Pak. J. Bot., 52(5): 1537-1544, 2020. DOI: http://dx.doi.org/10.30848/PJB2020-5(2)

COMPARATIVE STUDY OF GROWTH, PHYSIOLOGY AND YIELD ATTRIBUTES OF CAMELINA (*CAMELINA SATIVA* L.) AND CANOLA (*BRASSICA NAPUS* L.) UNDER DIFFERENT IRRIGATION REGIMES

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Abstract

Camelina (*Camelina sativa* L.) is an alternative oilseed crop having several attractive features making it a potential oilseed crop. To assess the physiology, growth and yield responses of different genotypes of camelina and canola crops under various irrigation regimes two field trials were conducted for consecutive growing seasons in 2013-14 and 2014-15. Randomized complete block design (RCBD with factorial arrangements was adopted. In this experiment two camelina genotypes (Camelina-611 and Camelina-618), and two canola genotypes (Punjab sarsoon and Faisal canola) were used with four levels of irrigations I_0 (two irrigations: 1st at vegetative stage and 2nd at reproductive stage), I_1 (one irrigation at vegetative stage), I_2 (one irrigation at reproductive stage), and I_3 (no irrigation). The results revealed that the maximum values of leaf gas exchange traits, chlorophyll and carotenoid content, leaf water relation, yield and yield components were noted when two irrigations (I_0) were applied and it was followed by one irrigation at vegetative stage (I_1). However, the minimum values of these traits were recorded in water deficit plants that received no irrigation (I_3). Among the genotypes Camelina-618 relatively performed well as compared to other genotypes regarding all the recorded parameters (leaf gas exchange, chlorophyll and carotenoid content, leaf water relation, yield and yield components) under both well-watered and water stressed conditions.

Key words: Oilseed crop, Camelina, Canola, Irrigation regimes, Water deficit, Physiology.

Introduction

Pakistan being an agricultural country is still deficient in edible oil production (Tahir *et al*., 2007). The deficiency of edible oil is the most important challenge in Pakistan. To meet the growing demand of edible oil in the country a huge amount of precious foreign exchange is spent on the import of edible oil (Shah *et al*., 2007). During 2014-15 the total edible oil consumption of the country was 3.20 million tones, of which 0.57 million tons (17%) was locally produced, while remaining 2.63 million tones (83%) was imported by spending US$ 2.50 billion (Anon., 2015).

Several oilseed crops such as cotton, sunflower, sesame, safflower, groundnut and rapeseed/mustard are cultivated in the country (Anon., 2015). Rapeseed/ mustard is the second largest source of oil after cotton in Pakistan (Sattar *et al*., 2013). Unfortunately, rapeseed/mustard oil is not used as regular cooking oil due to high content of erucic acid (Sattar *et al*., 2013). On the other hand, cotton oil contains cyclopropanile fatty acid and gossypol, which is injurious to human health (Waraich *et al*., 2013). In present situation canola is regarded as major oilseed crop in Pakistan being an important source of edible oil (Sattar *et al*., 2013). Canola oil is superior in quality as compared to conventional cooking oils, because it contains greater amount of polyunsaturated fatty acids (*n-3* and *n-6* fatty acids) and lower content of saturated fatty acids (Raza *et al*., 2015; EL Sabagh *et al*., 2019a). Canola has poor adaptation to drought stress and its yield is affected severely if water deficit occur at reproductive stage (Wright *et al*., 1997; Ahmadi & Bahrani, 2009). Increasing demand for vegetable oils and diversification of agriculture leads to investigate alternate oilseed crops with multipurpose food and non-food applications.

Camelina is a good example of such alternative oilseed crop (Wittkop *et al*., 2009). Camelina, a member of *Brassicaceae* family has more drought tolerance and ability of early maturity as compared to other *Brassica* oilseed crops (Gugel & Falk, 2006). It is rediscovered the great value of oilseed crop in North America, with favorable agronomic attributes and specialty oil properties (Gugel & Falk, 2006). Camelina is a low input requiring crop that can be cultivated under various climatic and soil conditions (Zubr, 2003). Oil content varied from 38-43% in camelina seed and seed protein content ranges from 27-32% (Gugel & Falk, 2006). High concentration (36-39%) of omega-3 fatty acid (linolenic acid, C 18:3) in camelina oil makes it an attractive crop for food oil (Gugel & Falk, 2006). Camelina meal has also been approved to use in the diets of chickens and beef cattle (Waraich *et al*., 2013). Camelina oil has also been used for biodiesel production (Frohlich & Rice, 2005) and it is also under investigation to use as aviation fuel (Shonnard *et al*., 2010).

