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Article

Alterations in Growth and Yield of Camelina Induced by Different Planting Densities under Water Deficit Stress

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Abstract: Camelina (*Camelina sativa* L.) is famous for its oil quality and unique fatty acid pattern. Growth and yield of crops reduced under water deficit conditions. Environmental threat such as drought or water deficit condition is the emerging problem which creates the negative impact on the growth of plants. Based upon the current situation a pot study was performed in rain out-shelter to explore the effect of different plant densities (15, 10 and 5 plants per pot) on growth and seed yield of two camelina genotypes under normal (100% WHC) and water deficit (60% WHC) conditions by using completely randomized design with factorial arrangement having three replicates. Results indicated that individual effects of plant densities and water deficit stress levels considerably influenced the growth and seed yield of camelina but interaction effects did not indicate any significant variation. Maximum values of leaf area index (LAI) and crop growth rate (CGR) were recorded in P_3 treatment (15 plants per pot). However, maximum values of leaf area duration (LAD), net assimilation rate (NAR), yield and yield components were observed in the treatment P_1 (5 plants per pot). Water deficit condition (60% WHC) significantly minimized the growth, seed yield (0.82 g/m^2) and yield components of camelina genotypes. Both camelina genotypes (611 and 618) did not differ significantly under water deficit conditions.

Keywords: *Camelina sativa*; crop growth rate; net assimilation rate; planting density; water stress

1 Introduction

Camelina (*Camelina sativa* L.) is a primitive oilseed crop of mustard family. It is an ancient oilseed crop that has gained considerable attention these days [1]. Camelina has many unique agronomic characteristics and potential industrial uses [2]. Camelina is relatively more heat, drought and cold tolerant compared to other oilseeds [3]. It is also a nutrient efficient and short duration crop having a life cycle of 90–110 days [4]. Seeds of camelina crop bear about 40–43% oil contents [5]. Major portion of camelina oil approximately 50–60% comprised of polyunsaturated fatty acids with 40–45% omega-3 fatty acids and 15–20% omega-6 fatty acids respectively [6]. Moreover, camelina seed meal has protein content of about 390–450 g kg^{-1} [7] along with glucosinulates ranging between 13.2–36.2 μmol g^{-1} [8]. Due to high protein content camelina seed and oil meal is also used for animal rations [9]. High concentrations of tocopherols and anti-oxidants have been found in camelina seed and raw oil which prevents it from rancidity and enhances storage time without any deterioration [10]. Average seed yield of camelina varies from 1.5 t ha^{-1} to 2.8 t ha^{-1} in different countries of the world [5]. Camelina competes well with weed species and compensate the fluctuations in plant populations [11]. Camelina oil is now being used as feed stock for biodiesel and investigations are underway to assess its utilization as a feed stock for aviation fuel [12,13].

Environmental stresses especially drought stress in the most arid and semi-arid parts of the world limits the yield of crop plants [14]. Water stress during stem elongation and flowering is the worst time for many grain crops [15] and short term exposure to water stresses during stem elongation, flowering and pod development mainly reduces the number of pods per plant that induces a significant decrease in seed yield [16].

Although many researchers have conducted research on various aspects of camelina, however, to the best of our knowledge, comparative analysis of different planting densities under water deficit conditions is sparse. Hence, this study was performed in a rain-exclusion structure to measure the effects of different plant densities on growth and yield of camelina against water deficit stress conditions. The findings of this study will provide a guideline to establish camelina as an alternative oilseed crop in those areas threatened by drought stress.

