Pak. J. Bot., 52(6): 1927-1939, 2020. DOI: http://dx.doi.org/10.30848/PJB2020-6(31)

ENHANCING DROUGHT TOLERANCE IN *CAMELINA SATIVA* L. AND CANOLA (*BRASSICA NAPUS* L.) THROUGH APPLICATION OF SELENIUM

ZAHOOR AHMAD[1,2], EJAZ AHMAD WARAICH[3], CELALEDDIN BARUTÇULAR[2], HESHAM ALHARBY[4], ATIF BAMAGOOS[4], FERHAT KIZILGECI[5], FERHAT ÖZTÜRK[6], AKBAR HOSSAIN[7], YOUSRY BAYOUMI[8] AND AYMAN EL SABAGH[9,10*]

[1]*Department of life Sciences, The Islamia University of Bahawalpur, Pakistan*
[2]*Department of Field Crops, Faculty of Agriculture, University of Çukurova, Turkey*
[3]*Department of Agronomy, University of Agriculture Faisalabad, Pakistan*
[4]*Department of Biological Sciences, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia*
[5]*Kiziltepe Vocational School, Mardin Artuklu University, Mardin, Turkey*
[6]*Department of Field Crops, Faculty of Agriculture, University of Sirnak, 73300 Sirnak, Turkey*
[7]*Bangladesh Wheat and Maize Research Institute, Nashipur, Dinajpur 5200, Bangladesh*
[8]*Horticulture Department, Faculty of Agriculture, Kafrelsheikh University, Egypt*
[9]*Department of Field Crops, Faculty of Agriculture, Siirt Univrsity, Turkey*
[10]*Department of Agronomy, Faculty of Agriculture, University of Kafrelsheikh, Egypt*
[*]*Corresponding author's email: ayman.elsabagh@agr.kfs.edu.eg*

Abstract

Considering the burning issue the present study was undertaken in pot culture at the Cholistan Institute of Desert Studies (CIDS), The Islamia University of Bahawalpur, Pakistan for enhancing drought tolerance in two oilseed crops (OC) crops camelina (*Camelina sativa* L.) and canola (*Canola napus* L.) through improving physiological, biochemical, and antioxidants activity by foliar application of selenium (Se) under drought stress. Two Camelina (i.e., 'Australian Camelina' and 'Canadian Camelina') and canola genotypes (i.e., 'AARI Canola' and 'UAF Canola') were used as plant materials during the growing season of 2016. Both Camelina and Canola genotypes were grown under normal (100% FC) and water deficit (drought stress) (40% FC) conditions. Four levels of Se: such as seeds priming with 75μM Se, foliar application of Se at 7.06 μM and foliar Se in combination with seeds priming (7.06 μM & 75μM) along with control were applied at the vegetative stage of both OC crops for screening drought tolerant genotypes. All treatments were arranged three times in a randomized complete block design. Both OC crops were grown upto the maturity and data on physiochemical, antioxidants and yield components were recorded during this study. Results of the present study indicated that the physio-biochemical parameters such as WP (water potential), OP (osmotic potential), TP (turgor pressure), proline, TSS (total soluble sugar), TFAA (total free amino acids), TPr (total proteins) and TS (total sugars); and total chlorophyll contents were improved by foliar application Se along with seed priming by Se in both OC crops in both drought stress and non-stress (control) conditions. Similarly, osmoprotectants such as GB (Glycinebetaine), anthocyanin, TPC (total phenolic contents) and flavonoids; as well as antioxidants such as APX (ascorbate peroxidase), SOD (superoxide dismutase), POD (peroxidase) and CAT (catalase) were also showed better enhancement in both OC crops through foliar application in combination with seed priming with Se (7.06 μM & 75μM) under normal as well as water deficit (drought) conditions. Yield and its components i.e., branches plant^{-1} (no.), 1000-seed weight (g), seed and biological yield (t ha^{-1}) of both OC crops were increased through foliar application in combination with seed priming by Se (7.06 μM & 75μM) under drought and non-drought stress conditions. Both camelina and Canola genotypes categorized based on all the above-mentioned parameters under the water deficit (drought stress) condition and foliar application of Se, the genotype 'Canadian Camelina' maintained the highest values for all these attributes. Therefore, it is revealed that foliar application in combination with seed priming by Se helps to improve drought tolerance of OC crops and also leads to an increase in the productivity of crops under drought stress. Among the genotypes, 'Canadian Camelina' performed the best when seeds of the genotypes were primed with Se in combination with foliar application of Se at the vegetative stage.

Key words: Camelina, Canola, Drought, Antioxidants, Osmoprotectants, Selenium.

Abbreviations: APX, Ascorbate peroxidase; CAT, Catalase; GB, Glycinebetaine; OC, oilseed crops; OP, Osmotic potential; POD; Peroxidase; SeCys, selenocysteine; SeMet, selenomethionine; TPr, Total proteins; SOD, Superoxide dismutase; TFAA, Total free amino acids; TP, Turgor pressure; TPC, Total phenolic contents; TS, Total sugars; TSS, Total soluble sugars; WP, Water potential.

Introduction

Oil crop *Brassica napus* L. is a valuable source of oil (45–50% v/v in the mature seeds) and protein (40% in rapeseed meal) for human and animal nutrition (Nega & Woldes, 2018). It also constitutes a large source of healthy phytochemicals, such as phenols, flavonoids, vitamins, fats, hydroxycinnamic acids, and carotenoids (Száková *et al*., 2017). In addition, stem and leaves of the plant having a high protein and small amount of fiber contents which is also used for animals feed (Kerr *et al*., 2007). The OC crop rape-seed comprises a high amount of C18 fatty acids, including oleic acid (C18:1, 60% v/v), linolenic acid (C18:3, ~10% v/v) and linoleic acid (C18:2, ~30% v/v) (Jahangir *et al*., 2012). Another type of OC crops is Camelina (*Camelina sativa* L.), which is belonged to the Brassicaceae family and widely grown in Pakistan. It is a short duration crop, its life cycle is about 60-90 days and possessing almost 35-45% oil contents in the seed. Recently, BioEnergy News (2010) reported that Camelina feedstock is a superior source of biodiesel for jet and airlines.

Due to climate change, from the last few decades, drought became a serious constraint for sustainable crop production in world-wide including Asia and South-Asia, particularly in the dry regions of Pakistan (Ali *et al*., 2017). Hydrological, meteorological and agricultural droughts cause deficit precipitation in certain regions and pose a significant threat for crop productivity, lead to threatening food security for the increasing population (Wang *et al*., 2012; Hao & Singh, 2015; Zhang *et al*., 2015). Water deficit stress (drought)alters the physiological and biochemical activities of the plant including photosynthesis rate, osmotic potential, turgor pressure and also caused serious damage in the cellular membrane, finally decreased the crop yield (Miao *et al*., 2015). The physiological, agronomical and developments are affected by environmental conditions during different growth stages (Islam *et al*., 2019). However, the production of canola is mostly restricted by drought, which can become critical in climate change (EL Sabagh *et al*., 2019). Therefore, to meet the food security of an increasing population, agricultural productivity can be maximized through mitigating the adverse effect of drought on crop productivity (Madadgar *et al*., 2017).

Under drought stress conditions the stomata of plants' leaf are closed and also the nutrients are unavailable to the plants. Therefore, for enhancing drought tolerance in plants the foliar application of different nutrients are the better way to mitigate the drought stress (EL Sabagh *et al*., 2020). Scientists used various techniques to protect cellular and oxidative damage and regulate enzymatic activities under drought stress conditions (Fahad *et al*., 2019). Se base or foliar fertilization was reported as the current best technology to enhance its accumulation in plants. The Se application has the advantage of proline enhancement (Xiaoqin *et al*., 2009), which enables the plants to overcome drought without influence on water uptake and plant biomass (Hajiboland *et al*., 2015). The foliar application of Se ions easily diffuses to epidermal cells which are transported by xylem and phloem and become the part of the plant body (Boldrin *et al*., 2013). Earlier studies reported that foliar application of Se under drought stress in carrots (Kápolna *et al*., 2009), onion, garlic (Kápolna *et al*., 2012; Põldma *et al*., 2011), cereals, OC crops etc. and got a significant positive result (Boldrin *et al*., 2013; Šindelářová *et al*., 2015). Thus, Se application has the potential to increase nutritional value, grains yields as well as enable plants for abiotic tolerance by starch accumulation in the chloroplast (Mozafariyan *et al*., 2017). Se also regulates various antioxidant enzymes and helps in the metabolic adjustment under drought stress conditions (Hasanuzzaman *et al*., 2011). Se is an essential microelement for human beings and also for animals, but it is not considered to be essential for higher plants, although numerous studies show benefits from Se addition to plants (Lyons *et al*., 2009). The Se acts as a growth regulator, abiotic stress modulator, anti-senescent, antioxidant and defensive molecule against pathogens at low concentrations in plants. Increases in antioxidant enzyme activity associated with applied Se have been observed (Djanaguiraman *et al*., 2010; Száková *et al*., 2017).

