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Full Length Article

Morpho-physiological and Biochemical Responses of *Camelina* (*Camelina sativa crantz*) Genotypes under Drought Stress

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Abstract

Camelina (*Camelina sativa*) a member of mustard family is being introduced as an alternate oilseed crop. Camelina is disease resistant, low input requiring crop with a short life cycle (80–100 days). The purpose of this study was to assess the response of camelina genotypes for seedling growth, gas exchange traits and some biochemical attributes under drought stress. Plants of two different camelina genotypes (7126 and 8046) were grown in pots maintained with four drought stress levels i.e., control (100% FC) and water stress (80, 60 and 40% FC). Drought stress significantly decreased shoot and root length, shoot and root fresh weight and their dry weights, photosynthetic rate (*Pn),* stomatal conductance (g_s), transpiration rate (*E*) and soluble proteins while free proline, soluble sugars and amino acid content increased in both camelina genotypes. Genotype 7126 showed better response regarding seedling traits, gas exchange traits and had higher accumulation of free proline, soluble sugars, amino acids and soluble proteins as compared to genotype 8046 at all drought stress levels. The results suggested that the drought tolerance potential of camelina is positively associated with the regulation of gas exchange characteristics and accumulation of osmoprotectants.

Keywords: Camelina; Drought stress; Photosynthetic rate; Free proline; Soluble sugars; Stomatal conductance

Introduction

Camelina (*Camelena sativa*) of mustard family is an annual oilseed crop (Gesch, 2014). It possesses a short life cycle (80–100 days), higher seed oil content (35–45%) and better water use efficiency as compared to canola (Mcvay and Khan, 2011). Camelina has gained much popularity in the recent years as potential oilseed feedstock to generate advanced biofuels and bioproducts (Gesch, 2014). Camelina oil has been found equally good as cooking oil (Pilgeram *et al*., 2007) as well as for diesel and jet fuel production (Moser, 2010). Camelina oil appears as an essential source of omega-3 fatty acids mainly because of higher percentage of linolenic acid (Hrastar *et al*., 2009) along with better oxidative stability (Abramovic and Abram, 2005). Consumption of camelina oil can be helpful to improve the general health of people (Rokka *et al*., 2002; Lu and Kang, 2008). Agricultural input requirement for camelina is relatively low which keeps its production cost low as a major attraction for the farmer (Gesch and Cermak, 2011). Camelina requires less nitrogen to obtain optimum yields as compared to canola (Wysocki *et al*., 2013), shows better resistance against drought and disease (Lenssen *et al*., 2012). Drought is one of the most prominent abiotic stresses that have devastating effects on crop productivity (Vallivodan and Nguyen, 2006). Growth and physiology of plants is adversely affected by drought stress (Waraich *et al*., 2013). To enhance crop productivity and crop yield under water limited conditions, development and selection of drought tolerant varieties is the best viable option (Siddique *et al*., 2000). Plants growing under drought stress conserve water by lowering their stomatal conductance as a result CO_2 fixation reduces and photosynthetic rate is decreased. Plants adopt different ways to reduce the effect of limited water or to increase their water absorption (Morison *et al*., 2008).

Accumulation of various compatible solutes (free proline, betaines and sugars) occurs in response to water deficit, which help maintain intercellular osmotic potential without disturbing the metabolic reactions of the plants (Sairam and Saxena, 2000). Many organic acids, ions, sugars and polyols, amino acids and quaternary amines are found to be accumulated for the osmotic adjustment of stressed cells and tissues (Rodríguez *et al*., 1997; Zhang *et al*., 1999). Free proline accumulation is helpful in osmotic adjustment, thus protecting enzymes and cellular structures (Kumar and Sharma, 2010). Proline also works to scavenge free radicles thus strengthens the biological membrane that results in adjustment of cell metabolism (Verbruggen and Hermans, 2008). Soluble sugar content also changes due to drought stress and play a positive role under moisture

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limited conditions (Koutroubas *et al*., 2004). The increased accumulations of soluble sugars maintain turgidity in leaves and protect the membranes and proteins from dehydration (Sawhney and Singh, 2002).

