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Determination of Some Seed Characteristics of False Flax (*Camelina sativa* L. Crantz) Genotypes Grown Under Semi-Temperate Conditions

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Camelina is an alternative low-input oil plant grown in marginal areas in Turkey. This study aimed to determine some quality characteristics of 39 camellia genotypes in ecological conditions in Bolu, Turkey. The field experiments were carried out in an augmented design with randomized blocks. In this work, some important properties such as thousand seed weight, oil content, fatty acid composition, and protein ratio were investigated. Results showed that mean data for thousand seed weight, oil ratio, and protein ratio were 0.63 – 1.5 g, 26.69 – 39.17%, and 21.81 – 29.81%, respectively. Considering the oil content of the genotypes used in the study, the PI 650158 genotype had the highest oil ratio, while the PI 650164 genotype had the highest seed protein ratio. In conclusion, the PI 311735 and PI 650158 genotypes were found to be within acceptable limits in terms of both oil and protein ratios in places with semi-temperate conditions.

Keywords: *Camelina sativa* (L.) Crantz, oil ratio, fatty acid composition, protein ratio

INTRODUCTION

Camelina sativa L., also known as false flax, German sesame, or Siberian oilseed, is an annual cruciferous oilseed plant belonging to the Brassicaceae family (Neupane et al. 2022). In recent years, it has received increasing attention as a climate-resistant oilseed which can be used as seed meal, biofuel, and jet fuel (Neupane et al. 2018). It can thrive successfully on marginal lands due to its wider climate tolerance compared to many other oilseed crops (Neupane et al. 2019). The natural growing area of the camelina plant is the Mediterranean and Central Asia (Putnam et al. 1993; Mcvay 2008; Lohaus et al. 2020).

Camelina was first cultivated in the Neolithic Age and was used as an oil plant during the Iron Age, spanning areas from the ancient Roman Empire to the steppes of Southeast Europe and Southwest Asia (Putnam et al. 1993). The plant also holds significance in many countries of Europe from the Bronze Age until the 1930s, particularly in France, Belgium, the Netherlands, and the Balkans (Pilgeram et al. 2007). It was also economically cultivated in Soviet Russia, Poland, and Sweden until the 1950s, and in the Soviet Union until the 1960s (Kurt and Seyis 2012). Over time, however, camelina production has declined as canola production increased (Mcvay 2008). Today, its agriculture is carried out in limited areas of Canada, Germany, Poland, and the former Soviet Union.

There are several widely known species in the genus *Camelina*, including *C. sativa, C. rumelica, C. laxa, C. microcarpa, C. anomala,* and *C. hispid*, of which only *C. sativa* has notable economic importance (Kurt and Seyis 2012; Mutlu 2012; Tunçtük et al. 2019). In Europe, its oil was first used in cooking, cosmetics and personal care, and mild detergent industries (Falasca et al. 2014). Camelina oil also has a high content of α-linolenic acid, tocopherols, and other antioxidants with health-promoting benefits (Faten and El Habbasha 2015); tocopherol levels typically reach 700 mg kg^{-1} (Kurt and Seyis 2012), while linolenic acid levels have about a 35 – 40% ratio to its

polyunsaturated oil — much greater than the ratio of rapeseed and soybean, which only reaches about 8% (Abramovi and Abram 2005). In addition, a study by Karvonen et al. (2002) found that camelina oil contains 2.5 times more linolenic acid compared to rapeseed oil and 4 times more linolenic acid compared to olive oil. As linolenic acid is an OMEGA-3 fatty acid found only in fish and flax oil, its high levels in camelina oil make the plant a significant contributor in meeting the demand for OMEGA-3-rich edible oils. The results of the study also showed that camelina oil is able to reduce cholesterol (LDL) by 12.2%, while rapeseed oil reduces it by only 5.4% and olive oil by only 7.7%.

Camelina is also used as a nutrient-rich component in chicken feed due to its OMEGA-3 fatty acid content, which aids in the production of healthier chicken meat and eggs for human consumption (Rokka et al. 2002; Eeva -Liisa et al. 2007; Ghobadi et al. 2021). After the oil of camelina seed is derived, the remaining pulp contains 10% fat, 45% protein, 13% fiber, 5% mineral matter, and a number of vitamins and other substances. The protein of camelina pulp is characterized by the presence of essential amino acids such as arginine, cysteine, lysine, methionine, and threonine. This composition of amino acids in camelina protein is especially suitable for poultry feeding (Günç Ergönül and Aksoylu Özbek 2020). In addition, camelina seed pulp is known to have a high protein and energy content in the nutrition of ruminants and pigs (Schuster and Friedt 1998; Matthäus and Zubr 2000). On the other hand, camelina flour is similar to soybean flour in biological value and contains 45–47 % crude protein and 10 – 11% fiber (Korsrud et al. 1978).

