



Cysteine-induced alterations in physicochemical parameters of oat (*Avena sativa* L. var. Scott and F-411) under drought stress

Original Article

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Introduction: Drought is one of the major abiotic stresses that drastically reduces crop yield throughout the world. Being precursor of glutathione biosynthesis and involvement in other metabolic processes, cysteine (Cys) has been shown to alter growth and development in plants. In this context, we investigated Cys-induced physicochemical alterations in oat (*Avena sativa* L. var. Scott and var. F-411) plants under drought stress. **Methods:** There were two levels of drought stress, i.e., control (100% field capacity) and drought (50% field capacity) and three levels of foliar application of Cys, i.e., 0, 10, and 20 mM. Experimental design was completely randomized block design. **Results:** Drought stress significantly decreased growth parameters, chlorophyll (Chl) contents, while increased leaf membrane permeability (MP), ascorbic acid (AsA), and activity of catalase (CAT) and peroxidase (POD) enzymes. Foliar application of varying Cys levels significantly increased root fresh weight, root length, photosynthetic pigments (chl. *a* and *b*), AsA contents in var. Scott, and shoot length, total free amino acids, total phenolics and free proline contents in var. F-411. **Discussion:** Of the two oat varieties, var. Scott proved better in root fresh weight, root length, chl. *a* and *b* contents, and total phenolic contents, while var. F-411 was higher in the values of shoot length, MP (%), total free amino acids, and free proline contents. Thus, on the basis of strong root system, total phenolics, and more photosynthetic contents (chl. *a* and *b* contents), var. Scott could be grown under semi-arid environments than that of var. F-411.

INTRODUCTION

Drought stress is one of the most significant environmental factors that seriously affect the yield of cereal crops in the entire world (Ahmad et al., 2017). Under the conditions of water scarcity or drought, several physiological and biochemical changes take place in plants (Kidokoro et al., 2009). Under drought, reactive oxygen species (ROS), such as singlet oxygen, superoxide radical, and hydrogen peroxide (H₂O₂), are generated (Jyoti & Sudesh, 2012) that lead to the degradation of proteins (Guo et al., 2018), enzymes, nucleic acids, and lipid peroxidation of membranes (Chen et al., 2000; Suttie & Reynolds, 2004). The production of ROS is controlled by a strong antioxidant defense system comprising of enzymatic and non-enzymatic antioxidant enzymes (Oliveira et al., 2018). In addition, osmoregulation (accumulation of organic and inorganic solutes) is considered a key mechanism that decreases the water potential of cell and maintains the turgor pressure without decreasing its cell volume or turgidity (Basu et al., 2016).

Oat (*Avena sativa* L.) belongs to family *Poaceae* that originated in Mediterranean period, but not older than barley and wheat (Suttie & Reynolds, 2004). It is among the eight most important world's cereal crops (Walsh et al., 2003) and has sixth position in terms of world cereal production (Dost, 1997). It is the rich dietary fiber's source like all other members of family *Gramineae* (Butt et al., 2008). Plants respond differently to varied levels of water stress (Jaleel et al., 2008). Among cereals, oat is the most vulnerable genus concerning drought stress at the early development phases (Mos et al., 2007).

Foliar application of amino acids has been considered as a promising approach to improve the growth of crop plants (Teixeira et al., 2017). Under abiotic stresses, foliar application of *N*-acetyl-cysteine (Cys) alleviated the adverse effects of salt stress (Genisel et al., 2015) and cadmium toxicity in barley genotypes (Sun et al., 2014). Cys, an α -amino acid, has a side thiol group and contributes in various enzymatic processes.

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In plants, biosynthesis of Cys significantly participates in fixing of environmental inorganic sulfur and gives only metabolic donor of sulfide for the synthesis of multiple secondary metabolites, iron–sulfur clusters, glutathione, methionine, vitamin cofactors, and phytochelatin. Both drought resistance and low temperature tolerance are due to Cys proteinases (Grudkowska & Zagdanska, 2010). Cys has been reported to induce shoot proliferation and increase mineral contents (N, K, and Ca) of apple rootstock under *in vitro* conditions (Sotiropoulos et al., 2005). Exogenous application of the mixture of Cys, alanine, glycine, and arginine, each at 100 ppm, increased plant height, area of leaf blade, weight of fresh bulbs and leaves, and diameter of neck and bulb. Application of Cys, at the rate of 100 ppm, generated greater yield, bulb and weight of clove, as compared to untreated and all other applications (El-Shabasi et al., 2005). Previously, there is no report regarding the effect of cyteine on oat plants under drought stress. Therefore, we hypothesized that exogenous application of Cys would induce physicochemical alterations in oat plants to overcome drought stress. To achieve this goal, foliar application of varying Cys levels was applied on two oat varieties (var. Scott and var. F-411) and changes in growth and different physicochemical attributes, such as chlorophyll (Chl), oxidative stress parameters, total soluble proteins, total free amino acids, various enzymatic and non-enzymatic antioxidants, and osmoprotectants, were assessed under drought stress and non-stress conditions. The results obtained might have potential implications for oat crop management under limited water regimes.