While, selenite (IV,VI) are the two major species present in soil and can be efficiently utilized by plants (Zhu *et al*., 2009). Plants take up selenate via S transporters and assimilate it into selenocysteine (SeCys) and selenomethionine (SeMet) that perform different roles in the plant (Ellis & Salt, 2003). (Klognerová *et al*., 2015) determined the Se compounds in Se-fortified and control oilseed rape plants, where SeMet was identified in the fortified plants. In the defatted oilseed rape meal, the predominant Se compound was SeMet (Seppänen *et al*., 2010).

Although, Se helps to reduce the effect of different environmental stresses induced in plants via drought, salinity, cold, intensive light, waterlogging and heavy metals toxicity (Djanaguiraman *et al*., 2010; Feng *et al*., 2010; Hasanuzzaman *et al*., 2011, 2012; Kaur *et al*., 2014). However, at high concentrations (>1 mg kg^{-1}), Se causes numerous toxicity symptoms which include chlorosis, withering, stunted growth, leaves drying, reduction in protein synthesis, premature and even show death in plants (Kaur *et al*., 2014). Drahoňovský *et al*., (2016) reported ambiguous changes in essential element contents in selenized wildlife plants. In the case of crops, various changes in the nutrient contents in wheat, oilseed rape, and broccoli after Se supplementation were observed (Filek *et al*., 2010; Šindelářová *et al*., 2015). Considering the burning issue of drought and to mitigate its adverse effect to meet the food security of the increasing population, a pot culture research was carried out for enhancing drought tolerance in two OC crops camelina (*Camelina sativa* L.) and canola (*Canola napus* L.) through improving physiological, biochemical, and antioxidants activity by foliar application of Se under drought stress.

Materials and Methods

Location and duration of the research: During the growing season of 2016, two OC crops crops' genotypes such as Camelina ('Canadian Camelina' and 'Australian Camelina') and Canola ('UAF Canola' and 'AARI Canola') were grown in a pot at the Cholistan Institute of Desert Studies (CIDS), The Islamia University of Bahawalpur, Pakistan.

Plant materials, treatments, and Design: Two OC crops' genotypes: Camelina ('Canadian Camelina' and 'Australian Camelina') and Canola ('UAF Canola' and 'AARI Canola') were used as experimental materials. Before sowing seeds were sterilized and rinsed with distilled water. The primed OC crops of both oil crops' genotypes (5.1 mg L^{-1} Se solution) were sown in pots containing 500g dried sand. Both Camelina and Canola genotypes were grown under normal (100% FC) and water deficit (drought stress) (40% FC) conditions. Four levels of Se such as Se priming @ 75µM, foliar Se @ 7.06 µM and foliar Se with priming (7.06 µM & 75µM) along with control were applied at the vegetative stage of both OC crops for screening drought tolerant genotypes. All treatments were arranged three times in a randomized complete block design. Irrigation was applied according to soil field capacity and fertilized by the recommended dose of NPK before sowing. The pots were separated into sets after completion of the germination stage. One set was kept under water stress at 40% field capacity and other without water stress. The Se @ 7.06 μM (0.48 mg L^{-1}) was applied as foliar at the vegetative stage and maintained up to one week.

Data collection: Data on chlorophyll content, physio-biochemical parameters, osmoprotectants and antioxidants concentration, and yield components were recorded from two OC crops grown under the pot culture. The physio-biochemical parameters such as WP (water potential), OP (osmotic potential), TP (turgor pressure), Pro (proline), TSS (total soluble sugar), TFAA (total free amino acids), TPr (total proteins) and TS (total sugars); and total chlorophyll contents were recorded. The concentration of several osmoprotectants such as GB (glycine betaine), anthocyanin, TPC (total phenolic contents) and flavonoids; as well as antioxidants such as APX (ascorbate peroxidase), SOD (superoxide dismutase), POD (peroxidase) and CAT (catalase). Besides these, yield and its components such as branches plant^{-1} (no.), 1000-seed weight (g), seed and biological yield (t ha^{-1}) were also recorded according to the following procedure:

Water relations parameters: The Scholander type pressure chamber was used to obtain water potential. For that parameter top, 3rd leaf was selected from every treatment and then frozen it at -20°C followed by Nawaz *et al*., (2015) method. After that turgor potential (ψp) was calculated by using this formula:

$$(\psi p) = (\psi w) - (\psi s) \qquad (1)$$

where, (ψp), turgor potential; (ψs), osmotic potential and (ψw), water potential.

Determination of physio-biochemical parameters: The biochemical parameters such as TSS, TSP, TFAA contents, and Pro contents of leaf were investigated as per the following protocols prescribed by Rosni *et al*., (2015); Abdel Latef & Tran (2016); Cao *et al*., (2017); Sood *et al*., (2017).

Measurement of chlorophyll contents: For leaf chlorophyll contents measurements, the SPAD-502 instrument was used as described by Ehsanzadeh *et al*., (2009).

Measurements of osmoprotectants and total phenolic contents: The ground tissues were oven-dried and then soaked in 10ml solution containing methanol, water, HCl in (79: 20: 1 v/ v) ratio followed by continuous shaking for 72 hours at 0°C in dark condition. The extracts were centrifuged after that absorbance was accomplished at 530 and 657 nm (Ribera-Fonseca *et al*., 2018). Rayleigh's formula was used for absorbance reading correction.

Corrected A530 = A530 – 1/3 A657 where, A530 reading obtained at 530 nm, similarly A657 obtained reading at 657 nm.

Anthocyanins (Zhao *et al*., 2017) and flavonoid content (Wang *et al*., 2017) were also calculated. For flavonoid content measurement 0.5 mL sample volume was incubated in 0.5 mL of $AlCl_3$ solution (2% in absolute ethanol) for one hour at room temperature. The absorbance was calculated at 420 nm and after that flavonoid content was measured in relation to equivalent Quercetin as a reference to the standard curve.

For GB measurements, 1g fresh leaf material from Camelina was taken followed by ground in 10mL ultra-pure water, after that 1mL extract was used and acidified in 1mL HCL (2N). Then 0.5mL was taken from acidified solution in a test tube which contained 0.2mL of I_3K (potassium tri-iodide) solution followed by ice bath shaking for 90 minutes. Then, a solution containing chilled ultra-pure water and 1, 2 dichloroethane was introduced in that mixture. Stream air was passed in a duration of 1- 2 minutes for blending double layer. The double beam Spectrophotometer (Hitachi-150-20, Japan) was used to determine the organic layer and then the standard curve figured out the glycine betaine concentrations (Salama *et al*., 2015).

For determination of soluble phenols, 1g leaf sample was ground in (10mL) 80% acetone and then centrifuged it at 4000 rpm for 10 minutes time duration. After that 20 μL of centrifuged material, 1.58 mL distilled water, Folin-Ciocalteu reagent 100 μL and sodium carbonate 300 μL solution were taken in a test tube then kept this mixture for 30 minutes at 40°C. Then absorbance of the respective sample was determined at 765 nm and calibration curve used for phenolic level measurement (Rosni *et al*., 2015).

Assay of antioxidant enzyme extraction: Spectrophotometrically techniques were used to determined antioxidants like APX, CAT, SOD, and POD. Ahmad & Haddad (2011) technique was used for antioxidants enzymes analysis, while for APX and SOD, Ahmad *et al*., (2017) and for CAT and POD analysis Cao *et al*., (2017); Mozafariyan *et al*., (2017) methods were used.

Yield and yield-related components: The branches per plant and 1000 grains weight from each replication were recorded. However, the total yield and biomass of each pot were also determined and then transferred that weight into tons ha^{-1} by conversion method.

Statistical analysis: Data were statistically analyzed by using MSTAT-C software (Russell, 1986). The significant difference among all means value was measured by using LSD (Least Significance Difference Test) test with 5% probability level (R Core Team, 2013).

Results

Improvement of physiological parameters through the application of Se in drought stress: Morphological characteristics of any plant, exhibit that plant is either healthy or under stress condition. In this study, different plant growth parameters were measured under water stress and control conditions and also measured after the foliar application of Se supplement. It was observed that a highly significant difference was observed among all the treatment combinations both under drought and non-stress conditions (Fig. 1). In general, the reduction in growth and development was observed when plants were grown in water deficit (drought stress) conditions. Among the genotype, 'Canadian Camelina' showed the highest chlorophyll contents under non-stress conditions, while maximum and minimum photosynthetic rate were measured in genotypes 'Australian Camelina' and 'AARI Canola' respectively under drought stress conditions. However, foliar application of Se in combination with Se at priming treatment had a positive impact on the photosynthetic rate in all genotypes both in drought and non-stress conditions.

