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Effect of sowing time on the yield and quality parameters of sunflower (*Helianthus annuus*) hybrids under semiarid irrigated conditions of northern India

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ABSTRACT

To evaluate the changes in seed yield and oil quality of sunflower (*Helianthus annuus* L.) in response to changing environmental conditions across different planting dates and genotypic variability, a field experiment was carried out during spring 2005-2008 at PAU, Ludhiana. Planting dates affected seed yields more than any of the other characteristics measured with significant yield reduction under delayed planting conditions. An increase in oleic with decrease in linoleic acid (r = –0.993*) was observed with each progressive delay in planting time. Change in the oleic/linoleic acid ratio under different planting dates suggests a possible role of environmental factors especially temperature on the seed development processes during reproductive phase further deciding the oil quality. Total heat units accumulated during the seed maturation period had positive correlation with oleic (r = 0.697*) and negative with linoleic correlation (r = –0.578*) acid. Further investigation is needed to get deeper insight into the effects on seed oil composition of the interaction between changes in temperature regime and/or planting time under field/controlled conditions for yield maximization and better quality sunflower oil.

Key words: Fatty acid concentration, Hybrids, Planting time, Seed yield, Sunflower

Sunflower (*Helianthus annuus* L.) as an oilseed crop offers tremendous adaptive plasticity to contrasting environmental conditions and cropping systems because of its short duration, higher per day productivity, photo-insensitivity, and quality edible oil. Sunflower oil is a valued healthy vegetable oil having favourable fatty acid composition signifying nutritional properties and specific uses (Warner *et al.* 2003, Burton *et al.* 2004). Sunflower oils rich in oleic acid content are considered healthy one (Jing *et al.* 1997, Hu *et al.* 2001), possessing high degree of oxidative stability. Human consumption of vegetable oils with high amounts of linoleic acid has also been demonstrated to reduce plasma cholesterol and as a consequence, the risk of cardiovascular diseases.

Numerous studies have extensively investigated the effect of planting time on seed/oil yield of standard sunflower genotypes (Asbag *et al.* 2009, Bagheripour *et al.* 2013, Lawal *et al.* 2011), however, the data on changes in seed oil quality due to these agronomic environmental manipulations are scanty, contrasting and have been poorly investigated. Therefore, with the advent of new sunflower hybrids having different growth characteristics and maturity duration, there is a need to evaluate the genetic variability of the response of potential productivity and quality characteristics when grown under different environmental conditions. The hypothesis of this study was to assess the changes in seed yield, oil productivity and FA composition of seed oil in relation to modified environmental conditions as a function of planting dates and sunflower hybrids.

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MATERIALS AND METHODS

A field study was conducted for four years (2005-2008) under irrigated conditions during spring season at Punjab Agricultural University, Ludhiana, India (30°56' N, 75°52' E, 247 m above msl). The region has a subtropical, semi-arid continental monsoon climate. Annual precipitation is about 760 mm, about 80% of which occurs from June to September. The soil of experimental site was characterized as loamy sand in texture (73% sand; 15% silt; 12% clay), non-saline (EC, 0.21 dS/m) with pH 7.9 containing 0.19% organic carbon, 112 kg/ha $KMnO_4$-N, 11.5 kg/ha Olsen's P and 161 kg/ha NH_4OAc-K in the surface soil (0-15 cm). The experiments were arranged in split-plot design replicated thrice each season with three planting dates (20 December, 20 January and 20 February) as main plots and three sunflower hybrids (PSH 569, PSFH 118 and SH 3322) as subplot treatments. The seeds of test sunflower hybrids were sown by dibbling method putting 2-3 seeds per hill in seven-row subplots measuring 5.1 m long spaced at 0.6 m

between rows and 0.3 m within rows. Later on, the plots were hand thinned to one plant per hill when the plants were at the four to six-leaf stage. The treatment plots were uniformly fertilized with 60 kg N, 30 kg P_2O_5 and 30 kg K_2O/ha through urea (46% N), di-ammonium phosphate (18% N, 46% P_2O_5) and muriate of potash (60% K_2O), respectively. Half dose of N and full dose of P and K were drilled at the time of sowing while remaining half dose of N was top dressed at 30-35 days after planting of sunflower.

