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Phenology, Morphology, Yield and Quality Characteristics of Mustard Species (*Brassica* spp.) Suitable for Energy Sector

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Abstract

There is a need to identify new renewable, sustainable and clean energy sources in the world. This study was conducted to determine the genotypes of different *Brassica* species suitable for the energy sector. A total of 21 genotypes, consisting of 19 lines (*B. juncea, B. nigra, Sinapis alba* and *B. rapa* ssp. oleifera) and two standards (ISCI-99 and Excalibur used as control) were evaluated in the study. The research was carried out during 2019–20 and 2020–21 growing seasons at Tokat, Turkey. The parameters related to yield and yield components (days to emergence, days to rosette formation, winter survival percentage, days to 50% flowering, days to 50% capsule formation, days to maturation, plant height, number of lateral branches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight, seed yield), crude oil percentage, crude oil yield, fatty acid components, biodiesel production and their technical properties for appropriateness to bioenergy production were investigated. The results showed that the yield, yield components, oil content, fatty acid components and biodiesel technical properties of lines were significantly dissimilar. Seed yields varied between 37 and 1195 kg ha^{-1} and the maximum seed yield was obtained in the second year of the study from the line 5. Oleic acid (C18:1; 17.12–26.8%), linoleic acid (C18:2; 13.15–24.60%), and erucic acid (C22:1; 12.13–42.76%) were the predominant fatty acids of the lines. The excess of monounsaturated fatty acids in the oils indicated that the fatty acid components are suitable for biodiesel production. Water content, cold filter plugging point, ester percentage, flash point, acid number, iodine number, and glyceride values of oils in all lines are within acceptable limits for biodiesel production according to TS EN 14214 standards. The yield and quality data of the species revealed that *B. juncea* and *B. rapa* lines have higher potential as a raw material source for biodiesel production.

Keywords *Brassica juncea* · *Brassica rapa* ssp. oleifera · *Sinapis alba* · *Brassica nigra* · Biodiesel · Fatty acids

Introduction

Many species in the *Brassicaceae* (*Cruciferae*) family are cultivated for dissimilar uses, especially in the food and energy sector. This family is represented by 85 genera and 567 taxa in Turkey (Davis 1965). *Sinapis alba* (white mustard), *S. arvensis* (wild mustard), *Brassica juncea* (brown mustard) and *B. nigra* (black mustard) are the commonly found species in the flora of Turkey (Guner et al. 2012).

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Mustard, which contain 25–35% oil in their seeds, have the potential to be an important raw material in the food and energy sector (Tonguc and Erbas 2012; Kayacetin et al. 2018a). White mustard, black mustard and brown mustard are found both in wild and cultivated in the fields globally (Kayacetin 2020a). These species in genus mustard also contain dissimilar compounds in their oils such as glycoside, arachidic acid, sinabin, lignoceric acid and erucic acid. These compounds are generally not suitable for direct consumption as vegetable oil due to high erucic acid (Kayacetin et al. 2016). However, fresh leaves and fresh flower shoots are used in making stew, salad, and used as spice. They are also used in pharmaceutical, beekeeping, and cosmetic industries. Making of green manure, soil conditioners, biofuel raw material, and animal feed cakes are is very popular (Mao et al. 2012; Singh et al. 2016; Kayacetin et al. 2018b). The black mustard has the sharpest flavor as a spice, while white mustard has the mildest flavor. Brown mustard is used to produce Dijon mustard (Palle-Reisch et al. 2013). A limited number of studies have been conducted in Turkey that have indicated that indigenous lines could also be used as spice (Turkish Food Codex) and in the biodiesel sector (TS EN 14214) (Eryilmaz and Ogut 2011; Kayacetin 2019) Therefore, cultivation, production and breeding of these species, could serve as protecting the local germ plasm and saving the foreign exchange spent on import of these genotypes from abroad for local use.

The latest developments in biofuels, oilseeds and other crops was discussed in the 2012–2021 assembly of the United Nations Food and Agriculture Organization (FAO) and the Organization for Economic Cooperation and Development (OECD) (OECD-FAO 2012). The report of the meeting mentioned that the increase in sustainability of crop productivity has a key role to meet the demands of the growing world population. Furthermore, the report indicated that the share transferred from agricultural production to biofuel production is continuously increasing, and the demand for agricultural production is expected to increase by 60% in the next 40 years. On the other hand, the amount of arable land is expected to increase by 5% only in the same period. The increase in plant production will be used in energy production rather than human or animal consuption (Food and Agriculture Organization 2008). The statements emphasize the conservational practices such as crop diversity, productivity, quality improvement and crop rotation in agriculture.

