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Effects of genotypes and sowing date on seed yield, oil content, and fatty acid profile of camelina (*Camelina sativa* L. Crantz) in the eastern region of Türkiye☆

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Abstract – Determining the appropriate sowing date can have a significant impact on increasing the yield potential of alternative crops such as camelina in semiarid agricultural ecosystems. This study aimed to determine the effects of sowing date and genotype on yield components, seed yield, oil yield, oil content and fatty acid profile of camelina. A split-plot experimental design using sowing dates (30–31 March, 5–8 April, 15–17 April, 25–28 April and 6–7 May) as main plot and genotypes as subplots was adopted during two growing seasons (2021–2022). The results of the present study showed that delaying sowing exposed the seed-filling period to high temperatures, which resulted in significant decreases in seed yield and oil content of camelina. Thus, the most positive results in terms of yield and yield components were obtained from the first and second sowing dates. In this respect, the highest seed yield (1982 kg ha^{-1}), oil yield (797 kg ha^{-1}) and seed oil content (40.2%) were obtained from the Arslanbey genotype. In addition, while the rates of linolenic acid (36.75%), palmitic acid (5.12%), stearic acid (2.55%), arachidic acid (1.55%) and eicosenoic acid (16.58%) in camelina seed showed high values at the first and second sowing times, these rates relatively decreased as the sowing time was delayed. On the contrary, the highest values in terms of linoleic acid and oleic acid were observed in the fourth sowing date. As a result, although the ecological conditions of the region are suitable for camelina cultivation, significant decreases in camelina seed yield and oil content were observed with the delay of sowing. In this context, it was determined that the suitable sowing time for spring camelina cultivation in the Mus province located in the east of Türkiye is the last week of March and the first week of April. However, further research is needed to optimize other agricultural inputs for camelina production in the region.

Keywords: *Camelina sativa* / oil quality / fatty acids / linolenic acid / sowing date

Résumé – Effets du génotype et de la date de semis sur le rendement en graines, la teneur en huile et le profil en acides gras de la caméline (*Camelina sativa* L. Crantz) dans une région orientale de la Turquie. Déterminer une date de semis appropriée peut avoir un impact significatif sur l'augmentation du potentiel de rendement de cultures alternatives telles que la caméline dans les écosystèmes agricoles semi-arides. L'objectif de cette étude était de déterminer les effets de la date de semis et du génotype sur les composantes du rendement, le rendement en graines, le rendement en huile, la teneur en huile et le profil en acides gras de la caméline. Un dispositif en parcelles divisées (split-plot), utilisant les dates de semis (30–31 mars, 5–8 avril, 15–17 avril, 25–28 avril et 6–7 mai) comme facteurs principaux et les génotypes comme sous-parcelles, a été mis en place durant deux saisons de culture (2021 et 2022). Les résultats de la présente étude ont montré que le retard de semis exposait la période de remplissage des graines à des températures élevées, ce qui entraînait des diminutions significatives du rendement en graines et de la teneur en huile de la caméline. Ainsi, les résultats les plus favorables en termes de rendement et de composantes du rendement ont été obtenus pour les première et deuxième dates de semis. À cet égard, les valeurs les plus élevées de rendement en graines (1982 kg ha^{-1}), de rendement en huile (797 kg ha^{-1}) et de teneur en huile (40,2 %)

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dans les graines ont été obtenues avec le génotype Arslanbey. De plus, tandis que les taux d'acide linolénique (36,75 %), d'acide palmitique (5,12 %), d'acide stéarique (2,55 %), d'acide arachidique (1,55 %) et d'acide eicosénoïque (16,58 %) dans les graines de caméline présentaient des valeurs élevées lors des première et deuxième dates de semis, ces taux diminuaient relativement lorsque la date de semis était retardée. À l'inverse, les valeurs les plus élevées en acide linoléique et en acide oléique ont été observées lors de la quatrième date de semis. En conclusion, bien que les conditions écologiques de la région soient favorables à la culture de la caméline, des diminutions significatives du rendement en graines et de la teneur en huile ont été observées lorsque la date de semis était retardée. Dans ce contexte, il a été déterminé que la période de semis la plus appropriée pour la culture printanière de la caméline dans la province de Mus, située à l'est de la Turquie, est la dernière semaine de mars et la première semaine d'avril. Toutefois, des recherches supplémentaires sont nécessaires pour optimiser les autres intrants agricoles pour la production de caméline dans la région.

Mots-clés : *Camelina sativa* / qualité de l'huile / acides gras / acide linolénique / date de semis

Highlights

- Determining the optimum sowing date for camelina in a given ecology and selecting the most productive genotypes contributed to optimizing crop productivity.
- In the Mus province in eastern Türkiye, the appropriate sowing date for camelina is the end of March and the first weeks of April.
- As sowing was delayed, seed formation periods were exposed to high temperatures, which negatively affected oil yield and fatty acid composition.

1 Introduction

Camelina (*Camelina sativa* L. Crantz) is an oilseed plant belonging to the *Brassicaceae* family. Camelina is adaptable to many different environmental conditions, making it unique among other oilseed crops (Murphy, 2016). Although the seed yield and oil composition of the camelina plant vary according to different climatic environments, studies have shown that it performs better than rapeseed in dry conditions (Zubr, 1997; Gugel and Falk, 2006). In addition, relatively lower input is required in Camelina cultivation (Urbaniak *et al.,* 2008). Therefore, it may be considered a more suitable crop for cultivation in less fertile lands and in areas where there is not enough precipitation to support other crops.

Camelina has a short life cycle of approximately 85–100 days and is an annual plant (Kurasiak-Popowska *et al.,* 2020; Sydor *et al.,* 2022; Mondor and Hernández-Álvarez, 2022). It is known that camelina first appeared as a weed in flax and grain fields in Southwest Asia and Southeastern Europe (Haldane, 1932). Although archaeological findings show that camelina cultivation dates back to 4000 BC in Central Europe, some studies indicate that the camelina plant was cultivated in the Eastern Anatolia Region in 700–900 BC (Dönmez and Belli, 2007; Berti *et al.,* 2016).

The oil obtained from camelina seeds is used in various areas. For example, it is frequently preferred in human nutrition as a functional food source (Rokka *et al.,* 2002; Zubr, 2003). In addition, it is also evaluated in the cosmetics industry and non-food applications (Schuster and Friedt, 1998; Zubr, 2003). Oil obtained from camelina is also considered as a renewable low-emission component of jet fuels (Shonnard *et al.,* 2010). Many researchers have reported that the oil contained in camelina seeds is 300 to 490 g kg^{-1} (Vollmann *et al.,* 2007; Blackshaw *et al.,* 2011; Mupondwa *et al.,* 2016). Camelina oil is rich in oleic (C18:1), linoleic (C18:2), linolenic (C18:3), eicosenoic (C20:1), palmitic (C16:0) and erucic (C22:1) acid (Putnam *et al.,* 1993; Singh *et al.,* 2014; Kurasiak-Popowska *et al.,* 2019). However, the yield and oil content of camelina seed may vary depending on ecological factors, cultivation practices and genotype. Additionally, although camelina seeds typically contain 2–4% erucic acid, varieties containing 0% erucic acid have been developed in recent years. For camelina seeds to be used in human nutrition, the erucic acid limit must be below 2% (Russo *et al.,* 2014).

