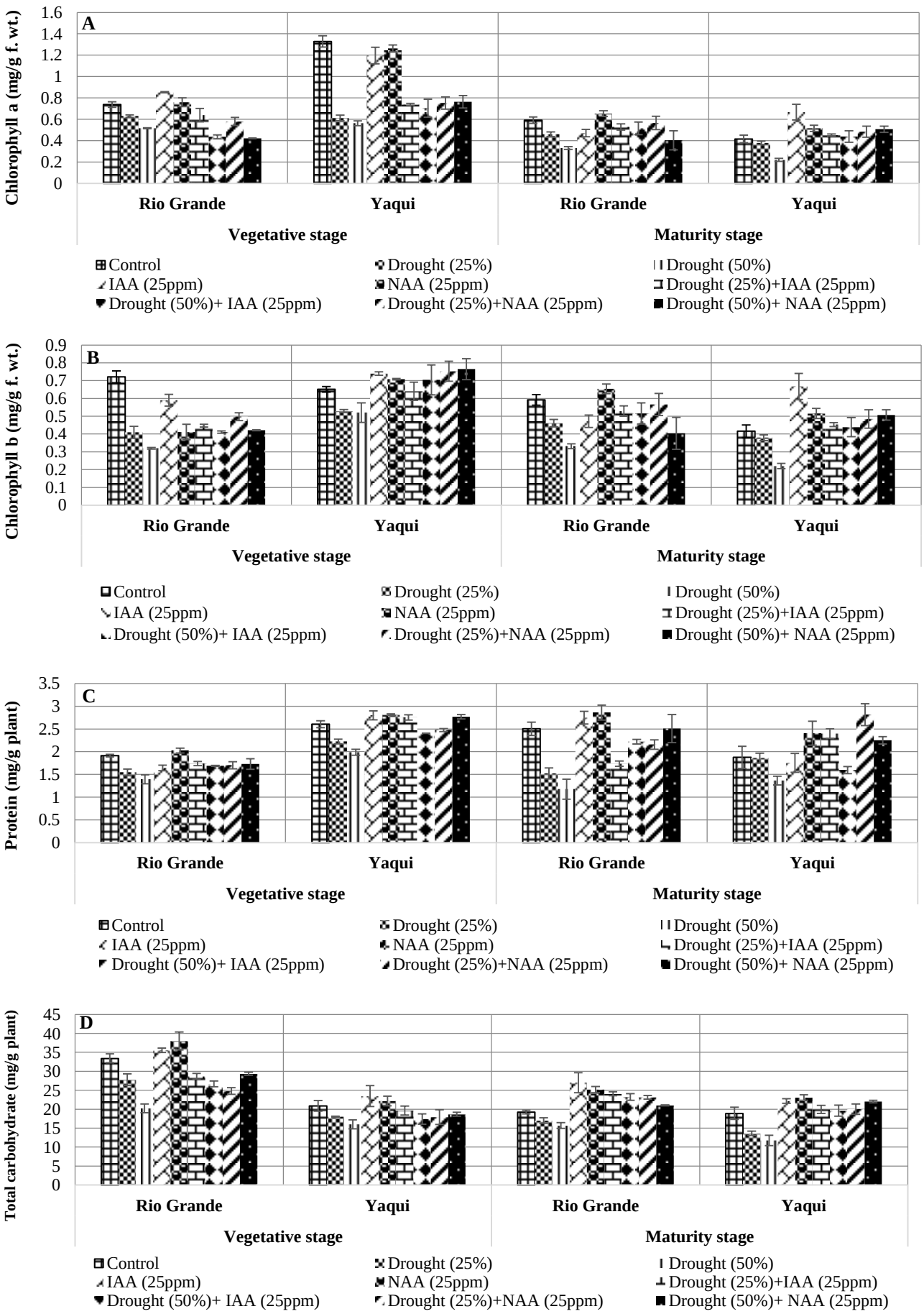

Fig. 4. Effect of IAA and NAA on various biochemical parameters of two tomato varieties under drought stress at vegetative and maturity stages.