2 Materials and Methods

Current pot experiment was done during 2013–2014 in a manually operated rain-out shelter equipped with movable, transparent flexible plastic sheet at Department of Crop Physiology, University of Agriculture, Faisalabad (UAF), Pakistan (31.25° N latitude, 73.09° E longitude and 184 m altitude). Camelina plant densities of 150, 300 and 450 plants m^{-2} corresponding to 5 (P_1), 10 (P_2) and 15 (P_3) plants per pot were used under full water and deficit water conditions. The experimental design used was completely randomized design (CRD) with factorial arrangement having three replicates. Seeds of two different camelina genotypes: 611 and 618 were taken from the Office of Research, Innovation and Commercialization (ORIC), UAF, Pakistan. The sand filled plastic pots wrapped with plastic bags and each pot was filled with 4 kg washed, sundried and fine sand. Water holding capacity (WHC) of sand was calculated by gravimetric method [17] for normal plants (100% WHC) i.e., 1000 ml water in each pot and 600 ml water for water deficit plants (60% WHC). Twenty seeds of both camelina genotypes were sown on 2nd November 2013 in plastic pots that were irrigated with distilled water. To get good germination and emergence 100% WHC was maintained in all pots at the commencement of experiment. Prior to impose water deficit stress, thinning was done and uniform sized healthy 5 (P_1), 10 (P_2) and 15 (P_3) plants were maintained in pots according to the treatment. Later on the water stress was applied 25 days after sowing (DAS) according to the specified levels. Recommended rates of nitrogen, phosphorus and potassium (50 kg ha^{-1}, 30 kg ha^{-1} and 60 kg ha^{-1}) respectively were applied at the time of sowing. All measurements of leaf area, LAI, CGR and LAD were recorded before maturity of the crop. Crop harvesting was completed on 20th March 2014.

During experiment leaf area was measured by taking plant samples from each pot with 15 days interval starting from 35 DAS up to 80 DAS. Leaves taken from each pot were weighed on electric balance and after completing weight measurement a subsample of 5g was taken from each sample lot to record leaf area with digital leaf area meter (JVC TK-5310). LAI was recorded (of three plants and average taken) as the ratio of leaf area to the pot surface area [18].

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

CGR (g m^{-2} d^{-1}) was estimated by harvesting the plants from each pot (36 pots), oven dried at the temperature 70°C and constant weight recorded. CGR was calculated after an interval of 15 days (from 35 DAS up to 80 DAS) by following formula [19].

$$\text{CGR} = (W_2 - W_1)/(T_2 - T_1)$$

where:

W_1 = oven dried weight of sample at first sampling

W_2 = oven dried weight of sample at second sampling

T_1 = time representing first sampling

T_2 = time representing second sampling

LAD (days) was estimated by using the formula given by Hunt [19]

$$\text{LAD} = (\text{LAI}_1 + \text{LAI}_2)(T_2 - T_1)/2$$

NAR = (TDM)/(LAD)

Total dry matter (TDM) was measured by using quadrate of 1 m^2.

Yield and yield contributing components such as plant height, number of branches per plant, number of pods per plant, 1000 seed weight and seed yield per m^2 were also recorded.

Data regarding all the above mentioned parameters was collected and Fisher's Analysis of Variance technique applied and Statistix software package 9.1 was used for statistical analysis. Least Significant Difference (LSD) test at 5% probability level was used for comparing the treatments' means [20].

3 Results

3.1 Leaf Area Index (LAI)

LAI being an essential parameter shows incremental phase of crops in agriculture. Analyzed data indicated that LAI was significantly ($p \leq 0.05$) influenced by different plant densities and water deficit levels. All the interaction effects were non-significant. Periodic data revealed that, LAI increased with the advancement in growth and maximum LAI (2.17) was observed 65 days after sowing in the treatment where 15 plants per pot was maintained (Fig. 1). In case of water deficit levels 100% WHC achieved maximum value (2.14) of LAI at 65 days after sowing (Fig. 1). Camelina genotypes did not differ significantly for LAI (Tab. 1)

3.2 Crop Growth Rate (g m^{-2} d^{-1})

Crop growth rate (CGR) is the primary growth parameter that denotes the total biomass production of the crop. Different plant densities significantly affected the CGR of camelina genotypes. The highest CGR (10.35 g m^{-2} d^{-1}) was recorded in the treatment P_3 (15 plants per pot) (Fig. 2). Water deficit levels also affected the CGR and substantial increase in water deficit conditions declined the CGR. Maximum CGR (10.56 g m^{-2} d^{-1}) was recorded in 100% WHC at 65 days after sowing (Fig. 2). The camelina genotypes showed uniform response with respect to crop growth (Tab. 2).