Drought stress is the foremost constraint for sustainable production of agriculture all over the world (Nawaz *et al*., 2012; EL Sabagh *et al*., 2019b). The availability of soil water considering one of the major important abiotic restrictive factors that influence the performing of crops (Micheletto *et al*., 2007).

With the decline of water in several regions of the world, increasing interest to investigate those crops that produce acceptable yield under water deficit conditions (Sinaki *et al*., 2007). Water deficiency resulted from drought or osmotic stress alters morphology, water relations, gas exchange and chlorophyll contents, responsible to trigger defensive mechanism in plants (Jackson *et al*., 1995; Fahad *et al*., 2019; EL Sabagh *et al*., 2019c). Water deficiency also induces negative impact on cell growth, that cause splitting of membrane proteins (McKersie *et al*., 1996; Jaleel *et al*., 2009). Heavy losses in the yield of major crops occurring in Pakistan due to the limited supply of irrigation water (Haq *et al*., 2014). The assessment and producing of new oilseed crops with high production under water stress condition is considered an important option to rescue small scale farmers for increasing income (Tabassum, 2004). Although various studies have been conducted on improvement of oilseed crops under drought conditions, yet comparative studies are very less in this regard. Present research work was planned to compare the growth, physiology and yield of an emerging oilseed crop, camelina with canola under varying irrigation levels for suitable irrigation scheduling.

Materials and Methods

Experimental site description: Two field trials were conducted during November-April in 2013-2014 and 2014-2015 on canola genotypes (Punjab sarson and Faisal canola) and camelina genotypes (Camelina-611 and Camelina-618) under different irrigation regimes at research area of Agronomy Department, Agriculture University, Faisalabad, Pakistan. The study site was located at31°25′ N and 73°09′ E longitude with 184.4 m elevation from the sea level.). The soil was clay loam with a pH of 7.4-7.6. The climatic conditions of the experimental sites were semi-arid with hot dry summer and severe cold in winter season. The average maximum temperature was 23.77°C during 2013-2014 growing season. Meteorological data was also recorded during both growing season (Table 1).

Experimental details: Canola cultivars Punjab sarson and Faisal canola was purchased from Ayub Agricultural Research Institute, Faisalabad and camelina lines Camelina-611 and Camelina-618 from Department of Plant Breeding and Genetics. The experiment was laid out in a randomized complete block design (RCBD) as factorial arrangements. The size plot was 2.5 m × 3.0 m. The crop was sown on 18th and 14thNovember, 2013 and 2014, respectively, with the help of a seed drill and the distance between rows was 45 cm. Plant population was maintained by thinning at early growth phase. Fertilization was done at the rate of 100 and 30 kg ha^{-1}of nitrogen (N) and phosphorus (P) by using the form of urea (46% N) and di-ammonium phosphate (DAP; 18% N, 46% P_2O_5), respectively. Half of the N and whole P were added as basal dose, and rest of the N was added with 1st irrigation. The control plants (I_0) received two irrigations (1st at vegetative stage and 2nd at reproductive stage) whereas other water application involved once apply water at vegetative stage (I_1), one at reproductive stage (I_2) and no irrigation (I_3), respectively. Both oil seed crops grown up to maturity and recording the following parameters.

Leaf gas exchange: Younger leaf with full maturity was used after 8th leaf phase to determine the instantaneous net CO_2 assimilation rate (*A*), transpiration (*E*), stomatal conductance (*gs*) and sub-stomatal CO_2 concentration (ci) by using an open system LCA-4 ADC portable infrared gas analyzer (Analytical Development Company, Hoddesdon, England).