MATERIALS AND METHODS

The experiment was conducted under natural climatic conditions in a completely randomized design with four replicates for each parameter. Plastic pots (24 × 17 cm) were filled with fertile loamy soil. The weight of both soil and pots was measured before watering the soil to field capacity (FC). The seeds of two oat varieties (var. Scott and var. F-411) were sown in loamy soil. Drought stress levels, i.e., 100% (FC100) and 50% FC (FC50), were applied to 2-weeks-old oat plants. For maintaining FC50, pots were weighted every other day and irrigated with measured amount of water (gravimetric method). After 6 weeks of germination, foliar application of 0, 10, and 20 mM Cys was applied. The data were collected after 3 weeks of foliar application (9-week-old plants) for the determination of various growth, physiological, and biochemical parameters.

Determination of growth and physicochemical parameters

The plants from each pot were uprooted, washed with distilled water to remove sand particles, and scored for shoot and root fresh biomass, shoot and root lengths, and total leaf area per plant (Carleton & Foote, 1965). Afterward, plant material was oven-dried at 72 °C for 72 hr and measured for shoot and root dry weights. Relative water contents (%) were measured as described earlier (Jones & Turner, 1978). Fresh leaf of 0.5 g was weighed and kept in deionized water overnight in a freezer. Then, turgid weight

of each sample was measured. Later, leaf samples were dried in an oven at 80 °C for 48 hr and dry weight was measured. Relative water content (%) was calculated by applying the following formula:

$$\text{RWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry Weight}} \times 100.$$

To measure the relative membrane permeability (RMP), fresh leaves (0.5 g) were chopped using scissors, placed in 10 ml of distilled water in test tubes, and vortexed for 10 s, and EC_0 was determined. Then, the test tubes were placed at 4 °C overnight and EC_1 was determined. Later on, the samples were autoclaved and EC_2 was determined. To measure RMP (%), the following formula was used:

$$\text{RMP (\%)} = (\text{EC}_1 - \text{EC}_0 / \text{EC}_2 - \text{EC}_0) \times 100.$$

Chl contents were determined by following the method of Arnon (1949). Fresh leaf tissue (0.5 g) was cut into small pieces and kept in 10 ml of 80% acetone at 4 °C for 24 hr, and absorbance of extract was read at 645 and 663 nm wavelengths with a spectrophotometer (Hitachi-U-1800, Japan). Total soluble sugars were determined as described by Perveen et al. (2016). Fresh leaf (0.1 g) was finely homogenized in 5 ml of 0.2% phosphate buffer. To 0.5 ml of supernatant, 3 ml of freshly prepared anthrone reagent was added, shaken well and placed in a water bath at 95 °C for 15 min, and cooled immediately. Absorbance of samples was recorded at 625 nm wavelengths.

H_2O_2 was estimated according to reported method (Velikova et al., 2000). Fresh leaf (0.5 g) was finely homogenized in 0.1% trichloroacetic acid (TCA; 5 ml) and centrifuged at $12,000 \times g$ for 15 min. To 0.5 ml of supernatant, 0.5 ml of sodium phosphate buffer and 1 ml of potassium iodide were added, vortexed, and absorbance of supernatant was recorded at 390 nm with the spectrophotometer.

Previously reported method (Carmak & Host, 1991) was used for malondialdehyde (MDA) determination. Fresh leaves (0.5 g) were finely homogenized in 10 ml of TCA (0.1%), centrifuged at $12,000 \times g$ for 12 min. To 1 ml of supernatant, 4 ml of 0.5% thiobarbituric acid prepared in 20% TCA was added, kept at 95 °C for 25 min in a water bath, and read the absorbance at 532 and 600 nm on spectrophotometer.

Total soluble proteins were calculated by following Bradford's (1976) method. Ascorbic acid (AsA) contents were determined by Mukherjee and Choudhuri (1983). Fresh leaves (0.5 g) were homogenized in 10 ml of 6% TCA. The reaction mixture consisted of 2 ml of dinitrophenylhydrazine (2%), 2 ml of supernatant, and 1 drop of thiourea, and the mixture was heated for 20 min in a water bath. Then, the reaction was terminated by cooling, 5 ml of 80% H_2SO_4 was added, and the absorbance of samples was recorded at 520 nm with spectrophotometer.

The amount of total phenolics was determined following the method of Julkenen-Titto (1985). Fresh leaf tissue (0.1 g) was finely homogenized in 2 ml of acetone (80%), centrifuged at $10,000 \times g$ for 12 min, and supernatant was collected in a microfuge tube. The reaction mixture consisted of 100 µl supernatant, 2 ml of distilled water, and

0.5 ml of Folin-Ciocalteu's reagent. To the above mixture, 2.5 ml of Na_2CO_3 (20%) was added, final volume was made up to 5 ml with distilled water and vortexed for 5 s. The absorbance of sample was determined at 750 nm with a spectrophotometer.