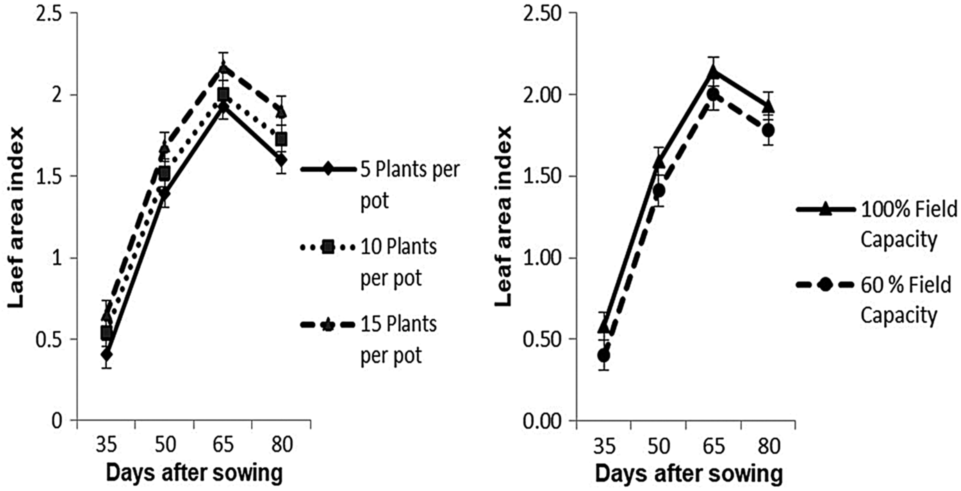

Figure 1: Leaf area index of *Camelina sativa* as affected by planting density and water stress

Table 1: Mean square values from analysis of variance of leaf area index of camelina genotypes under different plant densities and water stress levels

Source of Variation	d.f	LAI-1 At 1st harvest	LAI-2 At 2nd harvest	LAI-3 At 3rd harvest	LAI-4 At 4th harvest
Plant densities (Pd)	2	0.05241**	0.08391**	0.2328**	0.2700**
Varieties	1	0.0001 NS	0.0002 NS	0.000 NS	0.0001 NS
Stress	1	0.0521**	0.1122**	0.1640**	0.2010**
Pd * Variety	2	0.0001 NS	0.0006 NS	0.0006 NS	0.0001 NS
Pd * Stress	2	0.000 NS	0.0001 NS	0.0001 NS	0.0008 NS
Variety * Stress	1	0.0006 NS	0.0002 NS	0.0017 NS	0.0010 NS
Pd * Variety * Stress	2	0.000 NS	0.0001 NS	0.0005 NS	0.000 NS
Error	24	0.0025	0.0234	0.0224	0.0243

* = Significant at 0.05 probability level, ** = Significant at 0.0 1 probability level, NS = Non-significant

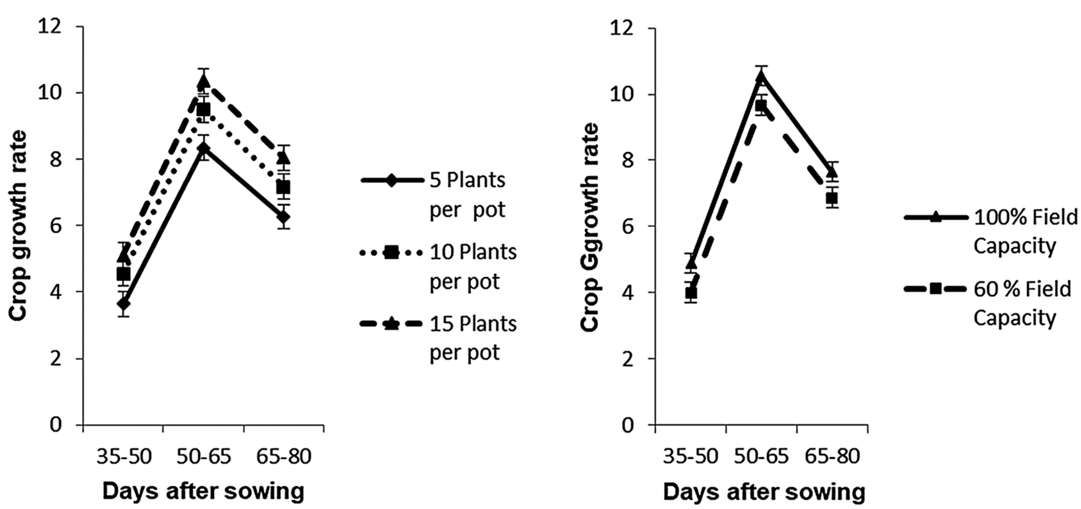

Figure 2: Crop growth rate (g m^{-2} d^{-1}) of *Camelina sativa* as affected by planting density and water stress