Leaf water relations: The leaf water potential was calculated by water potential apparatus (Model 600, Pressure chamber Instrument, PMS International Company) available in the Stress Physiology Lab., University of Agriculture, Faisalabad, Pakistan, following the method acceding to Scholander *et al*., (1965). The same leaf utilized for water potential measurement was frozen in a freezer (-20ºC). A drop thawed leaf sap was used directly in already calibrated cryoscopicosmometer (Osmomat 030-D, Cryoscopicosmometer printer, Genatec) for osmotic potential measurement. The pressure potential was calculated by using the formula of Hopkin (1999).

Pigments: The chlorophyll contents were measured according to procedure and formula which are describe by Arnon (1949).

Yield related attributes: Once the reach at maturity stage, camelina and canola plants in a area1m^2 section were manually harvested in each plot. The harvested plants were threshed and winnowed, and the chaff added to the straw fraction. Total above ground biomass (biological yield), seed yield and harvest index values were measured and converted to t ha^{-1}.

Statistical analysis: Data were collected and analyzed according to Fisher's analysis of variance technique. Treatment means were compared through least significant difference test used at 5% for comparison of the means of treatment (Steel *et al*., 1997).

Results

Leaf gas exchange attributes: Leaf gas exchange traits of camelina and canola genotypes were significantly ($p \leq 0.05$) affected by varying irrigation regimes in both the years 2013-14 and 2014-15 (Table 2). There was no significant interaction between irrigation and genotypes. The highest photosynthetic rate (16.17 µmol m^{-2} s^{-1}), transpiration rate (4.89 µmol m^{-2} s^{-1}), and stomatal conductance (0.45 µmol m^{-2} s^{-1}) were observed in the treatment (I_0) during second growing season (2014-15), and it was followed by the irrigation at vegetative stage (I_1). However, the lowest leaf gas exchange traits were noted where no irrigation was applied (I_3). Similar trend was observed during the first growing season. A significant genotypic effect for leaf gas exchange traits occurred during both years (Table 2). Camelina and canola genotypes varied significantly from each other regarding leaf gas exchange traits. Camelina-618 showed the maximum photosynthetic rate, transpiration rate and stomatal conductance (12.97µmol m^{-2} s^{-1}, 4.44 µmol m^{-2} s^{-1} and 0.34mol m^{-2} s^{-1}, respectively), which was followed by Camelina-611 and the minimum values of these parameters were recorded in Faisal canola during both the years 2013-14 and 2014-15 (Table 2).

Leaf water potential, osmotic and pressure potential: Leaf water relation parameters were significantly influenced by different levels of irrigation, camelina and canola genotypes in both the years 2013-14 and 2014-15 (Table 3). The maximum leaf water potential (-0.93 MPa), leaf osmotic potential (-1.32 MPa) and leaf pressure potential (0.39 MPa) were recorded during 2014-15 where two irrigations were applied (I_0), and it was followed by one irrigation at vegetative stage (I_1). The lowest values of leaf water potential (-1.49 MPa), leaf osmotic potential (-1.65 MPa) and leaf pressure potential (0.17 MPa) were noted with no irrigation (I_3) treatment (Table 3). Similar trend was noted during 2013-14.

Camelina and canola genotypes showed significant differences regarding leaf water relation characteristics during both growing seasons. During 2014-15, Camelina-618 showed the highest leaf water potential (-1.13 MPa), leaf osmotic potential (-1.44 MPa) and leaf pressure potential (0.32) MPa) and it was followed by Camelina-611. However, Faisal canola depicted the lowest leaf water potential (-1.24 MPa), leaf osmotic potential (-1.50 MPa) and leaf pressure potential (0.27 MPa) in 2014 -15. Same trend was observed in the year 2013-14 (Table 3).

Chlorophyll *a*, chlorophyll *b* and carotenoids: Data regarding chlorophyll *a*, chlorophyll *b* and carotenoid content in both crops was influenced significantly ($p \leq 0.05$) by varying irrigation regimes during both growing seasons (Table 4). The highest chlorophyll *a* (1.50 mg g^{-1}), chlorophyll *b* (0.89 mg g^{-1}) and carotenoid (1.43 mg g^{-1}) were observed under control conditions (I_0) during 2014-15, and it was followed by I_1. The minimum values of chlorophyll *a* (1.01 mg g^{-1}), chlorophyll *b* (0.29 mg g^{-1}) and carotenoid (0.95 mg g^{-1}) were noted under no irrigation (I_3) treatment (Table 4). Similar trend was observed during 2013-14.