Cold and drought stress encountered in oilseed production negatively affect the yield of oil crops. The oilseed crops should be grown in accordance with the needs of the industry to increase production (Kayacetin et al. 2018b). The cold resistance of brown and black mustard lines is high and the cold resistance of white mustard lines is low. The studies further mentioned that oil yields of white mustard is low; therefore, brown and black mustard lines is the most promising type in providing raw materials for biodiesel production (Uhl 2000; Kayacetin 2019).

The mustard can be an important alternative raw material in biodiesel production. However, there are only few registered mustard varieties in the world to meet the demands of the energy industry. The local mustard cultivars are not available in Turkey; therefore, studies should be carried out on evaluation of the local genetic resources of mustard in Turkey. Productive and high quality mustard varieties should be bred to meet the demands of energy industry. The purpose of this study was to evaluate, compare and study 21 genotypes of dissimilar genetic background to select the most suitable materials for the energy sector.

Material and Methods

The research was carried out at the Agricultural Application and Research Center of Tokat Gaziosmanpasa University Turkey during 2019–2020 and 2020–2021 growing seasons.

Table 1 Mustard lines used in the experiments

Species	Line no	Accession number	Source of seed	Seed color
Brassica juncea	1	PI 169077-3	USDA	Brown
	2	PI 120923-2	USDA	Brown
	3	PI 179191-10	USDA	Brown
	4	PI 175602-6	USDA	Brown
	5	PI 179192-11	USDA	Brown
	6	H8	FCCRIT	Brown
	7	S9	FCCRIT	Brown
	8	PI 169085-5	USDA	Brown
Brassica rapa ssp. oleifera	9	PI 169095-36	USDA	Brown
	10	PI 171521-40	USDA	Brown
	11	PI 179184-48	USDA	Brown
Brassica nigra	12	PI 169059-16	USDA	Brown
	13	PI 169066-18	USDA	Brown
	14	PI 169067-19	USDA	Brown
Brassica juncea (oriental)	15	PI 633086-20	USDA	Oriental-Yellow
	16	PI 649101-27	USDA	Oriental-Yellow
Sinapis alba	17	SA 1	FCCRIT	Yellow
	18	SA 2	FCCRIT	Yellow
	19	SA 5	FCCRIT	Yellow
Standards	20	ISCI-99 (*B. juncea*)	Private company	Brown
	21	Excalibur (*B. napus*)	Private company	Brown

Table 2 Some soil physical and chemical properties of the experimental field

Years	Texture	EC (dS m^{-1})	pH	$CaCO_3$ (%)	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Organic matter (%)
2019–2020	Clay loam	0.37	7.92	9.50	55.8	899	1.82
2020–2021	Clay loam	0.37	7.86	8.60	10.5	571	1.39

The research center is located between 40° 33′ north latitude and 36° 36′ east longitude, with altitude of 620 m asl. The study area has a transitional climate between the Central Anatolian climate and the Black Sea climate.

Nineteen (19) lines from dissimilar species of genus *Brassica* (*B. juncea* [brown mustard-10 lines], *B. nigra* [black mustard-3 lines], *S. alba* [yellow/white mustard-3 lines] and *B. rapa* ssp. oleifera [field mustard/oil turnip-3 lines]) and 2 standards (Standard1-ISCI-99 [*B. juncea*] and Standard2-Excalibur [*B. napus*]) were used as control (Table 1). The lines used in the study were obtained from the Gene Bank of the United States Department of Agriculture (USDA) and the Field Crops Central Research Institute, Ankara, Turkey (FCCRIT). The lines constituting the material of the study were characterized at FCCRIT, and the advanced lines were selected using with the Pure Line Selection Method by FCCRIT and were given an accession number (Table 1).

The soil samples of the experimental fields were collected from 0–30 cm depth, and analyzed in the soil quality and fertility laboratory of the Turkish Ministry of Agriculture and Forestry (Table 2). Soils in the experimental fields had clay loam texture and very low organic matter content. The soils were moderately calcareous and slightly alkaline. The soils were non-saline, rich in potassium and sufficient in phosphorus (Kacar 2012).

