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Effects of Planting Date and Low Irrigation on Quantitative and Qualitative Traits of Flax Seed

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Abstract: When there is a shortage for available water, low irrigation stress is one method to maintain productivity. Therefore, a study was conducted to determine the effect of planting date and low irrigation stress on two Spring varieties of Flax seed during Spring, 2008 in College of Abouraihan, University of Tehran, Iran. The highest plant height (60.3 cm), primary branch number per plant (4.46), capsule number per plant (65.9), seed number per capsule (5.78), seed yield (1763 kg h^{-1}), biologic yield (5935 kg h^{-1}), harvest index (29.9), oil percentage (41), oil yield (718 kg ha^{-1}), protein yield (361 kg ha^{-1}), linolenic percentage (48.4) and linoleic percentage (18.36) obtained in first sowing date and under full irrigation whereas by later sowing dates and limited irrigation stress especially at flowering and grain filling stages, this characters were reduced. The most oil yield (454 kg ha^{-1}) and linoleic (18.81) acid percentage obtained from serenade variety whereas lirina variety had the highest oil percentage (42.25), linolenic (47.9) and oleic (24.1) acids percentage. In this study, sowing date was a very important management tool in minimizing the negative impact of high temperature and moisture stress during the critical flowering and seed filling periods.

Key words: Fatty acids, limited irrigation, oil yield, sowing date, moisture, temperature

INTRODUCTION

The world population is projected to become a staggering 8.3 billion by 2030 from about 6 billion today which will aggravate food insecurity especially in the developing countries (FAO, 2009). The ability of agriculture to support a growing population has been a concern and continues to be on high priority on the global policy agenda. Flax seed (*Linum usitatissimum* L.) is the 6th largest oilseed crop in the world and is one of the oldest cultivated plants. Linseed type flax is a relatively short plant which produces many more secondary branches compared to the fiber type (Gill, 1987). Flax seed, containing a mixture of the fatty acids is rich in two essential fatty acids, α-Linolenic acid and linoleic acid to use flax oil in food applications where stability is essential (Green and Marshall, 1981). Linseed oil is used in the manufacturing of paints and varnish, oil cloth and linoleum. Although, flax is considered to be a cool season crop, air temperature <10°C in the Spring may inhibit growth and development which can delay flowering (Gusta *et al*., 1997). Flax is cultivated in almost all continents with temperate climates (Gill, 1987). Higher growing season temperatures can have dramatic impacts on agricultural productivity, farm incomes and food security (Battisti and Naylor, 2009). Delay in sowing led to increase in environmental temperature during reproductive growth of crop resulting in lower seed quality (Greven *et al*., 2004). Water stress is considered one of the most important factors limiting plant performance and yield in world and impact on growth, leaf photosynthesis and yield flax seed (Dutta *et al*., 1995). The highly positive effect of irrigation on seed confirms the key role of supplementary irrigation at critical growth stages particularly sensitive to water stress (Daun, 1993). Many grain crops have little yield response to water stress during vegetative stage and during late reproductive or grain fill growth stages. However, crops are sensitive to water stress during reproductive growth stage and yields will be impacted during this time period (Schneekloth *et al*., 2010). Under these conditions, optimal sowing dates and supplemental irrigation at reproductive stages, i.e., flowering and seed filling periods could be of a great management option to lessen the negative aspects of temperature and drought stress. Since, water resources in arid and semi arid environments are limited, this study aimed to evaluate the influence of irrigation and three sowing dates on linseed.

MATERIALS AND METHODS

The research was carried out in Agricultural Research Centre, University of Tehran, Abouraihan Faculty of Agriculture in the South-West of Tehran (Lat. 35°, 28′;

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Long. 51°, 44' and elevation 1280 m), Iran as strip split plot based on randomized complete block design with three replicates during Spring, 2008. The treatments comprised four limited irrigation: normal irrigation (I_0) during the growing period (I_0: irrigation after 60 mm evaporation from class A pan) as control, limited irrigation after 150 mm evaporation from stem elongation (I_1), flowering (I_2) and grain filling (I_3) just for one irrigation interval and three sowing dates (20 April, 10 May and 30 May) as main plots and variety at two levels (Lirina and Serenade) as subplots. Soil moisture determined gravimetrically using augers. All treatments were irrigated with equal amount for each time which was measured with the help of a 15 cm throat Parshall flume fixed in the irrigation channel. The data for day length (h), temperature (°C), relative humidity (%) and precipitation (mm) were obtained from Varamin meteorological substation (Fig. 1). Varamin is located in the central regions of Iran and has a mean annual temperature of 27°C and average rainfall of 170 mm. Soil samples were taken (0-30 cm) before sowing and soil analysis results showed that it was silty loam in texture

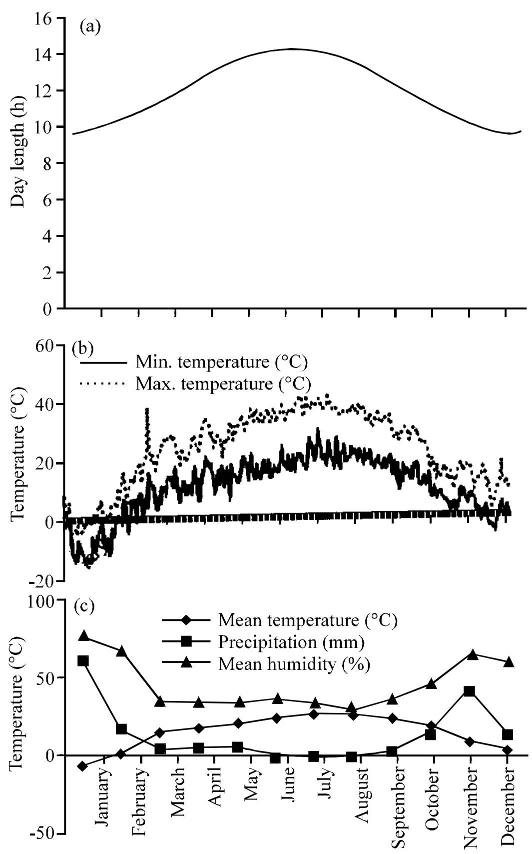


Fig. 1: Ambient temperature, rainfall and relative humidity during flax seed growing season of 2008 in Varamin

with pH of 7.28, contained 0.75% organic matter; total nitrogen of 0.09 ppm, assumable phosphorus of 4.8 ppm, exchangeable potassium of 390 ppm with no salinity problems (E.C. = 1.8 ds.m^{-1}). On the basis of soil analysis, 40 kg ha^{-1} urea, 40 kg ha^{-1} ammonium phosphate and 20 kg ha^{-1} potassium sulfate fertilizer were applied to the site and harrowed before seedbed preparation. Nitrogen was applied in two applications as split; half before sowing and the remaining half was applied top dressed at flower-bud-visibility stage. The area of each plot was 10 m^2 consisting of eight rows, 5 m long and 25 cm apart. Seeds were sown 4 cm apart at about 2-3 cm depth. A 1.0 m alley was left around each plot. Plots were over seeded and subsequently thinned to final plant density of about 100 plants m^{-2} at seedling stage. Weeds were controlled by both Trifluralin (2.5 L ha^{-1}) as pre plant and by hand as needed. Seed yields were taken at maturity by harvesting the center two rows of each plot for seed yield determination.