Compatible solute accumulation is necessary adaptation of plants against osmotic stress occurred due to water shortage (Serraj and Sinclair, 2002). A little work is reported on these aspects, the aim of this study was to determine the physiological responses as well as to assess the role of osmoprotectants (free proline, soluble sugars, amino acids, proteins) in alleviating the detrimental effects of drought stress in camelina genotypes.

Materials and Methods

This experiment was conducted in pots to evaluate the physico-chemical responses of camelina under various levels of drought stress. A factorial experiment in a completely randomized design with three replications was accomplished in the rainout shelter of Department of Agronomy, University of Agriculture, Faisalabad, Pakistan during November 2014. Two camelina genotypes V_1=7126 and V2= 8046, which were selected on the basis of our preliminary studies (Ahmed, 2016) that involved screening of eight genotypes and the most drought tolerant (7126) and sensitive (8046) ones were identified. Seeds were obtained from the Office of Research, Innovation and Commercialization (ORIC), University of Agriculture, Faisalabad. After surface sterilization, 15 seeds of each genotype were sown into plastic pots filled with 4 kg sand on 1st November, 2014. Before sowing, sand was sun-dried and sieved. After sowing, all pots were kept at 100% field capacity level to obtain good germination. Twenty days after sowing, 10 uniform sized healthy plants were maintained in each pot. At the time of sowing, recommended rates of phosphorus and potassium (30 kg ha^{-1} and 60 kg ha^{-1} respectively) were used. Nitrogen (50 kg ha^{-1}) was applied in two splits; half nitrogen (25 kg ha^{-1}) at the time of sowing and remaining half was added after 20 days of sowing. After 10 days, drought treatment was imposed. For drought imposition, one group of plants was grown under well watered condition (100% FC) and other was grown with 80, 60 and 40% FC. Drought stress was continued for 25 days. For each treatment pots were weighed on daily basis at about 9:00 am, measured the amount of water used in evapotranspiration (Allen *et al*., 1998) from each pot and then watered until its weight reached to pre-determined weight. Data on temperature, relative humidity, evapo-transpiration and sunshine hours was recorded and averaged as given below (Table 1). Data regarding seedling growth traits, gas exchange parameters, free proline, soluble sugars, amino acids and protein content were recorded.

Seedling Growth Traits

After forty days of sowing, seedling growth traits like shoot length, root length, shoot fresh weight, root fresh weight, shoot dry weight and root dry weight were measured. Three plants were harvested from each pot and washed gently with water to remove sand. Plant shoot and root lengths were measured with the help of a measuring tape. Then plants were cut into shoot and root to measures shoot, root fresh weights on electrical weighing balance (MK-500C, Japan). After that shoots and roots were put in paper bags separately and dried for 72 h at 60°C and then dry weight was recorded.

Gas Exchange Characteristics

A fully expanded youngest leaf of each plant at the onset of inflorescence, was used to measure the instantaneous photosynthetic rate (*A*), transpiration (*E*) and stomatal conductance (*gs*) with the help of an open system LCA-4 ADC portable infrared gas analyzer. The above parameters were recorded from 9.00 to 11.00 a.m. by adjusting: molar flow of air per unit leaf area 403.3 mmol m^{-2} S^{-1}, atmospheric pressure 99.9 kPa, vapor pressure of water into chamber was between 6.0 to 8.9 m bar, Photosynthetically active radiation (PAR) at leaf surface was maximum up to 1711 mol m^{-2} s^{-1}, leaf temperature was kept between 28.4 to 32.4°C, ambient temperature was adjusted between 22.4 to 27.9°C and ambient CO_2 concentration was 352 mol mol^{-1}.

