Research article

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Determination of Yield and Quality Characteristics of Various Genotypes of Black Cumin (*Nigella Sativa* L.) Cultivated Through Without Fertilizers

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ABSTRACT

Black cumin (*Nigella sativa* L.) is one of the essential spice plants used in Turkey. The present study investigated the yield and some agronomic, morphological, and qualitative characteristics of 31 different black cumin genotypes (30 lines and one control variety of Çameli) of domestic and foreign origin under the ecological conditions of the city of Ankara. The study was carried out in the experimental areas of İkizce Research and Application farm of Ankara Field Crops Central Research Institute during the vegetation periods of 2018-2019. The experiment was set up as three replications according to the Experiment Design in Randomized Blocks. According to the results of the research, the plant height of the genotypes in the experiment changed for two years between 17.1-33.5 cm, the height of the first capsule between 11.6-26.6 cm, the number of seeds in the capsule between 28.5-69.6 seeds capsule^{-1}, the number of branches between 2.0-3.4 pieces plant^{-1}, the number of capsules between 1.8-2.9 capsules plant^{-1}, thousand seed weight between 2.0-3.0 g, seed yield between 194.5-505.9 kg ha^{-1}, fixed oil rate between 27.2-35.3%, maturation (growth/harvest) time between 136.5-141.7 days and germination (emergence time) between 27.2-30.7 days. In terms of fatty acids, the most proportional fatty acids were found to be linoleic acid (45.45-55.62%), oleic acid (18.83-25.01%), palmitic acid (6.95-11.72%), stearic acid (3.50-4.77%), respectively. It has been determined as the result of the study that black cumin genotypes with the number 1 (Denizli), 4 (Burdur), 17 (Borsa) and 3 (Burdur) respectively performed better than other black cumin genotypes and Çameli variety in terms of seed yield and genotypes with the number 28 (Kırıkkale), 29 (Ankara) and 26 (Egypt) performed better in terms of fixed oil ratio under the ecological conditions of Ankara.

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Introduction

With the use of medicinal and aromatic plants in many different areas and different forms, especially in traditional and modern medicine, their popularity and the demand for them

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around the world are increasing day by day. The importance and therefore consumption of black cumin (*Nigella* spp.) have increased both in our country and the rest of the world owing to its wide range of uses, such as food, cosmetics, and medicinal drugs. The plant's production, which is at the forefront of the list of most exported plants in our country, is at a level that only meets a tiny part of domestic consumption. A significant part of the demand for the product is met through imports [1]. The increasing use of fixed oil obtained from seeds has increased the importance of black cumin cultivation in recent years. While the cultivation area of black cumin was 3261 decares and the production was 352 tons in 2013, these figures decreased to 1717 decares and 140 tons in 2014, and increased to 37.085 decares and 3603 tons in 2019 as a result of increasing demand. Although black cumin, which has an important place in our exports, was exported in an amount of about 65 tons and earned us 219.000 dollars in 2013, 2288 tons were imported in the same year, and we had a foreign exchange outflow of 1.910.000 dollars. In 2019, the black cumin export amount was 592.47 tons (1.236.915 dollars), the import amount was 2647.502 tons (2.531.796 dollars), while in 2020, the exports were 838.372 tons (2.186.684 dollars), and the imports were 3276.232 tons (1.964.851 dollars) [2]. The increase in interest in alternative plants in recent years has made black cumin, which is included in these plants, also popular. The fact that there is only one black cumin variety in our country, not only makes it impossible to meet the export demand but also makes it impossible to meet the requirement on this plant in different industries at the national level. Introduction materials are as important as local materials in obtaining varieties that can adapt to global climate change and meet expectations in terms of quality and yield. Having taken part in adaptation studies, black cumin genotypes grown in different geographies with similar ecological structure; lead obtaining important results with their responses to climate-soil and agronomic practices. At the same time, they play a very important role in the development of new varieties, especially in crossing, which is one of the basic steps of breeding, in increasing genetic variation. Revealing the true genetic potential of the plant in terms of yield and quality and also the presence of the mission of food and medicine, necessitate the cultivation method to be natural and healthy. This study aims to characterize the private sector and introduce black cumin genotypes in terms of agronomic, morphological, and quality, especially many local black cumin lines grown following without fertilizers and pesticides, and to be a source for research in different fields, especially breeding.

Materials and Methods

The study was carried out in the experimental areas of İkizce Research and Application farm of Ankara Field Crops Central Research Institute during the vegetation periods of 2018 - 2019. The study area is located at an altitude of 1055 m above sea level and between 39^0 12' -43^0 6' north latitudes and 35^0 58' –37^0 44' east longitudes. The experiment was set up as three replications according to the Experiment Design in Randomized Blocks. The parcels were 7.5 m^2 (5 m×5 rows×30 cm between rows) in size, 250 cm between the blocks, and 50 cm between the parcels. The material used was 30 black cumin (*Nigella sativa* L.) seeds from local domestic populations (Ankara, Burdur, Bursa, Denizli, Konya, Eskisehir, Afyonkarahisar, Diyarbakir, Kırıkkale), from abroad (Syria, Egypt, India, Pakistan, Ethiopia) and from gene banks included in the advanced yield experiment of the *Nigella sativa* breeding program of the Central Research Institute of Field Crops (TARM), and the Çameli cultivar was used as a control variable. No fertilization or spraying was applied (Fig 1-2-3).