Subsamples were dried at 105°C for moisture determination. Seed yield was adjusted to 9% moisture content and all other measurements were reported on a dry weight basis. Twenty plants were randomly collected from the central six rows with edging shears (0.1 m cutting width) and the following characteristics were recorded for each plot; Plant height (cm), primary branch number, capsule number per plant, seed number per capsule, thousand seed weight (gr), seed yield (kg ha^{-1}), biological yield (kg ha^{-1}), harvest index (%), oil percentage oil yield (kg ha^{-1}), protein percentage, protein yield (kg ha^{-1}), linolenic, linoleic, oleic, stearic and palmitic acids percentage. Seeds were threshed by hand and weight of seed (g m^{-2}) was recorded. Plots were harvested at maturity and seeds were dried to uniform moisture content for 24-48 h at 75-80°C.

Oil content was determined using nuclear magnetic resonance (Jambunathan *et al*., 1985). To estimate protein content, nitrogen concentration was determined using a Techniconautoanalyzer (Singh and Jambunathan, 1980). A factor of 5.46 was used to convert nitrogen into crude protein content. Seed samples were taken for total fatty acid analyses. Total fatty acid content was analyzed by using a method modified by Wu *et al.* (1994). In this method, seed samples were soaked in 2 mL of 2% sulphuric acid in dry methanol for 16 h at room temperature, followed by 80 min of heating at 90°C to convert the Fatty Acids into Methyl derivatives (FAMEs). Methyl heptadecanoate (17:0 ME) was added as an internal standard. The FAMEs were extracted in 2 mL water and 3 mL hexane and then determined by Gas Liquid Chromatography (GLC). The fatty acid methyl ester composition was analyzed by using a Varian 3400 gas chromatography equipped with a Supelcovax-10 fused slica capillary column (30 m × 0.25 μm film thickness). The column's initial temperature was kept at 160°C for 15 min so that in this temperature an increase could occur at the rate of 5°C min^{-1}. The temperatures of the injector and the dedector (FID) were 240 and 280°C, respectively. The carrier gas was nitrogen with a flow rate of 1-2 mL min^{-1}. Split ratio was adjusted to 30 mL min^{-1}. The injected volume of the sample was 1 μL. Fatty acids were identified by retention time relative to that of an authentic standard. The FAMEs were identified by comparing the retention times with those of the standards. Fatty acid content was computed as weight percentage of the total fatty acids by using the GC area counts for various FAMEs. Analysis of variances of data for each attribute and combined analysis of the split plot designs in 2 years were computed using the SAS computer program (SAS Institute, 2001). F test in combined analysis of the experiments was carried out using expected values of the mean squares which year and replication were assigned as random variables and sowing date and limited irrigation were considered as fixed variables.

The Duncan's multiple range tests at 5% level of probability was used to test significant main effects. The Mstat-C software package was used to test significant interaction effects between treatments (Mstat, 1993). Accumulated Growing Degree Days (GDD) were calculated by summing the daily degree day values (°C) obtained by adding the maximum and minimum temperatures for the day, dividing by two and subtracting the base temperature which for flax seed is 5°C. The coefficient of linear regression equation between the traits mean as the dependent variables and growth degree day of all the growth season of flax seed as the independent variable are calculated by SAS.

RESULTS

Effect of irrigation levels: All flax seed traits were significantly affected by limited irrigation stress in the analysis of variances except number of primary branches pre plant (Table 1). The highest plant height, number of primary branches pre plant, capsules number per plant, seed number per capsule, seed yield, biological yield, harvest index, oil yield and percentage, protein yield, linolenic and linoleic acids percentage of flax seed obtained from control irrigation treatment while limited irrigation stress during flowering and seed filling stages resulted in lowest these traits, respectively (Table 2). Limited irrigation stress during flowering had the highest thousand seed weight compared to other irrigation treatments while more protein percentage, oleic, stearic and palmitic acid percentage obtained from limited irrigation stress at seed filling stage (Table 2).

Effect of sowing date: Sowing dates had a significant effect on all flax seed traits (Table 1). The highest plant height, number of primary branches pre plant, capsules number per plant, seed number per capsule, thousand seed weight, seed yield, biological yield, harvest index, oil yield and percentage, protein yield, linolenic and linoleic acids percentage of flax seed acquired in the first sowing date against the lowest values of these traits recorded from last sowing date (Table 2). In the last sowing date protein percentage, oleic, stearic and palmitic acids percentage increased statistically.

Effect of variety: The analysis of variances revealed significant differences between both varieties for all flax seed traits (Table 1). Serenade produced more primary

Table 1: Analysis variance for the effect of limited irrigation stress, sowing dates and variety on two spring varieties of flax seed (r = 3)