Anthocyanin contents were determined by Zhang et al.'s (2009) method. For the determination of anthocyanin contents, fresh leaf (0.1 g) was homogenized in phosphate buffer (5 ml) and centrifuged, and absorbance of samples was measured at 600 nm using a spectrophotometer (Hitachi-U-1800, Japan).

Flavonoid contents were determined by Zhishen et al.'s (1999) method. Fresh leaves (0.5 g) were extracted in 80% acetone. The reaction mixture consisted of 0.5 ml of leaf extract, 2 ml of distilled water, 0.6 ml of NaNO_2 (5%), 0.5 ml of aluminium trichloride (10%), and 2 ml of NaOH (1 M). The absorbance of mixture was measured at 510 nm with a spectrophotometer.

Chance and Maehly's (1955) method was used for the determination of catalase (CAT) and peroxidase (POD) enzymes activities. Fresh leaves (0.5 g) were finely homogenized in 50 mM phosphate buffer of pH 7.8 in chilled pestle and mortar in an ice bath, centrifuged at $12,000 \times g$ for 15 min at 4 °C, and supernatant was stored at -20 °C for determination of CAT and POD activities. The reaction mixture for CAT consisted of phosphate buffer (50 mM), H_2O_2 (5.9 mM), and 0.1 ml of enzyme extract. The changes in absorbance of sample were read at 240 nm every 20 s. For POD determination, reaction mixture consisted of phosphate buffer (50 mM), guaiacol (20 mM), H_2O_2 (40 mM), and enzyme extract (0.1 ml). The absorbance of reaction mixture was measured every 20 s at 470 nm with a spectrophotometer.

Moore and Stein's (1957) method was used to estimate the total free amino acid contents. Fresh leaf tissue (0.5 g) was homogenized in 10 ml of citrate buffer, centrifuged at $15,000 \times g$ for 10 min, and further processed with 2% ninhydrin solution. The optical density of solution was recorded at 570 nm with the spectrophotometer.

Bates et al.'s (1973) method of color comparison was used to estimate the proline contents. Fresh leaf (0.5 g) was homogenized in 10 ml of sulfosalicylic acid and filtered with Whatman no. 2 filter paper. To 2 ml of filtrate, 2 ml each of acid ninhydrin and glacial acetic acid were added. The mixture was heated in a water bath at 95 °C for 1 hr and the reaction was terminated by placing the aliquots in an ice bath. Then, 4 ml of toluene was added to the mixture, vortexed for 12 s, and absorbance of chromophore layer was read at 520 nm with the spectrophotometer.

Glycinebetaine was determined according to the method of Grieve and Grattan (1983). Fresh leaf tissue (0.5 g) was finely homogenized in 10 ml of distilled water and filtered with Whatman filter paper. To 1 ml of filtrate, 1 ml of 2 NH_4SO_4 was added and to 0.5 ml of this mixture, 0.2 ml KI_3 was added in an ice bath and cooled at 0–4 °C for 90 min. Then, to this solution, 2.8 ml of cooled distilled water and 6 ml of 1-2-dichloroethane were added. Absorbance of colored layer was read at 365 nm using a spectrophotometer.

Statistical analysis of all parameters was performed using MSTAT computer program (MSTAT Development Team, 1989) according to Snedecor and Cochran (1980).

RESULTS

The data of this study showed that drought stress of FC50 exerted significantly adverse effects on the shoot fresh and dry weight of oat (*A. sativa* L. var. Scott and F-411) plants (Table 1; Fig. 1). Root fresh and dry weights significantly decreased under drought stress in both oat varieties. These oat varieties showed significant difference in terms of root fresh weight under drought stress and response toward foliar application of Cys. Oat variety Scott was high in root fresh weight and showed more positive response to foliarly applied Cys under control (FC100). Shoot and root lengths significantly decreased under drought stress in both oat varieties. Oat var. F-411 was high in shoot length under stressed or non-stressed conditions, whereas var. Scott was higher in root length under drought stress and foliar application of Cys. Total leaf area per plant significantly decreased under drought stress of FC50 (Table 1; Fig. 1).

Drought stress of FC50 and foliar application with varying levels of Cys did not change relative water contents (%) significantly in both oat varieties (Table 1; Fig. 1). Chl contents, chl. *a* and chl. *b*, decreased under drought stress. Oat var. Scott showed high chl. *a* and chl. *b* contents under drought stressed or non-stressed conditions. Foliar application of Cys significantly increased chl. *b* contents in both oat varieties (Table 1; Fig. 2).

Drought stress of FC50 and foliar application with varying levels of Cys did not change soluble sugar contents significantly in both oat varieties (Table 1; Fig. 2). Hydrogen peroxide (H_2O_2), MDA contents, and membrane permeability (MP; %) significantly increased under drought stress in both oat varieties (Table 1; Fig. 2). Foliar application of Cys did not alter these oxidative stress parameters significantly in both oat varieties. Of two oat varieties, var. F-411 showed more MP (%) value than that of var. Scott under drought stress (Table 1; Fig. 2).