Water relation parameters varied due to application of Se under drought stress: In the case of water potential, the maximum and non-significant difference were observed among all control plants under both normal and drought stress (water deficit) conditions. While, under the drought stress, seeds priming with Se, foliar Se and foliar application of Se in combination with seeds priming with Se showed the almost similar and positive result on water potential ability of plants. The maximum osmotic potential was observed only in control plants under the non-stressed conditions. Whereas, the non-significant difference was observed among all treatments as compared to control under the drought stress condition. Low turgor pressure was observed in all control plants under non-stress conditions. Under the same condition, foliar application of Se and foliar Se + seeds priming with Se treatments have a similar and positive effect in the genotypes 'Canadian Camelina' and 'Australian Camelina'. Considering both Canola genotypes, only the simultaneous application of foliar spray of Se and seeds priming with Se has a positive effect on the turgor pressure of water (Fig. 1). Therefore, it is confirmed that under drought stress condition Camelina genotypes showed the highest turgor pressure as compared to Canola genotypes (Fig. 1).

The biochemical process of two OC crops varied due to application of Se in drought stress: These results indicate that significant values among all measured non-enzymatic antioxidant parameters and non-significant results were observed in the combination of V × S × T. While, highly significant variations were observed for different genotypes and treatments. Significant variations could be found due to different genotypes and the application of different levels of Se under drought stress and non-stress conditions (Fig. 2). Among treatments, foliar application of Se in combination with seeds priming with Se showed the increasing level of proline content under both normal and water-deficit stress conditions. While minimum proline content in dry weight of plant biomass was observed in all control plants. In the case of TSS, both genotypes of Camelina showed the highest TSS per gram of fresh weight under all levels of treatment except control. While under drought stress, the highest TSS was found in the genotype 'Canadian Camelina' by the simultaneously applied Se i.e foliar and priming. Moreover, both Canola genotypes exhibited non-significant results among all treatments under both normal and drought stress conditions. While, in terms of total protein, the maximum protein content was observed in 'Canadian Camelina' and 'UAF Canola' followed by 'AARI Canola' and 'Australian Camelina' under both conditions. Accordingly, minimum protein content was measured in all control genotypes under both conditions (Fig. 2). Maximum total sugar content was found in both Camelina genotypes under the stress condition as compared to control and non-stressed condition. While the genotype 'UAF Canola' showed the non-significant effect on the sugar content of all treatments under stressed and non-stressed conditions. Another Canola variety ('AARI Canola') showed a significantly increased level of sugar content through the simultaneous application of Se (foliar Se + seed priming Se). While the non-significant difference was found when Se applied alone as foliar or as seeds priming (Fig. 2).

Osmoprotectants and total phenolic contents of two OC crops varied due to application of Se under drought stress: Osmoprotectants and total phenolic contents of two OC crops varied due to the application of Se under drought stress showed a different level of significance. While, all treatments had a highly significant effect on gibberellins, total Phenolic contents, anthocyanin and flavonoids production under both stress and non-stressed conditions as compared to control. Under the non-stress condition, foliar application of Se with its different combination enhanced the production of the primary hormone in the plant. While, in drought stress condition, foliar application of Se + seeds priming with Se increased the production of Gibberellins hormone among all genotypes as compared to control and other treatments. The highest TPC/gm was produced in both Camelina genotypes under both stress and non-stressed conditions. While in Canola genotypes significant difference was observed under both conditions. In the case of the production of plant pigments such as anthocyanin and flavonoids, a significant difference was observed for both Camelina and Canola genotypes. Under the non-stress condition, all treatments had a positive effect on the production of anthocyanin in genotype 'Canadian Camelina'. Similarly, an increased level of anthocyanin pigment was observed in 'Canadian Camelina' genotype under the drought stress condition; the remaining three genotypes exhibited almost the similar production of anthocyanin under the stress condition. According to the production of flavonoids pigment, non-significant results were found for all genotypes under stress and non-stress conditions (Fig. 3).

Antioxidants and osmoprotectants activity of two OC genotypes varied due to application of Se under drought stress condition: Water deficit stress tolerance may depend, at least in part, on the improvement of the antioxidative defense mechanism, which includes antioxidant compounds and many other antioxidant enzymes. In the present study, APX and SOD-enzymes significantly and actively produced under the stress condition among all genotypes and treatments as compared to control. Maximum APX and SOD-enzymes activity were recorded in genotype 'Canadian Camelina' and 'UAF Canola' under the drought stress condition. While genotype 'Australian Camelina' and 'AARI Canola' genotypes showed a similar response in favor of APX and SOD enzyme production under drought stress. Data on the increased level of POD and Catalase enzymes were also observed in the genotype 'Canadian Camelina' and 'UAF Canola' genotypes under both stressed and non-stressed conditions as compared to control (Fig. 4).

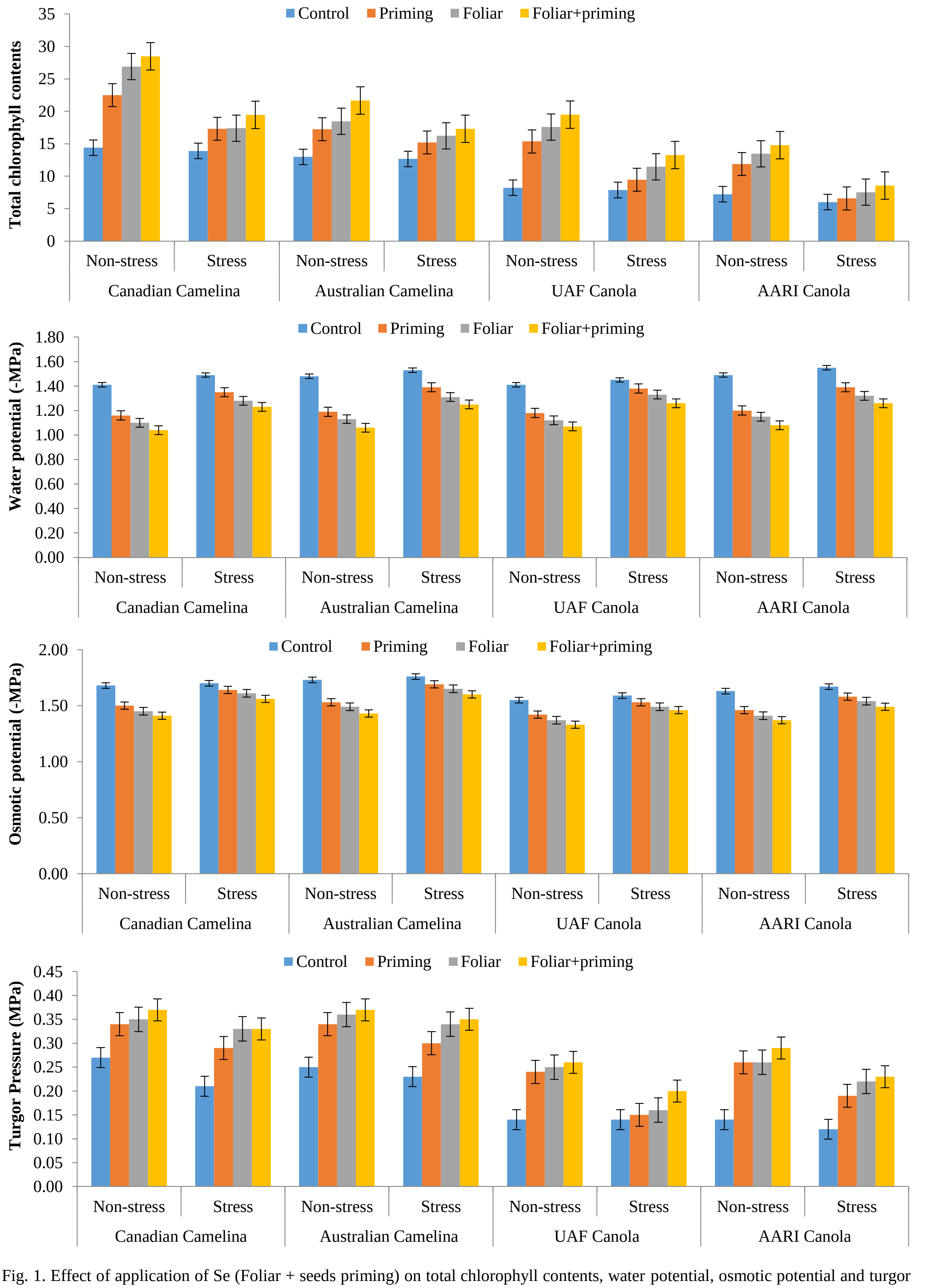

Fig. 1. Effect of application of Se (Foliar + seeds priming) on total chlorophyll contents, water potential, osmotic potential and turgor pressure of Camelina and Canola genotypes under normal and water-deficit stress conditions. ± SE in each bar was calculated from three replication for each value.