SOV	df	Plant height (cm)	Primary branch number	Capsule number per plant	Seed number per capsule	Thousand seed weight (g)	Seed yield (kg ha^{-1})	Biologic yield (kg ha^{-1})	Harvest index (%)	Protein (%)
Block	2	0.39^{NS}	0.064^{NS}	7.4^{NS}	0.009^{NS}	0.027^{NS}	2451^{NS}	7389^{NS}	0.44^{NS}	0.069^{NS}
I	3	66.2**	0.16^{ns}	2691.5**	1.1**	5.45**	2170090**	56833002**	389.1**	9.13**
E_1	6	3.13	0.063	19.29	0.011	0.018	3973	15435	0.77	0.032
T	2	76**	0.96*	2615**	2.46**	3.16**	2938588**	6613602**	629.2**	101**
E_2	4	1.25	0.1	4.35	0.006	0.014	1358	6961	0.278	0.015
I × T	6	2.35^{ns}	0.025^{NS}	37.41^{NS}	0.137**	0.32**	9721.4*	65862.5**	18.32**	3.26**
E_3	12	1.97	0.069	15.4	0.02	0.011	3021	12888	0.49	0.03
C	1	512**	9.92**	2576**	6.35**	4.87**	740139**	1936512**	550**	291**
I×C	3	1.83^{NS}	0.059^{NS}	19.41^{NS}	1.02^{NS}	0.096**	10898.6^{NS}	88395.3**	0.383^{NS}	0.05^{NS}
T×C	2	20.5*	0.22^{NS}	35.87^{NS}	0.018^{NS}	0.24**	4031.4^{NS}	16770.5^{NS}	1.12^{NS}	0.064^{NS}
I×T×C	6	1.57^{NS}	0.012^{NS}	3.07^{NS}	0.011^{NS}	0.017^{NS}	2021.1^{NS}	5413.6^{NS}	0.92^{NS}	0.417**
E_4	24	4.96	0.189	32.53	0.029	0.01	4714	16659	0.692	0.058

SOV	df	Protein yield (kg ha^{-1})	Oil (%)	Oil yield (kg ha^{-1})	Linolenic acid (%)	Linoleic acid (%)	Oleic acid (%)	Stearic acid (%)	Palmitic acid (%)
Block	2	184.8^{NS}	0.16^{NS}	297^{NS}	0.066^{NS}	0.004^{NS}	0.078^{NS}	0.008^{NS}	0.002^{NS}
I	3	93417**	7.42**	360493**	6.06**	1.67**	8.37**	0.37**	0.129**
E_1	6	194.5	0.086	738	0.008	0.02	0.21	0.022	0.013
T	2	85900**	39.7**	539889**	41.83**	11.8**	61.47**	1.76**	0.83**
E_2	4	35.7	0.022	252.8	0.065	0.041	0.13	0.015	0.007

Table 1: Continue

SOV	df	Protein yield (kg ha^{-1})	Oil (%)	Oil yield (kg ha^{-1})	Linolenic acid (%)	Linoleic acid (%)	Oleic acid (%)	Stearic acid (%)	Palmitic acid (%)
I×T	6	812.1**	1.6**	1345.6^{NS}	0.47**	0.25**	0.766**	0.03^{NS}	0.02^{NS}
E_3	12	149	0.045	500	0.047	0.018	0.081	0.027	0.016
C	1	143831**	458.9**	11453**	69.5**	83.1**	15.32**	9.14**	0.82**
I×C	3	1655.8**	0.22^{NS}	2362.7*	0.018^{NS}	0.023^{NS}	0.007^{NS}	0.027^{NS}	0.011^{NS}
T×C	2	1234.5*	0.34*	956.3^{NS}	0.169^{NS}	0.046^{NS}	0.638*	0.084^{NS}	0.097**
I×T×C	6	155.8^{NS}	0.097^{NS}	382.4^{NS}	0.049^{NS}	0.0086^{NS}	0.12^{NS}	0.01^{NS}	0.11^{NS}
E_4	24	237.5	0.087	777	0.064	0.029	0.128	0.273	0.008

*p = 0.05; **p = 0.01; NS: Non Significant; df: Degrees of freedom; I: Limited irrigation stress treatments; T: Sowing date treatments; C: Variety treatments

Table 2: Duncan's mean comparison test results for the effect of limited irrigation stress, sowing dates and variety (±SE) on flax seed

Treatments	Plant height (cm)	Primary branch number	Capsule number per plant	Seed number per capsule	Thousand seed weight (g)	Seed yield (kg ha^{-1})
Irrigation levels (I)						
I_0	58.2 ± 0.94^a	4.31 ± 0.13^a	60 ± 2.63^a	5.62 ± 0.09^a	4.49 ± 0.1^b	1535 ± 67.8^a
I_1	53.6 ± 0.7^c	4.1 ± 0.12^a	52.3 ± 3.05^b	5.57 ± 0.094^a	4.11 ± 0.08^c	1242 ± 76.9^b
I_2	55.7 ± 0.78^b	4.29 ± 0.1^a	31.4 ± 2.28^d	5.1 ± 0.1^c	4.61 ± 0.15^a	784 ± 77.8^d
I_3	56.7 ± 0.1^b	4.25 ± 0.14^a	44.6 ± 2.98^c	5.28 ± 0.13^b	3.39 ± 0.08^d	870 ± 79.6^c
Sowing date levels (T)						
T_1	57.9 ± 0.93^a	4.37 ± 0.11^a	55.3 ± 2.85^a	5.68 ± 0.06^a	4.46 ± 0.14^a	1392 ± 62^a
T_2	56 ± 0.79^b	4.33 ± 0.12^a	50.6 ± 2.67^b	5.46 ± 0.09^b	4.25 ± 0.12^b	1214 ± 69^b
T_3	54.3 ± 0.48^c	4 ± 0.08^b	35.4 ± 2.6^c	5.05 ± 0.1^c	3.75 ± 0.1^c	717 ± 71^c
Variety levels (C)						
C_1	58.7 ± 0.57^a	3.9 ± 0.07^b	41.1 ± 2.2^b	5.1 ± 0.06^b	4.41 ± 0.11^a	1006 ± 69.7^a
C_2	53.4 ± 0.37^b	4.6 ± 0.06^a	53.1 ± 2.6^a	5.7 ± 0.06^a	3.89 ± 0.08^b	1209 ± 72.2^b