In camelina cultivation, the selection of varieties with high seed yield, quality oil content, earliness, drought resistance and better utilization of available water in the soil is important (Obeng *et al.,* 2019). Temperature and the status of available water in the soil are the most important environmental factors affecting the seed yield of camelina. Seed yield and quality of camelina may be limited by low rainfall, water shotage and exposure to high temperatures during the seed formation period (Pavlista *et al.,* 2011). On the other hand, many studies have revealed that sowing date also affects camelina seed yield and quality (Gesch, 2014; Neupane *et al.,* 2019; Angelini *et al.,* 2020). In this context, early sowing may lead to various difficulties such as low temperature, disease and pest formation, while delaying sowing may negatively affect the development of camelina seed due to physiological maturity and carbohydrate deficiency. Therefore, determining the optimum sowing time for oilseed crops is of great importance and sowing time should be evaluated separately according to the climate of each region. Additionally, adaptation strategies such as changing sowing dates are needed to increase production and improve water use efficiency in arid regions. Establishing best management practices for camelina cultivation, including sowing dates, and selecting the most productive genotypes for a particular region will contribute to expanding camelina production. To date, no comprehensive evaluation has been made to determine the optimum sowing date for summer camelina cultivation in Mus, located in the eastern region of Türkiye. Therefore, the aim of the study was to develop region-specific recommendations for camelina cultivation in eastern Türkiye and to determine the genotypes with superior performance (in terms of seed yield and fatty quality) and the most appropriate sowing date.

Table 1. Soil chemical properties at depths of 0 to 30 cm.

Year	Soil depth (cm)	Soil structure	pH	Electrical conductivity (dS m^{-1})	Organic matter (%)	Total nitrogen (g kg^{-1})	Assumable phosphorus (mg kg^{-1})	Exchangeable potassium (mg kg^{-1})	Magnesium (mg kg^{-1})	Total S (g kg^{-1})	Active $CaCO_3$ (%)
2021	0–30	Clayey- loamy	7.70	0.63	2.15	0.15	12.8	468	154.2	0.2	1.61
2022			7.72	0.67	2.10	0.18	10.08	485	168.4	0.2	1.61

Table 2. Passport data of camelina genotypes.

Sr. No	Genotype	Code	Description	Origin
1	PI 258366	G1	Line	Former, Soviet Union
2	PI 258367	G2	Line	Former, Soviet Union
3	PI 650143	G3	Line	Germany
4	PI 304269	G4	Line	Sweden
5	PI 311735	G5	Line	Poland
6	PI 311736	G6	Line	Poland
7	PI 597833	G7	Line	Denmark
8	Arslanbey	G8	Variety	Türkiye

2 Materials and methods

2.1 Site description

Eight camelina genotypes were compared in five different sowing dates in a two-year field study (2021–2022) at the Experimental Center of the Department of Plant Production and Technologies, Faculty of Applied Sciences, Mus Alparslan University of Mus, Türkiye (located between 38.29°–39.29° northern latitudes and 41.06°–41.47° eastern longitudes, 1350 m above sea level). Mus is located in eastern Türkiye, with an average annual temperature of 11.5 °C and an average precipitation of 689.6 mm. Soil analysis results showed that it was clayey-loamy in texture with a pH of 7.70, contained 2.15% organic matter, total nitrogen of 0.15 g kg^{-1}, assumable phosphorus of 12.8 mg kg^{-1}, E.C: 0.63 dS.m^{-1}, magnesium 0.40 ppm (Tab. 1) and with no salinity problems.

2.2 Agricultural practices and experimental design

In this study, seven camelina genotypes and one standard variety were used as material. These selected genotypes have high adaptation ability and oil yield performance in different ecological regions. The experimental design was determined as a factorial trial design in randomized blocks with three replications (8 × 5). The first factor in the research was camelina varieties and the second factor was sowing dates. Identification information of the camelina varieties used as material in the study is given in Table 2.

Table 3 shows the sowing and harvesting dates of the two-year experiment.

This study was conducted using a randomized block split-plot experimental design with three replications. Thus, sowing date was determined as main plot and genotype sub-plot. Each plot consisted of four rows of 3 m length. In addition, the distance between plots and replications were 2 and 3 m, respectively. Camelina seeds sowing was performed by hand 5 cm apart, approximately 2 cm depth (Gesch *et al.,* 2017). Before sowing, the soil was ploughed to a depth of 30 cm and then disk harrowing to prepare the seedbed. An integrated management system in which mineral fertilization and conventional soil tillage were applied together was implemented in the trial. Fertilization dose was calculated by taking into account the soil analysis results. Potassium and phosphorus fertilization was done as 75 kg ha^{-1} P_2O_5 (triple superphosphate) and 45 kg ha^{-1} K_2SO_4 (potassium sulfate) pre-sowing. Nitrogen fertilization was applied at 55 kg ha^{-1} during the rosette stage of the plant. No chemical spraying against diseases and pests was required during the vegetation period. Additionally, weeds were controlled by manual weeding. Harvesting of camelina plants was done when most

Table 3. Sowing and harvesting dates of eight genotypes in 2021–2022.

Year	Sowing dates	Harvest dates
2021	30 March (First)	18 July
	5 April (Second)	22 July
	15 April (Third)	26 July
	25 April (Fourth)	30 July
	6 May (Fifth)	10 August
2022	31 March (First)	18 July
	8 April (Second)	23 July
	17 April (Third)	28 July
	28 April (Fourth)	2 August
	7 May (Fifth)	9 August

Table 4. Average monthly temperature, precipitation and humidity distribution in the two years (2021 and 2022) of the experiment and in the long term (30 years).

Months	Average temperature (°C)			Precipitation (mm)			Weather Humidity (%)		
	2021	2022	Long term mean	2021	2022	Long term mean	2021	2022	Long term mean
January	−5.52	−6.25	−5.34	94.00	88.0	103.92	85.0	83.90	82.0
February	−0.35	−2.69	−2.73	49.84	44.82	67.64	80.72	86.32	79.72
March	3.91	−0.53	3.25	166.4	203.48	131.38	69.84	83.61	71.45
April	13.68	11.70	11.22	7.82	28.0	67.13	48.76	52.38	55.33
May	18.74	13.80	15.81	11.61	80.0	72.22	39.91	60.43	54.17
June	23.40	22.00	21.50	0.64	9.0	25.84	26.70	41.35	39.44
July	27.23	26.11	26.20	0.46	1.0	9.66	27.93	27.17	27.78
August	26.35	27.25	26.57	0.42	0.0	3.52	28.95	24.83	25.74
Average	13.41	11.43	12.05	42.62	58.02	60.12	50.97	57.46	54.41

Mus Province Meteorology General Directorate, 2023.

of the siliques had dried and turned brown and the seeds were fully mature (seed moisture about ≤12%). During harvest, the number of siliques per plant, number of seeds per siliques, plant height (cm) and biomass (mg ha^{-1}), seed weight (g), seed yield (kg ha^{-1}) and oil yield (kg ha^{-1}) characteristics of plants taken from each plot were determined by taking 0.5 m edge effect into account. For the 100 seed weight of camelina varieties, four 100 seed samples were counted and weighed (Mirzaie *et al.*, 2020). Twenty mature plants were randomly selected from each plot to determine the number of siliques and seeds in the siliques. To calculate seed yield, camelina seeds were first threshed using sieves suitable for small seeds. Then the fresh weight of the seeds was measured.

2.3 Weather conditions

The weather conditions recorded during the study period are given in Table 4. Monthly mean air temperature during the camelina growing season was similar to the long-term mean temperature of the years. Average air temperatures have increased relatively since March. Therefore, it is possible to determine the appropriate sowing date for camelina seeds as the period between mid-March and early April. Similarly, one of the important points that determines the sowing date of camelina seeds is rainfall. Since camelina seeds are small, regular rainfall after sowing provided the best conditions for germination. Considering the growing season of camelina, these conditions are observed in the region in March, April and May (Tab. 4). In addition, the rainfall in these months allows farmers to meet the water needs of the plant through rainfall.

2.4 Oil content and oil yield

To determine the dry matter (DM) content of seeds taken from each plot, all samples were dried in an oven at 65 °C until they reached constant weight. They were then ground using a grinding device, and 5 g of each sample was prepared. The samples taken in cartridges were extracted with 250 mg hexane and kept in a Soxhlet (Soxhlet method; SIST EN ISO 659:1998) device for 6 h to obtain oil samples. Then, the oils were weighed on a precision scale and the oil content was calculated as a percentage (%). All analyses were performed in triplicate for each sample.