Agro-meteorological data was recorded daily from an automatic weather station located half-a-kilometer from the experimental field. Plants were monitored at every 2-3 days interval to determine the phenological growth stages for each planting date. Plots were considered to be in a particular growth stage, when 50% of the plants had reached a particular developmental stage. Crop cycle was calculated as the time of period from seed emergence to physiological maturity. The sunflower plants were hand harvested at the stage of physiological maturity when the back of the head turned from green to yellow and the bracts turned brown. At each harvest date, head samples for yield were harvested from the central five rows by discarding two external rows of each plot (borders), dried and threshed manually to determine the seed yield which was then expressed in kg/ha.

Oil content in the whole seed was determined by employing non-destructive method of oil estimation using nuclear magnetic resonance spectroscope (Newport Analyzer Model MK 111A) (Alexander *et al.* 1967). Chromatographic (Gas Liquid Chromatography) analysis was done to estimate the fatty acid composition of seed oil. A simple and convenient method for the quantitative preparation of volatile methyl esters of fatty acids isolated by CS2 extraction and a TLC technique was followed (Luddy *et al.* 1968). The esters thus prepared were analysed using solid state AIMIL gas chromatograph (M/s NUCON Engineers) equipped with flame ionization detector with a 10'×1/8" stainless steel column packed with 20% DEGS (diethyl glycol succinate) on 60-80 mesh chromosobe-W. The conditions for the separation were: over temperature 190°C, injector temperature 220°C, FID temperature 220°C, carrier (nitrogen) flow rate 30 ml/min, flame-1, attenuation 256 and recorded chart speed 5 mm/min. 1-2 µl of the sample was injected into GLC column by means of a 10 µl Hamilton" syringe. The peaks were identified by their retention time and also by using standard fatty acyl esters as internal standard in the test sample. The peak area was calculated by measuring the height of the peak and multiplying it by its width at the half height. The concentration of individual FA in the sunflower seed samples is given as percent by weight of the total FA in the oil from each treatment.

Individual parameters were subjected to one-way analysis of variance (ANOVA) technique according to the split-plot design using statistical programme OPSTAT (www.hau.ernet.in/opstat.html). The growing environments were also considered as a random variable. Treatment means were separated with Duncan's multiple range test (DMRT) at 5% level of significance.

Table 1 Seasonal changes in crop phenology, yield components and fatty acid composition of sunflower during the experimentation period

Trait	2005	2006	2007	2008
Seed emergence (days)	13.4^{b}	12.0^{a}	11.8^{a}	17.0^{c}
Star bud stage (days)	61.1^{b}	52.5^{a}	62.7^{c}	64.9^{d}
Completion of flowering (days)	81.6^{b}	80.4^{a}	83.6^{c}	85.0^{d}
Seed maturation period (days)	28.5^{c}	25.3^{b}	23.7^{a}	31.1^{d}
Maturity duration (days)	110.1^{c}	105.8^{a}	107.3^{b}	116.1^{d}
Seed yield (kg/ha)	2341^{a}	1833^{c}	1894^{bc}	2028^{b}
Oil content (%)	38.9^{b}	38.2^{bc}	40.0^{a}	37.8^{c}
Oil yield (kg/ha)	917^{a}	711^{c}	814^{b}	721^{c}
Palmitic acid (%)	6.46	6.81	6.48	6.65
Stearic acid (%)	3.44	3.65	3.40	3.53
Oleic acid (%)	50.29^{b}	47.39^{c}	51.21^{a}	49.85^{b}
Linoleic acid (%)	39.81^{b}	42.15^{a}	38.91^{c}	39.98^{b}

Data followed by different lower-case letters within rows differ significantly

RESULTS AND DISCUSSION

Growing environments

Seasonal variability in terms of capture and utilization of environmental driven resources during the crop growing period had significant effect on the onset and duration of different phenological events. The overall crop diminution in maturity duration was more prominent in 2006 and 2007 (Table 1). The daily mean aerial temperature coinciding with seed emergence period was comparatively lower in 2005 and 2008 (data not shown), taking significantly more number of calendar days to complete the phenophasic duration (Table 1). Contrarily, reverse was the case during the seed maturation period belonging to crop seasons of 2006 and 2007 where the reproductive period was curtailed by 4-6 days in response to increase in mean temperature from 0.1–1.6°C (Table 2).