Determination of Osmoprotectants

Free proline content was determined by following the method of Bates *et al*. (1973). Homogenized 0.5 g fresh leaf sample was mixed in 10 mL of 3% sulfosalicylic acid and the material was filtered and two mL from the filtered sample was taken and reacted with two mL acid ninhydrin solution in a test tube. Then two milliliters of glacial acetic acid were added in the test tube and sample mixture was heated for one h at 100°C. 4 mL toluene solution was used to extract this sample mixture. The chromophore comprising toluene was aspirated from the aqueous phase and absorbance was recorded on spectrophotometer at 520 nm. Toluene was used as a blank.

To estimate the total soluble sugars, 0.5 g fresh leaf sample from each treatment was taken and after its extraction with 80% ethanol it was incubated for 6 h at 60°C. Then extract was taken in 25 mL test tubes and 6 mL anthrone reagent was added in each tube and heated for 10 min. in boiling water. The tubes were cooled down for 10 min. and then put in incubator for 20 min at 25°C Absorbance was noted on a spectrophotometer at 635 nm. The total soluble concentration was estimated from standard curve by following the method described by Riazi *et al*. (1985). To estimate soluble proteins and total free amino acids 0.5 g leaf material was taken from each treatment and extracted in 0.2 M phosphate buffer (pH 7.0). Then the method described by Lowry *et al*. (1951) and Hamilton and Van Slyke (1973) was followed to measure the final

concentration of soluble proteins and amino acids.

Statistical Analysis

Analysis of variance was done to statically analyze the recorded data by using Statistix-9.1software. Least significant difference (LSD) test at 5% probability level was used to compare the significant mean (Steel *et al*., 1997).

Results

Seedling Growth Traits

Data regarding seedling growth traits indicated significant difference ($P \leq 0.001$) between camelina genotypes and drought stress levels. Interaction between genotypes and drought stress levels were also significant ($P \leq 0.05$) for all the seedling traits. Maximum shoot length (SL), root length (RL), shoot fresh weight (SFW), root fresh weight (RFW), shoot dry weight (SDW) and root dry weight (RDW) under control treatment (100% FC) and genotype 7126 performed better than genotype 8046 under normal and drought stress regarding all the seedling traits. Imposition of drought stress significantly decreased the seedling traits and at 40% FC maximum percentage reduction was observed for SDW (78%), followed by SFW (76%), RFW (66%), RDW (66%), RL (52%) and SL (51%) as compared to 100% FC (Control). At 60% FC compared to control (100% FC), the highest percentage reduction was recorded for SDW (50%), followed by RFW (49%), SFW (44%), RDW (36%), SL (30%) and RL (18%). Similarly at 80% FC, the maximum reduction was observed in RFW (36%), SDW (28%), SFW (20%), RDW (18%), SL (15%) and RL (11%) as compared to normally grown plants at 100% FC (Table 2).

Gas Exchange Parameters

Highly significant variations ($P \leq 0.001$) were recorded between camelina genotypes and drought stress levels for gas exchange characteristics (Table 3). Drought stress caused a gradual reduction in photosynthetic rate (P_n), stomatal conductance (g_s) and transpiration rate (E) of both genotypes at different water stress levels, however, camelina genotype 7126 maintained significantly higher values than genotype 8046 for these variables. At 100% FC, genotype 7126 exhibited the highest values for these characteristics. The imposition of drought stress at different FC levels i.e. 80%, 60% and 40% FC significantly reduced P_n by 16%, 37% and 49%, respectively (Fig. 1) with respect to normal plants (100% FC). Similar trend was noted for g_s as water stressed plants showed 15% (80% FC), 23% (60% FC) and 51% (40% FC) reduction (Fig. 2) than the plants grown under normal conditions (100% FC). A gradual decrease in E was also observed at different water stress levels with a reduction of 8, 25 and 39.5% at 80, 60 and 40% FC levels, respectively as compared to control (100% FC) (Fig. 3).