The oil yield was calculated according to the following formula:

Oil yield (kg ha^{-1}) = Oil content (%) / 100 × Seed yield (kg ha^{-1})

2.5 Fatty acid profile of seed oil

The fatty acid composition of the oil samples was determined according to the standard for the determination of fatty acid methyl esters (FAME) by gas chromatography. Accordingly, 0.1 g of oils from camelina samples were taken into 15 mL capped centrifuge tubes and 10 mL of hexane solvent was added. KOH, prepared by dissolving it in 0.5 mL of 2 N methanol, was added to the tubes containing the samples. After the mixture was shaken well, it was left in the dark for 2 h until the upper phase became clear. Samples taken from the upper phase were placed in the Shimadzu AOC-20i automatic injector. Fatty acid methyl esters were analyzed using a Shimadzu brand GCMS-TQ8030 (Shimadzu, Kyoto, Japan) instrument equipped with a TRCN-100 capillary column (100 m x 0.25 × 0.20 μm) and a flame ionization detector (FID). The injection port and FID temperature are 250 °C, 1/100 split ratio at 250 kPa pressure in split injection mode. Helium was used as the carrier gas. Samples injected as 1 μL into the device were compared with the GC-FID chromatogram obtained during a total of 50 min of analysis of the “Supelco Fame mix 37” standard mixture. Samples injected as 1 μL into the device were compared with the GC-FID chromatogram obtained during a total of 50 min of analysis of the “Supelco Fame mix 37” standard mixture. The amounts of palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), linolenic acid (C18:3), arachidic acid (C20:0) and eicosenoic acid (C20:1) contained in camelina oil are given as percentage (%).

2.6 Statistical analysis

All statistical analyses were performed with “ANOVA” statistical software. A three-way analysis of variance was

Table 5. Results obtained from combined ANOVA on the traits examined in camelina between 2021–2022 (means squares).

SV	DF	Plant height	NS	NSS	Biomass	TSW	Seed yield	Oil yield	Oil content
Y	1	0.56	252.34	0.32	251.206	0.0058	2137.19	1.2820	102.78
B(Y)	4	0.27	148.12	0.18	219.050	0.0042	2542.49	2.3452	15.22
G	7	2.25**	645.34*	0.542**	627.185*	0.0465**	65847**	5.3278**	87.52**
YxG	7	0.82	102.35	0.02	384.554	0.0026	2048.36	0.8712	29.80
SD	4	3.59**	487.18**	0.636*	728.275**	0.0582**	63858**	7.5692**	98.65**
YxSD	4	0.36	95.371	0.23	153.528	0.0078	1895.59	1.3460	23.17
SDxG	28	4.20**	649.72**	0.582**	598.722**	0.0689**	34729**	6.3451**	78.92**
YxSDxG	28	0.03	58.03	0.16	154.179	0.0048	1568.58	1.6523	15.68
Error	156	0.052	48.95	0.035	135.472	0.0062	585.61	0.0382	12.28
CV (%)		3.58	5.63	3.68	15.47	4.28	15.68	5.62	11.87

SV: Sources of variation, DF: Degrees of freedom, CV: Coefficient of variation, Y: Year, B: Block, G: Genotype, SD: Sowing date, NS: Number of siliques (plant^{-1}), NSS: Number of seeds (siliques^{-1}), TSW: 1000 seed weight. ns, *, **: non-significant, significant at the 5%, 1% probability levels, respectively.

performed using the JMP (pro 13) statistical package program to test the genotype, sowing date, year and their interactions on the measured traits. Additionally, Tukey's multiple comparison test was used to evaluate the statistical analysis of the results. Bartlett's homogeneity test was performed before combining the years and after determining that the years were homogeneous, combined analysis was performed.

3 Results

3.1 Agronomic traits

The combined ANOVA results showed that genotype, sowing date and genotype × sowing date interaction had significant effects on all agronomic traits (Tab. 5).

The effects of different sowing dates on camelina genotypes are given in Table 6. Accordingly, significant decreases occurred in the yield traits of all genotypes with the delay in sowing. For example, while plant height had the highest value at the first sowing date for all genotypes, this value decreased significantly as sowing was delayed. Therefore, the highest plant height was obtained from the G8 genotype (71 cm) on the first sowing date, while the G6 genotype (33 cm) gave the lowest performance for the trait on the fourth sowing date. This showed that sowing date has a significant effect on plant height.

The biomass of all genotypes decreased with delayed sowing (Tab. 6). Accordingly, while the genotypes showed high biomass values in the first and second sowing dates, this value decreased relatively in the fourth and fifth sowing dates. Biomass values of the genotypes varied between 8.5-3.4 mg ha^{-1} depending on the sowing dates. This situation shows the important effect of seasonal change in the different responses of camelina genotypes to sowing dates depending on temperature fluctuations and variability in rainfall distribution. Berti *et al.* (2011) reported in their study conducted in Chile that the highest biomass yield was obtained from the first sowing date and that biomass decreased critically with the delay of the sowing date. The number of siliques of camelina genotypes decreased significantly with the delay in sowing. In this respect, the highest number of siliques was obtained from the first sowing date. On the contrary, there were significant decreases in silique numbers of all genotypes on the fifth sowing date. Accordingly, the genotype G8 (168 silique plants^{-1}) produced the highest number of siliques in the first sowing, followed by the genotypes G2 (155 silique plants^{-1}) and G4 (138 silique plants^{-1}), respectively. Similarly, there were significant differences in the number of seeds per silique among camelina genotypes depending on the sowing dates. Additionally, the genotype G8 (13 seed silique^{-1}) showed the highest performance for the highest number of seeds per silique at the first sowing date. This indicates that the G8 genotype is better adapted to the ecological conditions of the region in terms of many traits. Tunctürk *et al.* (2019) reported that the number of siliques varied between 130–116 per plant at different sowing dates and this trait was significantly affected by the sowing date. Kıraly and Imbrea (2014) emphasized that the number of siliques per plant varies between 138.42–164.26 depending on the sowing date and the highest value was obtained from the first sowing. Sowing dates have a significant effect on seed weight of camelina genotypes (Tab. 6). So that, while the highest seed weight was obtained from the first and second sowing dates, significant decreases were observed in this value as the sowing date was delayed. In early sowing, the plant benefits from sunlight for a longer period of time and seed filing occurs at cooler temperatures. This is a factor that positively affects the seed weight. The G8 genotype showed the best results in terms of seed yield. Also, the G2 (1872 kg ha^{-1}) and G4 (1659 kg ha^{-1}) genotypes were prominent in terms of seed yield.

Statistically significant and meaningful differences were found among camelina genotypes and sowing dates in terms of oil yield (Tab. 6). In addition, oil yield of all genotypes decreased significantly with the delay of sowing date. For example, while the oil yield of the G8 genotype was 797 kg ha^{-1} on the first sowing date, it became 321 kg ha^{-1} on the fifth sowing date and this was observed in almost all genotypes. Because the delay in sowing shortened the vegetation period and the seed filling process of the plants was exposed to high temperatures. The oil content of the seed is the main determining factor affecting oil production. Delaying the sowing date resulted in significant decreases in oil content of all camelina genotypes. Unfavorable seasonal conditions in the late growing season, such as intense heat,

Table 6. Genotype x sowing date interaction for the examined traits (in 2021 and 2022).