Camelina and canola genotypes differed significantly from each other in relation to chlorophyll *a*, chlorophyll *b* and carotenoid content. The maximum chlorophyll *a*, chlorophyll *b* and carotenoid values (1.43, 0.78, 1.29 mg g^{-1}, respectively) were noted in Camelina-618, followed by Camelina-611 and the minimum chlorophyll *a*, chlorophyll *b* and carotenoid content (1.07, 0.43, 1.01 mg g^{-1}, respectively) were recorded in Faisal canola in 2014-15. Values of chlorophyll *a* and chlorophyll *b* were higher in 2014-15 as compared to 2013-14 in camelina and canola genotypes (Table 4).

Table 1. Metrological data of experimental site during 2013-14.

Observation	November 2013	December 2013	January 2014	February 2014	March 2014	April 2014
Temperature max. °C	26.10	20.50	19.10	20.00	24.70	32.20
Temperature min. °C	11.80	08.40	06.10	08.90	13.60	18.60
Rainfall (mm)	0.50	0.00	0.00	14.30	41.70	28.20
	Metrological data of experimental site during 2014-15					
Observation	**November 2014**	**December 2014**	**January 2015**	**February 2015**	**March 2015**	**April 2015**
Temperature max. °C	26.30	18.50	16.60	22.00	24.50	33.20
Temperature min. °C	11.50	05.90	06.90	11.10	13.60	20.70
Rainfall (mm)	10.00	0.00	12.20	20.50	67.90	32.80

Table 2. Leaf gas exchange traits of camelina and canola affected by different irrigations in the years 2013-14 and 2014-15.

Treatments	Photosynthetic rate (µmol m^{-2} s^{-1})		Transpiration rate (µmol m^{-2} s^{-1})		Stomatal conductance (mol m^{-2} s^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Irrigations						
2-Irrigations (I_0)	15.48 a	16.17 a	4.22a	4.89a	0.29a	0.45 a
1-Irrigation (I_1)	11.63 b	12.80 b	3.71b	4.40b	0.20b	0.33 b
1-Irrigation (I_2)	08.62 c	09.74 c	3.00c	3.89c	0.12c	0.21 c
No Irrigation (I_3)	06.05 d	07.34 d	2.53d	3.44d	0.08d	0.18 d
Genotypes						
Camelina-618	12.05 a	12.97 a	3.67 a	4.44 a	0.21 a	0.34 a
Camelina-611	10.42 b	11.54 b	3.45 b	4.23 b	0.18 b	0.31 b
Punjab Sarsoon	9.10 c	11.10 c	3.22 c	4.02bc	0.15 c	0.25 c
Faisal Canola	08.05 d	10.32 d	3.01 d	3.93 c	0.13 d	0.20 d

Table 3. Leaf water relation parameters of camelina and canola affected by different irrigations in the years 2013-14 and 2014-15.

Treatments	Leaf water potential (-MPa)		Leaf osmotic potential (-MPa)		Leaf pressure potential (MPa)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Irrigations						
2-Irrigations (I_0)	-1.03 a	-0.93 a	-1.35 a	-1.32 a	0.33 a	0.39 a
1-Irrigation (I_1)	-1.17 b	-1.09 b	-1.44 b	-1.42 b	0.27 b	0.32 b
1-Irrigation (I_2)	-1.28 c	-1.26 c	-1.51 c	-1.49 c	0.23 c	0.23 c
No Irrigation (I_3)	-1.49 d	-1.46 d	-1.65 d	-1.65 d	0.17 d	0.18 d
Genotypes						
Camelina-618	-1.17 a	-1.13 a	-1.45 a	-1.44 a	0.28 a	0.32 a
Camelina-611	-1.23 b	-1.17 b	-1.49 b	-1.45 b	0.24 b	0.28 b
Punjab Sarsoon	-1.29 c	-1.21 c	-1.51 c	-1.48 c	0.21 c	0.24 c
Faisal Canola	-1.35 d	-1.24 d	-1.54 d	-1.50 d	0.24 bc	0.27 bc

Values within columns followed by different letters are significantly different at $p<0.05$

Table 4. Chlorophyll*a*, *b* and carotenoid contents of camelina andcanola genotypes affected by different irrigations in the years 2013-14 and 2014-15.