Table 2: Mean square values from analysis of variance of crop growth rate of camelina genotypes under different plant densities and water stress levels

Source of Variation	d.f	CGR-1 At 1st harvest	CGR-2 At 2nd harvest	CGR-3 At 3rd harvest
Plant densities (Pd)	2	5.9447**	6.4255**	9.5867**
Varieties	1	0.0004 NS	0.0007 NS	0.0046 NS
Stress	1	1.5666**	1.9460**	1.2958**
Pd * Variety	2	0.0029 NS	0.0768 NS	0.0001 NS
Pd * Stress	2	0.0185 NS	0.0002 NS	0.0113 NS
Variety * Stress	1	0.0014 NS	0.0006 NS	0.0042 NS
Pd * Variety * Stress	2	0.0024 NS	0.0041 NS	0.0006 NS
Error	24	0.0289	0.0295	0.0409

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

3.3 Leaf Area Duration (Days)

The data of leaf area duration (LAD) was significantly influenced by different plant densities and water deficit levels. All the interaction effects were non-significant. LAD increased in linear fashion as growth progressed and maximum LAD of 67 days was observed under the treatment (P_1) where 5 plants per pot were grown (Fig. 3). As for as water stress levels are concerned, at 100% field capacity significantly higher LAD value (60 days) was recorded as compared to 60% field capacity having LAD of 54 days (Fig. 3). *Camelina* genotypes did not differ markedly in LAD (Tab. 3).

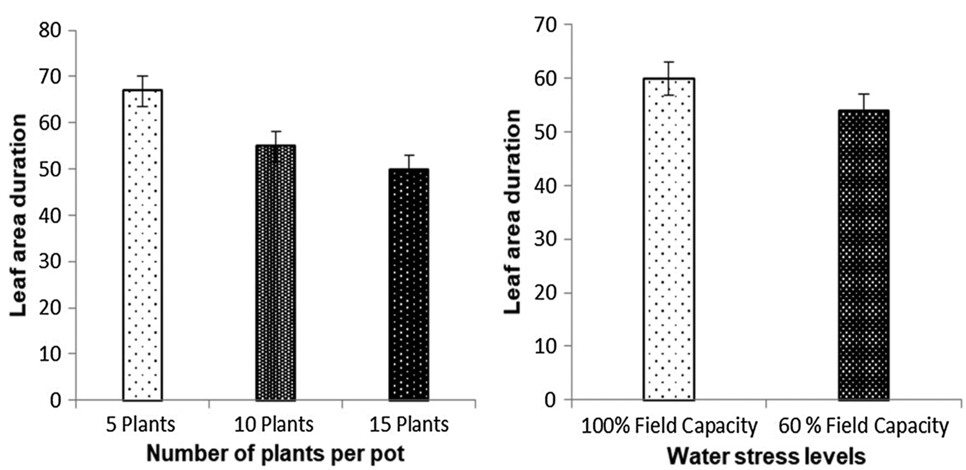

Figure 3: Leaf area duration (Days) of *Camelina sativa* as affected by planting density and water stress

3.4 Net Assimilation Rate (g m^{-2} d^{-1})

Different plant densities and water deficit levels independently had significant effect on net assimilation rate (NAR) of camelina genotypes. However, all the interaction effects were non-significant. Among different plant densities, P_1 treatment (5 plants per pot) showed maximum NAR (5.6 g m^{-2} d^{-1}) than other plant density treatments as shown in Fig. 4. In case of water stress levels significantly highest value