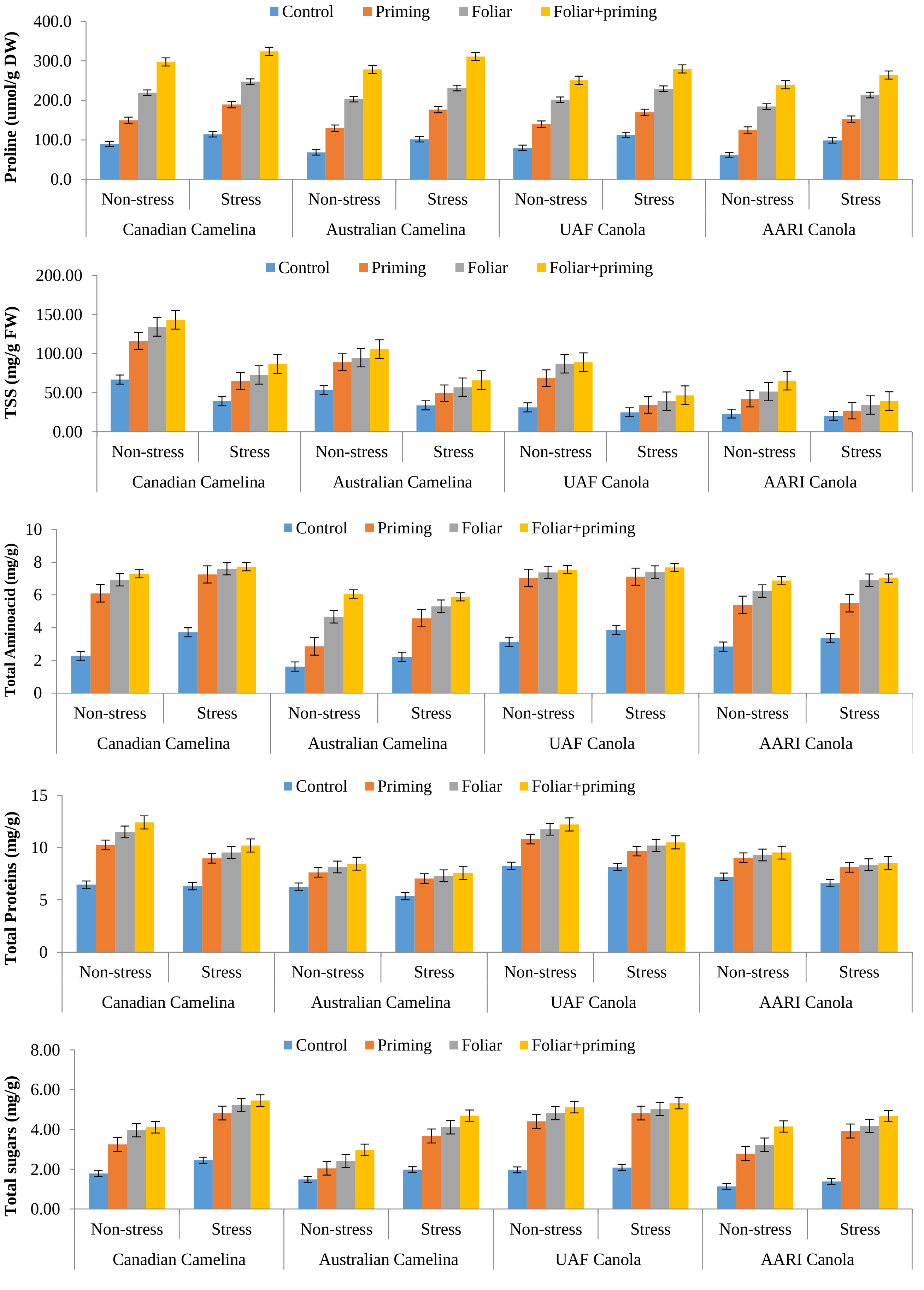

Fig. 2. Effect of application of Se (Foliar + Seeds priming) on proline, TSS, total amino acids, total proteins and total sugars of Camelina and Canola genotypes under normal and water-deficit stress conditions.

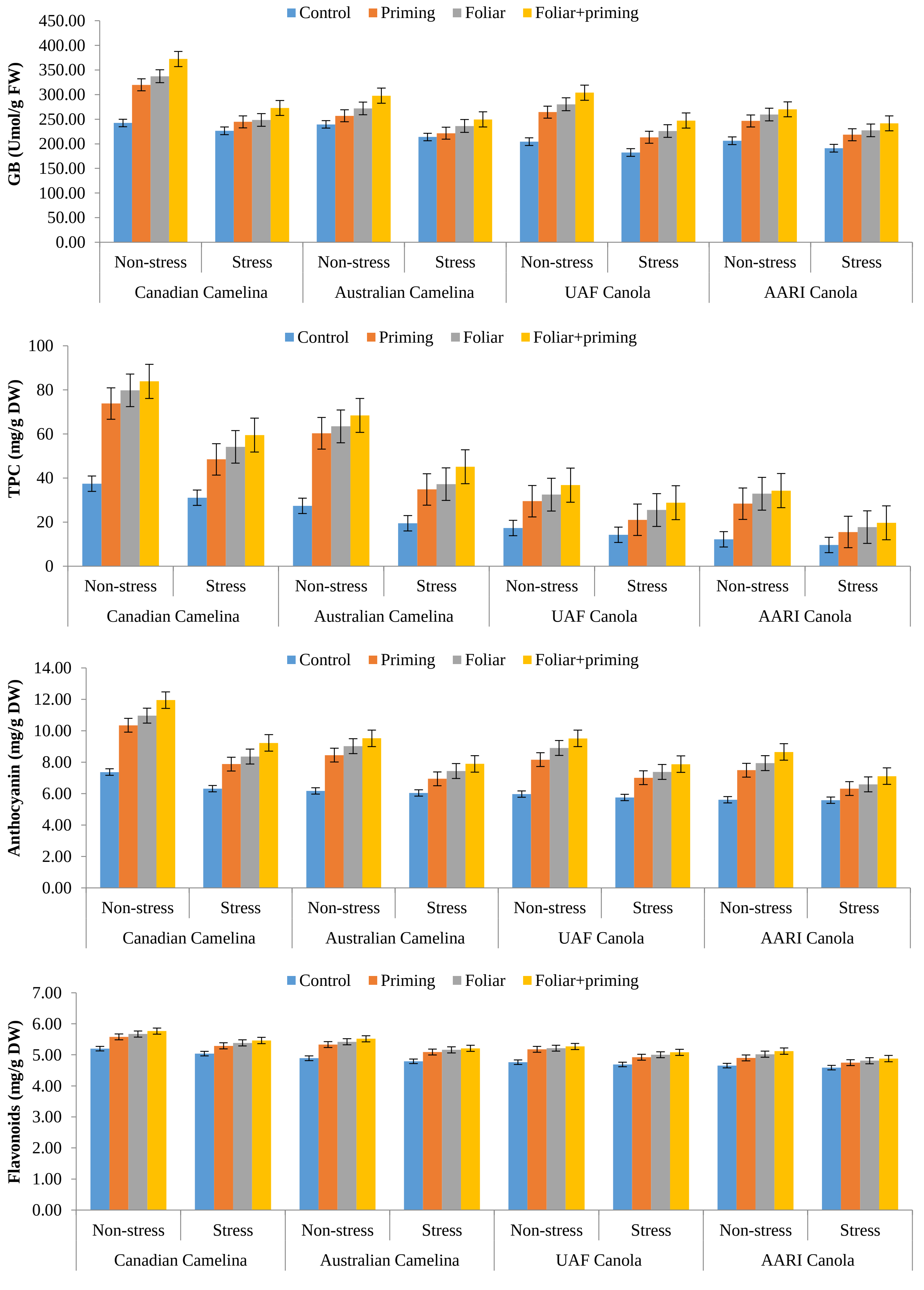

Fig. 3. Effect of application Se (Foliar + Seeds primed) on GB, TPC, anthocyanin and flavonoids of Camelina and Canola genotypes under normal and water-deficit stress conditions. ± SE in each bar was calculated from three replication for each value.