Table No. 1: Metrological data during the experimental period

Characters	November 2014	December 2014
Temperature (°C)	18.90	12.20
Relative humidity (%)	61.70	75.00
Evapotranspiration (mm)	1.80	1.50
Sunshine (h)	07.6	4.70

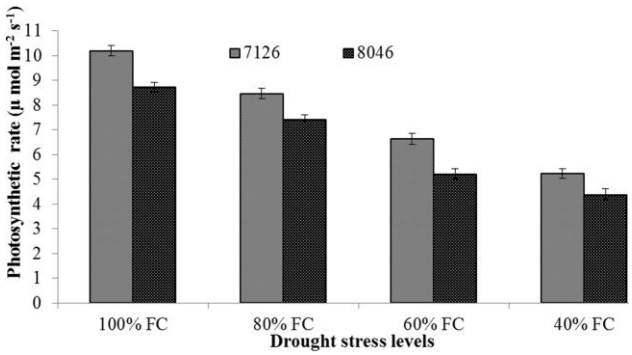

Fig. 1: Effect of different drought stress levels on photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) of two camelina genotypes (mean values ± SE)

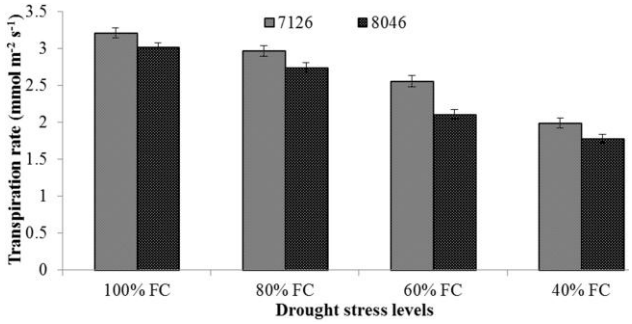

Fig. 2: Effect of different drought stress levels on transpiration rate (mmol H_2O m^{-2} s^{-1}) of two camelina genotypes (mean values ± SE)

Osmoprotectants

Leaf free proline, soluble sugars, amino acids and soluble proteins: A significant ($P \leq 0.001$) effect of different camelina genotypes, drought stress levels and their interaction ($P \leq 0.05$) was observed on leaf free proline, total soluble sugars and amino acid content in camelina plants (Table 4). An increase in free proline, soluble sugars and amino acid content was recorded by decreasing FC levels in camelina plants. Camelina genotype 7126 showed higher values of free proline, soluble sugars and amino acid content as compared to genotype 8046 under normal and drought stress conditions. Water stressed plants grown under 80, 60 and 40% FC showed a significant increase in free proline contents by 22, 89 and 160%, respectively compared to plants grown under normal conditions (Fig. 4). Similar

Table 2: Seedling trait values of two camelina genotypes across four water stress levels

Camelina genotypes	Water stress levels	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)
7126	100% FC (Control)	22.18a	23.23 a	4.24 a	3.07 a	2.72 a	1.10 a
	80% FC	18.97 c	20.90 bc	3.41 b	1.95 c	1.93 c	0.90 b
	60% FC	15.70 e	19.22 cd	2.36 d	1.53 d	1.39 e	0.72 d
	40% FC	11.89 g	11.58 e	0.83 f	1.02 f	0.57 g	0.38 f
8046	100% FC (Control)	20.49 b	22.07 ab	3.41 b	2.41 b	2.29 b	0.81 c
	80% FC	17.15 d	20.58 c	2.68 c	1.58 d	1.64 d	0.67 d
	60% FC	14.24 f	18.16 d	1.91 e	1.24 e	1.09 f	0.51 e
	40% FC	8.44 h	10.55 e	0.97 f	0.82 g	0.49 h	0.27 g
	LSD	1.36	1.87	0.20	0.18	0.06	0.05

Mean values sharing similar letters in a column are statistically non-significant ($P \leq 0.05$)