The plant is also an important source of biodiesel (Putnam et al. 1993; Vollmann et al. 2007); the high iodine value of the methyl ester in camelina oil allows it to be used for longer machine lubrication without the risk of spoilage (Fröhlich and Rice 2005). These numerous nutritional and chemical qualities of the camelina make it an alternative source of oil, especially in marginal areas such as various regions in Turkey.

This study aims to determine the performance of 39 camelina genotypes for agricultural and technological characteristics and the quality of its oil acid compositions.

MATERIALS AND METHODS

Description of Planting Materials

Seeds of 35 genotypes and four standard varieties of false flax (*Camelina sativa* (L.) Crantz) obtained from the United States Department of Agriculture (USDA) were used as planting materials for the study (Table 1).

Table 1. Accessions of *C. microcarpa* and *C. sativa* (L.) Crantz used in the study.

No	Accession No	Botanical Name	Country of Origin	No	Accession No	Botanical Name	Country of Origin
1	Ames 31219	*C. microcarpa*	Georgia	21	PI 650158	*C. sativa (L.)* Crantz	Poland
2	Ames 31220	*C. microcarpa*	Georgia	22	PI 650159	*C. sativa (L.)* Crantz	Poland
3	Ames 31231	*C. sativa (L.)* Crantz	Georgia	23	PI 650160	*C. sativa (L.)* Crantz	Former, Soviet Union
4	Ames 31232	*C. sativa (L.)* Crantz	Georgia	24	PI 650161	*C. sativa (L.)* Crantz	Former, Soviet Union
5	PI 258366	*C. sativa (L.)* Crantz	Former, Soviet Union	25	PI 650162	*C. sativa (L.)* Crantz	Poland
6	PI 258367	*C. sativa (L.)* Crantz	Former, Soviet Union	26	PI 650164	*C. sativa (L.)* Crantz	Austria
7	PI 304269	*C. sativa (L.)* Crantz	Sweden	27	PI 650166 (Standard)	*C. sativa (L.)* Crantz	Former, Soviet Union
8	PI 304270	*C. sativa (L.)* Crantz	Sweden	28	PI 650167 (Standard)	*C. sativa (L.)* Crantz	Przemysl, Poland
9	PI 304271	*C. sativa (L.)* Crantz	Sweden	29	PI 652885 (Standard)	*C. sativa (L.)* Crantz	Slovenia
10	PI 311735	*C. sativa (L.)* Crantz	Poland	30	PI 650153	*C. sativa (L.)* Crantz	Former, Soviet Union
11	PI 650141	*C. sativa (L.)* Crantz	Minnesota, United States	31	PI 650154	*C. sativa (L.)* Crantz	Former, Soviet Union
12	PI 650143	*C. sativa (L.)* Crantz	Germany	32	PI 650156	*C. sativa (L.)* Crantz	Former, Soviet Union
13	PI 650144	*C. sativa (L.)* Crantz	Denmark	33	PI 650157	*C. sativa (L.)* Crantz	Former, Soviet Union
14	PI 650146	*C. sativa (L.)* Crantz	Sweden	34	Einfact (Leindotter)	*C. sativa (L.)* Crantz	Germany
15	PI 650148	*C. sativa (L.)* Crantz	Mecklenburg-Vorpommern, Germany	35	PI 311736	*C. sativa (L.)* Crantz	Poland
16	PI 650149	*C. sativa (L.)* Crantz	Mecklenburg-Vorpommern, Germany	36	PI 597833	*C. sativa (L.)* Crantz	Denmark
17	PI 650150-1	*C. sativa (L.)* Crantz	Denmark	37	PI 633192	*C. sativa (L.)* Crantz	Germany
18	PI 650150-2	*C. sativa (L.)* Crantz	Denmark	38	PI 633193	*C. sativa (L.)* Crantz	Germany
19	PI 650151	*C. sativa (L.)* Crantz	Sweden	39	Arslanbey (Standard)	*C. sativa (L.)* Crantz	Türkiye
20	PI 650152	*C. sativa (L.)* Crantz	Germany				