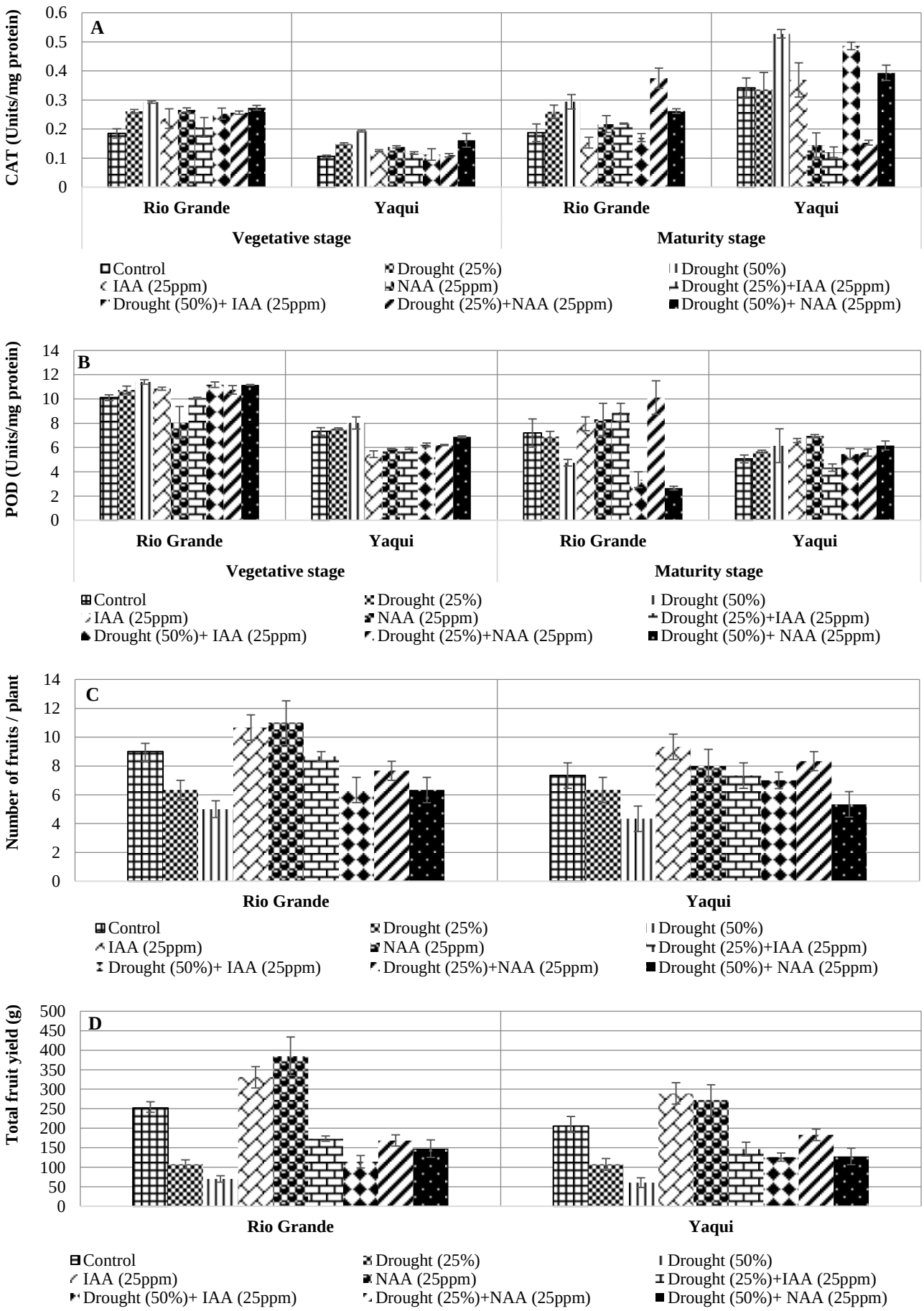

Fig. 5. Effect of IAA and NAA on various antioxidants activities and yield parameters of two tomato varieties under drought stress at vegetative and maturity stages.