The long-term average total precipitation of the experimental area was 395.3 mm. The total precipitation in the first year was 9.39% higher than the long-term average precipitation; and it was 26.61% lower in the second year of the experiment. The maximum average precipitation in long-term occurred in May, but June in the first year, and March in the second year. The long-term average, maximum and minimum temperature values and average relative humidity were 9.6 °C, 39.8 °C, –23.4 °C and 64.6%, respectively. The average relative humidity and temperature values during the experimental years were close to the long-term averages (Table 3). The maximum air temperature value was 3–5 °C lower, and the minimum air temperature was approximately 10 °C higher than the long-term temperatures. These changes in the temperatures can offer opportunities for winter sowing of mustard lines.

The seeds of all lines were sown on October 9 in the first year and October 6 in the second year. Each plot consisted of six rows with 6 m length. The inter-row distance was 30 cm, and sowing density was 200 plants per square meter (Kayacetin et al. 2018b). The experimental field was irrigated twice at 15-days intervals after sowing to ensure the emergence in both years. 100 kg N ha^{-1}, 50 kg P ha^{-1} and 35 kg S ha^{-1} were applied in all plots. Half of the nitrogen was applied during sowing and the remaining half was applied in March during the shooting stage. The weeds,

Table 3 Climate data of the experimental area for long-term and the growing seasons of the experiment

Climatic factors	Years	October	November	December	January	February	March	April	May	June	Total/Mean/Max./Min
Total precipitation (mm)	1951–2020	38.1	43.2	46.5	41.5	32.9	41.0	54.6	58.7	38.8	395.3
	2019–2020	3.7	25.0	37.1	52.8	66.2	32.9	22.0	36.9	81.6	358.2
	2020–2021	0.1	11.1	17.2	62.7	8.7	71.2	14.2	49.4	55.5	290.1
Mean relative humidity (%)	1951–2020	65.2	70.0	71.9	69.6	64.5	60.6	59.0	61.3	59.7	64.6
	2019–2020	60.9	65.9	76.0	73.9	70.8	62.6	56.8	59.1	63.8	65.5
	2020–2021	46.0	72.3	73.2	68.3	60.5	65.6	57.1	62.2	62.7	63.1
Mean air temperature (°C)	1951–2020	13.7	7.8	3.7	1.7	3.5	7.4	12.4	16.3	19.6	9.6
	2019–2020	17.4	9.0	5.8	3.0	4.0	9.8	11.1	17.0	20.7	10.9
	2020–2021	18.0	7.4	5.5	5.0	5.1	6.0	13.7	17.9	20.0	11.0
Max. air temperature (°C)	1951–2020	35.3	30.8	26.0	20.2	22.8	31.1	35.1	36.4	39.8	39.8
	2019–2020	31.3	22.4	16.5	12.0	18.1	25.1	26.0	35.0	34.9	34.9
	2020–2021	33.9	19.7	17.3	21.9	20.5	18.2	29.3	37.0	32.5	37.0
Min. air temperature (°C)	1951–2020	–3.2	–11.8	–21.0	–23.4	–22.1	–21.2	–6.3	–0.0	2.7	–23.4
	2019–2020	5.9	–2.3	–3.0	–6.2	–10.7	–3.0	–0.9	3.2	10.2	–10.7
	2020–2021	7.1	–4.5	–4.4	–9.4	–13.7	–3.2	1.3	2.1	8.7	–13.7

Directorate General of Meteorology Ankara, Turkey leafhoppers, apple blossom beetle, and aphids were controlled when necessary. The plants belonging to each genotype were harvested very carefully using a plot harvester.

The number of days to emergence, days to rosette formation, winter survival percentage, days to 50% flowering, days to 50% capsule formation, and days to maturation were determined for all lines. Furthermore, plant height, number of lateral branches, number of capsules, and number of seeds were also detected in five randomly selected plants from each plot. The seed yield, thousand seed weight, crude oil percentage, crude oil yield, fatty acid components, and biodiesel technical properties of the seeds were determined after the harvest (Kayacetin et al. 2018b). Two grams of ground seed samples from each lines were used to determine the crude oil percentages (%) by anhydrous ether extraction method in Soxhalet oil device. The seed samples collected from each plot were ground and the oil extracted was esterified. The percentages of palmitic, stearic, oleic, linoleic, linolenic, and erucic acid were determined by analyzing the esterified oil in a gas chromatography device equipped with an FID detector and 60 m capillary column. The oils obtained from the mustard lines were converted into biodiesel by trans-esterification method (Kayacetin et al. 2016). Since there were not enough seeds in the 2019–20 growing season, the biodiesel analyzes were carried out without repetition using the lines with sufficient seeds in the 2020–21 growing season.

