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Performance of canola cultivars under drought stress induced by withholding irrigation at different growth stages

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Abstract

Drought stress is a severe environmental constraint to plant productivity. However, plant species and varieties within species may differ significantly in their growth behavior to drought stress. In present study, growth and yield responses of three canola (Brassica napus L.) cultivars (CON-II, CON-III and Dunkeld) to drought stress were investigated under wire house conditions. Drought stress was created by withholding irrigation at critical growth stages viz. seedling, vegetative and reproductive. Results revealed significant differences among canola cultivars, in terms of plant height, number of branches plant^{-1}, biological yield, number of siliqua plant^{-1}, number of grains siliqua^{-1} and grain yield, to tolerate drought stress. Dunkeld and Con-III were found to be better to maintain their growth when drought stress was imposed at seedling and vegetative stages; while, reproductive stage was found more sensitive to limited moisture supply. Overall, Con-III performed better under drought stress at all growth stages compared with other cultivars as explained by higher biological yield, grain yield and number of branches and number of siliqua plant^{-1}. Current investigations suggested that canola is much sensitive to drought stress at reproductive stage and hence irrigation should not be skipped at this stage for successful production. Moreover, canola cultivar Con-III might be useful for better productions under drought environments.

Keyword: *Canola, drought stress, environmental constraint, growth stages, yield components*

Introduction

Shortage of good quality water limits the production of agricultural crops to varying degree throughout the world, particularly in arid and semi-arid regions (Yarnia *et al.*, 2011). Globally more than 1.2 billion hectares of land in rain-fed agricultural areas is at risk of severe drought stress (Kijni, 2006; Passioura, 2007). In Pakistan, heavy losses in the yield of major agricultural crops are occurring due to shortage of irrigation water (Anonymous, 2012). Singh *et al*. (2002) also documented that in India, long periods of drought stress resulted 60 – 100% yield losses in different crop species including canola (*Brassica napus* L.).

Under drought stress plant growth is affected by a number of morpho-physiological disorders that cause reduction in nutrient uptake and impaired active transport of photosynthates (Yuncai and Schmidhalter, 2005; Jaleel *et al*., 2009). Moreover, increased concentration of cell electrolytes under drought stress disturbed the normal metabolic functioning of cell organelles (Mahajan and Tuteja, 2005). Drought stress also affects relative water content, osmotic potential and leaf temperature (Chhabra *et al*., 2007; Fanaei *et al*., 2009). Similarly, cell turgidity, growth of cells and plant tissues are directly affected by drought stress (Reddi and Reddy, 1995). Canola is mainly grown in rain fed areas of Pakistan, where water availability is one of the most important limiting factors affecting plant growth and development.

Canola seed contains about 40 – 44% oil content (Carmody, 2001) and currently ranked at third position in the world in edible oil, after soybean and palm (Kandil and Gad, 2012). Pakistan is deficient in the production of edible oil and more than 72% of total requirements are met through imports costing huge amounts in foreign exchange (Anonymous, 2012). Canola is relatively poorly adapted to drought prone conditions (Wright *et al*., 1997) and its yield is often decreased if moisture stress occurred, particularly at reproductive stage (Ahmadi and Bahrani, 2009; Shirani Rad and Abbasian, 2011). The reduction in seed yield ranged from 19 – 39% compared with well watered control, when drought stress was imposed at reproductive stage (Gunasekara *et al*., 2006). Even temporary drought stress caused substantial losses in brassica by affecting growth and yield traits (Pervez *et al*., 2009). However, genetic variations among cultivars to tolerate drought stress have been reported in wide variety of crops including canola (Kauser *et al*., 2006).

Kusvuran (2012) reported that the plant responses to drought stress differ at various organizational levels depending upon duration and intensity of stress as well as plant species and its growth stage. Kumar and Singh (1987)

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documented that yield of *Brassica carinata* was doubled compared with *Brassica napus* under drought stress. It was further stated that better performance of *Brassica carinata* was associated with greater degree of its osmoregulation under drought stress. The resistance of crops against drought stress has been taken as one of the breeding objectives (Talebi, 2009).

In water deficit areas, one possible way to overcome drought is the development of crop cultivars capable of tolerating drought stress conditions (Hsiao, 1973). Keeping in view the importance of canola and dry climatic conditions prevailed in agro-ecological environment of Dera Ghazi Khan, Pakistan; present study was conducted to explore tolerance of canola against drought stress at seedling, vegetative and reproductive stages.