Discussion

It was noted from the results that desiccation stress influenced the morphological as well as physiological traits of tomato. Drought stress lessened the plant growth such as shoot and root length, shoots and root fresh and dry weights. Drought stress overall disturbs the plant's ability to perform a normal function such as decrease the photosynthetic rate, stomatal conductance, carbohydrate and protein content. Zeid & Shedeed (2006) reported that the length of hypocotyl and shoot and root biomass was decreased in alfalfa (*Medicago sativa* L.) under drought conditions. Fewer moisture contents declined shoot length significantly in a soybean plant (Specht *et al*., 2001). Drought stress reduced the number of seeds in safflower and such reduction was overcome by the foliar application of IAA and NAA (Asrar & Elhindi, 2011). On other hand, our results regarding total yield are correlated with the work of Specht *et al*., (2001) where drought application reduced the total seed yield in soybean and this drought-induced reduction was mitigated by the use of indole-3-acetic acid. Water deficit decreases the water potential in a plant cell in four varieties of the soybean plant which further reduced the turgor pressure and induced the reduction in root biomass and the number of pods as well as seed weight (Liu *et al*., 2004). In literature, nitrogen and phosphorus contents significantly reduced in tomato seedling grown in low soil moisture contents (Subramanian *et al*., 2006). In water deficit condition reduction in the plant, biomass is correlated with less cell proliferation and enlargement more senescence of leaves in okra (Bhatt & Srinivasa Rao, 2005). The number of leaves and leaf areas is significantly reduced in the various plant including wheat, maize and sorghum under less water availability (Farooq *et al*., 2010). Desiccation decreased photosynthetic pigments chlorophyll and carotenoids in cotton and rice (Jaleel *et al*., 2008). Similarly, in marigold both chlorophyll, a and b content severally reduced (Asrar & Elhindi, 2011). Underwater deficit condition chlorophyll pigments reduced significantly in safflower and bilberry (Tahkokorpi *et al*., 2007; Kiani *et al*., 2008). Dickin & Wright (2008) while working on six wheat cultivar under drought stress reported that the number of seed and seed weight markedly declined. It is further observed on eight maize cultivars where limited water supply significantly reduced grain yield (Monneveux *et al*., 2006). Four varieties of soybean cultivated on drought areas showed a reduction in the number of pods as well as number seed and also seed weight (Specht *et al*., 2001). Water stress showed a harmful effect on four varieties of potential oilseed crop sunflower where seed yield and capitulum diameter markedly reduced (Tahir & Mehid, 2001). Saifuddin *et al*., (2009) reported that IAA promotes rooting and vegetative propagation through stem cutting. On the other hand, a mixture of indole-butyric acid and naphthalene acetic acid with the concentration of (250-500 ppm) stimulated rooting in tomato (Singh *et al*., 1999). The tendency of later root formation in tomato seedling is increased by 8 fold with the application of 1.6 M–naphthalene acetic acid (Taylor & Scheuring, 2004). Application of auxin increased the hypocotyl length, fresh and dried seedling weight and dried hypocotyls weight of three wheat cultivars (Akbari *et al*., 2007). The foliar treatment of IAA promotes the plant height and dry weight in black seeds (Hussain *et al*., 2003). Combined application of 2, 4-D, IAA and NAA promoted plant growth and development by enhancing the number of branches and plant height in tomato (Singh *et al*., 2005; Patel *et al*., 2012). Foliar dosing of IAA on tomato plant growing media had a positive effect on plant development and produced the highest branches per plant (Ali *et al*., 2012). Kumar *et al*., (2001) while working on eight cotton varieties reported that foliar-applied auxin increased yield under severe drought stress. Foliar sprays of IAA produced more flowers, increased fruit set frequency and a higher number of fruits and greater yield in tomatoes as associated to control plants (Ali *et al*., 2012). Auxin treatment increases the number of seeds and pods per pea plant proper application time and type of variety also significant for a better result. IAA also increased the spike number, spikes weight and growth of tiller per plant (Wang *et al*., 2003). Plant growth regulator controls the abscission and application of plant hormone eventually gives better yield in tomato and soybean (Nahar & Ikeda, 2002). In the literature study, it was determined that the use of plant growth regulator increased the number of fruit, fruit size and total yield of tomato (Saifuddin *et al*., 2009). At the time of flowering, the application of IAA and NAA resulted in lessened fruit fall and enhanced the size of the fruit, boosted fruit setting and fruit yield in tomato (Gemici *et al*., 2006). Foliar spray of NAA (10ppm) on the cluster of small stems where flower development followed by pollination produced the highest yield (Rodrigues *et al*., 2001). Exogenous application of NAA with a concentration of 25ppm increased T.S.S and vitamin C content of tomato (Pudir & Yadav, 2001; Saha *et al*., 2009). Foliar application of NAA successfully increases the branch's number, plant height, promotes the fruit set and increases the diameter of tomato (Patel *et al*., 2012; Verma *et al*., 2014). NAA directly influences the physiological processes, root initiation, leaf senescence; fruit setting to promote the maturity stage enhance the quality of tomato (Pundir & Yadav, 2001; Bhosle *et al*., 2002; Meena, 2008).