Drought stress of FC50 and foliar application with varying levels of Cys did not change soluble protein contents significantly in both oat varieties (Table 1; Fig. 2). AsA contents significantly increased under drought stress of FC50 in both oat varieties. Foliar application with varying levels of Cys significantly increased AsA contents (Table 1; Fig. 2). Oat var. Scott showed higher phenolic contents than F-411 under drought stress conditions (Table 1; Fig. 3). Foliar application with varying levels of Cys significantly increased anthocyanin contents under drought stress conditions in both oat varieties (Table 1; Fig. 3).

Flavonoid contents did not alter either under drought stress or by foliar application of Cys in both oat varieties (Table 1; Fig. 3). CAT and POD activities significantly increased under drought stress in both oat varieties (Table 1; Fig. 3).

Of the two oat varieties, var. F-411 showed high amino acid contents than var. Scott under drought stress and foliar application of cysteine. Foliar application with varying levels of Cys significantly increased amino acid contents in var. F-411 under drought stressed conditions and decreased under non-stressed conditions, whereas reverse was true for var. Scott under drought stressed or non-stressed conditions. Foliar application with varying levels of Cys significantly increased proline contents in oat var. F-411

Table 1. Analysis of variance of the parameters of growth, RWC (%), chlorophyll, H₂O₂, MAD, MP (%), total soluble proteins, ascorbic acid, total phenolics, anthocyanin, flavonoids, activities of antioxidant enzymes, free amino acids, free proline, and glycinebetaine contents of oat (*Avena sativa* L.) plants foliarly sprayed with varying levels of cysteine (Cys) under drought stress and non-stress conditions

Source of variation	Varieties (Var)	Drought (D)	Cysteine (Cys)	Var × D	Var × Cys	D × Cys	Var × D × Cys	Error
Shoot fresh weight	0.725 ^{ns}	3.861**	0.633 ^{ns}	0.06 ^{ns}	0.940 ^{ns}	0.04 ^{ns}	0.143 ^{ns}	0.291
Shoot dry weight	0.027*	0.040**	0.008 ^{ns}	0.005 ^{ns}	0.0002 ^{ns}	0.0006 ^{ns}	0.006 ^{ns}	0.004
Root fresh weight	0.04**	0.139***	0.001 ^{ns}	0.015*	0.015*	0.017*	0.020**	0.003
Root dry weight	0.000 ^{ns}	0.004***	0.000 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	0.000
Shoot length	925.1***	232.5**	51.54 ^{ns}	237.6**	6.465 ^{ns}	1.520 ^{ns}	12.38 ^{ns}	19.97
Root length	2.006 ^{ns}	45.5**	0.465 ^{ns}	5.06 ^{ns}	6.465 ^{ns}	0.187 ^{ns}	26.68**	4.006
Total leaf area plant	1,145.8 ^{ns}	7,460.6*	896.1 ^{ns}	1.96 ^{ns}	695.2 ^{ns}	1,046.5 ^{ns}	1,205.3 ^{ns}	1,556.4
RWC (%)	91.92 ^{ns}	4.557 ^{ns}	74.04 ^{ns}	0.026 ^{ns}	37.04 ^{ns}	1.790 ^{ns}	19.42 ^{ns}	40.20
Chl. <i>a</i>	0.009*	0.066***	0.003	0.007*	0.000 ^{ns}	0.000 ^{ns}	0.005 ^{ns}	0.001
Chl. <i>b</i>	0.053***	0.051***	0.022**	0.003 ^{ns}	0.006 ^{ns}	0.001 ^{ns}	0.001 ^{ns}	0.002
Total soluble sugars	1.348 ^{ns}	0.862 ^{ns}	20.56 ^{ns}	5.393 ^{ns}	1.747 ^{ns}	7.325 ^{ns}	16.23 ^{ns}	8.446
H ₂ O ₂	0.127 ^{ns}	1.182**	0.102 ^{ns}	0.192 ^{ns}	0.251 ^{ns}	0.474 ^{ns}	0.097 ^{ns}	0.149
MDA	19.0 ^{ns}	894.8***	31.21 ^{ns}	18.62 ^{ns}	31.09 ^{ns}	137.8 ^{ns}	2.139 ^{ns}	52.71
MP (%)	2.993 ^{ns}	498.2**	0.107 ^{ns}	187.5*	19.9 ^{ns}	55.29 ^{ns}	107.7 ^{ns}	41.10
Total soluble proteins	0.422 ^{ns}	0.210 ^{ns}	0.007 ^{ns}	0.002 ^{ns}	0.239 ^{ns}	0.221 ^{ns}	0.136 ^{ns}	0.113
Ascorbic acid	0.004 ^{ns}	0.697**	0.418**	0.224 ^{ns}	0.098 ^{ns}	0.150 ^{ns}	0.263*	0.068
Total phenolics	59.77*	54.07 ^{ns}	6.699 ^{ns}	111.1**	16.58 ^{ns}	43.65 ^{ns}	21.96 ^{ns}	13.01
Anthocyanin	0.020 ^{ns}	1.695 ^{ns}	0.569 ^{ns}	0.000 ^{ns}	0.137 ^{ns}	7.545**	1.256 ^{ns}	1.28
Flavonoids	0.141 ^{ns}	0.363 ^{ns}	0.039 ^{ns}	0.782 ^{ns}	0.217 ^{ns}	0.077 ^{ns}	1.477 ^{ns}	0.571
CAT	0.006	6.793***	0.659 ^{ns}	0.007 ^{ns}	0.140 ^{ns}	0.248 ^{ns}	1.202 ^{ns}	0.425
POD	0.0000 ^{ns}	0.028**	0.005 ^{ns}	0.001 ^{ns}	0.003 ^{ns}	0.002 ^{ns}	0.005 ^{ns}	0.002
Total free amino acids	25.62*	0.008 ^{ns}	10.08 ^{ns}	9.051 ^{ns}	5.399 ^{ns}	4.141 ^{ns}	14.55*	3.687
GB	14.14 ^{ns}	9.427 ^{ns}	1.233 ^{ns}	0.839 ^{ns}	6.147 ^{ns}	4.03 ^{ns}	0.652 ^{ns}	4.175
Free proline	6.539 ^{ns}	39.16 ^{ns}	47.72 ^{ns}	0.591 ^{ns}	111.4**	4.405 ^{ns}	4.566 ^{ns}	18.05
df	1	1	2	1	2	2	2	24