Table 3: Mean square values from analysis of variance of leaf area duration of camelina genotypes under different plant densities and water stress levels

Source of variation	d.f	LAD	NAR
Plant densities (Pd)	2	592.47**	1.1757**
Varieties	1	0.023 NS	0.0047 NS
Stress	1	294.69**	0.148**
Pd * Variety	2	0.039 NS	0.059 NS
Pd * Stress	2	0.263 NS	0.011 NS
Variety * Stress	1	0.157 NS	0.06 NS
Pd * Variety * Stress	2	0.066 NS	0.06 NS
Error	24	25.121	0.0313 NS

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

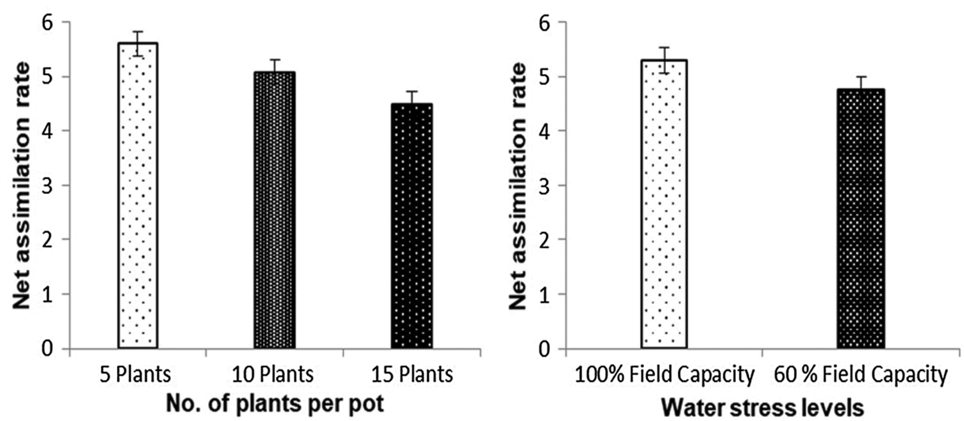

Figure 4: Net assimilation rate (g m^{-2} d^{-1}) of *Camelina sativa* as affected by planting density and water stress

of NAR (5.3 g m^{-2} d^{-1}) was noted at 100% WHC (Fig. 4). Camelina genotypes varied non-significantly for net assimilation rate (Tab. 3).

3.5 Agronomic Traits

The results from analysis of variance indicated that significant differences were observed between main effects, plant densities and water stress levels, for many of the agronomic traits quantified. However, non-significant interactions were observed between plant densities and water stress levels for any of the agronomic traits. Similarly camelina lines did not indicate any significant variation for agronomic traits. Data regarding agronomic traits revealed that maximum plant height, more number of branches per plant, greater number of pods per plant, maximum 1000-seed weight and seed yield per plant were recorded in the treatment (P_1) where 5 plants per pot were grown (Tab. 4). Visual observations for the different traits of agronomic were shown in the Figs. 5 and 6. Data of water deficit stress indicated that 100% WHC produced taller plants, more number of branches per plant, maximum number of pods per plant, highest 1000-seed weight and seed yield per pot as compared to 60% field capacity (Tab. 4).

Table 4: Seed yield and yield components of camelina genotypes as affected by different plant densities and water stress levels

Treatments	Plant height (cm)	Number of branches/plant	Number of pods/ plant	1000-seed weight (g)	Seed yield/ m^2 (g)
Plant densities					
P_1 (5 plants/pot)	72.22a	9a	83a	1.28a	156.25c
P_2 (10 plants/pot)	68.43b	8b	71b	1.19b	171.87b
P_3 (15 plants/pot)	61.74c	6a	63c	0.93c	187.51a
LSD Value	**3.70**	**0.89**	**5.12**	**0.07**	**5.05**
Water Stress Levels					
No Stress (100% FC)	69.34a	8a	79a	1.16a	0.96a
Water Stress (60% FC)	58.21b	6b	65b	1.02b	0.82b
LSD Value	**4.07**	**0.92**	**3.55**	**0.12**	**0.10**

Means sharing similar letter in a row or in a column are statistically non-significant ($p > 0.05$)