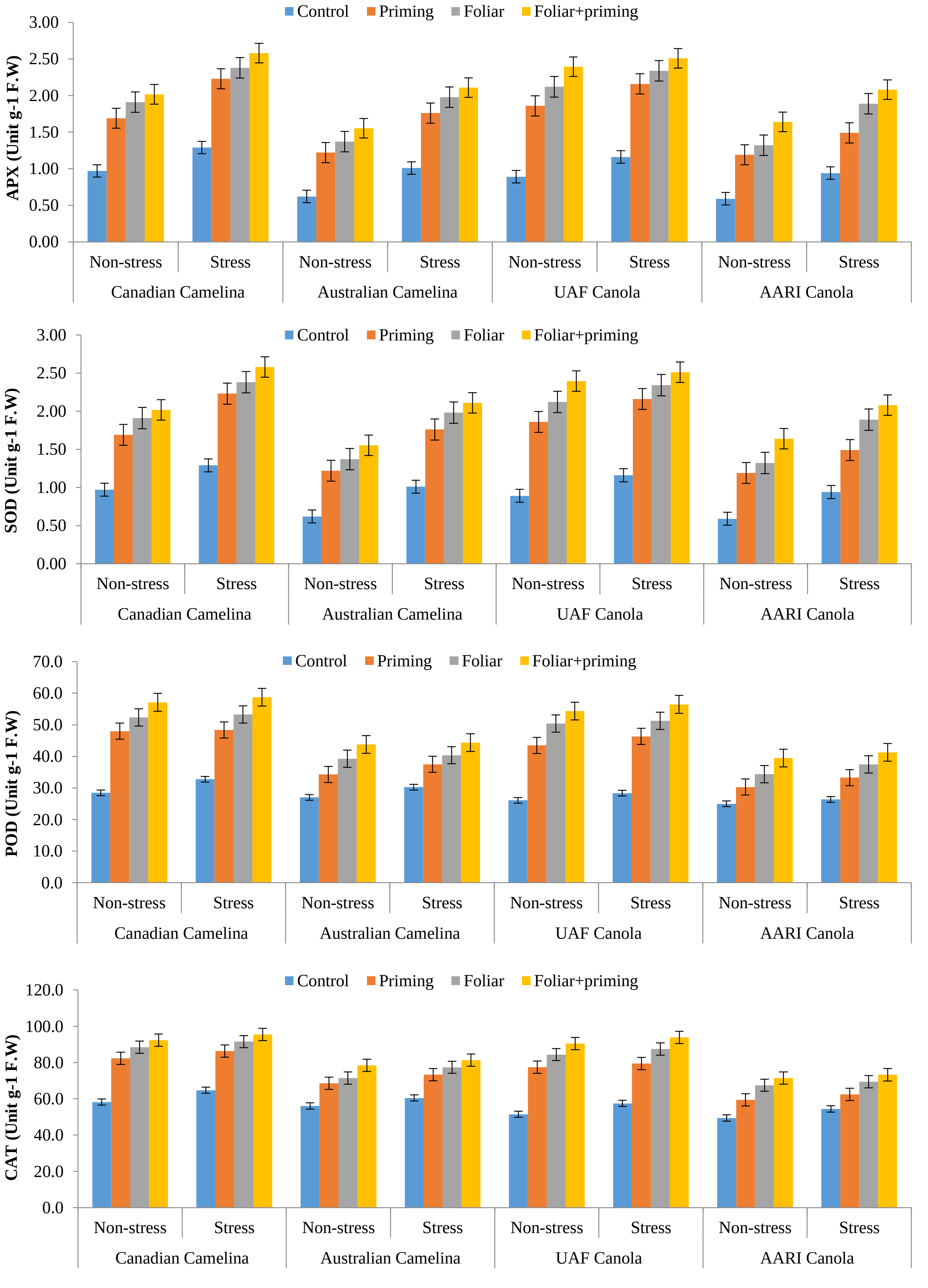

Fig. 4. Effect of application of Se (Foliar + Seeds priming) on APX, SOD, POD and CAT of Camelina and Canola genotypes under normal and water-deficit stress conditions. ± SE in each bar was calculated from three replication for each value.

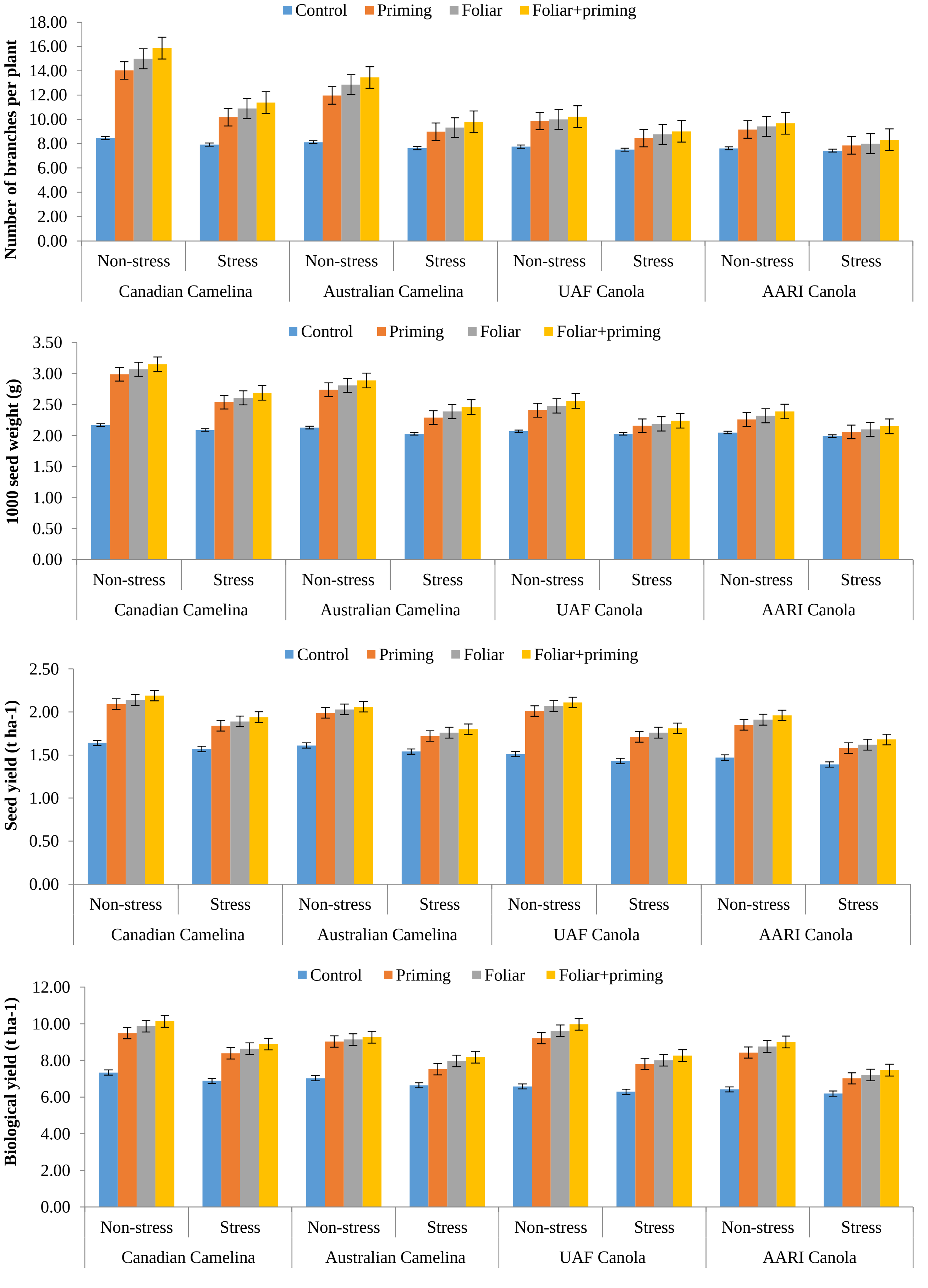

Fig. 5. Effect of application of Se (Foliar + Seeds priming) on branches plant^{-1}, 1000-seed weight, seed yield and biological yield of Camelina and Canola genotypes under normal and water-deficit stress conditions. ± SE in each bar was calculated from three replication for each value.

Yield parameters: Yield traits are good indicators under the stress conditions. By these parameters, we can easily categorized plants are resistant or susceptible or tolerant against stress conditions. In the present study, significant variations ($p \leq 0.01$) between the plant growth and yield parameters were observed due to the selection of genotypes and stress levels. Among the genotypes, Camelina genotypes exhibited the maximum branches plant^{-1}both under the drought stress and non-stress condition at all levels of Se treatments. Whereas, significantly the highest branches plant^{-1}was recorded at treatment four (foliar application of Se + seeds priming with Se). It was confirmed that water deficit condition significantly reduced seed weight, yield and biological yield in control plants or without sprayed plants. In the case of Canola genotypes, no-significant was found for 1000-seed weight. However, the maximum 1000-seed weight among all genotypes under non-stress and drought stress conditions were recorded from the genotype 'Canadian Camelina' (Fig. 5). Similarly, the maximum seed yield and biological yield were also observed from the genotype 'Canadian Camelina' followed by 'UAF Canola'; while the minimum was recorded from 'AARI Canola' under the water deficit stress condition (Fig. 5). Both Camelina and Canola genotypes categorized based on all above-mentioned parameters under the water deficit (drought stress) condition and foliar application of Se, the genotype 'Canadian Camelina' maintained the highest values for all these attributes.

Discussion

In the present search, OC crops of Camelina and Canola crops exhibited significant improvement in water relation parameters such as water potential (Ψw), turgor pressure and osmotic potential under both control and water-limited stress conditions when seeds of all genotypes were primed with Se and foliar application of Se at vegetative stage. Water retention of the plant tissues was significantly enhanced to the uptake of water by roots without declining the transpiration rate (E) by the Se application (Kuznetov *et al*., 2003). The Ψw was least negative (-ve) at tillering stage with fertigation and foliar-applied Se at 75 µM and 7.06 µM respectively. The data in the present study revealed that the exogenous application of Se increased the Ψw, the information has also confirmed the results of Germ *et al*., (2007). Likewise, a significant rise in water use efficiency (WUE), biological and economical yield of the maize crop was seen through the foliar-applied of Se by Sajedi *et al*., (2009). The addition of Se in plant growing media enhances leaf Ψw of maize under severe water deficit conditions also reported by Qiang-yun *et al*., (2008).