Site Description and Weather Conditions

The camelina plant is grown in summer and winter. Camelina is relatively drought-resistant and can be grown in areas with different climates and soil structures, excluding heavy clay and organic soils. Bolu's climate is a transition area between the maritime climate and the land (steppe) climate of Central Anatolia (Tanrikulu and Doğandor 2021). Both climates have a significant influence on the agriculture in the city. In places on the edge of the Black Sea, summers are cool, and winters are warm. The difference between summer and winter is minimal. In the interior, there is a vast temperature difference (70.9°C) between summer and winter. There is a considerable temperature difference between day and night. In the city's interior, winters are generally cold (-31.5°C) and snowy; summers are hot (+39.4°C) and droughty. Annual rainfall is between 535–1084 mm, with a third of the precipitation occurring during the winter period. In Bolu, where the study was conducted, total precipitation during the vegetation period in 2016 was 297.1 mm which was lower than the long-term average (340.9 mm), while the average temperature was 15.1°C which was higher than the long-term average (14.4°C) for the same months (Fig. 1). While the total amount of precipitation (347.0 mm) in the same period of 2017 was higher than the long-term average, the average temperature was actualized as 14.1°C, parallel to the long-term average (Fig. 1).

In 2016, it was determined that the trial soils with clay structure had no salt problem with a pH of 7.27, a lime value of 4.12%, and salt content of 0.045%. The useful phosphorus and potassium values were at appropriate levels, and the organic matter content was around 2.62% (Table 2).

In 2017, it was determined that the soil pH was 7.78, the lime value was around 6%, and the salt content was 0.04%. In the second year, compared to the first trial year, the soils of the trial site were poor in terms of useful phosphorus, potassium, and organic matter (Table 2).

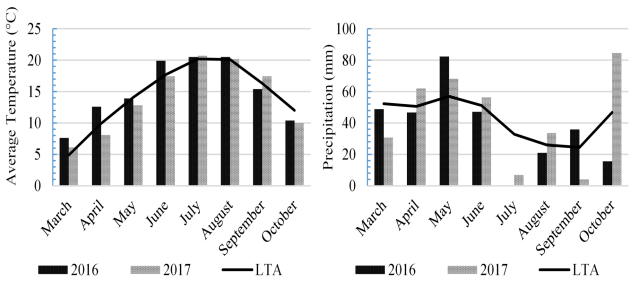


Fig. 1. Climate data during the growing period of camelina, 2016-2017.

Treatment and Study Design

The experiment was established in the experimental area of Abant İzzet Baysal University, Faculty of Agriculture and Natural Sciences, using the augmented trial design in randomized blocks. In the study, 35 camelina genotypes and four standard varieties were used as material.

Plots Establishment and Management

In the experiment, each plot was set up to be 5 m long and 0.75 m wide, with three rows at 25 cm intervals. In the experiment, an area of 1.50 m was left between the blocks and 0.50 m between the plots. In both years of research, sowing was done manually on October 15, with 8 kg of seeds per hectare. Germination of seeds was excellent in both years of the experiment. Weed control was done manually, and no fertilizer was used. The plants were harvested by hand on July 7, 2016 in the first year and July 20, 2017 in the second year. After threshing, thousand grain weight, oil ratios, fatty acid compositions, and protein ratios were analyzed in the laboratories of the Ankara Field Crops Central Research Institute. The composition of fatty acids was determined by using Shimadzu GC-2010 (Kyoto, Japan) gas chromatography. The protein ratio was determined using the Dumas method (Velp Scientifica NDA-701) according to AOAC 992.23 (Crude Protein Method in Cereal Grains and Oilseeds), and a coefficient of 6.25, which is a nitrogen factor, was used to calculate the protein.

Table 2. Some soil characteristics of the research site in the experimental area of Abant İzzet Baysal University, Faculty of Agriculture and Natural Sciences.

Years	Depth (cm)	Soil Texture	Total Salt (%)	pH	$CaCO_3$ (%)	Beneficial Nutrients for Plants (kg da^{-1})		Organic Matter (%)
						Phosphorus (P_2O_5)	Potassium (K_2O)	
2016	0-20	Clay	0.041	7.30	3.71	54.52	286.32	2.36
	20-40	Clay	0.059	7.23	4.52	63.26	348.99	2.87
		Average	0.045	7.27	4.12	58.89	317.66	2.62
2017	0-20	Clay	0.400	7.77	5.6	1.80	28.0	1.24
	20-40	Clay	0.400	7.81	6.4	2.70	25.0	1.14
		Average	0.400	7.78	6.0	2.25	26.5	1.19

Statistical Analysis of Data

Variance analysis of the data obtained in the study was performed using the JMP 13 statistical software program (SAS Institute, Cary, NC). The averages with significant differences were grouped by the LSD multiple comparison test.