Plant height (cm)								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	58 ± 0.2^{a}	66 ± 0.1^{a}	58 ± 0.2^{a}	60 ± 0.3^{a}	55 ± 0.1^{a}	54 ± 0.3^{a}	52 ± 0.1^{a}	71 ± 0.4^{a}
Second SD	55 ± 0.1^{ab}	60 ± 0.3^{b}	55 ± 0.2^{ab}	52 ± 0.1^{b}	51 ± 0.1^{ab}	50 ± 0.1^{ab}	49 ± 0.2^{ab}	65 ± 0.2^{b}
Third SD	51 ± 0.1^{b}	52 ± 0.1^{c}	50 ± 0.1^{b}	46 ± 0.2^{c}	48 ± 0.2^{b}	41 ± 0.2^{c}	45 ± 0.1^{b}	58 ± 0.2^{bc}
Fourth SD	50 ± 0.2^{b}	45 ± 0.2^{d}	43 ± 0.1^{c}	43 ± 0.2^{c}	42 ± 0.2^{bc}	35 ± 0.2^{d}	40 ± 0.2^{c}	55 ± 0.3^{bc}
Fifth SD	43 ± 0.1^{c}	40 ± 0.1^{de}	39 ± 0.1^{cd}	38 ± 0.1^{cd}	35 ± 0.1^{c}	33 ± 0.1^{d}	37 ± 0.3^{cd}	48 ± 0.2^{c}
Average	51.4	52.6	49	47.8	46.2	42.6	44.6	59.4
$LSD_{(SD\ x\ G)}$: 2.34**	$LSD_{(SD)}$: 2.16 ** $LSD_{(G)}$: 2.08**							
Biomass (mg ha^{-1})								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	6.8 ± 0.1^{a}	7.8 ± 0.2^{a}	7.2 ± 0.1^{a}	7.6 ± 0.3^{a}	7.4 ± 0.2^{a}	6.3 ± 0.2^{a}	6.9 ± 0.1^{a}	8.5 ± 0.3^{a}
Second SD	5.3 ± 0.1^{b}	5.7 ± 0.2^{b}	6.2 ± 0.1^{b}	6.2 ± 0.3^{b}	6.1 ± 0.2^{b}	5.0 ± 0.2^{b}	5.4 ± 0.1^{b}	7.1 ± 0.3^{b}
Third SD	4.8 ± 0.1^{c}	5.3 ± 0.2^{b}	5.3 ± 0.2^{c}	5.3 ± 0.2^{c}	5.6 ± 0.1^{c}	4.5 ± 0.2^{c}	4.8 ± 0.1^{c}	6.7 ± 0.2^{bc}
Fourth SD	4.2 ± 0.2^{cd}	4.5 ± 0.2^{c}	4.6 ± 0.2^{d}	4.2 ± 0.2^{d}	4.8 ± 0.1^{d}	4.1 ± 0.1^{cd}	4.5 ± 0.1^{c}	5.3 ± 0.2^{c}
Fifth SD	3.4 ± 0.1^{d}	3.9 ± 0.2^{d}	4.1 ± 0.2^{de}	4.0 ± 0.2^{d}	4.3 ± 0.3^{de}	3.5 ± 0.1^{d}	4.0 ± 0.1^{cd}	4.9 ± 0.1^{cd}
Average	4.9	5.4	5.4	5.4	5.6	4.6	5.1	6.5
$LSD_{(SD\ x\ G):}$ 0.78**	$LSD_{(SD):}$ 0.56 ** $LSD_{(G)}$: 0.33*							
Number of silique (per plant)								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	120 ± 3.6^{a}	155 ± 4.2^{a}	121 ± 4.2^{a}	138 ± 4.5^{a}	126 ± 3.2^{a}	122 ± 3.6^{a}	106 ± 2.8^{a}	168 ± 5.2^{a}
Second SD	118 ± 2.1^{a}	146 ± 3.6^{ab}	112 ± 4.0^{b}	125 ± 4.2^{b}	103 ± 3.2^{b}	113 ± 3.2^{ab}	93 ± 2.2^{b}	132 ± 4.8^{b}
Third SD	100 ± 2.0^{b}	95 ± 3.5^{c}	101 ± 3.6^{c}	112 ± 4.2^{bc}	97 ± 2.7^{bc}	100 ± 2.9^{b}	85 ± 2.0^{c}	128 ± 4.8^{bc}
Fourth SD	98 ± 2.2^{b}	87 ± 2.8^{cd}	92 ± 3.4^{d}	105 ± 3.5^{c}	90 ± 2.3^{c}	92 ± 2.5^{bc}	79 ± 1.5^{cd}	115 ± 3.2^{c}
Fifth SD	85 ± 3.1^{bc}	80 ± 2.3^{d}	83 ± 2.4^{de}	92 ± 3.0^{d}	81 ± 2.0^{cd}	82 ± 2.1^{c}	62 ± 1.2^{e}	100 ± 3.0^{d}
Average	104.2	112.6	101.8	114.4	99.4	101.8	85	128.6
$LSD_{(SD\ x\ G)}$: 10.50	$LSD_{(SD)}$: 11.08** $LSD_{(G):}$ 10.05*							
Number of seeds (per silique)								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	10 ± 0.1^{a}	12 ± 0.2^{a}	10 ± 0.2^{a}	11 ± 0.3^{a}	11 ± 0.2^{a}	11 ± 0.1^{a}	10 ± 0.2^{a}	13 ± 0.3^{a}
Second SD	10 ± 0.1^{a}	11 ± 0.2^{ab}	10 ± 0.1^{a}	11 ± 0.3^{a}	11 ± 0.2^{a}	10 ± 0.1^{ab}	9 ± 0.2^{ab}	12 ± 0.2^{ab}
Third SD	8 ± 0.1^{ab}	11 ± 0.2^{ab}	9 ± 0.1^{ab}	10 ± 0.3^{ab}	10 ± 0.2^{ab}	10 ± 0.1^{ab}	9 ± 0.2^{ab}	10 ± 0.2^{b}
Fourth SD	7 ± 0.1^{b}	9 ± 0.2^{b}	8 ± 0.1^{b}	9 ± 0.3^{b}	10 ± 0.2^{ab}	8 ± 0.1^{b}	8 ± 0.2^{b}	8 ± 0.2^{c}
Fifth SD	7 ± 0.1^{b}	8 ± 0.2^{c}	8 ± 0.1^{b}	7 ± 0.3^{c}	7 ± 0.2^{b}	7 ± 0.1^{bc}	7 ± 0.2^{bc}	8 ± 0.1^{c}
Average	8.4	10.2	9	9.6	9.8	9.2	8.6	8.6
$LSD_{(SD\ x\ G)}$: 1.48**	$LSD_{(SD)}$: 1.32 * $LSD_{(G):}$ 1.22**							
TSW (g)								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	1.28 ± 0.01^{a}	1.62 ± 0.02^{a}	1.39 ± 0.01^{a}	1.55 ± 0.02^{a}	1.25 ± 0.01^{a}	1.35 ± 0.03^{a}	1.19 ± 0.01^{a}	1.85 ± 0.02^{a}
Second SD	1.13 ± 0.01^{b}	1.52 ± 0.02^{b}	1.12 ± 0.01^{b}	1.43 ± 0.02^{b}	1.08 ± 0.01^{b}	1.22 ± 0.03^{b}	1.05 ± 0.01^{b}	1.78 ± 0.02^{ab}
Third SD	1.06 ± 0.01^{c}	1.35 ± 0.03^{c}	1.01 ± 0.01^{c}	1.28 ± 0.02^{c}	0.98 ± 0.01^{c}	1.04 ± 0.02^{c}	0.93 ± 0.01^{bc}	1.36 ± 0.02^{c}
Fourth SD	0.95 ± 0.01^{d}	1.10 ± 0.01^{d}	0.87 ± 0.01^{cd}	1.15 ± 0.02^{d}	0.92 ± 0.01^{cd}	0.92 ± 0.02^{cd}	0.90 ± 0.01^{bc}	1.12 ± 0.02^{d}
Fifth SD	0.87 ± 0.01^{e}	1.02 ± 0.02^{de}	0.83 ± 0.02^{d}	0.98 ± 0.02^{e}	0.87 ± 0.01^{d}	0.90 ± 0.02^{cd}	0.87 ± 0.01^{c}	1.08 ± 0.02^{de}
Average	1.05	1.32	1.04	1.27	1.02	1.08	0.98	1.43
$LSD_{(SD\ x\ G):}$ 0.04** $LSD_{(SD):}$ 0.02** $LSD_{(G):}$ 0.05**								

Table 6. (continued).

