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Modulating the phenology and yield of *camelina sativa* L. by varying sowing dates under water deficit stress conditions

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Abstract

Camelina (Camelina sativa L.) an oilseed crop has emerged as a potential source for biofuels and bio-products. Camelina is an economic crop due to its less requirements of agronomic inputs as compared to other oilseed crops. However, it is direly required to evaluate the adaptability of camelina and characterize its production potential. Therefore, a pot experiment was carried out in rain out shelter at the Department of Agronomy, University of Agriculture, Faisalabad, Pakistan to optimize appropriate sowing date with respect to growth and yield potential of different genotypes of camelina under drought stress. Completely randomized design with factorial arrangements was adopted. Three sowing dates with the difference of 10 days (November 13th, 23rd and December 03rd), two water regimes (100% FC and 60% FC) and two camlena genotypes (611 and 618) were used in this experiment. Results indicated that camelina growth and yield related traits were significantly influenced by difference in sowing dates and water regimes. Maximum leaf area index (LAI), crop growth rate (CGR), leaf area duration (LAD), net assimilation rate (NAR) and yield related traits were recorded with early sowing (13th November) which was followed by sowing on 23rd November and least values of these variables were recorded in late sowing (December 03rd). Plants grown under water deficit conditions (60% FC) showed the decreased values of LAI, CGR, LAD, NAR and yield related attributes as compared to normally irrigated plants (100% FC). However, the response of genotypes of camelina 611 and 618 remained statistically similar to each other.

Keywords: Camelina, sowing dates, Crop growth rate, Net assimilation rate, water stress

Introduction

Camelina, is an annual oilseed crop with short lifecycle and belongs to Mustard family (McVay and Khan, 2011). Its lifecycle normally lasts 90-110 days from emergence to maturity (Zubr, 1997). Oil content of camelina seed ranges between 38-44% (Vollmann *et al*., 2007). Major portion of seed oil (about 90%) consists of polyunsaturated fatty acids, making camelina an important source of omega-3 fatty acids (Vollmann *et al*., 2007; Hrastar *et al*., 2009). In recent decade camelina has emerged as a low agricultural input requiring crop with minimum cost of production (Gesch and Cermak, 2011). Camelina requires low nitrogen input as compared to canola and sunflower (Putnam *et al*., 1993). Camelina oil has also been considered as a feed stock for biodiesel (Aurore *et al*., 2003) and investigations are underway for aviation fuel (Shonnard *et al*., 2010). Camelina oil and meal is also used in animal feeds (Moloney *et al*., 2001). Camelina oil has wide industrial applications such as cosmetics, soaps, paints and resins (Pilgeram *et al*., 2007).

Sowing date is an important requisite in crop production which determines the timing and duration of vegetative and reproductive growth phases of the crop and ultimately the crop yield and seed quality (Dornbos, 2002; Bhuiyan *et al*., 2008). Selection of optimum sowing date positively links the climatic conditions with plant growth processes (Walton and Bowden, 1999; Hakan-ozer and Unsal, 1999). Previous studies conducted on sowing date of camelina under different environments provided varied results. In eastern Canada, sowing date could not affect the seed yield of camelina (Urbaniak *et al*., 2008). However, Pavlista *et al*. (2011) obtained maximum seed yields of camelina when planted at the end of March to mid-April. Whereas, Gesch and Cermack (2011) planted camelina in early October and obtained higher seed and oil yields. Thus establishing a suitable sowing date would be helping in maximizing camelina productivity for a given region. Water being an important abiotic element restricts crop production in many parts of the world (Araus *et al*., 2002). Physiological processes in plants like cell and tissue growth, photosynthesis and cell turgor, are directly influenced by water (Reddi and Reddi, 1995). In Pakistan mostly crops are damaged due to low and erratic rainfall which results in water shortage. About 60-100% yield losses has been reported due to prolonged water shortage in

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different crops (Singh *et al*., 2002). Evaluation and introduction of new oilseed crops with high yielding potential under scarce water resources availability is the only option to rescue small scale farmers for increased income (Tabassum, 2004). The aim of this study was to evaluate the growth and yield potential of camelina at varying sowing dates and different water levels in agro-climatic conditions of Faisalabad Pakistan.