Materials and Methods

A pot study was carried out in wire-house at College of Agriculture, Dera Ghazi Khan, Pakistan. The soil was collected from farmer's fallow field, air dried and sieved before filling the pots. The soil was analyzed for physical and chemical characteristics following the standard procedures (Table 1). The pot size was 32.5 cm of opening diameter, 37.5 cm height and 22.5 cm bottom diameter with capacity of 24 kg of soil pot^{-1}. The pots were arranged according to completely randomized design (CRD) in wire-house under ambient light and temperature. The pots were lined with polythene sheet to prevent the loss of water. Recommended dose of fertilizers (40-35-35 kg of nitrogen, phosphorus and potassium ha^{-1}) was applied in each pot as urea, diammonium phosphate and sulphate of potash, respectively. All the fertilizers were mixed in soil at the time of pot filling.

Table 1. Physico-chemical characteristics of soil used in the experiment

Characteristic	Unit	Value
Textural class		Sandy clay loam
Saturation percentage	%	28
pH_s		7.6
EC_e	dS m^{-1}	1.85
Organic matter	%	0.51
Total nitrogen	%	0.04
Available phosphorus	mg kg^{-1}	6.21
Extractable potassium	mg kg^{-1}	121

The average meteorological data of the experimental site is presented in Table 2. There were four treatments and three replications in this experiment. Drought stress was created by withholding the irrigation at critical growth stages viz. seedling, vegetative and reproductive stage. Gravimetric water contents were measured on weight basis by oven drying the soil samples (Black, 1965) drawn from the test pot of similar size and shape filled with same soil. The plants at respective growth stage were re-irrigated with uniform volume of water when gravimetric water contents in the test pot dropped to 50% of the field capacity. Normal watering was done before the onset or after completion of subjected drought stressed growth stage. The well watered (control) treatment received normal watering throughout the duration of experiment. The same procedure was followed for imposing drought stress at critical stages of plant growth.

Seeds of three canola cultivars (Con-II, Con-III and Dunkeld) were obtained from Ayub Agricultural Research Institute (AARI), Faisalabad. Cultivars Con-II and Con-III were originated in National Agricultural Research Council (NARC), Islamabad, Pakistan, whereas Dunkled has Australian Origin. Five seeds of each canola cultivar were sown in a pot according to lay-out plan and after seven days of germination a single healthy plant per pot was maintained through thinning. At maturity, the data regarding growth, yield and yield components were recorded and analyzed statistically (Steel *et al*., 1997) by using SPSS (version 18.0) statistical software.

Results

Effects of drought stress on growth of canola cultivars

Canola cultivars exhibited variable growth response to drought stress induced at critical growth stages. Cultivar Con-III attained more plant height under drought conditions at all stages of plant growth compared to others (Table 3), however, drought-induced reduction in plant height among cultivars was not significant. Among growth stages, the highest reduction in plant height under drought stress was at vegetative stage and accounted for 7, 12 and 14% in Con-III, Dunkeld and Con-II, respectively compared to well watered control conditions. Number of branches plant^{-1} was significantly higher in Con-III under drought conditions at all stages of plant growth (seedling, vegetative and reproductive) compared to Con-II and Dunkeld (Table 3). When compared with well watered control, the highest reduction in number of branches plant^{-1} was at vegetative stage and accounted for 22, 25 and 46% in Con-II, Con-III and Dunkeld, respectively, compared to well watered control.

The impact of drought stress on biological yield was statistically significant ($p \leq 0.05$). Induction of drought stress at various growth stages reduced the biological yield of all three canola cultivars (Table 3). The reduction in biological yield was highest when irrigation was skipped at reproductive stage; however, differences among canola

Table 2. Four years meteorological data of the experimental area

Month	Temperature(◦C)								Rain (mm)				Humidity (%)			
	2009		2010		2011		2012		2009	2010	2011	2010	2009	2010	2011	2012
	Max	Min	Max	Min	Max	Min	Max	Min								
January	17.5	6.4	16	5.91	18.2	4.52	19.4	4.9	1.7	2.8	2.81	-	60	65.4	68.2	66.1
February	21.2	9.5	20	11.6	22.4	9.5	20.9	5.22	5.52	1.1	11.4	-	74	72.1	70.2	72.5
March	28.4	21.2	26	19.5	23.5	11.5	27	11.6	7.21	85.4	6.42	-	62	51.3	66.4	58.5
April	39.8	25.5	40	24.3	38.2	22	34.4	18.9	-	2.2	-	31	20.5	22.9	23.8	24.2
May	44.5	30.5	45	27.1	43.3	25.3	43.7	25.5	1.05	-	12	-	19.5	21.1	20.4	21.4
June	45	25.3	43	28	38.4	31.5	45	30.7	-	-	8.4	-	41.5	39.5	41.2	44.2
July	41	28	42	29	39.1	29.3	40.1	30.1	28.5	25	-	-	45.6	56.3	58.7	48.2
August	38	30	37	29	39.3	29.3	40.2	29.7	54.6	249	52	-	72.4	75.1	62.8	70.7
September	34	23.4	35	22	32.2	24.9	36.3	25.6	14.8	-	101	140	60.6	58.1	73.6	67.6
October	31	21	32	20	33.5	18.3	34.4	22.9	-	-	16	-	51.3	50.2	53.7	55.1
November	25	17.8	29	14	30.2	13.9	32.5	21.1	3.8	-	-	-	39.6	38.7	47.4	45.1
December	20	8	22	5	21.8	6	21.2	10.4	5.9	6.4	-	-	54.8	52.2	39.1	40.2