Table 3: Analysis of variance table for photosynthetic rate (µmol CO_2 m^{-2} s^{-1}), transpiration rate (mmol H_2O m^{-2} s^{-1}) and stomatal conductance (mmol H_2O m^{-2} s^{-1}) of two camelina genotypes under different drought stress levels

SOV[a]	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})	Transpiration rate (mmol H_2O m^{-2} s^{-1})	Stomatal conductance (mmol H_2O m^{-2} s^{-1})
Genotypes (G)	***	***	***
Drought stress (S)	***	***	***
G×S	**	**	**
CV[b]	3.40	5.96	6.14

Table 4: Analysis of variance table for proline (mmol g^{-1} FW), total soluble sugars (mg g^{-1} FW), total free amino acids (mg g^{-1} FW) and total soluble proteins (mg g^{-1} FW) and contents of two camelina genotypes under different drought stress levels

SOV[a]	Proline (mmol g^{-1} FW)	Total soluble sugars (mg g^{-1} FW)	Total free amino acids (mg g^{-1} FW)	Total soluble proteins (mg g^{-1} FW)
Genotypes (G)	***	***	***	***
Drought stress (S)	***	***	***	***
G×S	*	*	*	*
CV[b]	4.11	6.96	4.83	3.83

*, **, *** = Significant at 0.05, 0.01 and 0.001 level; NS = Non significant respectively, [a]Source of variation, [b] coefficient of variation

increase in soluble sugars (83, 102 and 190%) was noted under different water stress levels i.e., 80, 60 and 40% FC, respectively as compared to control (Fig. 5). Total free amino acid content increased by 94, 197 and 230%, respectively in response to drought stress levels (80, 60 and 40% FC) as compared to normal plant (100% FC), respectively (Fig. 6). A significant ($P \leq 0.001$) reduction was observed in soluble protein content with the increase of water deficit. Camelina genotype 7126 showed higher values of soluble proteins than genotype 8046 at all drought stress levels. Drought stress treatments led to reduced soluble proteins and the reductions were 11, 32 and 53% with respect to 80, 60 and 40% FC levels as compared to control (100% FC) (Fig. 7).

Discussion

Results of present study revealed that phenotypic expression of all the seedling traits reduced under drought stress in camelina genotypes. Our results regarding seedling traits conforms with the earlier reports (Bibi *et al*., 2010; Ali *et al*., 2011) that most of the morphological and physiological traits at seedling stage were affected by drought stress. Reduced seedling growth occurred due to restricted cell division and enlargement under drought stress (Kramer, 1983). This impediment of cell division and elongation caused reduction in shoot length and root length due to tuberization and lignification in the root system that slows down the whole system of water stressed plant (Fraser *et al*., 1990). Shoot, root fresh and dry weights were also decreased due to water stress. Decrease in fresh and dry weights of plants was attributed to their small leaf size under drought stress (Bibi *et al*., 2012). Moreover, water stressed plants utilized limited amount of food energy provided by the seed in an efficient way for their growth and development (Khan *et al*., 2002; Rauf *et al*., 2007).

Results of this study showed that limited water supply during growth of camelina declined the net photosynthesis (*Pn)*, stomatal conductance (*gs*) and transpiration rate (*E*). Reduction in photosynthetic rate under drought stress occurred due to metabolic impairment and stomatal closure that hinders the carbon uptake through leaves (Cornic and Massacci, 1996: Tezara *et al*., 1999). The reduced photosynthetic rate under water deficit condition may be attributed to decreased mesophyll capacity for photosynthesis at cellular level due to reduced nitrogen availability for photosynthetic apparatus (Toth *et al*., 2002). The decrease in photosynthesis under limited water may be due to degradation of chlorophyll, disintegration and suppression of rubisco and stomatal closure (Hajduch *et al*., 2001; Pietrini *et al*., 2003). Stomatal regulation is a vital phenomenon in plants, because it prevents both desiccation and CO_2 acquisition (Dodd, 2003; Medici *et al*., 2007). Closing of stomata under limited water attributed to