Materials and Methods

A pot study was carried out in rain out shelter to investigate the effect of different sowing dates (13^{th} November, 23^{rd} November and 03^{rd} December) on the growth and production of *camelina sativa* genotypes under well-watered (100 % field capacity) and water deficit (60 % field capacity) conditions. The experiment was conducted in completely randomized design with factorial arrangement having three replicates in the department of Agronomy, University of Agriculture, Faisalabad. Seeds of camelina genotypes (611 and 618) were acquired from the Department of Plant Breeding and Genetics University of Agriculture, Faisalabad. Randomly selected 20 seeds of each cultivar were sterilized for five seconds with 5% sodium hypochlorite solution, washed them with distilled water and then air dried. Before sowing the soil (sand) was sun dried and sieved. The field capacity of sand was determined by gravimetric method. A random air dried screened sand sample was taken in a cylinder. Surface of sand was covered with filter paper and poured a small quantity of water to obtain uniform movement of water. Put the wet sand sample in a pre-weighed dish and then recorded the weight of sand plus dish. Sand was dried at 100 °C for 24 hrs. Then weighed the oven dried sand and dish. The gravimetric moisture content was calculated following formula (Bethlahmy and Nedavia, 1952; Gardner and others, 2001).

Gravimetric Moisture Content = wet weight – dry weight / dry weight - dish weight

Each plastic pot (15 cm dia×11 cm length) rapped with plastic bag was filled with 2 kg of sand and 20 seeds of both Camelina sativa genotypes (V_1:611and V_2:618) were sown on respective sowing dates in 2015 and irrigated with distilled water. At the initial stage of experiment the pots were irrigated properly to obtain good germination and emergence. Before imposing water stress thinning was done 14 days after germination and uniform sized 10 healthy plants were maintained in each pot. Twenty one (21) days after sowing of each treatment (keeping in view the respective sowing dates) water deficit stress was imposed by applying 300 mL of DI water to maintain 60% FC whereas 100% FC was maintained by the application of 500 mL water to the respective pots. To maintain field capacity levels (100% FC and 60% FC) pots were weighed on electrical balance daily at about 9:00 am, calculated the amount of water consumed in evapotranspiration and watered until the pot weight reached to pre-determined weight. Nitrogen (50 kg ha^{-1}), phosphorus (30 kg ha^{-1}) and potassium (60 kg ha^{-1}) were applied at the time of sowing using urea, single superphosphate and muriate of potash respectively. During the experimentation, leaf area index (LAI) was measured by using the formula given by (Watson, 1947).

$$LAI = \text{Leaf area} / \text{ground surface area}$$

Crop growth rate (CGR) (g m^{-2} d^{-1}) and leaf area duration (LAD) (days) and Net assimilation rate (NAR) (g m^{-2} d^{-1}) were calculated by using the formula given below (Hunt, 1978).

$$CGR= (W_2-W_1) / (T_2-T_1)$$
$$LAD= (LAI_1+LAI_2) (T_2-T_1) / 2$$
$$NAR= (TDM) / (LAD)$$

LAI_1= Leaf area index at first time in the crop growing season, LAI_2= Leaf area index at last time at crop maturity, W_1= oven dried weight at first sampling, W_2= oven dried weight at second sampling, T_1= time of first sampling, T_2= time of second sampling. TDM= Total dry matter accumulated (W_2-W_1). Moreover yield and yield contributing parameters were measured and data organized for statistical analysis.

Statistical analysis

Data were collected and analyzed by using Fisher's Analysis of Variance technique with Statistix software 9.1 package. Treatment means were compared through Least Significant Difference (LSD) test at 5% probability (Steel *et al.*, 1997).

Results

Leaf area index

Different sowing dates and water levels had a significant effect on leaf area index of camelina genotypes throughout the sampling period. All interaction effects were statistically non-significant. Analyzed data revealed that maximum leaf area index (2.19) was recorded at 65 day after sowing in the early sowing (November, 13^{th}) treatment (Figure 1). In case of water deficit stress normal watering (100%FC) achieved maximum value (2.08) of LAI at 65 days after sowing (Fig.1). Leaf area index in both camelina genotypes was statistically similar across different sowing dates and water regimes (Table 1).