Source: Meteorological Section of College of Agriculture, D.G. Khan

Table 3: Plant height, number of branches plant^{-1} and biological yield plant^{-1} of canola as influenced by drought stress at critical growth stages

Drought stress level	Plant height (cm)			No. of branches plant^{-1}			Biological yield (g plant^{-1})		
	Cultivars								
	Con-II	Con-III	Dunkeld	Con-II	Con-III	Dunkeld	Con-II	Con-III	Dunkeld
Well watered control	120.0 a	128.7 a	118.3 abc	9.0 cde	13.3 a	10.3 bcde	81.6 b	83.1 a	84.2 a
Irrigation skipped at seedling stage	101.5 d	122.0 a	104.7 bcd	7.6 de	14.7 ab	7.6 de	78.4 c	73.9 d	78.0 c
Irrigation skipped at vegetative stage	103.3 d	119.3 ab	104.6 bcd	7.0 e	12.2 abcd	5.6 e	77.5 c	70.3 e	67.1 ef
Irrigation skipped at reproductive stage	104.7 bcd	125.8 a	105.3 bcd	8.3 de	14.6 ab	8.2 de	63.3 f	62.1 f	66.5 ef
LSD value	13.34			4.45			1.3		

Values sharing same letter are not differed significantly at $p \leq 0.05$

cultivars were non-significant at this growth stage. Cultivar Con-II was highest in the production of biological yield (78.4 g) followed by Dunkeld (78 g) in treatment where drought stress was induced at seedling stage by skipping the irrigation. Likewise, drought stress at different growth stages also caused significant variation in straw yield of canola cultivars (Table 4). The lowest straw yield was recorded when drought was created at reproductive growth stage and interestingly, Con-III was lowest in the production of straw yield (46.4 g) compared to other cultivars. Regarding straw yield, Con-II produced highest when drought stress was induced at vegetative and seedling stage (63.1 and 63.4 g plant^{-1}).

Harvest index, ratio of grain yield to biological yield, was also affected by drought stress at different stages of plant growth (Table 4). When drought stress was induced at seedling stage, harvest index of Con-III was significantly higher (22%) than Con-II (18%) and Dunkeld (20%). Similarly, significantly higher harvest index was observed in Con-III compared to other canola cultivars when stress was created at vegetative and reproductive stages.

Effects of drought stress on yield and yield components of canola cultivars

Generally the number of siliqua plant^{-1} was decreased under drought stress at critical growth stages (Table 4). Under drought stress at seedling, vegetative and reproductive stage, cultivar Con-III produced higher number of siliqua plant^{-1} compared to other cultivars. In Con-II and Dunkeld, the reduction in the production of siliqua plant^{-1} at reproductive stage was 30 and 59% relative to respective controls. At reproductive stage cultivar Con-III produced about doubled number of siliqua plant^{-1} than Con-II and Dunkeld, respectively.

Drought stress also reduced the number of grains siliqua^{-1}; however cultivars showed variable response at various growth stages (Table 5). At reproductive stage under drought stress, the number of grains siliqua^{-1} in Con-III was 69 which was 17% higher than Con-II and Dunkeld. The cultivar Con-II produced the lowest grains siliqua^{-1} at both seedling and vegetative stages followed by Dunkeld.

Drought stress also caused reduction in 1000 grain weight of canola cultivars compared to control (Table 5), however, differences among cultivars for 1000 grain weight were non-significant at various growth stages. At reproductive stage Con-III and Dunkeld showed comparatively more 1000 grain weight (3.0 g), however, it was statistically similar with Con-II (2.7g), implying that the main effect of drought stress was on the number of grains siliqua^{-1} but not on 1000 grain weight.