Treatments	Chlorophyll *a* (mg g^{-1})		Chlorophyll *b* (mg g^{-1})		Carotenoid (mg g^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Irrigations						
2-Irrigations (I_0)	1.27 a	1.50 a	0.50 a	0.89 a	1.35 a	1.43 a
1-Irrigation (I_1)	1.15 b	1.32 b	0.38 b	0.78 b	1.19 b	1.23 b
1-Irrigation (I_2)	1.10 b	1.17 c	0.35 b	0.60 c	1.06 c	1.10 c
No Irrigation (I_3)	0.96 c	1.01 d	0.25 c	0.29 d	0.94 d	0.95 d
Genotypes						
Camelina-618	1.18 a	1.43a	0.41 a	0.78 a	1.22 a	1.29 a
Camelina-611	1.13 b	1.31b	0.38 b	0.67 b	1.16 b	1.16 b
Punjab Sarsoon	1.07 c	1.19 c	0.34 c	0.56 c	1.10 c	1.03 c
Faisal Canola	1.01 d	1.07 d	0.31 d	0.43 d	1.03 d	1.01 c

Values within columns followed by different letters are significantly different at $p<0.05$

Table 5. Yield components of camelina and canola genotypes affected by different irrigations in the years 2013-14 and 2014-15.

Treatments	Plant height (cm)		No. of pods per plant		1000-seed weight (g)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Irrigations						
2-irrigations (I_0)	141.30 a	149.03 a	507 a	553 a	2.27 a	2.43 a
1-Irrigation (I_1)	135.35 b	135.56 b	390 b	406 b	2.15 b	2.33 b
1-Irrigation (I_2)	123.25 c	127.35 c	220 c	271 c	2.08 bc	2.27 bc
No Irrigation (I_3)	108.13 d	120.15 d	1.92 c	206 d	1.98 c	2.18 c
Genotypes						
Camelina-618	112.92b	106.51b	354a	428 a	1.13 b	1.31b
Camelina-611	111.53 b	101.52 b	336ab	362 b	1.09 b	1.27 b
Punjab Sarsoon	144.07a	165.79a	318 ab	343b	3.07 a	3.27 a
Faisal Canola	140.68a	161.02 a	300 b	307b	3.17 a	3.36 a

Values within columns followed by different letters are significantly different at $p<0.05$

Yield related attributes: Yield related attributes were significantly ($p\leq0.05$) influenced by different irrigation rates during both the years of the study (Tables 5 and 6). The highest plant height (149 cm), number of pods per plant (553), 1000-seed weight (2.43 g), biological yield (10.06t ha^{-1}), seed yield (2.13 t ha^{-1}) and harvest index (21.15%) were recorded with two irrigations (I_0) followed by one irrigation at vegetative stage (I_1), and the minimum values of these traits were observed under no irrigation treatment (I_3).

In case of genotypes, the canola genotype Punjab sarsoon showed the longest plant (165.79 cm) and 1000-seed weight (3.36g), and the minimum values of said traits were noted in camelina-618. However, the maximum number of pods per plant (428), biological yield (8.76 t ha^{-1}), seed yield (1.66 t ha^{-1}) and harvest index (18.94 %) were observed in the camelina genotype Camelina-618 while the minimum values of these traits were recorded in the canola genotype Faisal canola (Tables 5 and 6).

Table 6. Yield and harvest index of camelina and canola genotypes affected by different irrigations in the years 2013-14 and 2014-15.