Table 1: Mean square values from analysis of variance of leaf area index of two camelina genotypes under different sowing dates and water deficit stress

Source of Variation	d.f	LAI-1	LAI-2	LAI-3	LAI-4
Plant densities (Pd)	2	0.11227**	0.21601**	0.2640**	0.21744 **
Varieties	1	0.0007NS	0.000 NS	0.0051 NS	0.0002 NS
Stress	1	0.03868**	0.13080**	0.1667 **	0.1456**
Pd*Variety	2	0.0006NS	0.0013 NS	0.0002 NS	0.0004 NS
Pd*Stress	2	0.005 NS	0.0001 NS	0.0008 NS	0.0007 NS
Variety *Stress	1	0.0009 NS	0.0002 NS	0.0001 NS	0.0063 NS
Pd*Variety* Stress	2	0.002NS	0.0001 NS	0.0004 NS	0.0031 NS
Error	24	0.0029	0.02399	0.02932	0.01813

Table 2: Mean square values from analysis of variance of crop growth rate of camelina genotypes under different sowing dates and water deficit stress.

Source of Variation	d.f	CGR-1 At 1st harvest	CGR-2 At 2nd harvest	CGR-3At3rd harvest
Plant densities (Pd)	2	7.9542**	2.5494**	4.5129**
Varieties	1	0.0121 NS	0.0001 NS	0.0030 NS
Stress	1	0.4669**	0.3927**	1.8723**
Pd*Variety	2	0.0963 NS	0.0016 NS	0.0013 NS
Pd*Stress	2	0.0171NS	0.0004 NS	0.0276NS
Variety *Stress	1	0.0245 NS	0.0001 NS	0.004 NS
Pd*Variety* Stress	2	0.0246 NS	0.008 NS	0.0022 NS
Error	24	0.0271	0.0653	0.0665

* = Significant at 0.05 probability level, ** = Significant at 0.01 probability level, NS = Non significant

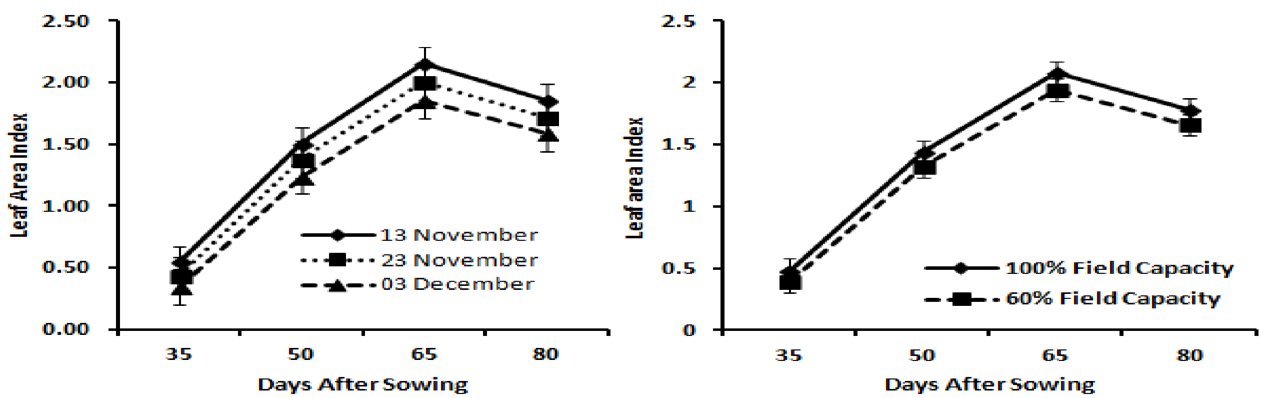

Figure 1: Leaf area index of *Camelina sativa* as affected by sowing date and water deficit stress

Crop growth rate (g m^{-2} d^{-1})

Crop growth rate is an important tool for the growth analysis of different field crops .CGR represents the gain in total plant dry biomass per unit of land in unit time. Statistical analysis of data indicated significant differences in CGR for sowing date and irrigation water levels. The highest crop growth rate (10.72 g m^{-2} d^{-1}) was recorded when crop was sown on 13th November (Figure 2). Decrease in crop growth was noted with the increase of water deficit stress. Highest CGR (10.17 g m^{-2} d^{-1}) was observed at 100% FC about 65 days after sowing (Fig.2). There was no significant difference between camelina genotypes regarding CGR (Table 2).