Table 2 Mean daily aerial temperature (°C) during the seed development period

Planting time	Hybrids	2005	2006	2007	2008
20 December	PSH 569	25.8	24.0	27.1	26.0
	PSFH 118	25.4	23.5	26.0	25.1
	SH 3322	27.2	25.3	28.1	27.4
	Mean	26.1	24.3	27.1	26.2
20 January	PSH 569	25.8	29.0	29.7	27.5
	PSFH 118	26.0	29.0	28.8	26.9
	SH 3322	26.9	29.6	30.4	28.7
	Mean	26.2	29.2	29.6	27.7
20 February	PSH 569	29.1	31.9	32.1	29.7
	PSFH 118	28.4	32.0	31.4	30.1
	SH 3322	30.3	32.3	31.6	29.6
	Mean	29.3	32.1	31.7	29.8

Yield depends on the ability of the crop to capture resources and, thus, is the interplay of many components contributing towards final harvest. Significant variation in seed yield of sunflower was noticed in evaluated seasons following the trend of 2005 > 2008 > 2007 > 2006 (Table 1). Mean seed yield of sunflower varied significantly over the years ranging from 1 833 kg/ha (2006) to 2 341 kg/ha (2005) (Table 1). Changes in environmental conditions as a result of extended reproductive period coupled with prolonged crop maturity (Table 1) might have compensated towards better source: sink ratio towards better expression of physio-morphic traits and yield components finally culminating in higher seed and oil yields in 2005 and 2008 compared to other evaluated environments. Similar findings demonstrating variable crop response towards seasonal variability have also been reported by Asbag *et al.* (2009) and Kaleem *et al.* (2010). Significantly higher oil yield of 917 kg/ha was recorded in 2005 followed by 814 kg/ha in 2007 (Table 1), both being significantly superior to the other growing seasons (2006 and 2008).

The seed oil content and fatty acid composition of sunflower oil was substantially altered by different growing environments. No definite trend was observed for saturated fatty acids (palmitic and stearic); however, significant variation in the values of unsaturated fatty acids (oleic and linoleic) was noticed (Table 1). The oleic/linoleic acid ratio was the maximum (1.32) in 2007 while minimum (1.12) in 2006.

Planting time

There was a consistent and significant reduction in number of calendar days to reach a particular phenophase with each successive delay in planting time (Table 3). The seed emergence period was shortened by 6-10 days, star bud stage by 16-26 days, flowering period by 17-29 days while seed maturation period by 1-4 days. The crop acquired almost 128 days to mature when planted on 20 December and the maturity duration decreased with delayed planting, taking only 93 days to mature when planted on 20 February. The sunflower crop acquired comparatively longer emergence period (additional 6-10 days) with earlier planting due to prevalence of comparatively lower temperature particularly during initial crop establishment stage. Concerning the effect of planting date, the slower seed germination and sub-optimal growth expressions at earlier planting prolonged the vegetative period (3–4 weeks) rather than seed filling/reproductive phase (1-4 days) when compared to later planting. In our experimental, it is interesting to note that the crop compensated for the maximum reduction in number of days for seed maturation period with each progressive delay in planting conditions in contrast to total crop duration.

Planting dates affected seed yields more than any of the other characteristics measured. The highest seed yield of 2 249 kg/ha was recorded when the crop was planted on 20 January though it was statistically at par with 20 December. Further delay in planting time drastically reduced the crop yields and yield decline to the tune of 33-37% in seed yield and 39-42% in oil yield was observed in comparison to earlier planting dates. The present study clearly indicated that very early planting (20 December) did not generate any advantage not only for the earliness but also for the improvement in yield components and yield. The decrease in seed yield with later plantings could be attributable to higher air temperatures at the time of seed development period (Table 2), and thus pollination and fertilization events were generally obstructed resulting in poor seed setting, hastened maturity, lesser accumulation/translocation of metabolites ascertaining lower crop yields and poor quality oil compared to early plantings.