Treatments	Biologic yield (kg ha^{-1})	Harvest index (%)	Protein (%)	Protein yield (kg ha^{-1})	Oil (%)	Oil yield (kg ha^{-1})
Irrigation levels (I)						
I_0	5624 ± 104^a	27.2 ± 0.1^a	21.29 ± 0.53^c	326 ± 16.1^a	40.26 ± 0.62^a	617 ± 27.8^a
I_1	4988 ± 131^b	24.7 ± 1.04^b	22.06 ± 0.64^b	272 ± 17.3^b	39.9 ± 0.66^b	495 ± 31^b
I_2	4374 ± 115^d	17.5 ± 1.43^d	22.05 ± 0.73^b	168 ± 15.7^d	40 ± 0.69^b	316 ± 32.3^c
I_3	4524 ± 113^c	18.8 ± 1.5^c	23.03 ± 0.68^a	197 ± 17.3^c	38.8 ± 0.72^c	338 ± 31^c
Sowing date levels (T)						
T_1	5315 ± 106^a	26.02 ± 0.9^a	20.5 ± 0.45^c	287 ± 15.7^a	40.8 ± 0.53^a	565 ± 24.2^a
T_2	5022 ± 111^b	$23.\ 9\pm0.1^b$	21.4 ± 0.42^b	262 ± 16.5^b	40.1 ± 0.52^b	484 ± 26.7^b
T_3	4296 ± 115^c	16.28 ± 1.3^c	24.4 ± 0.48^a	173 ± 16.7^c	38.3 ± 0.59^c	275 ± 27.8^c
Variety levels (C)						
C_1	5042 ± 113^a	19.3 ± 1^b	20.1 ± 0.32^b	196 ± 12.1^b	42.25 ± 0.19^a	428 ± 30.6^b
C_2	4714 ± 111^b	24.8 ± 1.03^a	24.12 ± 0.31^a	285 ± 15.2^a	37.2 ± 0.23^b	454 ± 28.5^a

Treatments	Linolenic acid (%)	Linoleic acid (%)	Oleic acid (%)	Stearic acid (%)	Palmitic acid (%)
Irrigation levels (I)					
I_0	47.39 ± 0.32^a	17.93 ± 0.28^a	23.11 ± 0.29^b	5.15 ± 0.1^b	6.25 ± 0.05^b
I_1	47.06 ± 0.37^b	17.89 ± 0.29^a	23.35 ± 0.33^b	5.14 ± 0.09^b	6.34 ± 0.056^b
I_2	47.04 ± 0.4^b	17.82 ± 0.33^a	23.43 ± 0.4^b	5.13 ± 0.11^b	6.34 ± 0.057^b
I_3	46.05 ± 0.34^c	17.28 ± 0.3^b	24.6 ± 0.37^a	5.43 ± 0.12^a	6.45 ± 0.04^a
Sowing date levels (T)					
T_1	48.12 ± 0.24^a	18.28 ± 0.22^a	22.18 ± 0.18^c	5 ± 0.09^b	6.21 ± 0.04^b
T_2	47.06 ± 0.23^b	17.96 ± 0.23^b	23.35 ± 0.16^b	5.1 ± 0.09^b	6.27 ± 0.03^b
T_3	45.5 ± 0.23^c	16.94 ± 0.25^c	25.35 ± 0.2^a	5.5 ± 0.08^a	6.56 ± 0.02^a
Variety levels (C)					
C_1	47.9 ± 0.22^a	16.65 ± 0.12^b	24.09 ± 0.23^a	4.86 ± 0.05^b	6.23 ± 0.04^b
C_2	45.9 ± 0.2^b	18.81 ± 0.1^a	23.17 ± 0.27^b	5.57 ± 0.05^a	6.45 ± 0.02^a

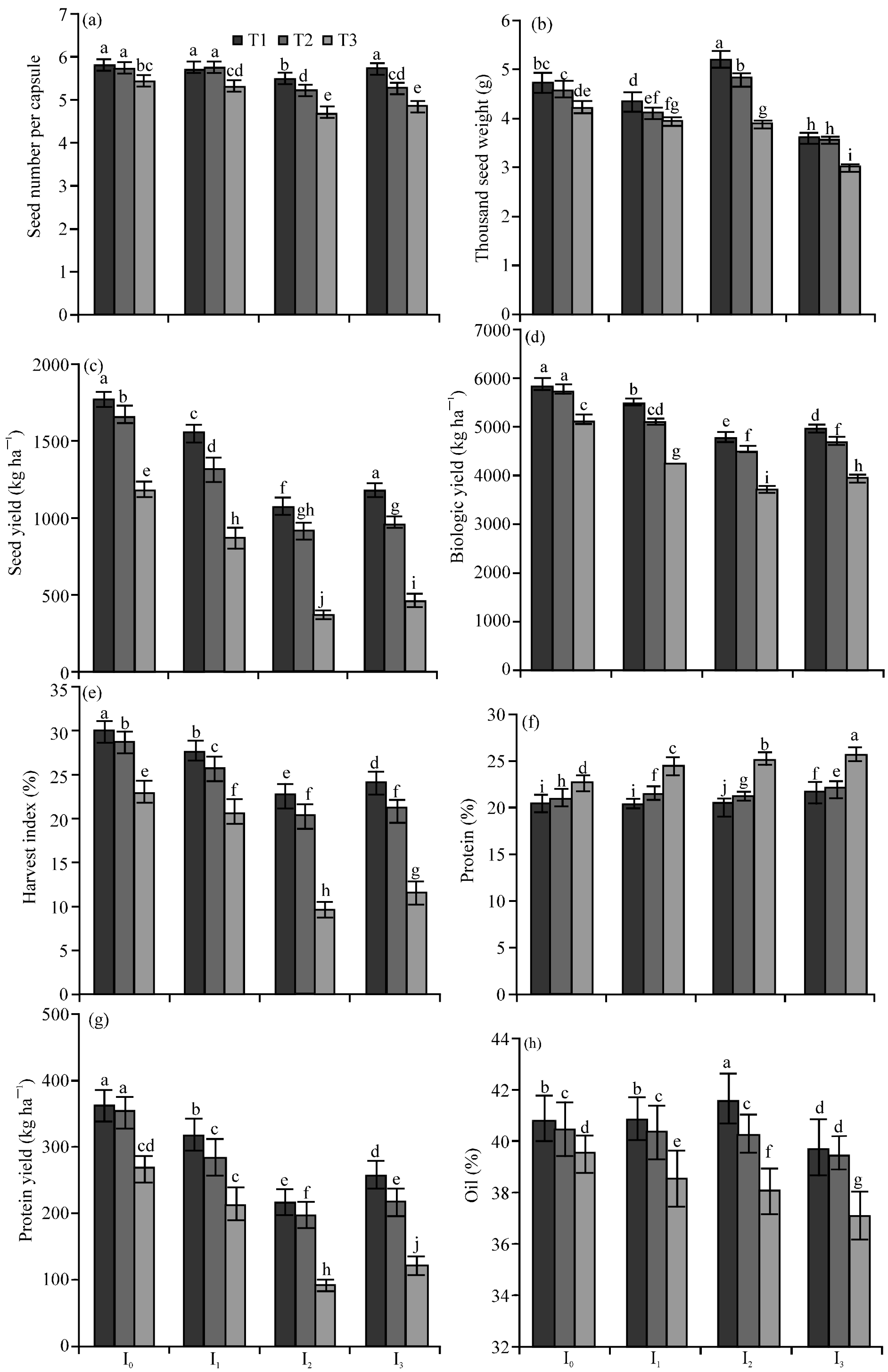
Mean of each group in columns of each treatment with similar letters are not significantly different (Duncan 5%). I_0: Normal irrigation at all growth stages; I_1: Limited irrigation stress at stem elongation stage; I_2: Limited irrigation stress at flowering stage; I_3: Limited irrigation stress at grain filling stage; T_1:20 April; T_2: 10 May; T_3: 30 May; C_1: Lirina C_2: Serenade