Leaf area duration (Days)

Analyzed data revealed that different sowing dates and water levels had significantly affected the LAD of camelina genotypes. No interaction effect was significant. Maximum LAD (68 days) was recorded in the treatment where crop was grown on 13th November (Figure 3). Between the water levels, 100% FC generated significantly higher LAD value (58 days) as compared to 60% FC having LAD of 50 days

Table 3: Mean square values from analysis of variance of leaf area duration of camelina genotypes under different sowing dates and water deficit stress

Source of Variation	d.f	LA	NAR
Plant densities (Pd)	2	645.78**	10.02**
Varieties	1	0.046NS	0.0047NS
Stress	1	598.61**	0.7773**
Pd*Variety	2	9.24NS	0.0013NS
Pd*Stress	2	21.80NS	0.0125NS
Variety *Stress	1	5.003NS	0.001NS
Pd*Variety* Stress	2	15.09NS	0.0012NS
Error	24	31.50	0.0313

* = Significant at 0.05 probability level, ** = Significant at 0.01 probability level, NS = Non significant

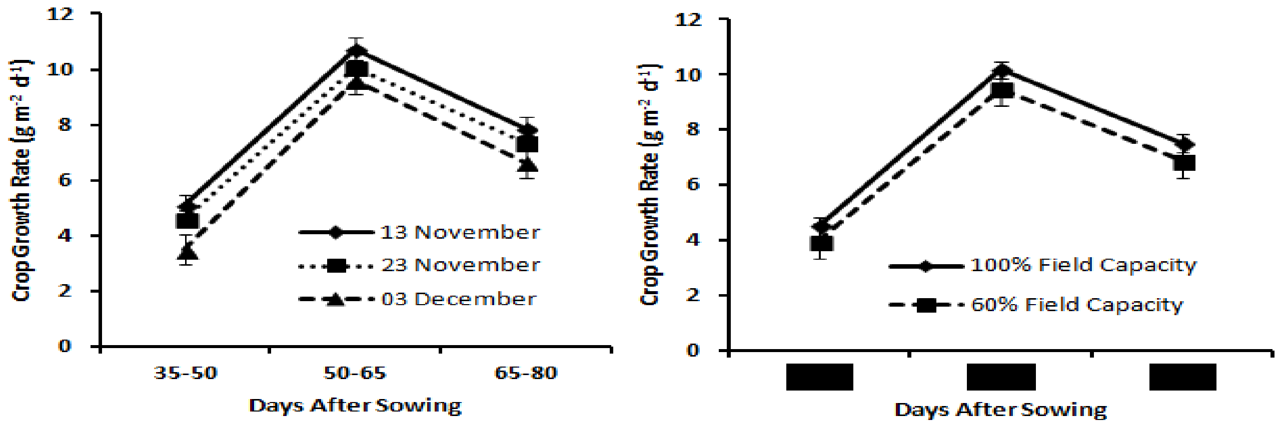

Figure 2: Crop growth rate of *Camelina sativa* as affected by sowing date and water deficit stress