Note. df: degrees of freedom; ns: non-significant; RWC (%): relative water content; chl. *a*: chlorophyll *a*; chl. *b*: chlorophyll *b*; H₂O₂: hydrogen peroxide; MDA: malondialdehyde; MP (%): membrane permeability in percentage; CAT: catalase; POD: peroxidase; GB: glycinebetaine.

*Significant at 0.05 level. **Significant at 0.01 level. ***Significant at 0.001 level.

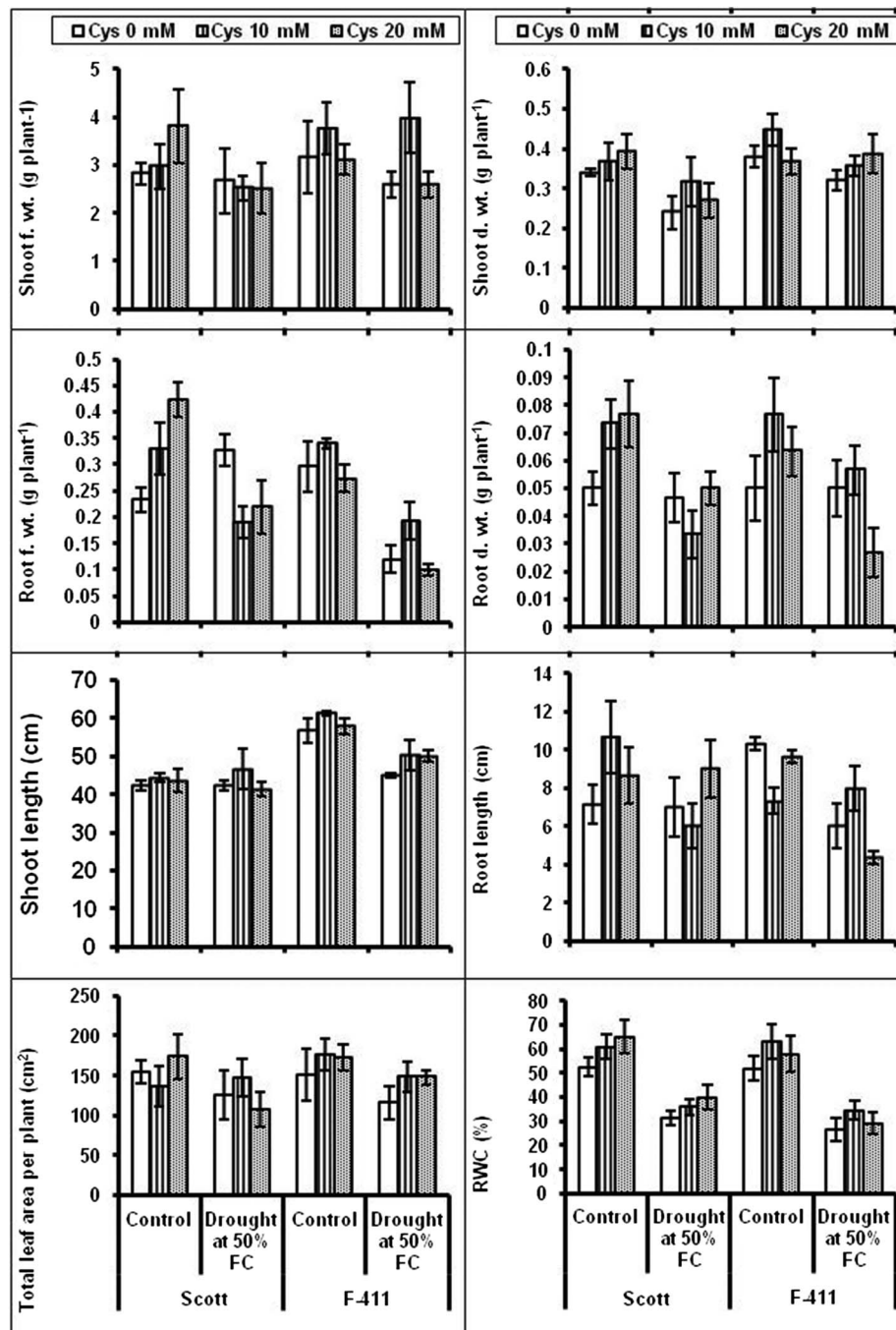


Fig. 1. Shoot and root fresh and dry weights, shoot and root lengths, total leaf area, and relative water content of oat (*Avena sativa* L.) plants foliarly sprayed with cysteine under drought stress and non-stress conditions

(Table 1; Fig. 3). Glycinebetaine contents did not change either under drought stress or by foliar application of Cys in both oat varieties (Table 1; Fig. 3).

DISCUSSION

Sulfur-containing defense compounds protect plants from various biotic and abiotic stresses (Dixit et al., 2015). For example, sulfur protects wheat plants against Mn toxicity by improving proline contents, ethylene signaling, and antioxidant defense system (Sheng et al., 2016). Cys contains a

thiol side chain that is nucleophile and scavenges ROS due to its own reducing property (antioxidant characteristics; El-Shabasi et al., 2005; Zagorchev et al., 2013). In this study, drought stress of FC50 significantly reduced parameters of growth and Chl contents, while relative water content (RWC) remained unchanged for oat plants. According to Suttie and Reynolds (2004), decrease in biomass and root and shoot length had been detected in all cultivars under drought stress conditions. It may cause decrease in relative turgidity and protoplasm dehydration, which is associated with loss of turgor and decrease in cell expansion and impediment of mitosis. Earlier studies also highlighted the