branches per plant, capsules number per plant, seed number per capsule, harvest index , oil yield, protein yield and percentage, linoleic, stearic and palmitic acids percentage compared to lirina variety but maximum oil percentage, linolenic and oleic acids percentage obtained from lirina (Table 2).

Interaction effect of sowing date and limited irrigation stress: The interaction effect of sowing dates and irrigation levels was significant for seed number per capsule, seed yield, biological yield, harvest index, protein percentage and yield, oil percentage, linolenic, linoleic and oleic acids percentage (Table 1).

The highest value of seed number per capsule, seed yield, biological yield, harvest index, protein yield, oil percentage, linolenic and linoleic acids percentage was acquired for April 20th sowing dates by control irrigation treatment while more protein and oleic acids percentages obtained in limited irrigation stress during grain filling on May 30th sowing date (Fig. 2).

Interaction effect of variety and limited irrigation stress: Variety x irrigation interaction effect was significant for thousand seed weight, biological yield, oil and protein yields (Table 1). The best oil and protein yield obtained from serenade variety under normal irrigation at all growth stages against the lowest value acquired under limited irrigation stress at



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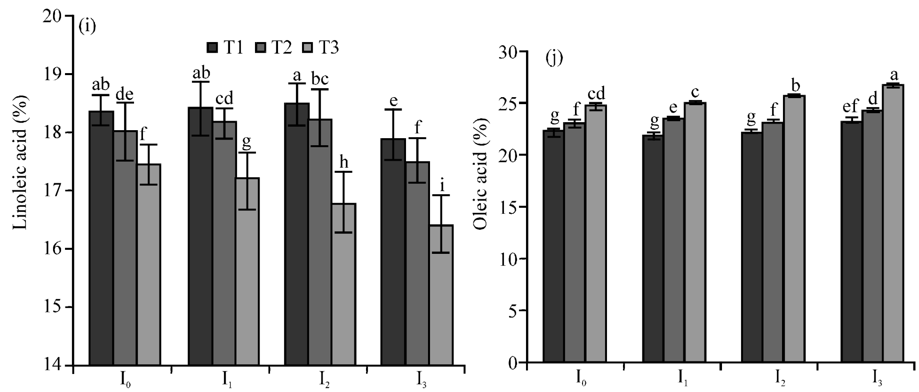

Fig. 2: Duncan's mean comparison test for the interaction effects of sowing dates and limited irrigation stress (±SE) on some of flax seed traits. Mean of each treatment with similar letters are not significantly different (Duncan 5%). I_0: Normal irrigation at all growth stages; I_1: Limited irrigation stress at stem elongation stage; I_2: Limited irrigation stress at flowering stage; I_3: Limited irrigation stress at grain filling stage; T_1: 20 April; T_2: 10 May; T_3: 30 May

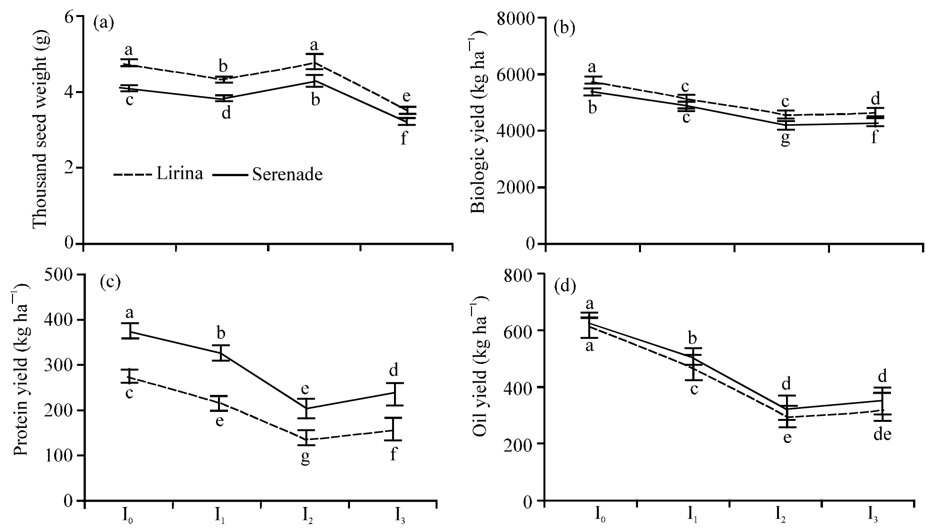

Fig. 3: Duncan's mean comparison test for the interaction effects variety and limited irrigation stress (±SE) on some of flax seed traits. Mean of each treatment with similar letters are not significantly different (Duncan 5%). I_0: Normal irrigation at all growth stages; I_1: Limited irrigation stress at stem elongation stage; I_2: Limited irrigation stress at flowering stage; I_3: Limited irrigation stress at grain filling stage; C_1: Lirina; C_2: Serenade

flowering and grain filling stages of flax seed (Fig. 3). The higher thousand seed weight and biological yield recorded for lirina variety by normal irrigation at all growth stages of flax seed.

Interaction effect of variety and sowing date: The interactive effect of variety and irrigation treatments on plant height, thousand seed weight, protein yield, oil percentage, oleic and palmitic acids percentage were significant (Table 1).

Lirina variety in the first sowing produced the higher values for plant height, thousand seed weight and oil percentage while the minimum of these traits were observed from serenade variety in the last sowing date (Fig. 4). The highest protein yield obtained from serenade in the first sowing date whereas the minimum obtained by lirina in the last sowing date. Lirina in the last sowing produced the most oleic acid percentage while the highest palmitic acid percentage observed by serenade in the first sowing date.