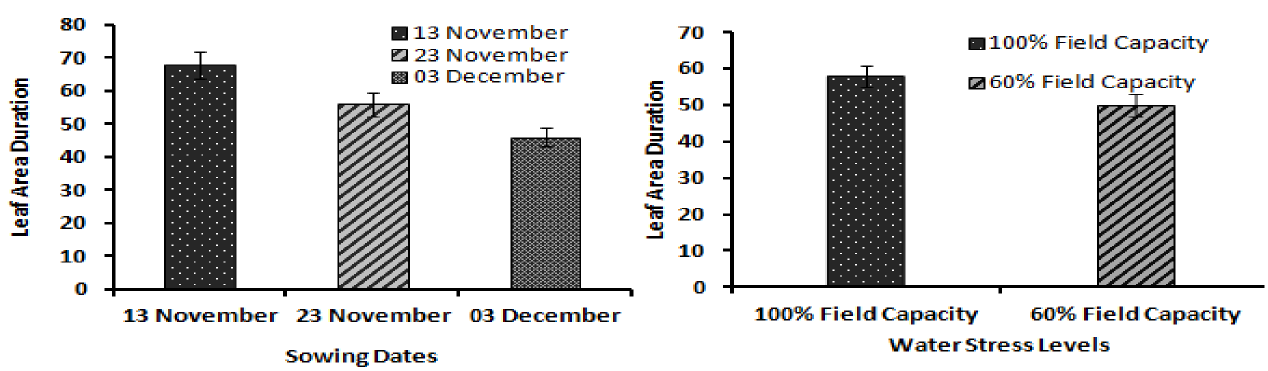

Figure 3: Leaf area duration of *Camelina sativa* as affected by sowing date and water deficit stress

(Figure 3). Camelina genotypes did not differ significantly for LAD (Table 3).

Net assimilation rate (g m^{-2} d^{-1})

Statistical data indicated that different sowing dates and water levels had significant effect on net assimilation rate of two camelina genotypes. All the possible interaction effects were non-significant. Among different sowing dates, the plants sown at 13th November showed maximum value (5.4 g m^{-2} d^{-1}) for NAR than other sowing dates (Figure 4). Likewise, 100% FC treatment produced the highest NAR value (4.95 g m^{-2} d^{-1}) as compared to 60% FC level (Fig.4). There was no significant difference between camelina genotypes.

Yield and yield components

The results from the analysis of variance revealed that significant differences were observed between the main

Table No 4: Seed yield and yield components of camelina genotypes as affected by different sowing dates and water deficit stress

Treatments	Plant height (cm)	Number of branches/plant	Number of pods/plant	1000-seed weight (g)	Seed yield/pot (g)
Sowing Dates					
Sd_1 (13th November)	74.25 a	9 a	87 a	1.31 a	3.99 a
Sd_2 (23rd November)	66.75 b	8 b	79 b	1.23 b	3.77 b
Sd_3 (03rd December)	59.91 c	7 c	71 c	1.09 c	3.09 c
LSD Value	**2.26**	**0.75**	**2.07**	**0.04**	**0.06**
Water Stress Levels					
No Stress (100% FC)	69.33 a	9 a	80 a	1.25 a	3.73 a
Water Stress (60% FC)	64.61 b	7 b	71 b	1.17 b	3.48 b
LSD Value	**1.84**	**0.61**	**1.69**	**0.05**	**0.05**
Camelina Genotypes					
Camelina-618	67.26 a	8 a	79 a	1.22 a	3.62 a
Camelina-611	66.61 a	8 a	78 a	1.20 a	3.59 a
LSD Value	**1.84**	**0.61**	**1.69**	**0.03**	**0.06**

Means sharing similar letter in a column are statistically non- significant (P>0.05)