The concentrations of anthocyanin and flavonoids color pigments of plant moderately reduced under water-limited stress. It is suggested that leaf desiccation affects the synthesis of anthocyanins and flavonoids pigments more than that of Chlorophyll (Chl) contents. The effect of Se on maize leaf pigments was clearly seen for flavonoids and anthocyanins. Wahid & Shabbir (2005) reported that a high concentration of anthocyanins supposed to protect the cellular structures from oxidative damages. Correspondingly, Fini *et al*., (2011) stated that the involvement of flavonoids to the antioxident defense mechanism and its importance in plant responses to drought have been widely accepted. Plant pigments especially Chl'a', Chl 'b' and total Chl contents are essential to sustain optimum photosynthetic activity (Nageswara *et al*., 2001). Water deficit stress checks the net photosynthesis rate by declining the Chl contents and damages photosynthetic mechanisms (Iturbe *et al*., 1998). The outcomes of our study related to the more reduction were noticed in total chlorophyll contents under drought stress also confirmed by earlier studies, who showed that the water deficit stress causes reduction of Chl contents in various crop plants such as wheat (Fotovat *et al*., 2007; Sajedi *et al*., 2015), sunflower (Manivannan *et al*., 2007), corn (Khayatnezhad *et al*., 2011) and chickpea (Mafakheri *et al*. 2010). Reactive oxygen species decrease the leaf Chl contents by damaging the chloroplasts (Smirnoff, 1995 and Ommen *et al*., 1999). The results of our findings also confirmed the results that Se seed treatment with foliar application resulted in higher leaf chl contents in both the crops such as Camelina and canola under control and water-limited conditions. The plants of the Camelina and Canola crops also sustained maximum Chl contents due to Se supply at both stages such as vegetative and reproductive. In contrast drought stress significantly declined the Chl contents at later growth stages (vegetative and reproductive stage) in rape-seed plants reported by Kumar & Paul (1997). Seed priming with Se in combination with foliar application of Se revealed that the maximum increase in leaf Chl contents in Camelina and canola under both normal and limited water conditions.

In our case, maximum TSS accumulation at vegetative stage under drought stress in priming and Se foliar treatments which is confirmed by previous studies, who reported that TSS accumulation under drought stress in various crops such as rice, wheat, and soybean (Mostajeran & Rahimi-Eichi, 2009; Akladious, 2012; Liu *et al*., 2011). TSS was increased by supplementation of Se in pear jujube, soybean, canola and potato (Zhao *et al*., 2013). Nawaz *et al*., (2013) indicated that TSS increased in wheat crop seeding due to seed priming in water deficit conditions. In addition to TSS, there was a remarkable increase in TSP and TFA observed by Se seed priming. Djanaguiraman *et al*., (2004) conducted research to support the above findings and declared that TSP enrichment of Se treated plants is the result of enhancement in nitrate reductase and TFA (total free amino acids) contents. Zhao *et al*., (2013) observed, 48-52% TSP increased by Se foliar in the jujube plant. Gowily *et al*., (1996) and Wu (1998), declared that increment of TFA concentration by Se is the result of amino acid metabolism disturbance which might be increased protein soluble contents and activity of nitrate reductase (Djanaguiraman *et al*., 2004). While, TFA accumulation is helpful for osmotic adjustment in the plant under water deficit conditions (Hsu & Kao, 2003) and it's verified by the current study.

However, proline is an important antioxidant enzyme which restricts the protein biosynthesis reduction under water stress condition (Cechin *et al*., 2008) and it might be used as stress tolerance selection criteria (Jaleel *et al*., 2007). It is the well reputable fact that proline contents increased by Se application in adverse conditions like cold, salinity and heavy metals toxicity stress (Abbas, 2012). In the present study, considerably proline content was increased in both selected genotypes in comparison with control plants. Obtained results are highly consistent with Yao *et al*., (2009) findings who obtained high proline contents by Se application in wheat-seedling water scarcity and Kuznetov *et al*., (2003) also detected 2-4 folds of proline enhancement in Se treated plants.

Under drought stress conditions, the ROS production enables plants to produce less molecular weight antioxidants to overcome the detrimental effects of ROS such as CAT, APX, SOD and POD (Asada, 2006). In the present study, alike results were achieved towards antioxidants activity improvement in Se foliar with priming treatments of both OC crops genotypes under applied stress. Yao *et al*., (2009) observed antioxidants increment in wheat and Habibi (2013) barley by Se application to overcome ROS species damage in drought stress.

Contradiction presents in previously published reports about Se application towards plant growth, development, and yield. Djanaguiraman *et al*., (2004) and Wang *et al*., (2013) reported that the growth and yield of rice, potato, lettuce and soybean increased by Se application. Yang *et al*., (2003) were found non-significant results by Se application on soybean growth and yield, whereas the decline in potato growth was also observed in Se treated plants (Germ *et al*., 2007). In our research, we noticed a remarkable increase in all yield-related components of canola and Camelina by foliar Se application plus seed priming. Our findings are highly compiled with Curtin *et al*., (2006) who stated that Se foliar application is more effective as compared to soil fertilization because Se ions diffuse more easily to epidermal cells which enhance its effectiveness towards growth and yield (Wójcik, 2004). However, the higher application rate of Se can cause leaf damage (Mozafariyan *et al*., 2017) which results in the reduction in metabolic activities and hence finally affects plant growth and yield.

Conclusions

This paper summarizes that all physicochemical parameters such as WP, OP, TP, Proline, TSS, TFAA, TPr and TS; and total chlorophyll contents as well as osmoprotectants and antioxidants such as GB, anthocyanin, TPC and flavonoids; APX, SOD, POD and CAT of both OC crops crops' genotypes were improved by foliar application Se in combination with seed priming by Se (7.06 µM & 75µM) under both drought stress and non-stress (control) conditions. Correspondingly, yield and its components i.e., branches plant^{-1} (no.), 1000-seed weight (g), seed and biological yield (t ha^{-1}) of both OC crops were improved through foliar application in combination with seed priming by Se (7.06 µM & 75µM) under drought and non-drought stress conditions. Considering on genotypes, 'Canadian Camelina' performed the best when seeds of the genotypes were primed with Se in combination with foliar application of Se at vegetative stage.

Acknowledgements

This research work funded by the HEC, Pakistan. The authors gratefully appreciated the Higher Education Commission (HEC) of Pakistan for funding this project under the SRGP program during IPFP.

References

Abbas, S.M. 2012. Effects of low temperature and selenium application on growth and the physiological changes in sorghum seedlings. *J. Stress Physiol. Biochem*., 8(1): 268-286.

Abdel Latef, A.A. and L.S.P. Tran. 2016. Impacts of priming with silicon on the growth and tolerance of maize plants to alkaline stress. *Front. Plant Sci.,*7(3): 1-10.

Ahmad, S.T. and R. Haddad. 2011. Study of silicon effects on antioxidant enzyme activities and osmotic adjustment of wheat under drought stress. *Czech J. Genet. Plant Breed*., 47(1): 17-27.

Ahmad, Z., E.A. Waraich, R. Ahmad and M. Shahbaz. 2017. Modulation in water relations, chlorophyll contents and antioxidants activity of maize by foliar phosphorus application under drought stress. *Pak. J. Bot.*, 49(1): 11-9.

Akladious, S.A. 2012. Influence of different soaking times with selenium on growth, metabolic activities of wheat seedlings under low temperature stress. *African J. Biotech.*, 11(82): 14792-14804.

Ali, S., Y. Liu, M. Ishaq, T. Shah, Abdullah, A. Ilyas and I.U. Din. 2017. Climate change and its impact on the yield of major food crops: Evidence from Pakistan. *Foods*., 6(39): 1-19.

Asada, K. 2006. Production and scavenging of reactive oxygen species in chloroplasts and their functions. *Plant Physiol.*, 141(2): 391-396.

BioEnergy News. 2010. Camelina biofuel powers US Navy F/A-18 test flight.

Boldrin, P.F., V. Faquin, S.J. Ramos, K.V.F. Boldrin, F.W. Ávila and L.R.G. Guilherme. 2013. Soil and foliar application of selenium in rice biofortification. *J. Food Compos Anal*., 31(2): 238-44.

Cao, B., Li, L. Wang; S. Gao, J. Xia and K. Xu. 2017. Silicon-mediated changes in radial hydraulic conductivity and cell wall stability are involved in silicon-induced drought resistance in tomato. *Protoplasma*., 254(6): 2295-304.

Cechin, I., N. Corniani, D.F.F. Terezinha and A.C. Cataneo. 2008.Ultraviolet-B and water stress effects on growth, gas exchange and oxidative stress in sunflower plants. *Rad. Environ. Biophy*., 47(3): 405-413.