Seed yield (kg ha^{-1})								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	1568 ± 18.4^{a}	1875 ± 17.9^{a}	1542 ± 12.6^{a}	1659 ± 13.4^{a}	1273 ± 12.6^{a}	1346 ± 13.8^{a}	1118 ± 12.4^{a}	1982 ± 18.2^{a}
Second SD	1432 ± 15.2^{ab}	1725 ± 17.5^{ab}	1341 ± 11.8^{b}	1622 ± 13.2^{a}	1148 ± 11^{ab}	1230 ± 8.5^{ab}	1058 ± 11.7^{ab}	1845 ± 17.4^{ab}
Third SD	1022 ± 15.1^{c}	1428 ± 16.3^{c}	935 ± 10.26^{c}	1235 ± 11.8^{b}	829 ± 10.5^{c}	915 ± 9.2^{c}	763 ± 10.3^{c}	1473 ± 12.5^{c}
Fourth SD	978 ± 13.5^{de}	1056 ± 11.8^{d}	826 ± 9.15^{cd}	985 ± 7.6^{c}	712 ± 8.6^{cd}	822 ± 7.6^{cd}	528 ± 9.1^{d}	1038 ± 11.3^{d}
Fifth SD	712 ± 11.6^{e}	846 ± 10.5^{e}	623 ± 9.10^{e}	805 ± 9.0^{cd}	583 ± 8.7^{e}	536 ± 7.2^{e}	486 ± 8.3^{de}	962 ± 7.6^{de}
Average	1142	1386	1053	1261	909	970	790	1460
$LSD_{(SD\ x\ G)}$: 112** $LSD_{(SD)}$: 106** $LSD_{(G)}$: 110**								

Oil yield (kg ha^{-1})								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	615 ± 6.8^{a}	744 ± 7.3^{a}	593 ± 5.2^{a}	647 ± 5.8^{a}	478 ± 4.8^{a}	514 ± 7.2^{a}	420 ± 5.9^{a}	797 ± 8.5^{a}
Second SD	552 ± 6.1^{b}	676 ± 6.2^{b}	509 ± 4.7^{ab}	596 ± 6.4^{ab}	415 ± 4.5^{ab}	471 ± 6.5^{b}	379 ± 5.5^{ab}	738 ± 7.6^{a}
Third SD	381 ± 7.2^{c}	536 ± 6.4^{bc}	347 ± 4.3^{c}	412 ± 5.1^{c}	288 ± 3.2^{b}	327 ± 6.1^{c}	253 ± 4.7^{c}	569 ± 6.4^{b}
Fourth SD	344 ± 5.3^{cd}	397 ± 5.4^{c}	298 ± 3.1^{cd}	321 ± 4.7^{d}	230 ± 5.1^{bc}	277 ± 5.8^{d}	177 ± 4.5^{d}	388 ± 6.0^{c}
Fifth SD	233 ± 4.6^{d}	302 ± 5.8^{d}	218 ± 2.8^{d}	244 ± 4.2^{e}	183 ± 4.0c	166 ± 5.0^{e}	147 ± 3.9^{de}	321 ± 5.3^{cd}
Average	425	531	393	444	318	351	275	562
$LSD_{(SD\ x\ G)}$: 45.28**	$LSD_{(SD)}$: 36.89** $LSD_{(G)}$: 40.28**							

Oil content (% dry weight matter)								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	39.2 ± 0.5^{a}	39.7 ± 0.4^{a}	38.5 ± 0.1^{a}	39.0 ± 0.6^{a}	37.6 ± 0.3^{a}	38.2 ± 0.5^{a}	37.5 ± 0.3^{a}	40.2 ± 0.2^{a}
Second SD	38.6 ± 0.5^{a}	39.2 ± 0.4^{a}	38.0 ± 0.1^{a}	36.8 ± 0.6^{b}	36.2 ± 0.3^{ab}	38.3 ± 0.5^{a}	35.8 ± 0.3^{ab}	40.0 ± 0.2^{a}
Third SD	37.3 ± 0.3^{ab}	37.6 ± 0.4^{b}	37.2 ± 0.1^{ab}	33.4 ± 0.4^{c}	34.8 ± 0.3^{c}	35.8 ± 0.5^{b}	33.2 ± 0.3^{b}	38.6 ± 0.2^{ab}
Fourth SD	35.2 ± 0.3^{c}	37.2 ± 0.4^{b}	36.1 ± 0.1^{b}	32.6 ± 0.4^{c}	32.4 ± 0.2^{cd}	33.7 ± 0.4^{bc}	33.1 ± 0.3^{b}	37.3 ± 0.2^{b}
Fifth SD	32.7 ± 0.3^{d}	35.8 ± 0.4^{c}	35.0 ± 0.1^{bc}	30.3 ± 0.4^{d}	31.4 ± 0.2^{d}	31.0 ± 0.4^{c}	30.2 ± 0.3^{c}	33.4 ± 0.2^{c}
Average	36.6	38	37	34.4	34.4	35.4	34	38
$LSD_{(SD\ x\ G)}$: 2.95**	$LSD_{(SD)}$: 2.06** $LSD_{(G)}$: 1.96 **							

SD x G: Sowing date x Genotype interaction. Values with different letters indicate significant groups at the 5% level.

significantly reduced the oil content on the fourth and fifth sowing dates. This showed that sowing date had a significant effect on oil content. In the present study, the G8 genotype showed the highest oil content (40.2%) in early sowing. Additionally G2 (39.7%), G1 (39.2%) and G4 (39.0%) genotypes also showed superiority in terms of oil content. These values are within the expected fat content range, which generally ranges from 30% to 45% (Righini *et al.,* 2016, Berti *et al.,* 2011; Gesch, 2014). However, the results of the current study can be considered quite high compared to the results of previous studies conducted in Italy on different genotypes, which reported that the oil content varied between 27% and 37% (Pecchia *et al.,* 2014; Manca *et al.,* 2013). In previously reported studies, Zhang *et al.* (2021) stated that the oil content varied between 27–32%, Berti *et al.* (2011), 39–46%, Krzyżaniak *et al.* (2019), 39–42%, Walia *et al.* (2021), 35–42%.

3.2 Correlation analysis

Correlation analyses were performed to better understand the relationship between sowing dates and yield components (Tab. 7). The analysis results showed that biomass with the highest correlation number with seed yield had the highest direct effect on seed yield at all four sowing dates. Additionally, the number of siliques per plant and the number of seeds per silique were determined to be the main yield components positively associated with seed yield of camelina. Similarly, a positive correlation was determined between silique number and oil yield. A positive relationship was found between seed weight and seed number in at the silique first and second sowing dates. Moreover, a significant relationship was found between seed weight and seed yield and oil yield at the first and second sowing dates, while no significant relationship was found at the other sowing dates. The findings of the present study are in agreement with the results of researchers who argued that there is a strong positive relationship between seed yield and oil yield in previous studies (Katar *et al.,* 2012; Angelini *et al.,* 2020; Göre *et al.,* 2023). Many researchers have reported significant positive relationships between camelina seed yield and yield components (Guy *et al.,* 2014; Hossain *et al.,* 2019). In the present study, no significant relationship was found between plant height and any yield

Table 7. Correlation coefficients between traits measured at different sowing dates based on two-year (2021 and 2022) averages.