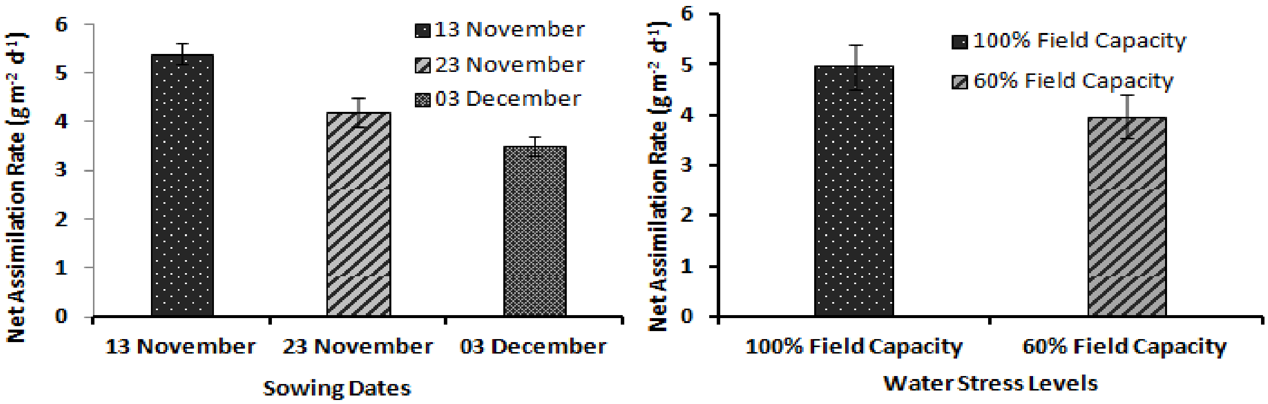

Figure 4: Net assimilation rate of *Camelina sativa* as affected by sowing date and water deficit stress

effects (planting date and water levels) for yield and yield contributing components but all the interaction effects were found to be non-significant for all these parameters. Data regarding yield and yield components indicated that maximum plant height, more number of branches per plant, highest number of pods per plant, 1000-seed weight and seed yield per plant were recorded in the early sowing date where plants were sown on 13th November as compared to 2nd (23rd November) and 3rd(3rd December) sowing dates respectively (Table.4). In case of water regimes, plants grown with 60 % FC showed less taller plants, lowest number of branches per plant, number of pods per plant, 1000-seed weight and less seed yield per plant compared with normally irrigated (100% FC) plants (Table.4). Statistically no significant difference was observed between camelina genotypes regarding yield and yield attributes (Table 4).

Discussion

Sowing date is probably the most important component of crop management. Because the time required for crop development is directly linked with different environmental factors coming ahead in the whole growth phase of the plant (De Bruin and Pederson, 2008). Leaf area and leaf photosynthetic efficiency are two fundamental factors that drive crop growth. Results in our study indicated maximum LAI in 1st planting date because plants had long growth duration, received more heating units and utilized sufficient photosynthetic materials resulting in more leaf area at flowering stage (65 DAS) (Yadavi *et al.*, 2015) and after that leaf area decreased due to shading of the lower leaves, mobilization of nutrients from leaves to grains and leaf senescence until harvesting time reached (Sharifi *et al.*, 2011; Toyota *et al.*, 2003). Delay in planting reduced LAI due to reduction in growth duration (meeting uncomfortable environmental conditions) (Munakamwe, 2008). Drought stress imposed during vegetative phase of growth caused shrinkage leaves leading to yellowing and aging of leaves (Cakir, 2004). Inhibition of expansion of developing foliage and reduced size of younger leaves could be resulted in reduced LAI under water deficit conditions (Acosta-Gallegos and White, 1995). Likewise, reduction in leaf area index due to limited water supply in sunflower crop was reported by Sadras *et al*. (1993).

Findings of our study revealed maximum crop growth rate due to early planting (13^{th} November) and decreased CGR with delayed planting. In early planting (13^{th} November) CGR increased faster than other two planting dates mainly due to rapid leaf area development, that received more radiation thus synthesizing more photosynthates used for plant growth and development. Our results are in line with Kamali *et al*. (2014) and Yadavi *et al*. (2015) who reported similar trend of CGR in barley and white beans grown under different sowing dates. Reduction in CGR under delayed planting occurred due to sub optimum temperature during the vegetative growth phase, as leaf development and dry matter accumulation greatly depends on temperature (Warrington and Kanemasu, 1983). Reduction in CGR under drought stress occurred mainly due to increased respiration and decreased photosynthetic efficiency. Water deficit by reducing leaf area expansion and photosynthetic capacity decreases total dry matter and finally CGR, because leaf responds to water deficit through stomatal closure that limits CO_2 supply to chloroplasts which ultimately decreases photosynthesis (Berkowitz *et al*., 1983; Muller and Whitsitt 1996). Our findings are in accordance with the conclusions of Goldani and Rezvani, (2007).

Results of present experiment showed that highest LAD was observed in 1^{st} planting date (13^{th} November) and LAD decreased with late planting. These outcomes are in accordance with the findings of Yadavi *et al*. (2015) who described that in early planting maximum LAD is due to optimum utilization of resources and high photosynthetic activity. According to the findings of Munakamwe, (2008) reduction in growth duration is responsible for decreased LAD because day duration is reduced and less amount of radiation is absorbed leading to less photosynthetic efficiency. According to our results negative correlation has been found between water deficit and LAD. Water deficit slows down photosynthetic process, accelerates yellowing and induces faster aging of leaves which causes reduction in LAD. Similar findings were reported by Sharif, (1999) in cereals.