RESULTS AND DISCUSSION

Variance analysis of the combined averages of the agricultural and technological characteristics of camelina genotypes are given in Table 3, and the averages and determined LSD groups are presented in Table 4.

Statistically significant (1%) differences were found between genotypes in terms of thousand grain weight, oil ratio, and protein ratio from the seed characteristics studied (Table 3). For this reason, the materials studied are suitable for use as genetic material in breeding studies regarding these properties. Although the oil ratio is one of the most important selection criteria in oilseed plants, the pulp of these plants is a valuable product in animal nutrition. Therefore, the protein ratio should also be considered as an important selection criterion in breeding oilseed plants.

1000 Seed Weight (g)

Another selection breeding criterion in oilseed plants is the1000 seed weight (Vollmann and Rajcan 2009). A high average 1000 seed weight is important in providing a faster and stronger output in adverse climate and soil conditions (Katar and Katar 2017). Results of this study found that the PI 650160 genotype had the highest 1000 seed weight with 1.5 g, while the Pi 650151 genotype had the lowest 1000 seed weight with 0.63 g (Table 4). This is similar to the results of various researches on 1000 seed weight: 1.24 g (Katar et al. 2012b), 1.16 g (Katar et al. 2012c), 0.44 g (Katar et al. 2012a), and 1.19 – 1.48 g (Arslan et al. 2014).

Oil Ratio (%)

The oil deficit in Turkey has been increasing for nearly 60 years; hence, it is important to determine what plant genotypes contain a high oil content and can be grown on alternative agricultural lands, so that these genotypes may be used as gene sources in breeding programs. As shown in Table 3, the highest oil ratio value was measured in the PI 650158 genotype with 39.17%, while the lowest oil ratio was observed in the Ames 31219 genotype with 26.69%. While the oil ratios in this research are similar to the results of Arslan et al. (2014) who obtained values between the range of 24.23 – 32.30%, the present study generated values that were still moderately lower than the following studies: 41% (Zubr and Matthäus 2002), 38 – 43% (Gugel and Falk 2006), and 35 – 40% (Urbaniak et al. 2008). Such possible variations have been reported to be caused by both genotype and environmental differences (Gesch et al. 2018; Anderson et al. 2019).

Table 3. Variance analysis of observed parameters in camelina genotypes.

Variation Sources	M.S. & Significance Status		
	1000 Seed Weight (g)	Oil Ratio (%)	Protein Ratio (%)
Blocks	0.0055	1.3023*	0.2292
Genotypes	0.0451**	6.8846**	3.2978**
Error	0.0055	0.314	0.3403
CV	6.35	1.59	2.32

*: significant at %5 probability level, **: significant at % 1 probability level.

Protein Ratio (%)

High protein content in oilseed plants is an important factor in increasing the nutritional properties of oilseed pulp. Hence, it is preferred that the oil and protein ratios in oilseed plants are as high as possible. Among the genotypes studied in this study, it was found that the PI 650164 genotype had the highest protein ratio at 29.81%, while the PI 258367 genotype had the lowest protein ratio at 21.81% (Table 4). The average protein ratio values obtained as a result of the study were consistent with the results of previous studies on the camellia plant, such as 27 – 32% (Gugel and Falk 2006), 26 – 27% (Gesch et al. 2018), and 30–31% (Anderson et al. 2019).

Fatty Acid Composition of the Camelina Oil

Aside from the oil ratio, another significant factor in assessing the nutritional value of oils derived from oilseed plants is the proportion of total saturated/ unsaturated fatty acids; particularly important to the members of the Brassicaceae family such as camelina is the ratio of erucic acid, an undesirable fatty acid contained in oil. The present study found that the ratio of erucic acid in the examined genotypes varies between 2.1% and 5% (Fig. 2). In particular, the PI 650152 genotype is the only genotype that complies with the ceiling limit for the ratio of erucic acid (2%) established by the Edible Oil Communiqué.