Chromatographic analysis of seed oil showed that fatty acid composition of seed oil varied considerably across planting dates (Fig 1a). The palmitic acid in seed oil concentration was maximum (7.08%) with earlier planting (20 December) which later on decreased with delayed plantings. Non-conspicuous differences were observed for stearic acid in response to planting time. The oleic acid increased significantly while linoleic acid proportion decreased consistently with each progressive delay in planting date. The experimental results showed an improvement of 5.74 and 2.49% in oleic acid concentration with each progressive delay in planting date while the

Table 3 Mean values for number of days to reach phenophasic development stage, seed yield and oil content of three sunflower hybrids planted during spring 2005-2008

Trait	Planting dates			Hybrids		
	20 Dec	20 Jan	20 Feb	PSH 569	PSFH 118	SH 3322
Seed emergence (days)	18.9 ^{c}	12.8 ^{b}	8.9 ^{a}	14.0 ^{b}	14.3 ^{b}	12.3 ^{a}
Star bud stage (days)	74.3 ^{c}	58.3 ^{b}	48.4 ^{a}	60.0 ^{b}	58.6 ^{a}	62.7 ^{c}
Completion of flowering (days)	98.4 ^{c}	80.7 ^{b}	68.8 ^{a}	82.1 ^{b}	79.7 ^{a}	86.1 ^{c}
Seed maturation period (days)	29.2 ^{c}	27.8 ^{b}	24.5 ^{a}	26.4 ^{b}	25.4 ^{c}	29.7 ^{a}
Maturity duration (days)	127.7 ^{c}	108.5 ^{b}	93.3 ^{a}	108.5 ^{b}	105.1 ^{a}	115.8 ^{c}
Seed yield (kg/ha)	2185 ^{a}	2249 ^{a}	1638 ^{b}	2122 ^{a}	1835 ^{b}	2116 ^{a}
Oil content (%)	39.3 ^{a}	39.2 ^{a}	37.8 ^{b}	40.2 ^{a}	35.9 ^{b}	40.0 ^{a}
Oil yield (kg/ha)	862 ^{a}	884 ^{a}	621 ^{b}	856 ^{a}	661 ^{b}	850 ^{a}

Within a row, means followed by different lower-case letters are statistically different at the 0.05 probability level according to Duncan's Multiple Range Test.

Table 4 Changes in seed yield (kg/ha) as a function of planting dates and sunflower hybrids

Planting dates	Hybrids			LSD
	PSH 569	PSFH 118	SH 3322	(P=0.05)
20 December	2 197 (895)	1 917 (685)	2 442 (995)	98 (45)
20 January	2 399 (985)	1 993 (718)	2 355 (950)	
20 February	1 769 (689)	1 594 (568)	1 550 (606)	

Figures in parentheses indicate oil yield (kg/ha).

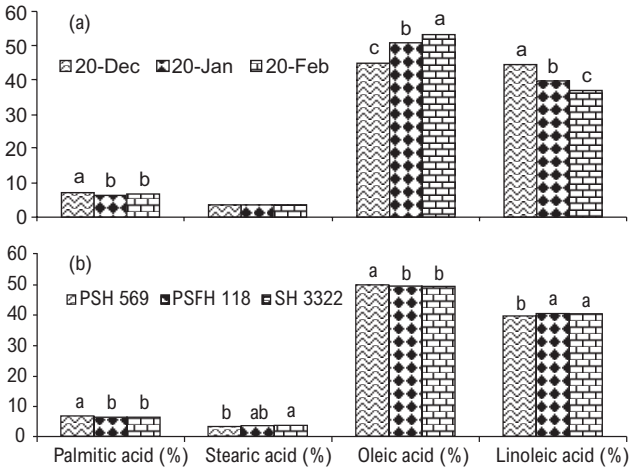

Fig 1 Effect of planting time (a) and hybrids (b) on the fatty acid composition of sunflower

corresponding values were estimated to be with reduction of 4.81 and 2.77% for linoleic acid for the same period. Different planting dates caused flowering and seed development to occur during periods of different temperatures, radiations and daylength (Sheoran *et al.* 2008). Variable environmental conditions especially temperature during seed maturation period substantially altered the concentration of both saturated and unsaturated fatty acids (Fig 3 and 4). The results showed that when the temperature increased towards the maturity of the crop, the palmitic acid decreased. Inverse relationship of heat units and palmitic acid (Fig 3) in the present study is in line with the findings of Qadir *et al.* (2006). The results indicated a strong negative correlation between oleic and linoleic acid fatty acids (Table 5). Unger (1980) and Cilardi *et al.* (1990) pointed out a decrease in oleic acid concentration and, conversely, an increase in linoleic acid in standard genotypes as seeding dates became later. Significant but opposite response of oleic and linoeic acid to heat units accumulated during the seed development period (Fig 4) is supportive to earlier findings demonstrating temperature as a major modifier altering oleic/linoleic ratio having its role in modulating the activation or synthesis of oleate desaturate enzyme (Garces and Mancha 1991, Izquierdo and Aguirrezabal 2008). Connor and Sadras (1992) also observed a possible alteration of the genetically programmed enzymatic activation having significant influence on oleic/linoleic ratio in response to different planting dates.