Traits	Sowing date	Plant height	Biomass	NS	NSS	TSW	Seed yield	Oil yield	Oil content
Plant height	First SD								
	Second SD								
	Third SD								
	Fourth SD								
	Fifth SD								
Biomass	First SD	0.128							
	Second SD	0.099							
	Third SD	0.146							
	Fourth SD	0.152							
	Fifth SD	0.085							
NC	First SD	0.326	0.778*						
	Second SD	0.328	0.681*						
	Third SD	0.311	0.312						
	Fourth SD	0.255	0.263						
	Fifth SD	0.248	0.182						
NS	First SD	0.087	0.475*	0.218					
	Second SD	0.055	0.428*	0.136					
	Third SD	−0.248	0.145	0.095					
	Fourth SD	−0.325	0.136	0.082					
	Fifth SD	−0.288	0.122	0.077					
TSW	First SD	0.215	0.095	0.082	0.475*				
	Second SD	0.208	0.082	0.058	0.456*				
	Third SD	0.149	0.056	0.045	0.115				
	Fourth SD	0.135	0.048	0.059	0.092				
	Fifth SD	0.122	0.075	0.040	0.087				
Seed yield	First SD	−0.028	0.975**	0.628**	0.578*	0.492*			
	Second SD	−0.056	0.956**	0.584**	0.461*	0.475*			
	Third SD	0.156	0.858**	0.486*	0.201	0.272			
	Fourth SD	0.183	0.762**	0.493*	0.193	0.164			
	Fifth SD	0.210	0.752**	0.472*	0.158	0.183			
Oil Yield	First SD	−0.022	0.543*	0.785**	0.468*	0.586*	0.596*		
	Second SD	0.018	0.487*	0.672**	0.216	0.471*	0.438*		
	Third SD	0.009	0.273	0.425*	0.203	0.215	0.425*		
	Fourth SD	0.015	0.268	0.456*	0.152	0.218	0.216		
	Fifth SD	0.010	0.145	0.321	0.087	0.183	0.138		
Oil content	First SD	0.172	0.322	0.215	0.055	0.472*	0.087	0.618**	
	Second SD	0.155	0.282	0.210	0.048	0.315	0.084	0.561*	
	Third SD	0.077	0.158	0.149	0.062	0.148	0.095	0.282	
	Fourth SD	0.108	0.098	0.092	0.028	0.047	0.047	0.158	
	Fifth SD	0.022	0.125	0.125	0.032	0.056	0.063	0.129	

*, **: Significant at the 5%, 1% probability levels, respectively.

component. These findings are consistent with the results of Göre et al. (2023) reporting positive and non-significant correlations between plant height and yield components. On the contrary, Gehringer et al. (2006) and NeuPane et al. (2020) reported that there is a positive and significant correlation between plant length and seed yield in similar studies.

3.3 Fatty acids composition

Fatty acid composition of camelina genotypes depending on sowing dates is given in Table 8. Statistically significant differences were detected among sowing dates and genotypes in terms of linolenic acid. This shows that the fatty acid profile of camelina is clearly affected by sowing dates. Accordingly, the G8 genotype produced the highest amount of linolenic acid (36.75%) on the first sowing date. On the contrary, the lowest amount of linolenic acid was obtained from the G3 genotype (30.22%) on the fourth sowing date. Delaying sowing resulted in significant decreases in the amount of linolenic acid. Sowing date had a significant effect on the linoleic and oleic acid content of camelina (Tab. 8). Interestingly, an increase in linoleic and oleic acid content was observed with the delay of

Table 8. Fatty acid content (%) based on five different sowing date of camelina genotypes.

Linolenic acid (C18:3)

	G1	G2	G3	G4	G5	G6	G7	G8
First SD	35.73^{a}	36.54^{a}	34.67^{a}	35.87^{a}	34.71^{a}	35.18^{a}	34.49^{a}	36.75^{a}
Second SD	35.18^{a}	36.02^{a}	34.25^{a}	35.21^{a}	34.25^{a}	35.10^{a}	34.22^{a}	36.12^{a}
Third SD	34.55^{b}	35.53^{ab}	33.23^{ab}	34.56^{ab}	33.27^{ab}	34.22^{ab}	33.56^{ab}	35.02^{ab}
Fourth SD	33.75^{ab}	34.15^{b}	31.68^{b}	33.62^{b}	32.18^{b}	34.03^{ab}	33.10^{ab}	34.45^{b}
Fifth SD	32.92^{c}	33.58^{bc}	30.22^{bc}	31.28^{c}	31.72^{bc}	33.17^{b}	32.95^{b}	34.00^{b}
Average	34.4	35.16	32.81	34.10	33.22	34.35	33.67	35.26
$LSD_{(SD\ x\ G)}$	5.28**							

Linoleic acid (C18:2)

	G1	G2	G3	G4	G5	G6	G7	G8
First SD	16.05^{bc}	16.47^{c}	15.26^{c}	16.72^{bc}	16.18^{bc}	16.32^{bc}	16.21^{c}	16.95^{c}
Second SD	17.85^{b}	17.45^{bc}	16.73^{b}	17.51^{b}	17.12^{b}	17.25^{b}	17.10^{ab}	17.82^{bc}
Third SD	18.27^{ab}	18.28^{b}	17.48^{ab}	18.36^{ab}	17.75^{ab}	18.45^{ab}	17.48^{ab}	18.62^{b}
Fourth SD	19.88^{a}	20.68^{ab}	18.52^{a}	19.82^{a}	18.10^{a}	19.03^{a}	18.16^{a}	20.87^{a}
Fifth SD	18.42^{ab}	17.16^{bc}	17.73^{ab}	18.75^{ab}	17.56^{ab}	18.22^{ab}	17.45^{ab}	18.98^{ab}
Average	18.09	18.00	17.45	18.4	17.54	18.05	17.28	18.64
$LSD_{(SD\ x\ G)}$	1.56*							

Oleic acid (C18:1)

	G1	G2	G3	G4	G5	G6	G7	G8
First SD	15.13^{ab}	15.54^{b}	14.48^{bc}	15.62^{b}	15.28^{b}	15.48^{bc}	15.28^{ab}	16.32^{b}
Second SD	15.28^{ab}	15.68^{b}	15.32^{ab}	16.05^{ab}	16.19^{ab}	16.25^{b}	15.68^{ab}	16.68^{b}
Third SD	15.69^{ab}	16.25^{ab}	15.75^{ab}	16.48^{ab}	16.75^{ab}	16.46^{b}	16.22^{a}	16.83^{ab}
Fourth SD	16.72^{a}	18.23^{a}	16.15^{a}	17.98^{a}	17.23^{a}	18.12^{a}	16.92^{a}	18.75^{a}
Fifth SD	16.68^{a}	17.12^{a}	16.95^{a}	16.45^{a}	16.12^{ab}	16.57^{b}	16.54^{a}	16.26^{b}
Average	16	16.5	15.73	16.71	16.51	16.73	16.12	16.96
$LSD_{(SD\ x\ G)}$	1.85*							

Palmitic acid (C16:0)

	G1	G2	G3	G4	G5	G6	G7	G8
First SD	4.58^{a}	4.78^{a}	3.96^{a}	4.65^{a}	3.78^{a}	4.45^{a}	3.67^{a}	5.12^{a}
Second SD	4.67^{a}	4.15^{ab}	3.54^{a}	4.72^{a}	3.52^{a}	4.54^{a}	3.55^{a}	4.95^{ab}
Third SD	4.17^{ab}	4.03^{ab}	3.28^{a}	4.31^{a}	3.15^{a}	4.13^{a}	3.28^{a}	4.38^{ab}
Fourth SD	3.61^{b}	3.87^{b}	2.85^{b}	3.35^{ab}	2.86^{ab}	3.17^{ab}	2.86^{ab}	3.65^{b}
Fifth SD	3.08^{bc}	3.58^{b}	2.13^{bc}	3.08^{ab}	2.21^{b}	2.69^{b}	2.41^{ab}	3.15^{b}
Average	4.02	4.08	3.15	4.02	3.10	3.80	3.15	4.25
$LSD_{(SD\ x\ G)}$	0.19*							