Correlation analysis between flax seed traits: The correlation coefficient (r) of seed yield with yield components were highly significant and positive.

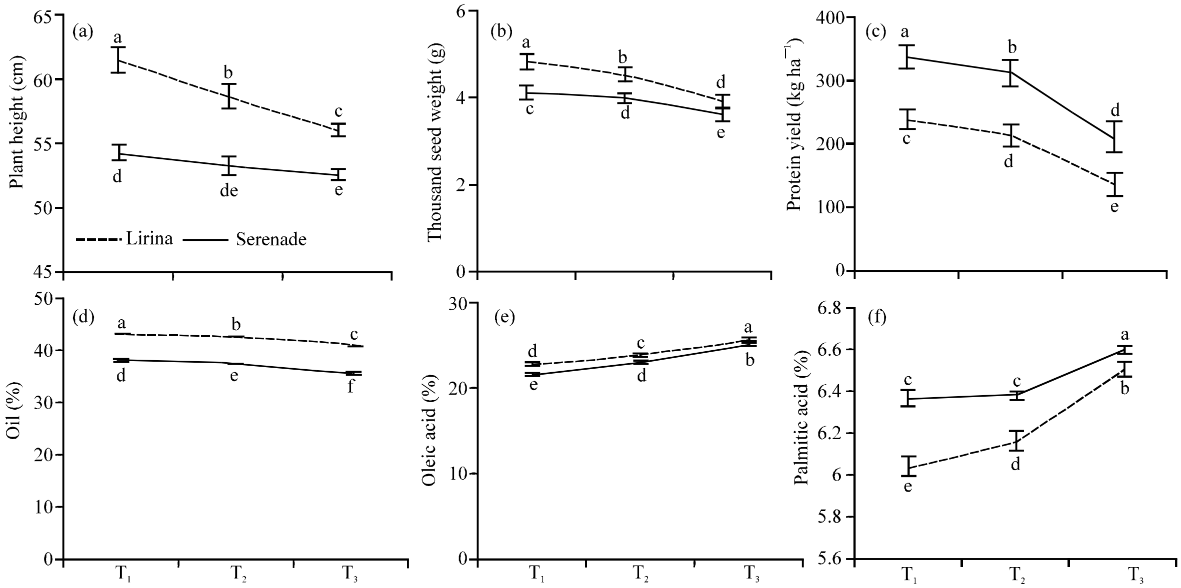

Fig. 4: Duncan's mean comparison test for the interaction effects of variety and sowing date (±SE) on some of flax seed traits. Mean of each treatment with similar letters are not significantly different (Duncan 5%). T_1: 20 April; T_2: 10 May; T_3: 30 May; C_1: Lirina; C_2: Serenade

Table 3: Correlation coefficients for the effect of limited irrigation stress, sowing dates and variety on two spring varieties of flax seed (r = 3)

Traits	Plant height	Primary branch	Capsule per plant	Seed per capsule	Thousand seed weight	Seed yield	Biologic yield	Harvest index
Plant height	1.00							
Primary branch	-0.47*	1.00						
Capsule per plant	-0.009	0.55**	1.00					
Seed per capsule	-0.22	0.71**	0.89**	1.00				
Thousand seed weight	0.52**	-0.17	0.05	0.04	1.00			
Seed yield	0.17	0.45*	0.95**	0.84**	0.37	1.00		
Biologic yield	0.56**	0.05	0.74**	0.5*	0.55**	0.87**	1.00	
Harvest index	-0.02	0.58**	0.94**	0.93**	0.27	0.96**	0.73**	1.00

Traits	Protein (%)	Oil (%)	Protein yield	Oil yield	Linolenic acid	Linoleic acid	Oleic acid	Stearic acid	Palmitic acid
Protein (%)	1.00								
Oil (%)	-0.95	1.00							
yield protein	-0.08	-0.16	1.00						
yield oil	-0.5**	0.28	0.88**	1.00					
Linolenic	-0.97**	0.89**	0.18	0.59**	1.00				
Linoleic	0.28	-0.54**	0.74**	0.47*	-0.15	1.00			
Oleic	0.39	-0.14	-0.75**	-0.8**	-0.53**	-0.73**	1.00		
Stearic	0.95	-0.96**	0.07	-0.38	-0.93**	0.39	0.27	1.00	
Palmitic	0.88	-0.77**	-0.27	-0.65**	-0.91**	0.03	0.54**	0.87**	1.00*

$p \le 0.05$; $^{**}p \le 0.01$

Highly significant and positive correlation was noted in seed yield with number of capsules plant, seed number per capsule, biological yield and harvest index (Table 3). Correlation analysis of relations among fatty acids, oil and protein percentage of linseed oil is shown in Table 4.

The data indicated that oleic acid content had a significantly negative correlation with linoleic acid whereas stearic acid had a significantly positive correlation with palmitic acid against a negative correlation with linolenic acid. Oil percentage had a positive correlation with linolenic acid and significantly negative correlation with protein percentage. Oleic acid had a significantly positive correlation with palmitic and stearic acids but negative correlation with protein and oil yields.

Regression analysis between Growth Degree Day (GDD) and the flax seed traits: The relationship between Growth Degree Day (GDD) (x) and the flax seed traits (Y) was significant for primary branch number per

Table 4: Flax seed growing period (Duration) under different treatments of sowing dates and limited irrigation stress in 2008

		T_1				T_2				T_3			
Seeds	Periods	I_0	I_1	I_2	I_3	I_0	I_1	I_2	I_3	I_0	I_1	I_2	I_3
Lirina	Duration (Day)	94	89	79	82	87	82	71	76	73	65	53	58
	GDD (°C day)	1702	1590	1382	1442	1686	1581	1323	1440	1500	1329	1053	1166
Serenade	Duration (Day)	102	98	89	91	96	91	79	85	79	73	63	67
	GDD (°C day)	1890	1791	1590	1631	1882	1581	1507	1646	1627	1500	1286	1329

Table 5: Regression relationship between growth degree day and some quantitative traits of flax seed during growing season (pooled values for both varieties)

Traits	Primary branch number	Capsule number per plant	Seed number per capsule	Seed yield	Biologic yield	Oil yield	Protein yield
a	2.37**	-60.2**	2.33**	-1933**	1176^{ns}	-729**	-421**
b	0.001*	0.07**	0.002**	1.99**	2.43**	0.77**	0.44**
R^2	0.34	0.91	0.77	0.90	0.53	0.80	0.92