Curtin, D., R. Hanson, T.N. Lindley and R.C. Butler. 2006. Selenium concentration in wheat (*Triticum aestivum*) grain as influenced by method, rate, and timing of sodium selenate application. NZL. *J. Crop Hortic. Sci.*, 34: 329-339.

Djanaguiraman, M. and P.V.V. Prasad. 2010. Seppanen, M. Selenium protects sorghum leaves from oxidative damage under high temperature stress by enhancing antioxidant defense system. *Plant Physiol. Biochem*., 48(12): 999-1007.

Djanaguiraman, M., D.A.K. Devi, A. Shanker, J. Annie Sheeba and U. Bangarusamy. 2004. Impact of selenium spray on monocarpic senescence of soybean (*Glycine max* L.). *Food Agri. Environ*., 2(2): 44-47.

Drahoňovský, J., J. Száková, O. Mestek, J. Tremlová, A. Kaňa and J. Najmanová. 2016. Selenium uptake, transformation and inter-element interactions by selected wildlife plant species after foliar selenate application. *Environ. Exp. Bot*., 125: 12-9.

Ehsanzadeh, P., M.S. Nekoonam, J.N. Azhar, H. Pourhadian and S. Shaydaee. 2009. Growth, chlorophyll, and cation concentration of tetraploid wheat on a solution high in sodium chloride salt: Hulled versus free-threshing genotypes. *J. Plant Nutr*., 32(1): 58-70.

EL Sabagh, A., A. Hossain, C. Barutçular, M.S. Islam, D. Ratnasekera, N. Kumar, R.S. Meena, H.S. Gharib, H. Saneoka and J.A. Teixeira da Silva. 2019. Drought and salinity stress management for higher and sustainable canola (*Brassica napus* L.) production: a critical review. *Aust. J. Crop Sci*., 13(01): 88-97.

EL Sabagh, A., A. Hossain, M.S. Islam, C. Barutcular, D. Ratnasekera, O. Gormus, K. Amanet, M. Mubeen, W. Nasim, S.Fahad and M. Tariq. 2020. Drought and heat stress in cotton (*Gossypium hirsutum* L.): Consequences and their possible mitigation strategies. In: (Ed.): Hasanuzzaman, M. Agronomic Crops. Springer, Singapore.

Ellis, D.R. and D.E. Salt. 2003. Plants, selenium and human health. Vol. 6, *Current Opinion in Plant Biology*, 273-9.

Fahad, S., A. Ullah, U. Ali, E. Ali, S. Saud, K. Rehman and V. Turan. 2019. 7 Drought tolerance in plantsrole of phytohormones and scavenging system of ROS. Plant Tolerance to Environmental Stress: Role of Phytoprotectants.

Feng, J., Q. Shi, X. Wang, M. Wei, F. Yang and H. Xu. 2010. Silicon supplementation ameliorated the inhibition of photosynthesis and nitrate metabolism by cadmium (Cd) toxicity in *Cucumis sativus* L. *Sci Hortic*. (Amsterdam)**.,** 123(4): 521-30.

Filek, M., M. Zembala, A. Kornaś, S. Walas, H. Mrowiec and H. Hartikainen. 2010. The uptake and translocation of macro- and microelements in rape and wheat seedlings as affected by selenium supply level. *Plant Soil*., 336(1): 303-12.

Fotovat, R., M. Valizadeh and M. Toorehi. 2007. Association between water-use-efficiency components and total chlorophyll content (SPAD) in wheat (*Triticum aestivum* L.) under well-watered and drought stress conditions. *J. Food. Agric. Environ.*, 5: 225-227.

Germ, M., V. Stibilj, J. Osvald and I. Kreft. 2007. Effect of selenium foliar application on chicory (*Cichorium intybus* L.). *J. Agri. Food Chem*., 55: 795-798.

Gowily, A.M., M.B. Mahmoud, M.F. Abdel-Lateef, A.A.Razak and T.E. Ramadan. 1996. Influence of selenium, TBZ and their mixture on metabolic activities of some fungi. *African J. Mycol. Biotechol*., 4: 45-56.

Habibi, G. 2013. Effect of drought stress and selenium spraying on photosynthesis and antioxidant activity of spring barley. *Acta agri. Slov.*, 101-1: 31-39.

Hajiboland, R., N. Sadeghzadeh, N. Ebrahimi and B. Sadeghzadeh. 2015. Influence of selenium in drought-stressed wheat plants under greenhouse and field conditions. *Acta agri. Sloven*., 175-91.

Hao, Z. and V.P. Singh. 2015. Drought characterization from a multivariate perspective: A review. *J Hydrol*., 527: 668-78.

Hasanuzzaman, M., M.A. Hossain and M. Fujita. 2011. Selenium-induced up-regulation of the antioxidant defense and methylglyoxal detoxification system reduces salinity-induced damage in rapeseed seedlings. *Biol. Trace Elem. Res*., 143(3): 1704-21.

Hasanuzzaman, M., M.A. Hossain and M. Fujita. 2012. Exogenous selenium pretreatment protects rapeseed seedlings from cadmium-induced oxidative stress by upregulating antioxidant defense and methylglyoxal detoxification systems. *Biol. Trace Elem. Res.,* 149(2): 248-61.

Hsu, Y.T. and C.H. Kao. 2003. Changes in protein and amino acid contents in two cultivars of rice seedlings with different apparent tolerance to cadmium. *Plant Growth Reg*., 40: 147-155.

Islam, M.R., C. Barutcular, F. Çig, A. El Sabagh, M.A. Alam, M.M. Kamal, R. Zaman, A. Hossain, H. Alharby, A. Bamagoos and M. Farooq. 2019. Assessing impact of thermal units on growth and development of mustard varieties grown under optimum sown conditions. *J. Agrometeorology*, 21(3): 270-281.

Iturbe, O.I., P.R. Escuredo, C. Arrese-Igor and M. Becana. 1998. Oxidative damage in pea plants exposed to water deficit or paraquat. *Plant Physiol*., 116: 173-181.

Jahangir, M., I.B. Abdel-Farid, S. Simoh, H.K. Kim and R.C.Y. Verpoorte. 2012. Investigation of brassica biochemical status by NMR-based metabolomics. *Acta Hort*., 936: 163-172.

Jaleel, C.A., R. Gopi, P. Manivannan and R. Panneerselvam. 2007. Antioxidative potentials as a protective mechanism in *Catharanthus roseus* (L.) G. Don. Plants under salinity stress. *Turkish J. Bot.*, 31: 245-251.

Kápolna, E., K.H. Laursen, S. Husted and E.H. Larsen. 2012. Bio-fortification and isotopic labelling of Se metabolites in onions and carrots following foliar application of Se and 77Se. *Food Chem*., 133(3): 650-7.

Kápolna, E., P.R. Hillestrøm, K.H. Laursen, S. Husted and E.H. Larsen. 2009. Effect of foliar application of selenium on its uptake and speciation in carrot. *Food Chem.,* 115(4): 1357-63.

Kaur, N., S. Sharma, S. Kaur and H. Nayyar. 2014. Selenium in agriculture: A nutrient or contaminant for crops? *Arch. Agron. and Soil Sci*., 60. 1593-624.

Kerr, C., J. Walker Elaine and Booth. 2001. Agricultural aspects of rape and other Brassica products. *Eur. J. Lipid Sci. Technol.*, 103: 441-6.

Khayatnezhad, M., R. Gholamin, S. Jamaati-e-Somarin and R. Zabihi-e-Mahmoodabad. 2011. The leaf chlorophyll content and stress resistance relationship considering in Corn cultivars (*Zea mays* L.). *Adv. Environ. Biol.*, 5(1): 118-122.

Klognerová, K.,M. Vosmanská, J. Száková and O. Mestek. 2015. Effect of growing conditions on selenium speciation in rapeseed (*Brassica napus*) tissue. *Chem. List*., 109: 216-22.

Kumar, P.B. and N.K. Paul. 1997. Effect of water stress on chlorophyll, proline and sugar accumulation in rape. *Bangladesh J. Bot.*, 26: 1983-85.

Kuznetsov, V.V., V.P. Kholodova, V.I.V. Kuznetsov and B.A. Yagodin. 2003. Selenium regulates the water status of plants exposed to drought. *Dok. Biol. Sci*., 390: 266-268.

Liu, B., Y. Li, X. Liu, C. Wang, J. Jin and S.J. Herbert. 2011. Lower total soluble sugars in vegetative parts of soybean plants are responsible for reduced pod number under shading conditions. *Aus. J. Crop Sci.*, 5(13): 1852-1857.

Lyons, G.H., Y. Genc, K. Soole, J.C.R. Stangoulis, F. Liu and R.D. Graham. 2009. Selenium increases seed production in Brassica. *Plant Soil*, 318(1-2): 73-80.

Madadgar, S., A. AghaKouchak, A. Farahmand, S.J. Davis. 2017. Probabilistic estimates of drought impacts on agricultural production. *Geophys Res. Lett.,* 44(15): 7799-807.