The differences in the traits determined between the mustard lines and standards were assessed using analysis of variance (ANOVA). The means of the traits of respective mustard lines were compared using a LSD's test ($p < 0.05$) (Sall et al. 2017). All statistical analysis were carried out using the JMP 13 Statistical Software.

Results and Discussion

Although the emergence period varied with the species, the days to emergence was 38–48 days in the first year and 7–11 days in the second year. The first emergence in both years of the study took place in the lines belonging to *S. alba*. The emergence of *B. juncea, S. alba* and *B. rapa* lines was more homogeneous. Germination-emergence problems were experienced in line Excalibur during the first year, and in the lines belonging to *B. nigra* lines during both years. Variability in the days to emergence can be attributed to fluctuations in soil temperature and moisture levels at sowing time and the fluctuations in temperature and hot and dry climatic conditions during fall caused emergence problems (Salimi 2009; Kayacetin 2021).

Only the lines belonging to *S. alba* showed rapid germination and development during winter months at rosette stage during the first year. However, the line 14 could not germinate to reach rosete stage during winter months the *S. alba* lines, which developed rapidly, reached the winter in a very advanced rozette stage. The transition of the species to the rosette stage took 79–92 days in the 2019–20 growing season and 21–42 days in the 2020–21 growing season. Lack of snowfall and low temperatures (–11 °C) during the months of Dec and Jan, induced damage and mortalities in some lines, which failed to reach rosette stage. Kolsarıcı and Basalma (1988) mentioned that the plants reaching 10–13 cm height and completing the rosette stage can withstand temperatures as low as –15 °C and even –20 °C under snow cover in winter months. Genetic characteristics and environmental conditions had significant effects on the number of days at rosette stage. The days to germination of the species in days to the rosette stage. The maximum winter damage in the first year was observed in

Table 4 Phenotypic traits of the lines

Species	Days to emergence (d)		Days to rosette formation (d)		Winter survival percentage (%)	
	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21
B. juncea	47	11	92	28	28.9–49.1	57.3–79.1
B. rapa ssp. oleifera	47	8	79	28	23.8–57.2	28.9–44.5
B. nigra	48	11	87	42	45.6–78.5	51.2–68.0
S. alba	38	7	91	21	15.4–27.7	All died
ISCI-99	47	9	92	28	45.9	61.1
Excalibur	47	9	92	28	35.4	27.4
Species	**Days to 50% flowering (d)**		**Days to 50% capsule formation (d)**		**Days to 90% maturity (d)**	
	2019–20	**2020–21**	**2019–20**	**2020–21**	**2019–20**	**2020–21**
B. juncea	210	206	219	229	259	271
B. rapa ssp. oleifera	181	184	192	212	243	257
B. nigra	221	219	251	246	297	288
S. alba	192	–	204	–	250	–
ISCI-99	210	202	219	226	259	271
Excalibur	210	196	219	216	259	271

B. nigra (45.6–78.5%), while the maximum winter damage in the second year was recorded in *S. alba* (100%). The winter damage rate of ISCI-99 was 45.9% (the first year) and 61.1% (the second year) while the winter damage rate for Excalibur was 35.4% (first year) and 27.4% (second year) in the experiment (Table 4). Therefore, sowing time studies specific to the species are desired.

The first flowering occurred in *B. rapa* lines, which was followed by *S. alba* lines. The duration of flowering period was 181–221 and 186–219 days in 2019–20 and 2020–21 growing seasons in the same order. The temperature and precipitation differences were observed in both experimental years, which also affected the days of flowering. The flowering period was significantly affected by climatic conditions, especially low temperature based elongation in the flowering period (Bhargava et al. 1983). Furthermore, flowering periods were prolonged depending on the delay in emergence. Then, with the sudden increase in temperatures in the spring, the plants entered the generative period earlier. This situation shortened the vegetation period in plants and negatively affected the yield. Genetic characteristics of the lines and environmental conditions had significant effect on the differences in days to flowering of the lines used in the study in agreement with Tobe et al. (2013); Gizlenci (2017); Singh et al. (2017).