Fig 1. A view of the field experiments, **Fig 2**. Black cumin flower, **Fig 3**. Black cumin capsule

Sowing was carried out by hand on 20-21 March in 2018 and 12-13 March in 2019. In 2018, irrigation was done twice, the first in March and the other in April (Figure 4).

Fig 4. A view of irrigation treatments in black cumin

The majority of the harvest was collected from the last week of July and through the remaining part of the first week of August. In 2019, irrigation was done once in May, and the harvest was completed, mainly in the first week of August and the rest in the second week of the same month (Figure 5). At the same time, isolation work was carried out against foreign pollination of the plant (Figure 6).

Fig 5. A view of the field experiments (Harvest Time)

Fig 6. A view of isolation treatments in black cumin

Fixed oil ratio was determined by solvent (petroleum ether) extraction method in Soxterm 2000 oil analyzer (ISO 659:2009). Shimadzu GC-2010 (Japan), flame ionization detector (FID), and Technochrome Capillary column (100 m×0.25 mm and 0.2 µm film thickness) were used to determine the fixed fatty acid composition. In identifying fatty acids, Restek 35077, Food Industry FAME mix (USA) was used as a standard. Analysis of variance and LSD test (in MSTAT-C statistical package program) were performed on the analyzed characters. All statistical analyses were first performed separately according to locations, then they were performed jointly.

Soil and climate characteristics of the experimental site

According to the sample extracted from the 0-20 cm depth of the experimental area, the soil texture was clayey-loamy, slightly alkaline, very calcareous, unsalted, low in organic matter, phosphorus, manganese, and zinc, copper was sufficient, iron was moderate, magnesium and calcium were at a reasonable level, and potassium was found to be high (Table 1).

Table 1. Some physical and chemical properties of experiment area soil

Saturation Percentage %	Texture	EC ds/m	pH	Lime (CaCO3)	Available								Organic matter %
					P_2O	K_2O	Ca	Mg	Cu	Fe	Mn	Zn	
					(kg / da)		(ppm)						
64	Clay-loamy	0.64	7.73	30.0	4.50	306	7420	905	1.33	3.38	3.03	0.30	1.97

(Source: Soil, Fertilizer and Water Resources Central Research Institute)

Climatic data of Ankara conditions where the experiment was carried out are given in Table 2. In 2018, flood damage occurred on 26-27 May due to excessive precipitation, hail damage occurred on 28 May, and excessive precipitation damage occurred on 31 July. In 2019, a significant part of the parcels remained underwater and mud, as heavy rain and hail occurred on 12 June and flood damage occurred on 21-22 June and 15-19 July due to excessive precipitation (Table 2). As a result, many yield elements were negatively affected.

Table 2. Climatic figures of the experiment area (Ankara/ Gölbaşı) during the research years

	Total Precipitation (mm)			Average Temperature (°C)			Average Relative Humidity (%)		
Months	**2018**	**2019**	**Long-Term (2010-2020)**	**2018**	**2019**	**Long-Term (2010-2020)**	**2018**	**2019**	**Long-Term (2010-2020)**
March	61.4	20.6	25.8	7.9	4.7	5	65.9	58.4	25.8
April	2.6	23.4	18.1	12.2	7.9	9.6	52.1	61.1	18.1
May	122.8	25.2	51.6	15.3	15.1	14.3	65.8	55.4	51.6
June	27	63.5	19	18.7	18.6	18.4	56.7	58.8	19
July	9.6	7.2	4	21.8	17.8	22.2	48.1	54.3	4
August	2.4	9.2	8.5	22.2	20.7	22.3	41.5	47.3	8.5
Tot./Ave.	225.8	149.1	127	16.35	14.1	15.3	55.0	55.9	21.2

(Source: Agronomy Central Research Institute / Department of GIS and UA)

Result and Discussion

Emergence time

In terms of emergence time, there was a 1% difference in genotypes in 2018 and a 5% significance level in recurrences. There were no statistically significant differences in any respect in 2019. According to the results of the variance analysis performed by combining the years, there were statistically significant differences at the 1% significance level in terms of genotypes and years. In contrast, the recurrence and year × genotype interaction were not statistically significant. The emergence time of the genotypes varied between 21.3-26.3 days (experimental mean 23.9 days) in 2018, 32.7-37.0 days (experimental mean 33.9 days) in 2019, and 27.2-30.7 days (experimental mean 28.9 days) in the combined analysis. Genotype 13 (Konya) was the genotype that germinated the earliest (Table 4). According to the results of the combined analysis, the number of genotypes that completed emergence 50% earlier than Çameli variety was found to be 14. The results of emergence time (27.2-30.7 days) showed that the genotypes included in the experiment were later than the results reported by Şahin (2013) (16-25 days), Ertaş (2016) (15-16 days) and Telci (1995) (15-16 days) and Gülhan and Taner (2020) (average values of two years 12.5-25 days). Emergence is one of the yield criteria most affected by climatic factors. Compared to 2018, the low rainfall and low soil temperature in the germination period of the plant in 2019 caused a delay in the emergence.