Treatments	Biological yield ($t\ ha^{-1}$)		Grain yield ($t\ ha^{-1}$)		Harvest index (%)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Irrigations						
2-Irrigations (I_0)	9.41 a	10.06 a	1.68 a	2.13 a	17.82 a	21.15 a
1-Irrigation (I_1)	7.95 b	8.52 b	1.32 b	1.59 b	16.66 b	18.64 b
1-Irrigation (I_2)	6.67 c	7.51 c	0.97 c	1.29 c	14.44 c	17.18 c
No Irrigation (I_3)	5.34 d	6.21 d	0.69 d	0.89 d	12.82 d	14.12 d
Genotypes						
Camelina-618	7.85 a	8.76 a	1.30 a	1.66 a	16.56 a	18.94 a
Camelina-611	7.55 b	8.30 b	1.19 b	1.51 b	15.76 b	18.19 b
Punjab Sarsoon	7.27 c	7.93 c	1.09 c	1.38 c	14.99 c	17.40 c
Faisal Canola	6.95 d	7.58 d	0.99 d	1.26 d	14.24 d	16.62 d

Values within columns followed by different letters are significantly different at $p<0.05$

Discussion

The results of this study demonstrated that water deficiency in crop plants decreased the photosynthetic rate, transpiration rate and stomatal conductance in camelina and canola genotypes. Generally, the performance of physiological development in plants like cell and tissue growth, photosynthesis, and cell turgor were directly affected by water (Waraich *et al*., 2017). This was mainly attributed to stomatal closure under water deficit situation. According to Maroco *et al*., (1997) and Chaves *et al*., (2009), the stomatal closure under water deficit situation attributed to reduce the pressure of leaf turgor and atmospheric moisture along with chemical indicators created by roots. Water deficit condition reduces the total dry matter by the reduction of leaf area expansion and photosynthetic capacity, because leaf responds to water deficit condition through stomatal closure that limits CO_2 supply to chloroplasts which ultimately reduces photosynthesis (Waraich *et al*., 2017). Hence, concerning to Flexas *et al*., (2004) and Chaves *et al*., (2009), the reduction in photosynthetic rate under limited water condition attributed to suppression of mesophyll conductance and stomatal closure under stressful environments. Drought stress condition harmfully influences cell growth, causing separation of membrane proteins (Jaleel *et al*., 2009). Dulai *et al*., (2006) observed that the closing of stomata also decreases the Ci (internal CO_2 concentration), stops ATP synthesis, declines Rubisco activity that finally reduces photosynthetic rate (Pn) under the condition of drought stress. The transpiration rate reduction is indication for a plant response representing water conservation and limited water deficit through stomata (Jones *et al*., 1985). Considering the decrease in soil water availability to plant directly influences its metabolic processes and physiological functions, such as stomatal aperture, which affect both photosynthetic carbon assimilation and transpiration (Rao *et al*., 1987). Under limited water supply reduction in transpiration rate has been well documented in various studies (Egret & Tevini, 2002; Bogale *et al*., 2011; Rahbarian *et al*., 2011), possibly attributed to the reduction in photosynthesis and stomatal conductance under water deficit stress as happened in present study. Camelina-618 showed the maximum gas exchange traits, so our results are in agree with the findings of (Waraich *et al*., 2015) who observed the highest leaf gas exchange traits in Camelina-618 under different drought stress levels. Maintenance of turgor by decreasing of Ψs is the key defense strategy of plants to survive under environmental stresses mainly drought stress (Nawaz *et al*., 2012). Water deficit caused solute accumulation that potentially decreased the osmotic potential of the cell (Subbarao *et al*., 2000; Khan *et al*., 2010; Muller *et al*., 2012). Decreased water potential (Ψw) in turn helps to maintain the turgor pressure of plant (Ψp) by active lowering of Ψs (Serraj & Sinclare, 2002). Similar findings were also reported by (Hura *et al*., 2007) who revealed more negative osmotic potential, and retaining the turgor potential which shown the tendency of better osmotic adjustment when plants of triticale varieties grown under drought stress. Variations in tissue elasticity under drought, changes the relationship between cell volume and turgor pressure that might be responsible for drought tolerance (Saito & Terashima, 2004). Better maintenance of leaf water, osmotic and turgor potential were observed in Camelina-618 which is consistent with the reports of Waraich *et al*., (2015).