The days to seed pod formation were dissimilar among the lines and species, which was 192–251 days in the first year of the experiment, and 212–246 days in the second year. The *B. rapa* lines were completely encapsulated in May. The temperature and precipitation values were dissimilar in both growing seasons of the experiment. The increase in precipitation in the second year from the sowing date influenced the prolongation of the vegetation period. The flowering period was affected by climatic conditions. Low temperatures elongated the flowering period (Bhargava et al. 1983). The days to maturation were between 243 and 297 in the first year, and 257–288 days in the second year. The differences in days to maturation between the species in the second year were shorter compared to the first year due to the higher average temperature values in the second year. The results revealed that the increase in temperature accelerated the flowering, while low temperatures delayed the flowering (Kayacetin 2020). Singh et al. (2017) and Kayacetin (2022) have mentioned that high temperatures during crop maturation induced negative impacts on plant growth and dissimilar ontogenetic growth parameters. Temperature increase caused the plants to mature in a shorter time (Wu

Table 5 Plant height, number of lateral branches, number of capsules and, number of seeds for the lines of the dissimilar species in genus *Brassica* used in the study

Lines		Plant height (cm)**		Number of lateral branches (branch plant^{-1})**		Number of capsules (capsule plant^{-1})**		Number of seeds (seed capsule^{-1})**	
		2020	2021	2020	2021	2020	2021	2020	2021
B. juncea	1	149.8b	163.4a	6.9bc	9.2b–f	214.2b	192.2d	11.9f	14.8c
	2	145.9b	156.2ab	7.2bc	10.0bcd	181.1bc	244.5bcd	12.7ef	15.4 cd
	3	149.9b	153.6ab	7.5b	9.0c–f	151.7bc	264.3abc	13.7de	16.8 cd
	4	145.2b	161.0a	6.9bc	9.0c–f	123.1c	303.3ab	12.8ef	15.2c
	5	152.5b	164.7a	7.0bc	9.6b–e	153.1bc	251.8bcd	13.3e	15.2c
	6	151.6b	159.6ab	6.7bc	9.0c–f	126.7c	257.2abc	13.2e	14.8c
	7	150.1b	159.4ab	7.2bc	10.3bc	136.2bc	267.2abc	13.4e	15.5 cd
	8	157.9b	159.7ab	6.9bc	9.4bcd	173.7bc	316.3a	13.0e	15.8 cd
B. rapa ssp. oleifera	9	89.2e	158.7ab	6.0c	10.3bc	334.8a	260.5abc	16.8b	16.6 cd
	10	91.7e	161.7a	6.3bc	10.0bcd	330.8a	281.8abc	15.8c	15.5 cd
	11	92.5e	158.3ab	7.4b	10.5b	390.0a	260.5abc	19.7a	16.1 cd
B. nigra	12	174.3a	172.2a	14.5a	11.8a	175.3bc	224.3 cd	16.0bc	5.3e
	13	–	174.0a	–	12.8a	–	256.9abc	–	4.7e
	14	–	116.9c	–	10.3bc	–	248.8bcd	–	11.9d
B. juncea (oriental)	15	149.5b	159.7ab	7.5b	8.0 fg	196.3bc	261.8abc	12.7ef	14.8c
	16	151.4b	164.1a	6.5bc	8.5ef	160.2bc	246.9bcd	14.5d	16.0 cd
S. alba	17	114.7d	–	6.0c	–	170.3bc	–	4.2g	–
	18	130.2c	–	7.5b	–	185.7bc	–	4.4g	–
	19	114.6d	–	6.3bc	–	170.8bc	–	4.4g	–
ISCI-99	20	154.7b	173.1a	7.4b	8.8def	147.1bc	237.3 cd	13.5e	17.7b
Excalibur	21	–	140.9b	–	7.1g	–	118.0e	–	28.6a
CV (%)		6.7	7.2	9.1	7.9	25.1	14.6	4.2	9.4

** significant at $p < 0.01$

Table 6 Thousand seed weight, seed yield, crude oil percentage and crude oil yield values for the lines of dissimilar species in genus *Brassica* used in the study