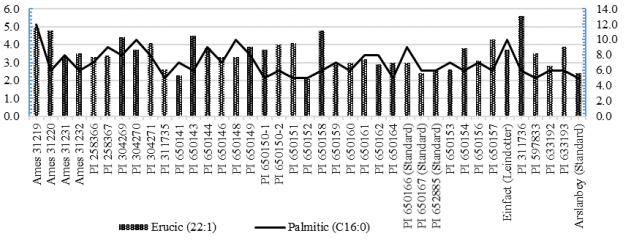


Fig. 2. The erucic and palmitic acid ratios (%) in the fatty acid composition of the camelina.

Linolenic acid ratios were the highest obtained values in the present study (8 –36% or 18:3), followed by eicosenoic acid (12–23% or 20:1). Linoleic acid and oleic acids, meanwhile, showed similar values (Fig. 3). These four acids have been identified by previous researches as the main fatty acids of camelina oil (Berti et al. 2011; ighini et al. 2016; Gesch et al. 2018). The average values of other fixed fatty acids in this study were found to be similar to the observations of Zubr and Matthäus (2002) and Urbaniak et al. (2008), with linolenic acid being the highest (Anderson et al. 2019).

Table 4. Mean comparison of the *C. macrocarpa* and *C. sativa* (L.) Crantz genotypes, at 1% level of significance using LSD.

No	Accession No./ Genotype Name	1000 Seed Weight (g)	Oil Ratio (%)	Protein Ratio (%)
1	Ames 31219	0.74 r-t	26.69 q	25.81 d-i
2	Ames 31220	0.84 o-s	32.69 m-o	24.81 f-l
3	Ames 31231	0.94 j-r	38.69 ab	23.81 j-n
4	Ames 31232	1.29 a-e	35.69 e-j	24.81 f-l
5	Arslanbey (Standard)	1.36 ab	37.93 a-c	25.50 e-i
6	Einfact (Leindotter)	1.03 f-q	36.42 c-h	24.06 i-m
7	PI 650166 (Standard)	1.17 c-h	33.93 k-m	24.50 h-l
8	PI 650167 (Standard)	1.07 g-m	35.95 e-h	24.75 g-k
9	PI 652885 (Standard)	1.09 f-k	34.98 g-j	24.50 h-l
10	PI 258366	1.27 a-f	32.69 m-o	24.81 f-l
11	PI 258367	1.32 a-d	37.69 a-d	21.81 o
12	PI 304269	1.09 e-n	35.69 e-j	25.81 d-i
13	PI 304270	1.12 d-m	37.69 a-d	23.81 j-n
14	PI 304271	1.32 a-d	34.69 g-l	24.81 f-l
15	PI 311735	1.34 a-c	38.69 ab	28.81 a-c
16	PI 311736	0.83 p-s	35.42 f-k	29.06 ab
17	PI 597833	0.88 l-r	35.42 f-k	26.06 d-h
18	PI 633192	1.05 e-o	37.42 a-e	23.06 l-n
19	PI 633193	1.03 f-q	37.42 a-e	24.06 i-m
20	PI 650141	0.93 k-r	36.72 b-f	28.31 a-c
21	PI 650143	0.80 q-s	32.72 l-o	25.31 e-j
22	PI 650144	0.90 l-r	35.72 d-i	27.31 b-d
23	PI 650146	1.15 c-j	34.72 g-k	25.31 e-j
24	PI 650148	0.85 n-r	34.72 g-k	22.31 mn
25	PI 650149	1.15 c-j	35.72 d-i	24.31 g-l
26	PI 650150-1	1.23 b-h	31.72 op	25.31 e-j
27	PI 650150-2	1.25 b-g	31.72 op	25.31 e-j
28	PI 650151	0.63 st	33.72 j-n	24.31 g-l
29	PI 650152	1.08 d-o	34.72 g-k	23.31 k-n
30	PI 650153	0.98 i-r	35.42 f-k	24.06 i-m
31	PI 650154	1.03 f-q	37.42 a-e	27.06 c-e
32	PI 650156	0.93 j-r	35.42 f-k	26.06 d-h
33	PI 650157	1.00 h-q	31.42 op	24.06 i-m
34	PI 650158	1.20 b-i	39.17 a	27.81 b-d
35	PI 650159	1.10 c-m	36.17 d-h	24.81 g-l
36	PI 650160	1.50 a	38.17 a-c	26.81 c-f
37	PI 650161	1.15 c-k	32.17 no	24.81 g-l
38	PI 650162	1.07 e-p	36.17 d-h	24.81 g-l
39	PI 650164	1.12 c-l	35.17 f-k	29.81 a