Conclusion

It was concluded that drought stress levels (25 & 50%) significantly reduced the growth parameters, biochemical, physiological and yield attributes in both tomato varieties. Foliar applications of NAA and IAA alleviated the drought effects by increasing growth and physiological attributes. Exogenous application of the NAA was more effective to alleviate the drought effect than IAA. Variety Rio Grande showed better performance under drought than Yaqui.

References

Abebie, B. and L. Desalegn. 2010. Effects of gibberellic acid and 2, 4-dichloro-phenoxyacetic acid spray on fruit yield and quality of tomato (*Lycopersicon esculentum*). *J. Plant Breed. Crop Sci.*, 2(10): 316-324.

Akbari, G., S.A. Sanavy and S. Yousefzadeh. 2007. Effect of auxin and salt stress (NaCl) on seed germination of wheat cultivars (*Triticum aestivum* L.). *Pak. J. Biol. Sci.*, 10(15): 2557-2561.

Ali, M.A., S. Sharmin, A.I. Saki and M. Moniruzzaman. 2012. Effect of plant growth regulators on growth and yield of tomato (*Lycopersicon esculentum*) varieties. *Int. J. Sustain. Agric. Tech.*, 8(1): 1-6.

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol.*, 24(1): 1-15.

Asrar, A.W.A. and K.M. Elhindi. 2011. Alleviation of drought stress of marigold (*Tagetes erecta*) plants by using arbuscular mycorrhizal fungi. *Saudi J. Biol. Sci.*, 18(1): 93-98.

Batlang, U. 2008. Benzyladenine plus gibberellins (GA4+7) increase fruit size and yield in greenhouse-grown hot pepper (*Capsicum annuum* L.). *J. Biol. Sci.*, 8(3): 659-662.

Bhatt, R.M. and N.S. Rao. 2005. Influence of pod load on response of okra to water stress. *Ind. J. Plant Physiol.*, 10(1): 54-68.

Bhosle, A.B., S.B. Khorbhade, P.B. Sanap and M.J. Gorad. 2002. Effect of plant hormones on growth and yield of summer tomato (*Lycopersicon esculentum*). *Orissa J. Hort.*, 30(2): 63-65.

Blum, A. 2005. Drought resistance, water-use efficiency, and yield potential are they compatible, dissonant, or mutually exclusive? *Aust. J. Agric. Res.*, 56(11): 1159-1168.

Bradford, M.M. 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Anal. Biochem.*, 72(1-2): 248-254.

Chance, B. and A.C. Maehly. 1955. Assay of Catalase and Peroxidase. *Methods in Enzy*., 2: 764-775.

Choudhury, S., N. Islam, M.D. Sarkar and M.A. Ali. 2013. Growth and yield of summer tomato as influenced by plant growth regulators. *Int. J. Sust. Agri.*, 5(1): 25-28.

Denniss, S.G., T.D. Haffner, J.T. Kroetsch, S.R. Davidson, J.W. Rush and R.L. Hughson. 2008. Effect of short-term lycopene supplementation and postprandial dyslipidemia on plasma antioxidants and biomarkers of endothelial health in young, healthy individuals. *Vascular Health and Risk Manag.*, 4(1): 213-225.

Dhaliwal, M.S., S.K. Jindal, L.K. Dhaliwal, A.K. Gaikwad and S.P. Sharma. 2017. Growth and yield of tomato influenced by condition of culture, mulch, and planting date. *Int. J. Veg. Sci.*, 23(1): 4-17.

Dickin, E. and D. Wright. 2008. The effects of winter waterlogging and summer drought on the growth and yield of winter wheat (*Triticum aestivum* L.). *Europ. J. Agron.*, 28(3): 234-244.

Dorais, M. 2005. Effect of cultural management on tomato fruit health qualities. In *International Symposium on Human Health Effects of Fruits and Vegetables,* 744*:* 279-294.

Farooq, M., N. Kobayashi, O. Ito, A. Wahid and R. Serraj. 2010. Broader leaves result in better performance of rice under drought stress. *J. Plant Physiol.,* 167(13): 1066-1075.