Lines		Thousand seed weight (g)**		Seed yield (kg ha^{-1})**		Crude oil percentage (%)		Crude oil yield (kg ha^{-1})	
		2020	2021	2020	2021	2020	2021	2020	2021
B. juncea	1	1.15de	1.68g	492d	831b–e	21.5	25.3	106	211
	2	0.92ef	1.73 fg	396e	677de	20.8	26.3	82	178
	3	1.05def	1.67g	461d	717cde	21.7	26.4	10	188
	4	0.99def	1.77d–g	352ef	865bcd	23	22.4	81	194
	5	1.15de	1.99bc	461d	1195a	23.7	25.5	109	305
	6	1.22de	2.08abc	491d	651de	22.7	24.3	111	158
	7	1.47c	2.21ab	398e	604e	18.6	22.2	74	134
	8	1.14de	1.93cde	514d	1178a	22.8	20.4	117	240
B. rapa ssp. oleifera	9	0.77f	1.77efg	75hi	934bc	21	26.1	16	243
	10	0.77f	1.74efg	103h	744b–e	21.8	24.5	23	182
	11	0.77f	1.63g	37i	679de	20.4	14.4	7	98
B. nigra	12	0.85f	0.51h	74i	23g	17.7	–	13	–
	13	–	0.39h	–	36g	–	–	–	–
	14	–	1.62g	–	255f	–	15.5	–	39
B. juncea (oriental)	15	0.81f	1.87c–f	322f	910bc	22.7	21.6	73	197
	16	0.89ef	2.17ab	34ef	1352a	22.3	20.2	76	274
S. alba	17	4.56a	–	129a	–	10.9	–	141	–
	18	4.20b	–	724c	–	15	–	109	–
	19	4.02b	–	901b	–	13.4	–	121	–
ISCI-99	20	1.17de	1.96 cd	249g	961b	30.1	22.4	75	215
Excalibur	21	–	2.21a	–	658de	–	15.6	–	102
CV (%)		11.7	7.7	9.2	17.2	Statistical analysis could not be performed because there were no repications			

** significant at $p < 0.01$

et al. 2011). Furthermore, a shortened time to first flowering is a sign of early maturation, and a prolonged maturation time is a sign of late flowering lines (Ozer and Oral 1997).

The maximum plant height in both growing seasons was recorded in lines 12 and 13 (174.3 cm and 174.0 cm, respectively), while the minimum plant height were measured in lines 9 (89.2 cm) and 10 (91.7 cm) (Table 5). The maximum number of lateral branches was obtained in line 12 (14.5 branches plants^{-1}) and the minimum branching was recorded in lines 9 and 17 (6.0 branches plant^{-1}). The maximum number of seed capsules that directly contributes to the seed yield was obtained in line 11 (390.0 plant^{-1}) and the number of seeds per pod in line 21 (28.6 seed capsule^{-1}). Line 17 (4.6 and 2.2 g) had the maximum thousand seed weight, which also contributed significantly to the yield. The maximum seed yields were obtained in 17 (1290 kg ha^{-1}) and 16 (1352 kg ha^{-1}) lines, and the minimum values were recorded in lines 11 (37 kg ha^{-1}) and 12 (23 kg ha^{-1}). The number of lateral branches in all mustard species, the number of capsules in the plant, the number of seeds in the capsules, and thousand seed weight directly affected the seed yield to be obtained per unit area (Kumar et al. 2018; Kayacetin 2019). Seed productivity increased or decreased depending on increase or decrease of one or more of these parameters.

Crude oil percentages of mustard lines ranged from 30.1% (20) to 10.9% (17). The maximum crude oil yield determined by seed yield and oil percentage was obtained from line 5 (305 kg ha^{-1}) (Table 6). Agronomic practices such as sowing time, sowing density, irrigation and fertility, especially genetic structure, are effective on seed yield and crude oil percentages in mustard (Mondal et al. 2018; Kayacetin 2020a, 2022).

The analysis of fatty acid components was performed on 17 lines without replications due to the lack of sufficient seeds. The minimum saturated fatty acids were obtained in line Excalibur (3.66%) and line 11 (3.70%) in 2021. The minimum palmitic (2.40%), stearic (0.50%) and arachidic acid (0.26%) percentages were obtained from lines 10, 2 and 8 in the first year. The maximum monounsaturated fatty acids percentage in the first year was obtained in the line 16 (67.19%), and in the line 11 (61.81%) in the second year. The maximum oleic, eicosanoid and erucic acid percentages were obtained from lines 2 (26.28%), 5 (14.02%) and 11 (34.34%), respectively. The maximum polyunsaturated fatty acids content was measured in line 2

Table 7 Fatty acid component values for the lines of dissimilar species in genus *Brassica* used in the study