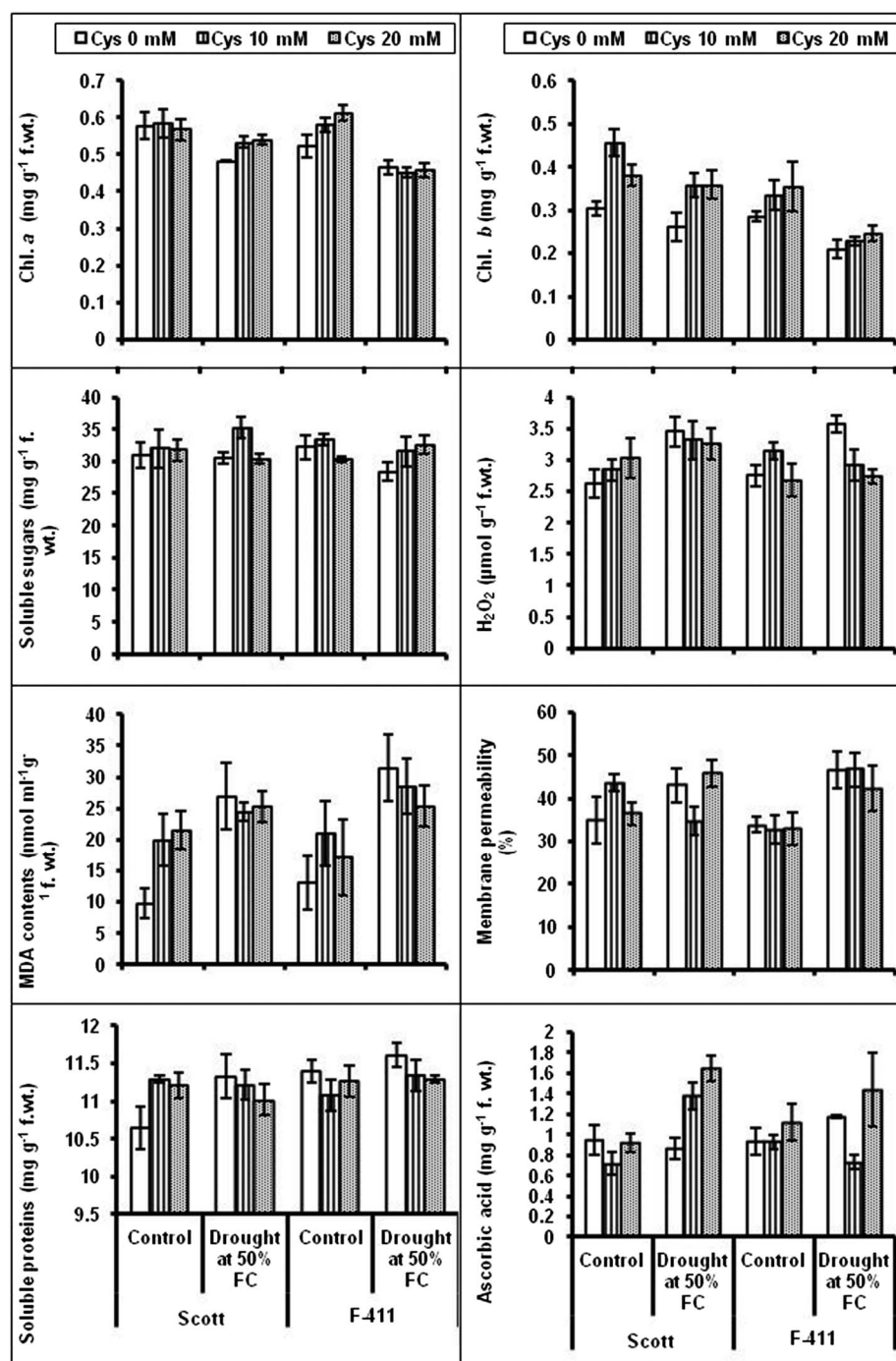


Fig. 2. Chlorophyll, hydrogen peroxide, malondialdehyde, membrane permeability, soluble proteins, and ascorbic acid contents of oat (*Avena sativa* L.) plants foliarly sprayed with cysteine under drought stress and non-stress conditions

decline in Chl contents under drought stress conditions (Perveen et al., 2016). It was reported in many research articles that exogenous amino acids applications enhanced plants growth, fruits production, and nutrients in garlic (Awad et al., 2007), cucumber (El-Shabasi et al., 2005), onion (Amin et al., 2011), etc. Amin et al. (2011) stated that the effect of amino acid glutamine in enhancing the photo-synthetic pigments of onion (*Allium cepa* L.) leaves may be due to sulfur bonds of Cys and Met that act as electron donor in the leaf and save cell from free radicals. Zhang et al. (2009) stated that decline in leaf RWC indicates a decrease

of turgor potential that results in inadequate water availability for the cell expansion processes in plants.

In order to cope with drought stress conditions, plants have adapted an inherent mechanism of stress tolerance that comprises a strong antioxidant defense system and osmotic adjustments (Guo et al., 2018; Oliveira et al., 2018). Drought stress induces oxidative stress that leads to the production of MDA (lipid peroxidation) in *Lycium ruthenicum* Murr. seedling (Guo et al., 2018). MDA is a product of peroxidation of unsaturated fatty acids in phospholipids, and lipid peroxidation level is used as indicator