Results of this study are similar with those of Spheri & Golparvar (2011) who reported that the chlorophyll contents decreased under irrigation deficit stress in canola cultivars. Many studies showed that chlorophyll contents decreased under water deficit stress in many crops such as wheat (Fotovat *et al*., 2007), sunflower (Mannivannan *et al*., 2007) corn (Khayatnezhad *et al*., 2011) and chickpea (Mafakheri *et al*., 2010). Reduction in pigments content is a clear indication of oxidative stress occurring either due to fast breakdown or slow synthesis of these pigments (Smirnoff, 1993). Excess energy absorbed by the photosynthetic machinery produced reactive oxygen species (ROS) to avoid disintegration of chlorophyll pigments (Herbimger *et al*., 2002). Thylakoid membranes are also deteriorated by drought stress (Huseynoya *et al*., 2009; Anjum *et al*., 2011) that leads to reduce photosynthetic capacity. Our results regarding carotenoid contents are in line with several reports that showed decrease in chlorophyll and carotenoid pigments in various plant species under drought stress (Loggini *et al*., 1999). Plants show various protective mechanisms such as synthesis of protective pigments like carotenoid and anthocyanin and dissipation of excess energy against ROS (Efeoglu *et al*., 2009). It helps to protect the integrity of chloroplast membrane and maintains the photosynthetic activity despite the attack of ROS (Dwivedi *et al*., 1995).

Results of present study revealed that deficit irrigation significantly decreased seed yield and yield attributes compared to normal irrigation in both crops. However, canola crop showed taller plant and higher 1000-seed weight compared to camelina, while camelina crop gave more number of pods per plant, biological yield, seed yield and harvest index values compared to canola. Our results are according to the findings of Raza *et al*., (2015) who observed similar decrease in yield and yield related traits under deficit irrigation, and alike differences between canola and camelina genotypes. Reduced plant height under deficit irrigation treatment occurred because plant cells had less turgidity, less cell division and elongation. Findings of Mesbah, (2009) supported our results. Among the seed yield components, the number of pods per plant showed the highest sensitivity to moisture deficit stress. Plants facing water deficit stress at flowering and pod formation stages showed significant decrease in the number of pods per plant due to severe flower and pod abscissions (Sinaki *et al*., 2007). Imposition of water deficit stress after flowering stage reduced the number of pods per plant due to shortening of the flowering period and reduction in growth duration, resulting in infertility of some flowers and their abscission (Wright *et al*., 1995). Camelina showed more number of pods per plant as compared to canola in all irrigation treatments, and this might be due to their genetic potential (Raza *et al*., 2015). Reduction in 1000-seed weight under deficit irrigation is also consistent with the findings of earlier researchers (Sadaqat *et al*., 2003; Sinaki *et al*., 2007; Nasri *et al*., 2008) who reported that water deficit probably disrupted photosynthesis, reduced assimilate synthesis required for seed filling might cause seed shrinkage and seed weight loss. Among the crop genotypes, canola genotypes had the highest 1000-seed weight compared to camelina which is in line with the findings of Raza *et al*. (2015). Biological yield is a combination of different factors like number of branches per plant, number of pods per plant and seed weight, as these traits were decreased due to deficit irrigation, resulting biological yield also decreased. These results are consistent with those of Faraji *et al*., (2009). Decrease in seed yield and harvest index owing to water deficit stress has also been reported by Sinaki *et al*., (2007), Rad & Zandi (2012) thus validating our findings. Sinaki *et al*., (2007), Rad & Zandi (2012) also elucidated that water deficiency decreased the transmission of assimilates to shoot organs thus reducing yield components and hence, seed yield and harvest index decreased with the reduction of these components. Camelina genotypes had more seed yield, biological yield and harvest index compared to canola cultivars. These results are in line with the findings of Raza *et al*., (2015).

Conclusion and recommendations

It is concluded from the results of present study that deficit irrigation negatively affected the growth, physiology and yield of canola and camelina crops. Maximum growth and yield was recorded with two irrigations (one at vegetative stage and second at reproductive phase). Among the crop genotypes, camelina-618 performed better and gave higher yield as compared to canola genotypes.

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(Received for publication 12 January 2019)