Lines	Palmitic acid		Stearic acid		Arachidic acid		ΣSaturated fatty acid		Oleic acid		Eicosenoic acid		Erucic acid		Σ Mono unsaturated fatty acid		Linoleic acid		Linolenic acid		ΣPoly unsaturated fatty acid	
	C 16:0		C 18:0		C 20:0				C 18:1		C 20:1		C 22:1				C 18:2		C 18:3			
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
1	–	2.93	–	1.15	–	1.04	–	5.12	–	21.64	–	1.04	–	19.22	–	41.90	–	22.20	–	14.39	–	36.59
2	3.66	2.95	1.74	0.50	0.98	0.55	6.38	4.00	24.96	26.28	13.30	0.55	17.91	13.50	56.17	40.32	22.29	23.64	12.12	14.85	34.41	38.49
3	3.65	3.40	1.77	1.40	0.89	0.54	6.31	5.34	24.67	24.14	13.82	0.54	20.37	12.13	58.86	36.81	20.91	24.09	11.65	15.43	32.56	39.51
4	3.57	3.14	1.68	1.49	0.92	0.44	6.17	5.07	23.68	24.43	13.51	0.44	21.67	13.11	58.86	37.97	20.85	23.69	11.55	15.28	32.40	38.97
5	3.45	3.25	1.67	0.85	1.07	0.48	6.19	4.58	23.50	24.56	14.02	0.48	21.06	12.57	58.58	37.60	21.03	23.69	12.05	16.48	33.08	40.17
6	3.56	3.20	1.62	1.29	0.84	0.83	6.02	5.31	24.60	23.67	13.69	0.83	20.61	12.13	58.90	36.62	21.69	24.60	11.12	16.04	32.81	40.64
7	3.65	3.26	1.69	1.15	0.95	0.72	6.29	5.13	23.96	20.91	13.46	0.72	19.70	17.74	57.12	39.36	20.98	22.86	12.67	15.37	33.65	38.22
8	3.53	2.92	1.62	0.90	1.00	0.26	6.15	4.07	23.23	19.56	13.82	0.26	20.34	28.40	57.39	48.22	22.24	20.14	12.00	13.15	34.24	33.28
9	3.63	2.93	1.45	1.15	0.95	1.04	6.03	5.12	20.33	21.64	13.98	1.04	23.24	19.22	57.55	41.90	21.38	22.20	12.09	14.39	33.47	36.59
10	3.59	2.40	1.62	1.09	0.94	0.26	6.15	3.75	23.34	18.44	14.01	0.26	20.27	42.20	57.62	60.90	21.70	13.55	12.16	7.62	33.86	21.17
11	2.90	2.49	1.24	0.93	0.88	0.28	5.02	3.70	20.20	18.77	12.44	0.28	34.34	42.76	66.98	61.81	15.65	13.15	8.27	6.86	23.92	20.01
12	3.13	–	1.31	–	0.88	–	5.32	–	20.61	–	12.31	–	30.68	–	63.60	–	16.64	–	8.43	–	25.07	–
14	2.95	2.78	1.31	1.05	0.73	0.39	4.99	4.22	19.45	17.12	12.10	0.39	31.62	31.59	63.17	49.10	15.20	16.62	7.89	12.28	23.09	28.90
15	3.30	2.76	1.39	1.34	0.72	0.34	5.41	4.43	21.15	20.34	12.63	0.34	28.47	25.85	62.25	46.52	16.76	21.31	8.40	12.40	25.16	33.71
16	3.05	2.40	1.32	1.07	0.79	0.34	5.16	3.81	21.08	22.68	12.89	0.34	33.22	24.48	67.19	47.49	14.93	20.26	7.00	12.53	21.93	32.79
20	–	2.91	–	1.33	–	1.07	–	5.30	–	17.81	–	1.07	–	25.96	–	44.83	–	21.35	–	12.77	–	34.12
21	–	2.50	–	0.90	–	0.26	–	3.66	–	18.56	–	0.26	–	28.31	–	47.13	–	20.14	–	13.15	–	33.28

Table 8 Biodiesel technical characteristics for the lines of dissimilar species in genus *Brassica* used in the study and the values of TS EN 14214 standard