Correlation Analysis Results

Only the genotypic characteristics were effective in the relationships between all parameters examined, as the compared genotypes were not treated with fertilizers or other factors, and since the data reflected the highest heritability. Oleic acid was significantly and negatively associated with linoleic (r = - 0.321*) and linolenic acids (r = - 0.687**) while it had a significant and positive association with eicosenoic (r = 0.695**) and palmitic acids (r = 0.667) (Table 5). Results showed that the range of variability in the genotypes could be utilized for the improvement of traits. As seen in Table 5, linoleic acid was negatively and significantly associated with eicosenoic (r = - 0.455**) and palmitic acid (r = - 0.429**) while it was positively correlated with linolenic acid (r = 0.489**) and 1000 seed weight (r = 0.369*). The eicosenoic acid was negatively and significantly correlated with linolenic acid (r = - 0.845**), while it was positively related to palmitic acids (r = 0.880**). A significant and negative correlation was also observed between linolenic and palmitic acid (r = - 0.923**), while it was determined to have a significant and positive association with protein

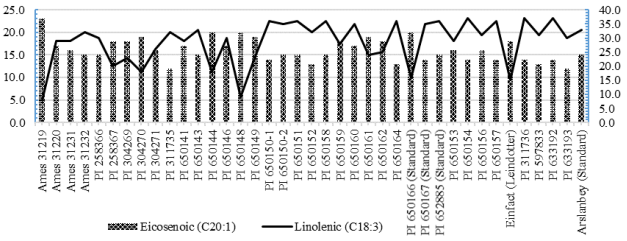


Fig. 3. The eicosenoic and linolenic acid ratios (%) in the fatty acid composition of the camelina.

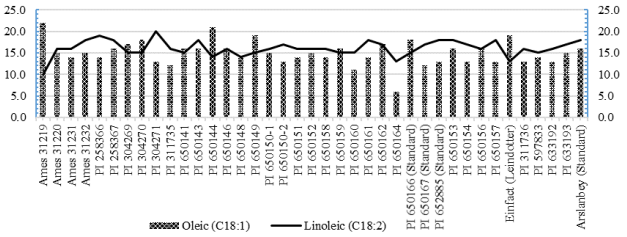


Fig. 4. The oleic and linoleic acid ratios (%) in the fatty acid composition of the camelina.

Table 5. Correlation coefficients among the observed of characters of camelina genotypes.

Observed Properties	OL-A	LNO-A	ES-A	LNN-A	E-A	P-A	TSW	OR	PR
Oleic acid (OL-A)	1	-0.321 *	0.695 **	-0.687 **	0.199	0.667 **	-0.261	-0.209	-0.292
Linoleic acid (LNO-A)		1	-0.455 **	0.489 **	-0.155	-0.429 **	0.369 *	0.144	-0.254
Eicosenoic acid (ES-A)			1	-0.845 **	0.16	0.88 **	-0.147	-0.28	-0.241
Linolenic acid (LNN-A)				1	-0.101	-0.923 **	0.167	0.209	0.337 *
Erucic acid (E-A)					1	0.191	-0.364 *	-0.361 *	0.157
Palmitic acid (P-A)						1	-0.163	-0.198	-0.323 *
1000 seed weight (TSW)							1	0.346 *	0.022
Oil ratio (OR)								1	0.11
Protein ratio (PR)									1

*. Correlation is significant at the 0.05 level.
**. Correlation is significant at the 0.01 level.

ratio (r = 0.337*). As observed in Table 5, erucic acid had a significant and weak correlation with 1000 seed weight (r = - 0.364*) and oil ratio (r = - 0.361*). Palmitic acid also had a negative and significantly weak correlation with protein ratio (r = - 0.323*), while 1000 seed weight had a positive and significant correlation with oil ratio (r = 0.346*).

CONCLUSION

As a result of the analysis of oil, crude protein, and fatty acid content of camelina seeds, it was determined that there were significant differences between genotypes in terms of oil and protein ratio. The PI 650158 genotype was found to have the highest oil ratio (39.17%) but only ranked third in the LSD group in terms of protein ratio, while the PI 650164 genotype had the highest crude protein content (29.81%) but only ranked fifth in the LSD group in terms of oil ratio. The PI 311735 and PI 650158 genotypes were found to be within acceptable limits in terms of both oil and protein ratio despite one being negatively affected by the other. These findings will prove to be useful for future studies on the cultivar breeding of camelina genotypes in areas with temperate ecological conditions.

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Declaration of Competing Interest

The authors declare that there is no conflict of interest. The authors alone are responsible for the content of the paper.

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