Gemici, M., T. Bengu and T. Kit. 2006. Effects of 2, 4-D and 4-CPA on yield and quality of the tomato, *Lycopersicon esculentum*. *J. Faculty of Sci.*, 29: 24-32.

Golldack, D., C. Li, H. Mohan and N. Probst. 2014. Tolerance to drought and salt stress in plants: unraveling the signaling networks. *Front. Plant Sci.*, 5: 151-164.

Harris, D., R.S. Tripathi and A. Joshi. 2002. On-farm seed priming to improve crop establishment and yield in dry direct-seeded rice. *Direct seeding: Res. Strateg. Opport.,* 8: 231-240.

Hussain, K., F. Rabbi and M. Rafiq. 2003. Effect of different concentration of IAA on growth and yield of black seeds (*Nigella sativa* L.). *Sarhad J. Agri.*, 19(4): 23-26.

Jaleel, C.A., P. Manivannan, G.M.A. Lakshmanan, M. Gomathinayagam and R. Panneerselvam. 2008. Alterations in morphological parameters and photosynthetic pigment responses of *Catharanthus roseus* under soil water deficits. *Colloids and Surfaces B: Biointerfaces*, 61(2): 298-303.

Kiani, S.P., P. Maury, A. Sarrafi and P. Grieu. 2008. QTL analysis of chlorophyll fluorescence parameters in sunflower (*Helianthus annuus* L.) under well-watered and water-stressed conditions. *Plant Sci.*, 175(4): 565-573.

Kumar, B., D.M. Pandey, C.L. Goswami and S. Jain. 2001. Effect of growth regulators on photosynthesis, transpiration and related parameters in water stressed cotton. *Biol. Plant*, 44(3): 475-478.

Kumar, R., S.S. Solankey and M. Singh. 2012. Breeding for drought tolerance in vegetables. *Veg. Sci.*, 39(1): 1-15.

Liu, F., C.R. Jensen and M.N. Andersen. 2004. Drought stress effect on carbohydrate concentration in soybean leaves and pods during early reproductive development: its implication in altering pod set. *Field Crops Res.*, 86(1): 1-13.

Llanes, A., A. Andrade, S. Alemano and V. Luna. 2016. Alterations of endogenous hormonal levels in plants under drought and salinity. *Amer. J. Plant Sci.*, 7(9): 1357-1368.

Meena, A.K., K. Kadirvelu, G.K. Mishra, C. Rajagopal and P.N. Nagar. 2008. Adsorptive removal of heavy metals from aqueous solution by treated sawdust (*Acacia arabica*). *J. Hazard. Mat.*, 150(3): 604-611.

Mirondo, R. and S. Barringer. 2015. Improvement of flavor and viscosity in hot and cold break tomato juice and sauce by peel removal. *J. Food Sci.*, 80(1): 171-179.

Monneveux, P., C. Sanchez, D. Beck and G.O. Edmeades. 2006. Drought tolerance improvement in tropical maize source populations: evidence of progress. *Crop Sci.,* 46(1): 180-191.

Nahar, B.S. and T. Ikeda. 2002. Effect of different concentrations of Figaron on production and abscission of reproductive organs, growth, and yield in soybean (*Glycine max* L.). *Field Crops Res.,* 78(1): 41-50.

Naika, S., J. Juede, M. Goffau, M. Hilmi and D.B. Van. 2005. Cultivation of tomato. Production, processing and marketing. In: (Ed.): Van Dam, B. Digigrafi, Wageningen, The Netherlands.

Naika, S., J. Lidt, M. Goffau, M. Hilmi and B. Dam. 2005. *Cultivation of Tomato Production, Processing and Marketing*. 4th ed, Agromisa Foundation and CTA, Wageningen, 14: 1-92.

Patel, J.S., H.H. Sitapara and K.A. Patel. 2012. Influence of plant growth regulators on growth, yield and quality of tomato and brinjal, *Int. J. Forest. Crop Improv.*, 3(2): 116-118.

Pudir, J.P.S. and P.K. Yadav. 2001. Note on effect of GA3 NAA and 2, 4-D on growth, yield and quality of tomato var. *Punjab Chuhara. Curr. Agric.,* 25: 137-138.