Manivannan, P., C. Abdul Jaleel, B. Sankar, A. Kishorekumar, R. Somasundaram, G.M.A. Lakshmanan and R. Panneerselvam. 2007. Growth, biochemical modifications and proline metabolism in *Helianthus annuus* L. as induced by drought stress. *Coll. Surf. B: Biointerfaces,* 59: 141-149.

Miao, Y., Z. Zhu, Q. Guo, H. Ma and L. Zhu. 2015. Alternate wetting and drying irrigation-mediated changes in the growth, photosynthesis and yield of the medicinal plant Tulipa edulis. *Ind. Crops Prod*., 66: 81-8.

Mostajeran, A. and V. Rahimi-Eichi. 2009. Effects of drought stress on growth and yield of rice (*Oryza sativa* L.) cultivars and accumulation of proline and soluble sugars in sheath and blades of their different age's leaves. *American-Eurasian J. Agric. Environ. Sci*., 5(2): 264-272.

Mozafariyan, M., M. Pessarakli and K. Saghafi. 2017. Effects of selenium on some morphological and physiological traits of tomato plants grown under hydroponic condition. *J. Plant Nutr*., 40(2): 139-44.

Nageswara, R.R.C., H.S. Talwar and G.C. Wright. 2001. Rapid assessment of specific leaf area and leaf nitrogen in peanut (*Arachis hypogaea* L.) using chlorophyll meter. *J. Agron. Crop Sci.*, 189: 175-182.

Nawaz, F., M.Y. Ashraf, R. Ahmad and E.A. Waraich. 2013. Selenium (Se) seed priming induced growth and biochemical changes in wheat under water deficit conditions. *Biol. Trace Elem. Res*., 151: 284-293. doi: 10.1007/s12011-012-9556-9.

Nawaz, F., R. Ahmad, M.Y. Ashraf, E.A. Waraich and S.Z. Khan. 2015. Effect of selenium foliar spray on physiological and biochemical processes and chemical constituents of wheat under drought stress. *Ecotoxicol. Environ. Saf.*, 113: 191-200.

Nega, T. and Y. Woldes. 2018. Review on nutritional limitations and opportunities of using rapeseed meal and other rape seed by-products in animal feeding. *J. Nutr. Health Food Eng*., 8(1): 43-48.

Ommen, O.E., A. Donnelly, S. Vanhoutvin, M. Van-Oijen and R. Manderscheid. 1999. Chlorophyll content of spring wheat flag leaves grown under elevated CO_2 concentrations and other environmental stresses within the ESPACE-wheat project. *Eur. J. Agron*., 10: 197-203.

Põldma, P., T. Tõnutare, A. Viitak, A. Luik and U. Moor. 2011. Effect of selenium treatment on mineral nutrition,bulbsize,and antioxidant properties of garlic (*Allium sativum* L.). Agric. *Food Chem*., 59: 5498-5503.

Qiang-yun, S., M. Turakainen, M. Seppanen and P. Makela. 2008. Effects of selenium on maize ovary development at pollination stage under drought stress. *Agri. Sci. China*., 7: 1298-1307.

R Core Team. 2013. R:A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0.

Ribera-Fonseca, A., C. Rumpel, M.D.L.L. Mora, M. Nikolic and P. Cartes. 2018. Sodium silicate and calcium silicate differentially affect silicon and aluminium uptake, antioxidant performance and phenolics metabolism of ryegrass in an acid Andisol. *Crop Pasture Sci*., 69(2): 205-15.

Rosni, M.S., A. Fisal, A. Azwan, F.Y. Chye and P. Matanjun. 2015. Crude proteins, total soluble proteins, total phenolic contents and SDS-PAGE profile of fifteen varieties of seaweed from Semporna, Sabah, Malaysia. *Int. Food Res. J*., 22(4): 1483-93.

Russell, F. 1986. MSTAT Micro-Computer Statistical Programme. Michigan State. East Lansing, Michigan, USA.

Sajedi, K.H.A., M.M.F. Mansour and H.A. Al-Malawi. 2015. Glycinebetaine priming improves salt tolerance of wheat. *Biol.*, 70(10): 1334-9.

Sajedi, N.A., M.R. Ardakani, A. Naderi, H. Madani and M.M.A. Boojar. 2009. Response of maize to nutrients foliar application under water deficit stress conditions. *Am. J. Agri. Biol. Sci*., 4: 242-248.

Seppänen, M.M., J. Kontturi, I.L. Heras, Y. Madrid, C. Cámara and H. Hartikainen. 2010. Agronomic biofortification of Brassica with selenium-enrichment of SeMet and its identification in Brassica seeds and meal. *Plant Soil*., 337(1): 273-83.

Šindelářová, K., J. Száková, J. Tremlová, O. Mestek, L. Praus and A. Kaňa. 2015. The response of broccoli (*Brassica oleracea* convar. italica) varieties on foliar application of selenium: uptake, translocation, and speciation. Food Addit Contam - Part A *Chem. Anal. Control Expo. Risk Assess.*, 32(12): 2027-38.

Smirnoff, N. 1995. Antioxidant systems and plant response to the environment. In: (Ed.): Smirnoff, V. Environment and Plant Metabolism: Flexibility and Acclimation, BIOS Scientific Publishers, Oxford, UK.

Sood, V., D. Rawat, R. Khanna, S. Sharma, P.K. Gupta and S. Alam. 2017. Study of Carnitine/Acylcarnitine and Amino Acid Profile in Children and Adults with Acute Liver Failure. J. Pediatr. *Gastroenterol Nutr*., 64(6): 869-75.

Száková, J., L. Praus, J. Tremlová, M. Kulhánek and P. Tlustoš. 2017. Efficiency of foliar selenium application on oilseed rape (*Brassica napus* L.) as influenced by rainfall and soil characteristics. *Arch. Agron. Soil Sci.*, 63(9): 1240-54.

Wahid, A. and A. Shabbir. 2005. Induction of heat stress tolerance in barley seedlings by pre-sowing seed treatment with glycinebetaine. *Plant Growth Reg.,* 46: 133-141.

Wang Yu-Dong, X. Wang and Y. Wong. 2013. Generation of selenium-enriched rice with enhanced grain yield, selenium content and bioavailability through fertilization with selenite. *Food Chem.,* 141: 2385-2393.

Wang, L., P. D'Odorico, J.P. Evans, D.J. Eldridge, M.F. McCabe and K.K. Caylor. 2012. Dryland ecohydrology and climate change: Critical issues and technical advances. *Hydrol Earth Syst Sci*., 16(8): 2585-2603.

Wang, X., J. Cao, X. Dai, J. Xiao, Y. Wu and Q. Wang. 2017. Total flavonoid concentrations of bryophytes from Tianmu Mountain, Zhejiang Province (China): Phylogeny and ecological factors. *PLoS One*., 12(3): e0173003. doi:10.1371/journal. pone.0173003

Wójcik, P. 2004. Uptake of mineral nutrients from foliar fertilization. *J. Fruit Ornam. Plant Res*. (special ed.)., 12: 201-218.

Wu, L. 1998. Selenium accumulation and uptake by crop and grassland plant species. p. 657-685. In: (Eds.): Willia, T., J.R. Frankenberger, & R.A. Engberg. Environmental Chemistry of Selenium. Marcel Dekker, New York, USA.

Xiaoqin, Y., C. Jianzhou and W. Guangyin. 2009. Effects of drought stress and selenium supply on growth and physiological characteristics of wheat seedlings. *Acta Physiol. Plant*., 31(5): 1031-1036.

Yang, F., L. Chen, Q. Hu and G. Pan. 2003. Effect of the application of selenium on selenium content of soybean and its products. *Biol. Trace Elem. Res.,* 93: 249-256.

Yao X., J. Chu and G. Wang. 2009. Effects of selenium on wheat seedlings under drought stress. *Biol. Trace Elem. Res*., 130: 283-290.

Zhang, Q., X. Gu, V.P. Singh, D. Kong and X. Chen. 2015. Spatiotemporal behavior of floods and droughts and their impacts on agriculture in China. *Glob Planet Change*., 131: 63-72.

Zhao, L., F. Temelli and L. Chen. 2017. Encapsulation of anthocyanin in liposomes using supercritical carbon dioxide: Effects of anthocyanin and sterol concentrations. *J. Funct. Foods*., 34: 159-67.

Zhao, Y., P. Wu, Y. Wang and H. Feng. 2013. Different approaches for selenium biofortification of pear-jujube (*Zizyphus jujuba* M. cv. Lizao) and associated effects on fruit quality. *J. Food, Agri. Environ*., 11(2): 529-534.

Zhu, Y.G., E.A.H. Pilon-Smits, F.J. Zhao, P.N. Williams and A.A. Meharg. 2009. Selenium in higher plants: understanding mechanisms for biofortification and phytoremediation. *Trends Plant Sci*., 14(8): 436-442.

(Received for publication 22 February 2019)