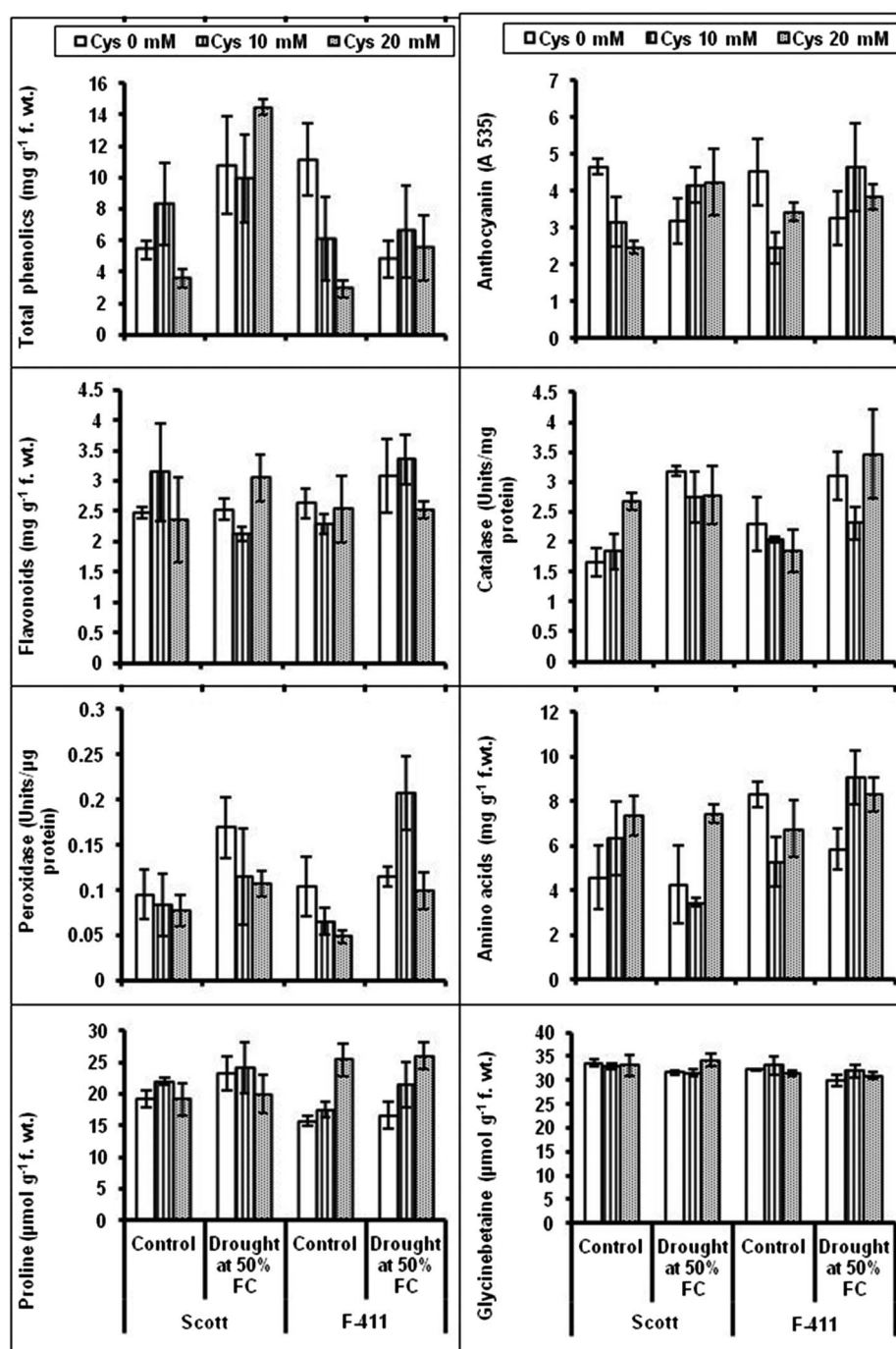


Fig. 3. Total phenolics, anthocyanin, flavonoid, activities of catalase and peroxidase, free amino acids, free proline, and glycinebetaine contents of oat (*Avena sativa* L.) plants foliarly sprayed with cysteine under drought stress and non-stress conditions

of free radical damage to cell membranes under stress conditions (Hessini et al., 2009). In this study, drought stress-induced oxidative stress parameters such as H₂O₂, MDA, and MP (%) significantly increased; however, foliar application of Cys did not alter these attributes significantly.

Free proline and total soluble sugars act as organic solutes for osmotic adjustment and increased under drought stress (Guo et al., 2018). It has been reported that total soluble proteins initially decreased and then increased in the leaves of *L. ruthenicum* Murr. seedlings under drought stress conditions (Guo et al., 2018). Total phenolic contents

act as secondary plant metabolites and protect plants from the damaging effects of ROS (Mandal et al., 2010). In this study, drought stress had no substantial effect on the free proline, glycine betaine (GB), total soluble sugars, total soluble proteins, total free amino acids, total phenolics, flavonoid, and anthocyanin contents in both oat varieties. However, when plants were treated with Cys, free proline, total free amino acids, and anthocyanin contents were increased, whereas GB, total soluble sugars, total soluble proteins, total phenolics, and flavonoid contents remained unaffected under drought stressed or non-stressed conditions. AsA contents increased under both drought stress

and by foliar application of Cys in both oat varieties. It has been reported that seed treatment with Cys considerably decreased the aldehydes as compared to untreated plants (Azarakhsh et al., 2015).

Antioxidant enzymes, such as superoxide dismutase (SOD), POD, and CAT activities, have been reported to increase initially and then decreased in the leaves of *L. ruthenicum* Murr. seedling under drought stress (Guo et al., 2018). Increased SOD, POD, and CAT activities have been considered to scavenge ROS (Liu et al., 2013). For example, POD and CAT convert H_2O_2 into O_2 and H_2O (Guo et al., 2012). In this study, CAT and POD activities increased under drought stress in both oat