Rodrigues, M.J., S.D. Warade and S.D. Patil. 2001. Effect of growth regulators and truss sequence on hybrid seed yield of tomato hybrid. *Adv. in Plant Sci.*, 14(2): 495-500.

Rout, G.R. 2006. Effect of auxins on adventitious root development from single node cuttings of *Camellia sinensis* (L.) Kuntze and associated biochemical changes. *Plant Grow. Reg.*, 48(2): 111-117.

Saha, P., N. Das, P. Deb and C.P. Suresh. 2009. Effect of NAA and GA3 on yield and quality of tomato (*Lycopersicon esculentum*). *Environ. Ecol.*, 27(3): 1048-1050.

Saifuddin, M., A.B.M.S. Hossain, O. Normaniza, B.A. Nasrulhaq and K.M. Moneruzzaman. 2009. The effects of naphthaleneacetic acid and gibberellic acid in prolonging bract longevity and delaying discoloration of *Bougainvillea spectabilis*. *Biotech.*, 8(3): 343-350.

Singh, D.K. 1999. Response of hybrid tomato to growth regulators. *Ind. J. Agric. Sci.*, 69(7): 523-525.

Singh, K. and S. Rathore. 1998. Seed and protein yield of mung in response to treatment with indole acetic acid (IAA). *Plant Physio.*, 32(2): 133-137.

Singh, P. and G.K. Goyal. 2008. Dietary lycopene: Its properties and anticarcinogenic effects. *Comp. Rev. Food Sci. Food Saf.*, 7(3): 255-270.

Singh, R. and A.K. Sant. 2005. Effect of plant growth regulator's and micronutrient mixture on the growth and yield of tomato. *Bioved.*, 16(1-2): 101-105.

Specht, J.E., K. Chase, M. Macrander, G.L. Graef, J. Chung, J.P. Markwell and K.G. Lark. 2001. Soybean response to water: a QTL analysis of drought tolerance. *Crop Sci.*, 41(2): 493-509.

Steel, R.G.D. and J.H. Torrie. 1986. Principles and procedures of statistics. 2nd Edition, McGraw Hill Book Co. Inc., New York, 336-354.

Subramanian, K.S., P. Santhanakrishnan and P. Balasubramanian. 2006. Responses of field grown tomato plants to arbuscular mycorrhizal fungal colonization under varying intensities of drought stress. *Sci. Hort.*, 107(3): 245-253.

Tahir, M.H.N. and S.S. Mehid. 2001. Evaluation of open pollinated sunflower (*Helianthus annuus* L.) populations under water stress and normal conditions. *Int. J. Agri. Biol.*, 3: 236-238.

Tahkokorpi, M., K. Taulavuori, K. Laine and E. Taulavuori. 2007. After-effects of drought-related winter stress in previous and current year stems of *Vaccinium myrtillus* L. *Environ. Exp. Bot.*, 61(1): 85-93.

Taylor, B.H. and C.F. Scheuring. 2004. A molecular market for lateral root intiation: The RSI-1 gene of tomato (*Lycopersicon esculentum*) is activated in early lateral root primordial. *Mol. Gen. Genet.*, 243(2): 148-157.

Verma, P.P.S., M.L. Meena and S.K. Meena. 2014. Influence of Plant Growth Regulators on Growth, Flowering and Quality of Tomato (*Lycopersicon esculentum*), cv. H-86. *Ind. J. Hill Farm.*, 27(2): 19-22.

Wang, W., B. Vinocur and A. Altman. 2003. Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. *Planta*, 218(1): 1-14.

Wu, Y. and D.J. Cosgrove. 2000. Adaptation of roots to low water potentials by changes in cell wall extensibility and cell wall proteins. *J. Exp. Bot.*, 51(350): 1543-1553.

Zeid, I.M. and Z.A. Shedeed. 2006. Response of alfalfa to putrescine treatment under drought stress. *Biol. Plant.*, 50(4): 635-648.

Zhang, X., G. Lu, W. Long, X. Zou, F. Li and T. Nishio. 2014. Recent progress in drought and salt tolerance studies in Brassica crops. *Breed. Sci.*, 64(1): 60-73.

Zlatev, Z. and F.C. Lidon. 2012. An overview on drought induced changes in plant growth, water relations and photosynthesis. *Emir. J. Food Agric.*, 21: 57-72.

(Received for publication 14 September 2021)