Drought stress particularly at reproductive stage of canola growth also caused significant reduction in grain yield of three canola cultivars compared to well watered control (Table 4). Cultivar Con-III produced higher grain yield compared to Con-II and Dunkeld at seedling, vegetative and reproductive stages under drought stress. The reduction in grain yield plant^{-1} at reproductive stage was 15, 29 and 35% in Con-III, Con-II and Dunkeld, respectively, when compared with respective controls.

Correlation among various growth traits under drought stress

Correlation among various traits under drought stress was calculated and presented in Table 6. Grain yield showed positive correlation with plant height, number of branches plant^{-1}, number of siliqua plant^{-1}, biological yield and 1000 grain weight, however, surprisingly it developed negative correlations with grains siliqua^{-1}. Number of branches plant^{-1} caused significant increase in siliqua plant-^{1}. The relationships of plant height was significantly positive with number of branches plant^{-1}, siliqua plant^{-1} and grains siliqua^{-1}, however it was negative with biological yield and straw yield.

Discussion

The reduction in growth under drought stress might be attributed to reduced nutrient uptake and their transport from root to shoot due to restricted transpiration rates, impaired active transport and membrane permeability (Yuncai and Schmidhalter, 2005). Moreover, under drought stress, the nutrient film around the soil particle became thin; therefore, the distance for movement of ions increased resulting in poor diffusion of ions into the plant roots (Umar, 2006). As plant reproductive organs or seeds are made from recently acquired or previously stored resources in the vegetative parts of the plant (Chiariello and Gulmon 1991), therefore the reduction in water uptake might have resulted in poor siliqua and seed formation. Similarly, drought stress and high temperature could cause negative impact on crop yield by affecting both source and sink for assimilates (Paulsen 1994; Mendham and Salisbury, 1995). It has been observed that seed yield can be hampered, even by short period of soil moisture stress during reproductive stages (Ahmadi and Bahrani, 2009).

The number of siliqua plant^{-1} is the most responsive of all the yield components in canola (Diepenbrock, 2000). Maximum grain yield obtained in case of CON-III cultivar can be attributed to its high number of branches plant^{-1} and siliqua plant^{-1}. The siliqua enhances the plant capacity for seed formation and also provides materials for seed filling through photosynthesis (Germchi *et al*., 2010). It was also evident from the earlier work of Panda *et al*. (2004) who

Table 4: Straw yield, harvest index and number of siliqua plant^{-1} of canola as influenced by drought stress at critical growth stages

Drought stress level	Straw yield (g plant^{-1})			Harvest index (%)			No. of siliqua plant^{-1}		
	Cultivars								
	Con-II	Con-III	Dunkeld	Con-II	Con-III	Dunkeld	Con-II	Con-III	Dunkeld
Well watered control	67.9 a	64.2 ab	64.6 ab	20.5 bc	22.6 b	23.3 ab	157.0 bc	353.7 a	327.0 ab
Irrigation skipped at seedling stage	63.4 ab	56.8 bc	62.7 b	17.9 cd	21.8 bc	19.6 bc	144.0 bc	261.7 abc	225.3 abc
Irrigation skipped at vegetative stage	63.1 ab	53.8 d	52.5 d	17.4 cd	23.5 ab	22.4 b	122.7 bc	251.7 abc	149.7 bc
Irrigation skipped at reproductive stage	51.4 de	46.4 ef	53.8 d	18.8 c	25.6 a	19.1 c	110.3 c	230.3 abc	135.8 bc
LSD value	4.16			1.11			172.29		

Values sharing same letter are not differed significantly at $p \leq 0.05$

Table 5: Number of grains siliqua^{-1}, 1000 grain weight and grain yield plant^{-1} of canola as influenced by drought stress at critical growth stages

Drought stress level	Plant height (cm)			No. of branches plant^{-1}			Biological yield (g plant^{-1})		
	Cultivars								
	Con-II	Con-III	Dunkeld	Con-II	Con-III	Dunkeld	Con-II	Con-III	Dunkeld
Well water	16.5 fgh	31.3 a	22.7 cde	3.7 abc	4.7 a	4.2 ab	16.7 bc	18.8 ab	19.6 a
Irrigation skipped at seedling stage	15.0 gh	25.3 bcd	21.0 def	3.0 bc	3.3 abc	3.7 abc	14.0 cde (84)	17.1 b (91)	15.3 cd (78)
Irrigation skipped at vegetative stage	15.3 gh	27.7 abc	19.3 efg	2.5 c	3.7 abc	3.5 abc	13.5 cde (81)	16.5 bc (88)	15.0 cd (77)
Irrigation skipped at reproductive stage	12.7 h	21.4 def	18.3 efg	2.7 c	3.0 bc	3.1 bc	11.9 ef (71)	15.9 c (85)	12.7 de (65)
LSD value	4.96			1.34			1.92		