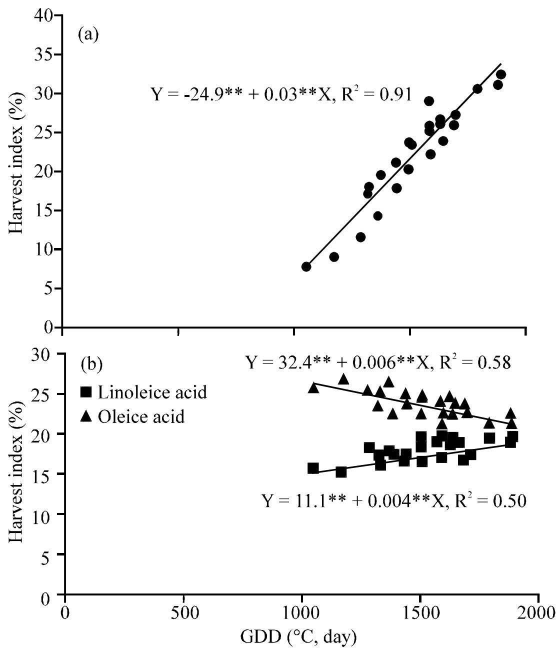

Fig. 5: Regression relationship between growth day degree with harvest index, linoleice and oleice acids of flax seed during growing season (pooled values for both varieties)

plant, capsule number per plant, seed number per capsule, seed yield, biological yield, harvest index, oil and protein yield, linoleice and oleice acids percentage in pooled values for lirina and serenade varieties (Table 5, Fig. 5). A regression analysis revealed that flax seed traits were increasing with the increase of GDD. The highest value of GDD was recorded in the first sowing date compared to second and third sowing date of flax seed in the both varieties.

The results revealed that duration (days) for the maturity of flax seed by normal irrigation were highest and reduced with limited irrigation stress at stem elongation, flowering and grain filling stages (Table 4).

DISCUSSION

Plant height: In this study, plant height significantly differed under different irrigation and sowing date treatments. This result could be explained by differences in the weather conditions and supplementary irrigation from stem elongation stage to late grain distribution (Fig. 1 and 4). The result in agree with findings of Sankari (2000) who found that humidity and temperature differences caused a wide variation between flax seed cultivars for mean plant height. Ahlawat and Gangaiah (2009) noted that limited irrigation stress during the growth stages reduced the plant height. With delayed sowing, high temperature hastens the development, shortens the duration and reduces the growth per day from sowing to harvest thus reduces plant height (Table 4 and 2). In other reports, water and temperature stress have been shown to reduce plant height in linseed (Tiver and Williams, 1943) by increasing respiratory losses.

Primary branch number: Delaying in sowing and water stress, led to decrease number of primary branches per plant (Table 2). Number of primary branches per plant is genetically controlled characteristic (Vender *et al*., 1995), however planting geometry may have reasonable effect on the development of branches (Singh, 2001). Rahimi reported that high temperature reduced the number of tillers because the period between a thesis and senescence was curtailed by relatively higher temperature.

Capsule number per plant: The sowing dates identified optimum capsule number per plant acquired by full irrigation on April sowing date (Table 2). The lower capsule number observed with later flowering may be due to a temperature effect on pollination, ovary survival in delayed sowing dates. These results affirmed by Ford (1964). Linseed is susceptible to water stress at the seedling stage at flowering and during early seed development. It appears that water stress hampered flowering and reduced the probability of developing flower to pod and its occurrence during flowering and pod formation resulted in pod abortion (Kimber and McGregor, 1995).

Seed number per capsule: At this study was produced maximum seed number per capsule with full irrigation when sown on April 20th and on May 10th sowing (Table 2, Fig. 2). These results affirmed by Prasad and Sharma (1975). Flowering was the most sensitive stage to water stress, probably due to susceptibility of pollen development, anthesis and fertilization led to lower seed yield (Faraji *et al*., 2009).

Thousand seed weight: Mean thousand seed weight depended on sowing date and cultivar as both factors interacted significantly with irrigation levels (Fig. 2-4). Thousand seed weight closely related to green photosynthetic area which is responsible for carbohydrate formation, grain filling and final grain yield. Results show a higher seed yield under full irrigation (Table 2, Fig. 2 and 3). This increase in yield could be ascribed to favorable moisture conditions resulting from irrigations at critical phenological stages of initiation of flowering and seed filling. Such finding consisted in with results of Ahlawat and Gangaiah (2009). For spring-delay sown seed flax seed, there is less possibility of compensation due to the shortened vegetative phase however the decrease in mean seed weight in the present study slightly was compensated for by an increase in the number of capsules per plant.

Seed yield: Seed yield was maximum in first sowing date and decreased with delayed sowing dates (Table 2, Fig. 2 and 3) which may be due to a high temperature effect on pollination, ovary survival or seed development. Sowing date and irrigation studies with flax seed identified maximum seed yield from an early sowing with supplementary irrigation from flowering to late grain fill (Lisson and Mendham, 2001). This increase in yield could be ascribed to favorable moisture conditions resulting from irrigations at critical phenological stages of initiation of flowering and seed filling. A similar increase in yield with irrigation was also reported by Husain *et al.* (2000).

Biological yield: The results showed that the optimum sowing date was from the second half of April to May 10th sowing date (Table 2, Fig. 2). This result in agree with results of Garsid (2004). In comparison, biological yield under limited irrigation stress at flowering and seed filling stages was significantly lower than other irrigation treatments (Table 2, Fig. 2, 3). These results affirmed by Evans (1993). It appears that water stress hampered flowering and reduced the probability of developing flower to capsule and its occurrence during flowering and capsule formation resulted in capsule abortion and therefore produce more yield and biological yield.

Harvest index: Harvest index was maximum in first sowing date and decreased with delayed sowing dates (Table 2) because the grain formation stages coincided with favorable lower temperature while by late-sowing date flax seed suffered severely from heat stress during grain formation led to abnormal development and poor production. These results coincide with finding of Dybing and Zimmerman (1965) who found the minimum harvest index at higher temperature. Results show a higher harvest index by full irrigation (Table 2, Fig. 2). Results of this study agree with findings of Pandey *et al.* (2001) who stated the reason of harvest index reduction at severe drought stress is the higher sensitivity of reproduction growth to undesirable conditions in compared to generative growth.