Hybrids

Genotypic variability for maturity duration, potential yield components and oil quality indicators was observed in sunflower hybrids under the influence of different planting dates and growing environments. Though sunflower hybrid SH 3322 was the earliest one to emerge but it took maximum number of calendar days to mature (116 days) in

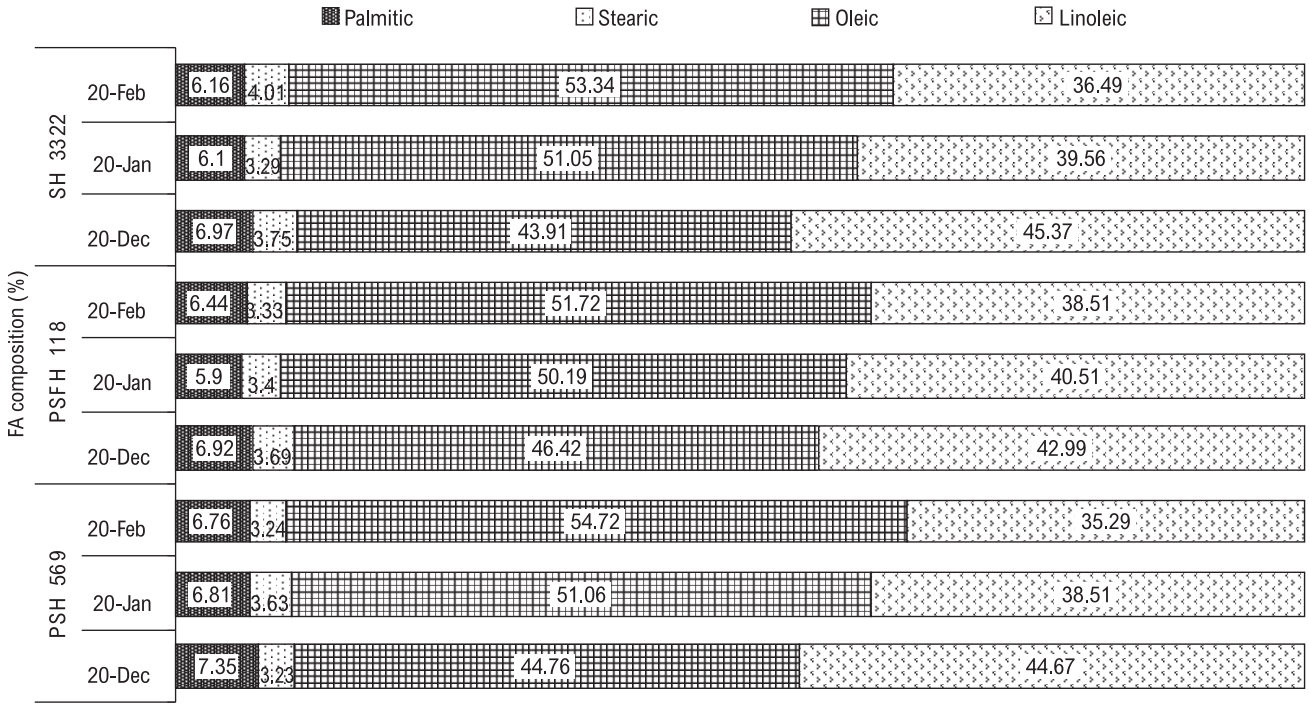

Fig 2 Change in fatty acid composition (%) of sunflower hybrids sown on different planting dates

Table 5 Inter-relationships among different variables

Trait pairs	Correlation coefficient
Seed yield vs oil content	0.689*
Seed yield vs oil yield	0.981**
Oleic acid vs linoleic acid	–0.993**
THT (seed maturation) vs oleic acid	0.697*
THT (seed maturation) vs linoleic acid	–0.578*
THT (crop cycle) vs oleic acid	0.785*
THT (crop cycle) vs linoleic acid	–0.723*