Figure 5: Optimization of planting density of *Camelina sativa* under water stress (plants at initial stage)

Figure 6: Optimization of planting density of *Camelina sativa* under water stress (plants at maturity)

4 Discussion

Planting density is assumed as an important factor to measure the ability of crops in capturing of resources. Plant density has direct impact on biomass, crop yield and economic returns in most of the crops [21]. Results of current study revealed that LAI increased against high plant densities which might be owing to more number of plants per unit area. Our results are in consistent with the verdicts of Ma et al. [22] who found escalation in leaf area index with increasing planting density in maize. Increased leaf area causes increased absorption of sunlight which leads to more crop growth rate [23]. On the other hand decrease in LAI in response of water deficit stress would be the consequence of leaf shrinkage, aging and leaf yellowing thus contributing towards reduction in LAI [24], this conclusion related to our present study. Consistent with our findings Sadras et al. [25] has also elucidated a decline in leaf area in sunflower crop due to increase in water deficit stress.

Results of our study showed that crop growth rate increased with high plant density. Our findings are harmonized with Ozoni Davaji et al. [26] who inferred that CGR is directly related to photosynthetic activity in plant, therefore increased plant density, plant distribution and leaf area per unit area are more uniform resultantly plants absorbed more radiation, which increased photosynthetic rate and produced higher CGR. Our results are according to the outcomes of Madani et al. [27] who elucidated that increase in crop growth rate is associated with high plant density. Decrease in CGR under water deficit stress condition is might be the result of increased respiration and decreased photosynthesis [28].

Our findings regarding leaf area duration (LAD) indicated that increasing plant density has negative impact on leaf area duration. These findings are reinforced by Ma et al. [22] and Naeem et al. [29], who stated that reduced photosynthetic efficiency because of high plant density would have resulted in decreased LAD. LAD is also negatively correlated with water deficit stress.

NAR decreases due to higher plant population per unit area. Consistent with our findings [30] elucidated that at higher plant densities, due to greater number of plants per unit area, competition between plants might have increased and penetration of light reduced that caused reduce accumulation of dry matter in plants resultantly NAR is decreased at higher plant population. Decrease in net assimilation rate due to increased plant density also reported by Pourhadian et al. [31]. Net assimilation rate followed falling trend in response of water stress. In accordance with our results Madani et al. [27] also reported reduction in net assimilation rate under the application of water deficit stress which might be the result of reduced LAI and LAD.

The results regarding agronomic traits indicated that at high pant density less taller plants, reduced number of branches per plant, less number of pods per plant, 1000-seed weight and seed yield per plant were produced. Our results are inconsistent with Mobasser et al. [32] who reported that plants developed under high plant densities showed small height, have fewer branches and less number of pods per plant compared to those developed under low densities. This would be due to reduced LAI, LAD and poor CGR. In spite of that overall yield per pot increased at higher plant density. Increasing number of plants per unit area reduces plant yield attributes, such as branches and pod number per plant, yet at high planting density system, leaf area index and light energy utilization increases and contributes towards increased overall seed yield [33].

Water deficit stress has also adversely affected the seed yield and yield related components in camelina genotypes. Reduction in yield and yield components under reduced supply of water would be due to shrinkage of cells, reduced cell expansion that resulted in poor production and yield [34]. Most sensitive yield component to water deficiency is pod number per plant [35]. Apparently water deficit stress might have hindered the development of flower into pod which resulted in empty pods [36]. Reduced number of branches per plant also inconsistent with the results of Halvorson et al. [37] who described that more branches per plant entirely dependent on the supply of moisture during growth period. Decreased seed yield might be the result of interrupted moisture supply from flowering to seed maturity stage [38]. At the later stages of reproductive growth implication of water deficit stress may cause limited availability of food assimilates for seed yield by endorsing leaf shedding and accelerating maturity [15].

5 Conclusion

Different plant densities and water stress levels significantly affected the growth and development of *Camelina sativa* genotypes. However, maximum LAI and CGR were observed in the treatment T_3 where 15 plants per pot were grown. While maximum LAD and yield components and seed yield per plant were recorded under the treatment T_1 where 5 plants per pot were maintained.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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