Stearic acid (C18:0)

	G1	G2	G3	G4	G5	G6	G7	G8
First SD	2.45^{a}	2.55^{a}	2.22^{a}	2.52^{a}	2.16^{a}	2.38^{a}	2.25^{a}	2.48^{a}
Second SD	2.40^{a}	2.50^{a}	2.14^{a}	2.42^{a}	1.96^{ab}	2.42^{a}	2.20^{a}	2.41^{a}
Third SD	2.13^{ab}	2.18^{ab}	1.93^{ab}	2.21^{ab}	1.83^{ab}	2.11^{ab}	1.89^{b}	2.00^{ab}
Fourth SD	1.57^{b}	1.55^{b}	1.76^{ab}	1.58^{b}	1.48^{b}	1.67^{b}	1.32^{bc}	1.82^{ab}
Fifth SD	1.24^{bc}	1.28^{bc}	1.15^{b}	1.23^{bc}	1.20^{bc}	1.34^{bc}	1.15^{c}	1.35^{b}
Average	1.97	2.01	1.84	2	1.98	1.98	1.76	2.01
$LSD_{(SD\ x\ G)}$	0.08*							

Table 8. (continued).

Arachidic acid (C20:0)								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	1.40[a]	1.55[a]	1.41[a]	1.46[a]	1.38[a]	1.50[a]	1.52[a]	1.48[a]
Second SD	1.38[a]	1.53[a]	1.40[a]	1.44[a]	1.32[ab]	1.50[a]	1.48[a]	1.45[a]
Third SD	1.30[ab]	1.42[ab]	1.32[ab]	1.38[ab]	1.32[ab]	1.42[ab]	1.40[ab]	1.37[ab]
Fourth SD	1.30[ab]	1.34[b]	1.32[ab]	1.38[ab]	1.30[b]	1.40[ab]	1.38[ab]	1.35[ab]
Fifth SD	1.22[b]	1.26[bc]	1.30[ab]	1.31[b]	1.30[b]	1.34[b]	1.32[b]	1.30[b]
Average	1.32	1.42	1.35	1.40	1.32	1.43	1.42	1.39
$LSD_{(S \times G)}$	0.39*							
Eicosenoic acid (C20:1)								
	G1	G2	G3	G4	G5	G6	G7	G8
First SD	16.14[a]	15.82[a]	16.58[a]	15.87[a]	16.42[a]	15.68[a]	16.38[a]	15.08[a]
Second SD	15.42[ab]	15.63[ab]	15.21[ab]	15.16[ab]	16.01[ab]	15.10[ab]	16.11[ab]	15.00[a]
Third SD	15.06[b]	14.87[b]	14.28[c]	14.52[b]	15.28[b]	14.78[c]	15.86[b]	14.65[ab]
Fourth SD	14.72[bc]	14.56[bc]	14.12[cd]	14.23[bc]	14.49[bc]	14.32[cd]	15.13[c]	14.28[b]
Fifth SD	14.24[c]	14.28[c]	14.10[cd]	14.21[bc]	14.10[c]	14.04[d]	14.62[cd]	14.08[bc]
Average	15.11	15.03	14.85	14.80	15.26	14.78	15.62	14.61
$LSD_{(SD \times G)}$:	2.25*							

*, **: Significant at the 5%, 1% probability levels, respectively.

sowing date. Thus, while the linoleic and oleic acid contents of camelina seeds were 15.26–16.95% and 14.48–16.32% in early sowings, these values increased relatively in late sowings. Accordingly, the highest values in terms of linoleic acid were obtained from G8 (20.87%), G2 (20.16%) and G1 (19.88%) genotypes at the fourth sowing time, respectively. Our results in the present study were consistent with the findings of previous studies sowing an increase in oleic (C18:1) and linoleic acids (C18:2) at high temperatures and an increase in α-linolenic (C18:3) acid at low temperatures (Pavlista *et al.,* 2011; Righini *et al.,* 2019; Obeng *et al.,* 2019; Angelini *et al.,* 2020). The highest values for palmitic acid were obtained from the first and second sowing dates, respectively. Moreover, decrease in palmitic acid content was observed in all genotypes with the delay in sowing. Similarly, the palmitic acid content of the G8 genotype was higher than the other genotypes. Stearic acid and arachidic acid contents of camelina genotypes also decreased with the delay in sowing (Tab. 8). Significant changes were detected in the eicosenoic acid content of camelina genotypes depending on different sowing dates. In the present study, all genotypes showed the highest value in terms of eicosenoic acid content on the first and second sowing dates. On the contrary, delaying sowing caused significant decreases in eicosenoic acid content. Eicosenoic acid can be a valuable source of medium −chain fatty acid for biobased industry (Righini *et al.,* 2016). The fatty acid composition obtained in the present study is consistent with previous findings of other researchers (Zubr and Matthaus, 2002; Kirkhus *et al.,* 2013).

4 Discussion

4.1 Weather conditions

The general evaluation of the regional climatic conditions shows the suitability of camelina seed cultivation. Camelina seeds are known as a cool spring crop. Another important point in determining the appropriate sowing date for camelina seeds is precipitation. Since camelina has small seeds, the best conditions for optimum germination are continuous rainfall after sowing. The inclusion of camelina in rainfed agricultural cropping patterns both enriches crop rotation and helps preserve soil nutrients (Borzoo *et al.,* 2021). This could contribute to ensuring the sustainability of rainfed agriculture. In this respect, it is important to determine the sowing date when camelina genotypes will benefit best from rainfall. There are many studies that argue that weather conditions have a greater effect on camelina seed yield than genotype (Ghamkhar *et al.,* 2010; Masella *et al.,* 2014; Zanetti *et al.,* 2021). Temperature and soil moisture are the most important environmental factors affecting camelina seed yield and oil quality. Seed yield and oil quality of camelina can be limited by heat stress, water scarcity or low rainfall during the reproductive period (Obour *et al.,* 2015; Pavlista *et al.,* 2011). Kirkhus *et al.* (2013) reported that environmental factors such as temperature and precipitation affect both the oil content and nutrient composition levels of camelina seeds. Arid climatic conditions can also cause significant changes in the fatty acid composition (Posé *et al.,* 2009). Obour *et al.* (2017) reported that significant decreases occurred in seed yield and oil concentration of camelina due to high temperatures during flowering and seed filling periods. Therefore, determining the appropriate sowing date to reduce heat stress during flowering and seed filling and to ensure adequate soil water availability will increase the yield and quality of camelina in Eastern Türkiye.