THT, Thermal time; *significant at P=0.05; **significant at P=0.01

comparison to other two hybrids (Table 3). The total crop duration was shortened by 7-10 days in both PSH 569 and PSFH 118 compared to SH 3322. Sunflower hybrid PSH 569 recorded the highest seed yield (2 122 kg/ha), oil content (40.2%) and oil yield (856 kg/ha). Non-conspicuous differences in seed and oil yield were observed for sunflower hybrids PSH 569 and SH 3322 but both were significantly superior to PSFH 118, excelling 15.3-15.6% in seed yield, 4.1-4.3% in oil concentration and 28.6-29.5% in oil yield.

Significant differences in oil fatty acid composition were also observed for test hybrids (Fig 1b). On an average, the unsaturated fatty acids constitute about 90% of the total oil concentration, rest being the saturated fatty acids. The highest palmitic (6.97%) and lowest stearic (3.37%) acid was recoded in hybrid PSH 569 (Fig 1b). Both PSFH 118 and SH 3322 were found statistically at par with each other in respect to unsaturated (oleic and linoleic) fatty acid composition, though both differed significantly from PSH 569. Changes in seed yield and fatty acid composition for sunflower hybrids having different maturity groups has also been reported in earlier studies (Balalic *et al.* 2010, Zheljazkov *et al.* 2011).

Planting time×hybrids

Interactive analysis of planting dates×sunflower hybrids elucidated consistent improvement in seed yield of sunflower up to 20 January for hybrids PSH 569 and PSFH 118 while each progressive delay in planting time put forth significant reduction in seed yield for SH 3322 (Table 4). Within same planting date, SH 3322 performed significantly better at earlier planting (20 December); however, the yield performance of PSH 569 was relatively better in comparison to rest of the hybrids when sown either on 20 January or 20 February. PSFH 118 was the least performer among test hybrids irrespective of the planting time. This could be attributed to the total crop duration attained by different maturity group hybrids where the test hybrid SH 3322 took the maximum duration (116 days) to mature as against the 105-110 days for PSFH 118 and PSH 569 leading to variable response towards physio-morphic and quality traits in relation to planting time (Table 3). Variable response of different maturity hybrids under different planting dates has also been reported by Kaleem *et al.* (2011). Significantly higher seed yield of 2 442 kg/ha was obtained when sunflower hybrid SH 3322 was planted on 20 December, though it was found statistically at par with both PSH 569 and SH 3322 when sown on 20 January. Maximum yield decline was perceived in February month planting date irrespective of the sunflower hybrids with 34.2% yield reduction in SH 3322 followed by PSH 569 (26.3%) and minimum (20.0%) in PSFH 118. Oil yield followed the trend of seed yield.

Numerically marginal though non-significant difference in the composition of palmitic acid was noticed across evaluated hybrids. However, stearic acid, mono (oleic) and poly (linoelic) unsaturated fatty acid varied widely when grown under different planting dates (Fig 2). SH 3322 had the highest values of stearic acid at first and last planting date while PSH 569 accumulated higher stearic acid when planted on 20 January. With each progressive delay in planting time, there was a consistent increase in the composition of oleic acid percentage for all test hybrids, however, reverse was the trend for linoleic acid where it progressively declined with delayed planting conditions. The mean per cent increase in the values of oleic acid concentration of seed oil was more prominent when the sunflower planting (irrespective of sunflower hybrids) was extended from 20 December to 20 January with the maximum under SH 3322 (7.14%) followed by PSH 569 (6.30%) and least increase was recorded in PSFH 118 (3.77%).

Correlation studies

Positive and highly significant correlation of seed yield with oil yield (r = 0.981*) was observed, indicating a direct dependence of oil productivity on seed yield and oil concentration (Table 5). Strong but negative correlation (r= –0.993**) between mono (oleic) and poly (linoleic) unsaturated fatty acid showed an inverse relation between these two seed oil quality parameters viewing an inter-dependence among themselves. Total heat units in terms of thermal time accumulated during seed maturation period had direct bearing on the composition of fatty acids, having being positive correlation with oleic acid (r = 0.697*) and negative correlation with linoleic acid (r = –0.578*) concentration. Similar trend was observed for heat units accumulation for total crop duration in relation to oleic and linoleic acid composition.

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