Values sharing same letter are not differed significantly at $p \leq 0.05$

Table 6: Correlations among different growth traits of canola cultivars under drought stress

	Plant height	Branches plant^{-1}	Siliqua plant^{-1}	Grain siliqua^{-1}	Biological yield	1000 grain weight	Grain yield plant^{-1}	Harvest index
Branches plant^{-1}	0.857**							
Siliqua plant^{-1}	0.852**	0.858**						
Grain siliqua^{-1}	0.829**	0.646*	0.709*					
Biological yield	–0.165^{NS}	–0.024^{NS}	0.055^{NS}	–0.521*				
1000 grain weight	0.155^{NS}	0.095^{NS}	0.211^{NS}	0.322^{NS}	–0.504*			
Grain yield plant^{-1}	0.247^{NS}	0.395^{NS}	0.436*	–0.028^{NS}	0.645*	0.180^{NS}		
Harvest index %	0.439*	0.416*	0.276^{NS}	0.476*	–0.221^{NS}	0.554*	0.438*	
Straw yield	–0.104^{NS}	0.074^{NS}	0.186^{NS}	–0.117^{NS}	0.660*	–0.139^{NS}	0.585*	0.233^{NS}

**. Correlation is significant at the 0.01 probability level (2-tailed); *. Correlation is significant at the 0.05 probability level (2-tailed) reported that increase in number of siliqua plant^{-1} and number of branches plant^{-1} directly influenced the seed yield in mustard. Surender *et al*. (1999) also reported an increase in seed yield with the increase in number of siliqua plant^{-1}. Similarly, a significant correlation was found between number of siliqua plant^{-1} and seed yield in *B. napus* and *B. compestris* (Ozer *et al*., 1999).

Water shortage at any stage of plant development may cause negative effect on its growth; however, some stages are more sensitive than others. The duration of drought stress is more important than its intensity (Korte *et al*., 1983). Gan *et al*. (2004) observed more pronounced effect when drought stress was applied at flowering and pod filling stages. Fernandez (1992) also reported that drought stress at flowering and pollination stage caused greatest effect on grain yield of canola. In current study, we found that cultivar CON-II and Dunkeld were sensitive to drought stress at reproductive stage, however, these cultivars maintained their growth when drought stress was imposed at early seedling and vegetative stages by skipping irrigation. The better growth at vegetative stage also contributed towards final yield. The number of branches also established significant positive association and contributed towards seed yield (Joshi *et al*., 1992; Yadav and Singh, 1996). Drought stress during the flowering and grain filling period also caused negative impact on seed formation, oil contents and grain yield (Faraji *et al*., 2009). The cultivar CON-III showed high harvest index compared to CON-II indicating better adaptation and higher yield under drought stress. Ali *et al*. (2003) also reported a strong correlation between harvest index and seed yield. Abedi and Pakniyat (2010) reported variations in plant biomass production under drought stress in some cultivars of brassica.

In *Brassicaceae*, number of grains plant^{-1} is related to number of siliqua plant^{-1} and number of grain siliqua^{-1}, therefore drought stress at this stage reduced the seed number plant^{-1} (Wright *et al*., 1995). Champolivier and Merrin (1996) reported that number of grains plant^{-1} was the most important yield component in canola influenced by drought stress. Drought stress at vegetative growth stage also resulted less number of branches and siliqua plant^{-1}. Similarly, reduction in 1000 grain weight might be attributed to closure of stomata and reduction in leaf expansion and photosynthesis rate due to limited supply of water and nutrients (Kumar *et al*., 1993; Mondal and Khajuria, 2000). Kamkar *et al*. (2011) observed a reduction in 1000 grain weight under drought stress conditions. Moreover, the reduction in the production and translocation of photosynthates to the developing seed might cause loss in grain weight. The canola cultivars showed variable response to drought stress and variation mainly depended on the cultivar, growth stage and the plant's ability to tolerate drought stress (Azizi *et al*., 1999).

Conclusion

Canola cultivars differed in their ability to tolerate drought stress and Con-III was better compared to Dunkeld and CON-II for yield and yield components under drought stress. The reproductive growth stage was found to be more sensitive to spells of drought stress than other growth stages. The generated information suggested that managing water supply at reproductive stage to reduce yield losses in canola under the environments with low moisture availability.

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