Protein percentage and yield: The changes of protein percentage in the present study were probably dependent on the interaction of these characters with environmental factors such as water supply and high temperature during seed filling stages flax seed (Fig. 2-4). These results affirmed by Dwivedi *et al.* (1990). Growing conditions and crop management practices also influence protein percentage (Dwivedi *et al*., 1993). The lower protein yield obtained in May 9th and especially May 30th sowing dates (Table 2, Fig. 4) could be due to higher temperatures which occurred during the seed filling period that resulted in reduction of seed yield. Sowing date is a major determinant of seed quality and quantity (Castillo *et al*., 1994). Water deficit during flowering and seed filling stages reduced protein yield (Fig. 2 and 3). Singh (1991) stated that this behavior might be ascribable to yield potential and the interaction of these characters with environmental factors such as water supply.

Oil percentage and yield: Climatic conditions could be considered as a determining factor for oil percentage and yield. In delay sowing, the reduction of oil percentage and yield (Table 2, Fig. 4) was due to unfavorable weather conditions (Fig. 1). This may be due to that increased temperature and water stress during seed filling was a major cause of reduced oil percentage and yield. Similar results have been reported by Garsid (2004) and Silva (2005). Experiments carried out in controlled conditions showed that high temperatures during the ripening phase reduce oil yield and quality of flax seed (Dybing and Zimmerman, 1965). In the present study, water stress caused a reduction in the oil percentage of both cultivars (Table 2, Fig. 2) which is in agreement with the results of Sosulski and Gore (1964) for linseed. The best oil yield was obtained from full irrigation treatment followed by limited irrigation stress at stem elongation stage (Table 2, Fig. 3, 4). This increase in yield could be ascribed to favorable moisture conditions resulting from irrigations at critical phonological stages of initiation of flowering and seed filling. It appears that water stress hampered flowering and reduced the probability of developing flower to capsule and its occurrence during flowering and capsule formation resulted in capsule abortion (Kimber and McGregor, 1995).

Fatty acids: The changes in fatty acids composition in the present study were probably due to the effect of water deficits and high temperatures during the seed-filling period with late sowing and drought treatments. Temperature is generally considered to be the most critical climatic factor affecting quality (Mcgnocon and Censon, 1961). Cool climatic conditions delay the maturity of the flax seed and thus provide a longer period for oil and fatty acid synthesis (Palevitch, 1987). The results of present study showed a decrease in linolenic acid percentage during the last sowing date (Table 2, Fig. 2). These results coincide with finding of Green (1986) and Golombek *et al.* (1995) who reported high temperature during seed development decreases linoleic and linolenic acid in several oilseed crops. Canvin (1965) reported that the fatty acid compositions of the seed oils of rape, sunflower and flax depended on temperature when the plants were grown under laboratory conditions while safflower and castor oils were not affected. The percentage of oleic, stearic and palmitic acids varied inversely with the linolenic acid percentage. Stearic and oleic acids increased while linoleic and linolenic acids decreased by low irrigation stress (Table 2, Fig. 3). This results in consisted with finding of Green (1986) and Wolf *et al.* (1982). The oleic/linoleic ratio increased due to water stress at different growth stages and a maximum increase was observed at the reproductive stage (Table 2, Fig. 2 and 4). Water stress during the grain filling period caused a significant increase in the oleic/linoleic ratio in high oleic genotypes of sunflowers (Baldini *et al.*, 2000). This effect of high temperature and water stresses on oleic and linoleic acids percentage may be attributed to the activity of the enzyme $\Delta 12$ desaturase (Baldini *et al.*, 2000; Browse and Slack, 1983). In contrast, Unger (1982) found very little differences in oleic/linoleic ratios in sunflower under different water regimes. The differences in the results of the two studies may be due to the imposition of drought at different growth stages. Fatty acid composition was different in lirina and serenade cultivars (Table 2). In consisted with the results Connor and Sadras (1992) reported that fatty acid composition differs between cultivars due to changes in environmental conditions. The oleic/linoleic ratio increased due to water stress at different growth stages and a maximum increase was observed at the reproductive stage. These results are not in agreement with finding of Baldini *et al.* (2002) who that reported the saturated fatty acid contents (palmitic acid and stearic acid) in sunflower did not vary under different water regimes.

Correlation analysis between flax seed traits: The results (Table 3) show that the positive response yield of flax seed to irrigation was due to the significant positive correlation of capsule number per plant and seed number per capsule with seed yield. These findings correspond with results of Albrechtsen and Dybing (1973) who found higher capsule number per plant and seed number per capsule increase seed yield. Rad *et al.* (2005) reported that there were positive correlation between seed yield and seed weight and biological yield. This study also proved that there is a positive and closely correlation between harvest index and seed yield under conditions limited irrigation stress. These results agree with finding of Baldini and Vannozzi. Strong negative correlation was observed between oil and protein percentage in seeds, this result in agree with finding of Dwivedi *et al.* (1990). The inverse relationship between oleic and linoleic acid were reported by Praveena *et al.* (2000). Besides, linolenic acid had a significantly positive correlation with oil percentage and significantly negative correlation with protein percentage. This relationship might be due to environmental factors, especially temperature during the period of seed development and maturation. Limited irrigation stress during flowering or capsule-filling stages may favor increased protein percentage and thereby decreasing oil percentage (Nel, 2001).

Regression analysis between Growth Degree Day (GDD) and the flax seed traits: Delay in sowing and limited irrigation stress led to more rapid development of flax seed, decreased the days from emergence to flowering and to physiological maturity, duration of flowering and seed filling and decreased the opportunity of flax seed to recover (Table 4). Day length and photoperiod are also important factors responsible for the different growth behavior of grain flax seed (Fig. 1). Shortening of the growing cycle decrease the amount of radiation intercepted during the growing season and thus total dry matter at harvest (Dybing and Zimmerman, 1965). Stresses imposed at a later stage of development reduced sink size, shorten the duration of seed filling and decreased the opportunity of crop to recover. There was a positive linear relationship between GDD and all of flax seed studied traits (Table 5, Fig. 5). These results are in consistent with the findings of Bremner and Radley (1966) and Turner (2004).

CONCLUSION

The results of this study shown that water stress during linseed reproductive growth stages particularly flowering and capsule formation is a critical period that leads to decreased most of flax seed traits. The results revealed that for linseed production, sowing in early April is preferable in Iran central regions. The results of the present study may be helpful for the recommendation of optimum sowing date and limited irrigation stress for spring linseed in similar climatic conditions.

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