varieties. Abbas et al. (2015) reported that enhanced POD activities and protein contents stimulate growth and improve abiotic stress tolerance in *Phoenix dactylifera* L. offshoots. Moreover, vegetative plants and seeds treated with Cys, at all stages significantly enhanced the CAT activity. It means Cys decreased the generation of ROS that were generated by water stress and reduced the oxidative damage. This reduction of ROS by Cys might be due to its antioxidant characteristics. It means, by functioning as ROS scavenger, Cys reduced the demand of antioxidant's system activation as described by Grieve and Grattan (1983).

CONCLUSION FOR FUTURE BIOLOGY

In arid and semi-arid regions, there is a dire need to develop drought tolerant crop varieties/lines that can produce high yield. The results obtained in this research work will contribute to introduce drought tolerant oat varieties, e.g., var. Scott that can be used as a cereal food crop under drought stress conditions. Furthermore, exogenous application of plant growth regulators (Cys in this case) can increase crop yield under water-limited environment. In this study, foliar application of Cys reduced drought-induced oxidative stress damages and increased growth under drought stress through increased photosynthetic pigments (chl. *a* and *b*) and AsA contents in var. Scott, and shoot length, total free amino acids, total phenolics, and free proline contents in var. F-411. Of the two oat varieties, var. Scott could be considered more drought tolerant than that of var. F-411 due to strong root system, total phenolics, and more photosynthetic contents (chl. *a* and *b* contents) and could be grown under semi-arid environments to feed growing world population particularly in developing countries.

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Data Accessibility: The article's supporting and digital research material can be accessed from scholarly articles given in Google Scholar by adding keywords included in the manuscript.

Competing Interests: The authors declare no competing interests.

Authors' Contributions: SP contributed in writing up of manuscript, design, and conduction of experiment. MI, MS, NI, SZ, and TM equally contributed in laboratory analysis, manuscript revision, and proofreading.

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