4.2 Agronomic traits

Determining the appropriate sowing date for camelina is a critical factor that can affect crop productivity. In the present study, only data from the harvest period were reported because plant population densities at seedling emergence and after were similar. In both years of the study, sowing dates significantly affected the agronomic traits of camelina and hence the yield components. The reason why yield components are higher on the first and second sowing dates compared to other sowing dates seems to be the favorable temperatures in April and May. Because the favorable temperatures in these months cause plants to grow faster, resulting in stronger and more productive plants. Generally, the yield and yield components of the plant are directly related to suitable environmental conditions and the growth period of the plant. Therefore, the longer the plant's growing period and the more suitable the ecological conditions are, the higher the yield (Mirzaie *et al.,* 2020). In late sowings, plant height is shortened due to the limited effect of environmental conditions and inadequate growth period (Rameeh, 2012). Chauhan *et al.* (1993) reported that the increase in yield-related components in early sowings is a result of more water, mineral and light absorption by the plant canopies, which also increases the efficiency of photosynthesis. Yadavi *et al.* (2015) stated that plant height contributes more to yield in early sowings. Similarly, the findings of the present study showed that delay in sowing negatively affected the components contributing to yield such as plant height in camelina. These results are consistent with previous studies (Angelini *et al.,* 1997; Berti *et al.,* 2011; Waraich *et al.,* 2017). Sowing date is one of the important agricultural practices affecting yield components due to the length of the vegetation period, temperature changes during sensitive phenological events and weather changes that the plant is exposed to from sowing to physiological maturity (Pavlista *et al.,* 2011; Waraich *et al.,* 2017; Aybar Yalınkılıc *et al.,* 2025). So that, significant differences were observed among camelina genotypes depending on the sowing dates for seed yield. This shows that sowing date has a significant and distinct effect on seed yield. Moreover, as sowing was delayed, seed yield decreased significantly and the lowest seed yield was observed on the fifth sowing date. These results highlight the importance of determining the appropriate genotype and sowing date for camelina cultivation in a given region. Berti *et al.* (2011), stated that seed weight was quite high at the first sowing date (third week of April) and decreased significantly with delayed sowing. Many researchers have reported that the seed weight of camelina varies between 0.7 and 1.8 g depending on various factors (Angelini *et al.,* 2020; Vollmann *et al.,* 2007; Zanetti *et al.,* 2017). Choosing the best agronomic management practices, including sowing dates for a given region or environment, and identifying the most productive genotypes will contribute to improving camelina production (Gesch, 2014). The results of sowing date studies on camelina seed yield have varied. For example, Urbaniak *et al.* (2008) reported that sowing date had no significant effect on seed yield for camelina grown in Eastern Canada. In contrast, Pavlista *et al.* (2011) found that the highest yields from camelina seeds were obtained when planted in late March to early April in Nebraska, USA. Vollmann *et al.* (2007) reported that seed yield among camelina genotypes in Austria varied between 1574 and 2248 kg ha^{-1}. Similarly, Gugel and Falk (2006) reported that seed yields in Canada ranged from 962 to 3320 kg ha^{-1}, while Urbaniak *et al.* (2008) evaluated nine camelina cultivars and found that seed yields varied significantly in the range of 552–2567 kg ha^{-1}. Differences in sowing dates also had a significant effect on the oil yield of genotypes. In the present study, the lowest oil yield was obtained from the delayed sowing dates. Gugel and Falk (2006) reported that relatively cool and dry weather during the seed filling period can support high seed yield. Other researchers have also reported significant decreases in oil yield with delayed sowing (Gallardo *et al.,* 2014; Pereyra-Irujo and Aguirrezabal, 2007). However, contrary to previous findings, Zheljazkov *et al.* (2011) reported that genotype x sowing date interaction did not significantly affect oil yield. Zhang *et al.* (2021) stated that the seed yield of camelina ranged from 331–778 kg ha^{-1} in China and this trait was affected by environment, genotype and agricultural practices. In previous studies, Gesch (2014) reported that oil yield for camelina cultivars ranged from 743−2300 kg ha^{-1}, while Lohaus *et al.* (2020) reported that oil yield ranged from 656−910 kg ha^{-1} in a study with eight camelina cultivars in Northern Nevada. In this context, it was noted that the suitable sowing period for camelina in the Mus province in eastern Türkiye is the first weeks of April.

4.3 Fatty acids composition

In the present study, it was determined that different sowing dates had a significant effect on oil content and fatty acid composition. Shirani Rad *et al.* (2023) stated that sowing date has a significant effect on the oil content of camelina and the oil content decreases significantly with delaying sowing. It is known that temperature changes during seed formation in oilseed plants greatly affect the conversion of carbohydrates to lipids, which may cause differences in oil content (Righini *et al.,* 2019; Obeng *et al.,* 2019). High temperatures during flowering and seed filling affect the enzymes responsible for fatty acid metabolism, resulting in a decrease in the content of fatty acids (Vollmann *et al.,* 2007; Valesco *et al.,* 2002). Angelini *et al.* (2020) reported that the linolenic acid content of camelina in Italy varied between 33.76% and 36.68% and the fatty acid profile was affected by the sowing date. Similarly, Shirani Rad *et al.* (2023) stated that the linolenic acid content of camelina plant varies between 32.46% and 33.08% depending on different sowing dates. Cold weather delays the maturation of camelina seeds, allowing more time for the synthesis of oils and fatty acids (Mirzaie *et al.,* 2020). Xie *et al.* (2020) oil content and fatty acid composition are genetically controlled, but these features are also affected by climatic factors, geographical location, agricultural practices and growth season. The decrease in oleic and linoleic acid ratio in early sowings is due to the role of temperature on the activity of oleate desaturase enzyme. Because the synthesis and inhibition of oleate desaturation occur at low and high temperatures, respectively (Mirshekari *et al.,* 2012; Izquierdo *et al.,* 2006; Rondanini *et al.,* 2003). Additionally, linoleic acid content ranged from 12.6–16.6% in Central and Northern Europe (Zubr and Matthaus, 2002), 15.4–19.3% in Chile (Berti *et al.,* 2011), and 19–20% in Western Nebraska (Pavlista *et al.,* 2011). Berti *et al.* (2011) reported that the contents of stearic acid, oleic acid, linoleic acid, linolenic acid and eicosenic acid of camelina seeds in Osorno and Los Angeles varied between 1.88–2.59%, 14.74–18.72%, 15.35–18.16%, 31.48–37.43% and 14.05–15.49%, respectively. As in other oilseed crops, climatic conditions are one of the main factors affecting the oil content and fatty acid profile in camelina (Angelini *et al.,* 2020). McVay and Lamb (2008), reported that sowing in Montana in late February and early March yield higher quality oil than sowing in mid-April or later. The sowing date is an important consideration in camelina production due to its influence on the growing environment conditions. Temperature changes in various physiological periods of the plant depending on the sowing date are one of the important factors affecting the oil yield and quality of camelina. Generally, high temperature during the seed filling period can cause seed shedding, reduced seed number and reduced grain filling (Hatfield and Prueger, 2015). Obour *et al.* (2017) reported that temperatures above 25°C during seed development reduced the proportion of some fatty acids. Therefore, camelina cultivation should be carried out in a way that ensures that flowering and seed filling coincide with periods of sufficient soil water and suitable growth temperature. This shows that determining the appropriate sowing date for camelina production is of critical importance.

5 Conclusions

Camelina is an important oilseed for biodiesel production and is also an important food source due to the rich fatty acids its oil contains. In addition, camelina can be preferred by farmers due to its low input cost in agriculture, high adaptability and the use of its oil in various industrial areas. Camelina has performed quite well as an oilseed crop in the Mus province in eastern Türkiye. The agronomic traits and fatty acid composition of camelina varied significantly over the years depending on the variety and sowing date, and these traits were primarily affected by temperature and precipitation patterns. Although camelina shows significant changes depending on genotype and sowing date, important agronomic characteristics that allow it to be evaluated as an alternative oilseed crop in the region where the study was conducted were determined. In the present study, delaying sowing had negative effects on almost all agronomic characters. In addition, it was determined that the delay in sowing had a significant effect on fatty acids. Considering the results obtained from the study and the climatic conditions of the region together, it was determined that the suitable sowing date for camelina is the last week of March and the first week of April. According to the two-year results of the study, G8, G2 and G4 genotypes gave promising results in terms of seed yield and fatty acid profile. These findings thus suggest that camelina could be an alternative oilseed crop that can contribute to the diversification of traditional rain-fed cereal-based cropping systems, thereby enhancing their sustainability, especially in less favourable agricultural areas.

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Conflicts of interest

The authors declare that they have no conflicts of interest in relation to this article.

Author contribution statement

Silan Çiçek Bayram: Methodology, validation, writing-review & editing, supervision. Nazlı Aybar Yalınkılıç: Conceptualization, investigation, writing-original draft preparation, visualization. Sema Basbağ: Investigation, visualization.

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