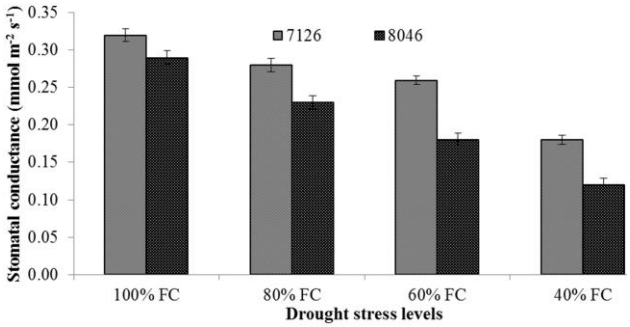

Fig. 3: Effect of different drought stress levels on stomatal conductance (mmol H_2O m^{-2} s^{-1}) of two camelina genotypes (mean values ± SE)

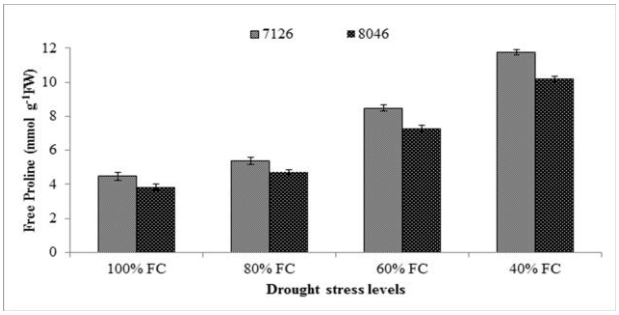

Fig. 4: Effect of different drought stress levels on leaf proline contents (m mol g^{-1} FW) of two camelina genotypes (mean values ± SE)

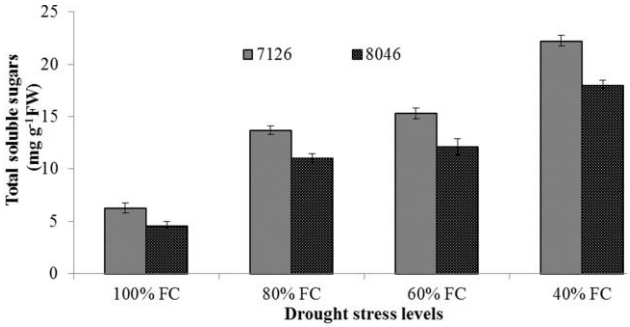

Fig. 5: Effect of different drought stress levels on total soluble sugars (mg g^{-1} FW) of two camelina genotypes (mean values ± SE)

reduction in leaf turgor pressure and atmospheric humidity along with chemical signals generated by roots (Maroco *et al*., 1997; Chaves *et al*., 2009). Hence, decline of photosynthetic rate under stress conditions happens due to suppression of mesophyll conductance and closing of stomata under stressful conditions (Flexas *et al*., 2004; Chaves *et al*., 2009). The stomata closure reduces *Ci* (internal CO_2 concentration), prevent ATP synthesis, decreases Rubisco activity that eventually limits photosynthetic rate (*Pn*) under drought stress (Dulai *et al*., 2006). Reduction in transpiration rate is a plant response

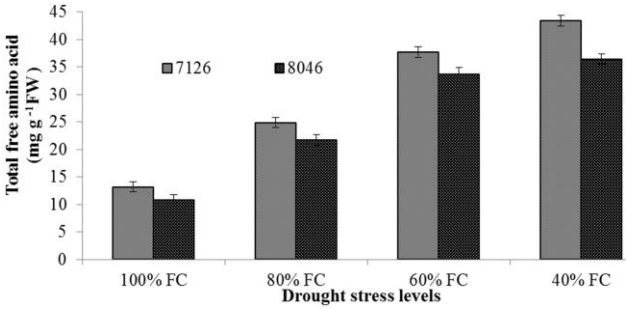

Fig. 6: Effect of different drought stress levels on total free amino acids (mg g^{-1} FW) of two camelina genotypes (mean values ± SE)