Genotypes	Acid number (mg KOH/g)	Water content (ppm)	Iodine number (g iodine/100 g)	Cold filtration plug point (°C)	Flash point (°C)	Glyceride (% m/m)				
						Monoglyceride content	Diglyceride content	Triglyceride content	Free glycerol	Total glycerol
1	0.38	335	116.91	–4	190	0.265	0.040	0.014	0.01	0.08
2	0.5	300	119.76	–4	205	0.325	0.047	0.010	0.01	0.10
4	0.45	170	118.25	–8	190	0.36	0.045	0.007	0.01	0.11
5	0.45	180	114.08	–7	185	0.34	0.045	0.007	0.01	0.10
6	0.38	320	119.89	–5	190	0.36	0.060	0.050	0.01	0.12
7	0.45	170	118.39	–8	195	0.365	0.045	0.010	0.01	0.11
8	0.43	235	119.40	–5	200	0.25	0.054	0.020	0.01	0.08
9	0.17	460	105.83	–2	205	0.21	0.045	0.080	0.01	0.08
10	0.27	420	105.90	–3	195	0.2	0.047	0.075	0.01	0.08
11	0.20	445	104.32	–3	190	0.2	0.030	0.090	0.01	0.07
15	0.26	300	119.83	–11	195	0.39	0.060	0.050	0.01	0.12
16	0.21	350	118.00	–10	195	0.38	0.060	0.040	0.01	0.12
20	0.47	200	109.83	–4	200	0.51	0.100	0.078	0.01	0.17
21	0.37	205	109.4	–5	200	0.51	0.130	0.070	0.01	0.16
TS EN 14214	Min.–Max –0.50	Min.–Max –500	Min.–Max –120.00	Min.–Max –20–20 °C	Min.–Max 120-	Min.–Max –0.80	Min.–Max –0.20	Min.–Max –0.20	Min.–Max –0.02	Min.–Max –0.25

(34.41%) in the first year, and line 6 (40.64%) in the second year (Table 7). The differences in fatty acids composition differed among the mustard species in agreement with Karaca and Aytac (2007). The fatty acid composition of oily plants is not always constant and the synthesis of fatty acids may vary depending on genetics, ecological, morphological, physiological, and cultural conditions (Aslam et al. 2009; Batoll et al. 2022). Therefore, the information on the variation in the fatty acid composition of oil plants under dissimilar conditions is important for the oil quality. Furthermore, the amount and type of fatty acids are important for the utilization of the oils. The information on the fatty acid composition of oils enables the production of oils according to intended use. Thus, the desired oils can be produced with the cultivation of appropriate lines in appropriate regions (Karaca and Aytac 2007; Kayacetin et al. 2016). The relatively high percentage of monounsaturated fatty acids in the fatty acids was determined in mustard lines that indicated the extent of their suitability for biodiesel production.

The biodiesel technical properties determined from the seeds obtained from the lines in the second year are given in Table 8. Acid number of seeds ranged between 0.17 and 0.50 (mg KOH/g), water content between 110 and 480 (ppm), iodine number between 97.30 and 119.89 (g iodine/100 g), cold filtratiogen plug point 5 to –12 °C, flash point 170–205 °C, monoglyceride content 0.22–0.51% m/m, diglyceride content 0.02–0.17% m/m, triglyceride content 0.003–0.13% m/m, free glycerol 0.01–0.10% m/m and total glycerol 0.06–0.17% L. The biodiesel standard according to TS EN 14214 are given below. The acid number should be less than 0.5 mg KOH/g, the maximum water content is 500 ppm, the iodine number is less than 120 g iodine/100 g, the flash point is above 120 °C, the maximum monoglyceride content should be 0.80, the maximum diglyceride content is 0.2% m/m, the maximum triglyceride is content 0.2% m/m, the maximum free glycerol content is 0.02% m/m and the total glycerol content is 0.25% m/m (Turkish Standards Institution 2019). The results showed that all lines analyzed complied with biodiesel standards. The suitability of the iodine number, which is the most important obstacle to the use of domestic resources in biodiesel production, is very important for the dissemination of the results.

Conclusion

Lines of *B. juncea* and *B. rapa* performed better compared to the standard cultivars used in the study. The future studies should be carried out using these species. Despite all the adverse climatic conditions, the results obtained for the lines used in the study showed improved performance compared to the standard lines used in the study.

The biodiesel produced from the oil of mustard species complied with the criteria of TS EN 14214. The compatibility of fatty acids composition, reveals that biodiesel can be produced from the mustard lines of dissimilar orgin from *B. juncea* and *B. rapa* mustard species, and could be used in provision of raw materials for dissimilar industries, to boost the Turkish economy.

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Author Contribution A. Kinay: Conceptualization, investigation, methodology, formal analysis, resources, writing-original draft preparation, writing-review and editing. F. Kayacetin: Conceptualization, investigation, methodology, formal analysis, resources, writing-original draft preparation, writing-review and editing, statistical analysis, project administration. All authors have read and agreed to the published version of the manuscript.

Conflict of interest A. Kinay and F. Kayacetin declare that they have no competing interests.

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