Net assimilation rate determined the amount of dry matter produced by leaves. Results of this study indicated that maximum NAR is recorded in the plants, planted on November 13. These conclusions are according to the verdicts of Khayat *et al*. (2015) who noted maximum NAR in early planted rapeseed genotypes mainly due to high photosynthetic activity. Delayed planting showed reduction in NAR because of increase in temperature, premature senescence and reduced LAI (Solymanzadeh *et al.*, 2007; Din *et al*., 2011). Net assimilation rate is significantly reduced by drought stress in this study. As water deficit brings about stomata closure, photosynthetic rate decreases compared to crop leaf area, thus net assimilation rate reduces as well (Mojaddam *et al*., 2012). Our results are in agreement with Moradi *et al*. (2008) and Hejri *et al*. (2008) who reported significant decrease in NAR with increasing drought stress.

Results of yield and yield contributing components indicated that early planted (13^{th} November) camelina produced maximum plant height, more number of branches per plant, more seed pods per plant, 1000-seed weight and maximum seed yield. Results from our study coincide with the conclusions of Chauhan *et al*. (1993) that increase in seed yield and yield related components due to early planting resulted from more absorption of light, water and minerals by plant canopies which resulted in increased photosynthetic efficiency. Gugel and Falk, (2006) also found that relatively cool and dry conditions favor high seed yields in camelina. Findings of our study are in accordance with Urbaniak *et al*. (2008) where they found correlation between number of branches per plant and number of pods per plant which was also highly correlated with seed yield in camelina. Higher thousand seed weight in early planting dates is also reported by Berti *et al*. (2011). Larger LAI, CGR and plant height have contributed towards higher yield in early planting (Yadavi *et al.,* 2015).

Results of present study described that delay in planting negatively affected yield and yield contributing factors. In late planting, plant height reduced due to insufficient growth period and limited effect of environmental conditions (Rameeh, 2012). Delayed planting and end season heat contributed to physiological limitations in the flowering period. This happened due to poor growth of the plant or reduced leaf expansion. Therefore nourished ingredients had limited availability at the end of flowering, hence decrease in number of pods per plant occurred (Poriesa *et al*., 2007). 1000-seed weight decreased under late sowing because grain filling period had high temperatures that prevented maximum grain filling. Our results have conformity with the findings of other researchers (Rahnama and Bakhshandeh, 2005; Rabiee *et al*., 2004). Short growing season, reduction in flowering time, weak pollination and poor seed filling had contributed to reduce seed yield under late sown conditions (Uzun *et al*., 2009; Turhan *et al*., 2011).

Drought stress has adversely influenced the seed yield and yield related traits such as plant height, number of branches per plant, number of pods per plant, 1000-seed weight in *Camelina sativa*. Our results are according to the findings of Sangtarash *et al*. (2009) where they found decrease in plant height with imposed drought stress. Most sensitive yield component to drought stress is number of pods per plant (Diepenbrock, 2000). Apparently water deficit stress hindered flowering and reduced the possibility of developing flower into pod resulting in pod abortion (Kimber and McGregor, 1995). Reduced number of branches per plant is also in accordance with the findings of Halvorson *et al*. (2001) who reported that number of branches per plant entirely dependent on the supply of moisture during growth period. Decreased seed yield is the result of interrupted water supply from flowering to seed maturity stage (Sharghi *et al*., 2011). At the later stages of reproductive growth implication of water deficit stress reduces the source supply for seed yield by enhancing leaf shedding and accelerating maturity (Gan *et al*., 2004).

Conclusion

It is evident from this study that growth and yield of camelina genotypes is strongly influenced by sowing date and drought stress levels. Early planting (13^{th} November) of camelina resulted in maximum LAI, CGR, LAD and NAR which in turn strongly correlated with maximum yield in camelina. Similarly maximum growth and yield was achieved with 100 % field capacity level as compared to 60 % field capacity.

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