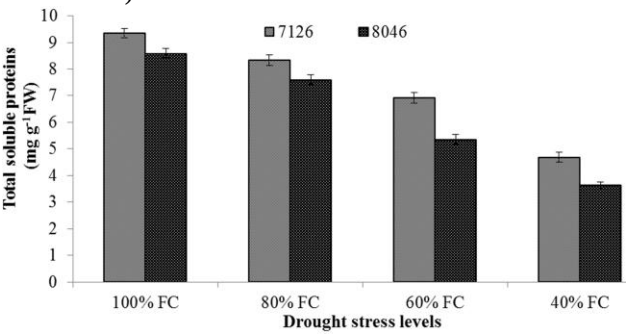

Fig. 7: Effect of different drought stress levels on total soluble proteins (mg g^{-1} FW) of two camelina genotypes (mean values ± SE)

that indicates water conservation and reduced water loss through stomata (Jones *et al*., 1985). Various studies revealed that transpiration rate decreased under drought stress (Egret and Tevini, 2002; Rahbarian *et al*., 2011), which possibly resulted from reduced photosynthetic rate and stomatal conductance in drought affected plants as happened in present study.

Our results regarding free proline content are in agreement with those reported by Unyayar *et al*. (2009) who revealed that high concentration of free proline content in sunflower leaf becomes a solute under drought stress and play its role in intercellular osmotic adjustment. The increased free proline accumulation in water stressed plants might be due to reduced protein biosynthesis (Cechin *et al*., 2008) and can be regarded as an important selection criterion for stress tolerance (Jaleel *et al*., 2007). Declined free proline dehydrogenase (proline catabolic enzyme) might be another reason of increased free proline accumulation (Sundaresan and Sudhakaran, 1995; Lee and Liu, 1999).

Increase in total soluble sugars under various drought stress levels was observed in camelina genotypes in our study. The elevated sugar content might be resulted from starch degradation under drought stress due to amylase activity (Ghasempour *et al*., 1998). Reduction in starch content might be attributed to inhibition of starch synthesis under water limited conditions (Geigenberger *et al*., 1997). Rise in sucrose with fall in starch concentration is also

reported by Abdel–Nasser and Abdel-Aal (2002) in safflower.

In this study, accelerated accumulation of amino acids was observed in camelina against drought stress. Similar findings were also reported by Ashraf and Iram (2005). Elevation in free amino acid content under water limited condition occur due to increased degradation of protein causing an increase in osmotic potential that leads to develop tolerance in plants against drought stress. Moreover free amino acids promote the uptake of K^+ and Ca^+ thereby helping in osmoregulation through inorganic solutes (Navari-Izzo *et al.*, 1990). Higher content of free amino acids under drought has been observed in crops like wheat, sorghum, pepper (Yadav *et al*., 2005) and cotton (Parida *et al*., 2007).

Results of present study showed a decline in soluble protein content with escalation of drought stress in camelina genotypes. Our results are in agreement with Mohammadkhani and Heidari (2008) who reported decrease in soluble protein content in leaves and roots of maize under limited water conditions. This decline of proteins might be attributed to less rate of protein biosynthesis and higher degradation of proteins under drought stress (Rodrigues *et al*., 2005), that is important to generate low molecular weight osmolytes for osmotic adjustment (Nayyar and Walia, 2003).

Conclusion

Water stress significantly influenced the seedling growth traits, physiological and biochemical processes in camelina. Genotype 7126 (drought tolerant) performed better than the genotype 8046 under water deficit conditions. Moreover, it can be inferred that camelina tolerates limited availability of water through regulation of its photosynthetic machinery and accumulation of free proline, soluble sugars and free amino acids. However, further studies are proposed to understand the molecular mechanisms responsible for improving drought tolerance in camelina.

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