Maturation time

In terms of maturation time, there was a significant difference at the 1% significance level in genotypes in 2018, while there were statistically significant differences at the 1% probability limit only in terms of recurrences in 2019. According to the results of variance analysis made by combining the years, there were 1% statistically significant differences in genotypes, recurrences and years. In contrast, the year × genotype interaction was not statistically significant. The maturation time of the genotypes varied between 129.0-136.7 days in 2018, 143.3-147.3 days in 2019, and 136.5-141.7 days in the combined analysis. The average of the years was 131.0, 144.5 and combined 137.8 days, respectively. The genotype that reached the earliest maturation efficiency was the number 1 genotype (Denizli) (Table 4). It was determined that almost all of the materials (26 genotypes) in the experiment were genotypes that reached harvest maturity earlier than Çameli variety. The values (136.5-141.7 days) of the genotypes included in the experiment were later than Telci's (1995) (117-127 days), Safaei et al. (2017) summer plantings in Iranian conditions (103 days), and those of Gülhan and Taner (2020) (average values of two years 87.5-131 days) in terms of maturation time. It has been determined that they are close to the results of Şahin (2013) (115-140 days) and Ertaş (2016) (108-151 days). The factors affecting the harvest time were genotype, agronomic activities, and climate. Untimely and long-term rains also affected the maturation of the plant.

Plant height

Statistically significant differences were found between the genotypes in plant height at the 1% probability limit in both years and, 1% between the recurrences in 2018. According to the results of the combined variance analysis of the years related to the plant height values, there were differences at the 1% significance level between genotypes, years, and replications. In comparison, the year × genotype interaction was statistically significant at the 1% probability limit. While the plant heights of the genotypes varied between 19.2-45.0 cm (experimental mean 31.2 cm) in 2018, 14.9-28.7 cm (experimental mean 20.2 cm) in 2019, and between 17.1-33.5 cm according to the combined analysis results of the two years, the experimental (mean 25.7 cm), Kırıkkale population number 28 was the highest sized black cumin genotype (Table 4) . According to the results of two years (25.7 cm), it was determined that 11 genotypes had a taller plant height than Çameli variety.

The values of the genotypes in terms of plant height included in the experiment were lower than the values (17.1-33.5 cm) found by Taqi (2013) (42.98-43.05 cm), Baytöre and Yaver (2014) (34.5-53.6 cm), Tektaş (2015) (63.9-70.4 cm), Ertaş (2016) (45.4-47.6 cm) and Koşar and Özel (2018) (47.8-68.6 cm). The results of Özel and Demirbilek (2000) (18.6-23.8 cm), Özel et al. (2001) (24.5 cm), Özel et al. (2007) (30.6-31.4 cm), Akgören (2011) (16.6-25.2 cm), Koşar et al. (2013) (28.7-39.4 cm) and Gülhan and Taner (2020) (14-35 cm) were consistent with the high results.

These wide variations between the lower and upper limits of the plant heights found in the studies are thought to be due to the untimely and excessive precipitation, although variable across the genotypes used in the research.

First capsule height

In terms of first capsule height, statistically significant differences were found at the 1% probability limit for the genotypes used in the experiment in both years. According to the results of the variance analysis performed by combining the years, statistically significant differences of 1% were found in terms of genotypes, years, and year × genotype interaction. While the first capsule height of the genotypes changed between 13.6-37.8 cm (experimental mean 25.5 cm) in 2018, and 9.0-22.0 cm (14.4 cm average) in 2019, and between 11.6-26.6 cm according to the combined analysis results of the two years (experimental mean 20.0 cm), the Kırıkkale population numbered 28 was the black cumin genotype with the highest first capsule height (Table 4). Due to the positive relationship between the height of the first capsule and the height of the plant, according to the combined analysis result (test mean 20.0 cm), genotypes with a higher plant height than Çameli are also genotypes with the first capsule height, which are 12 in total. In terms of plant height, the genotypes in the experiment (11.6-26.6 cm) were among the figures found by Şahin (2013) (16.9-41.6 cm) but were lower. The genotypes with the highest first capsule height differed in both years are explained by the statistical significance of the combined analysis results of the genotypes, years, and year × genotype interaction. It has been determined in many studies that the height of the first pod, which is an important feature for machine harvesting, can vary according to the plant density, ecological conditions, and climate. However, it depends on the genotype structure. The genotypes with the highest first pod height were obtained in 2018, as in the plant length criterion when the years are compared.

Thousand seed weight

Statistically significant differences were found between genotypes in terms of thousand seed weight, at the probability limit of 5% in 2018, 1% in 2019, and 1% in 2018 between replications. According to the results of the combined variance analysis of the years in terms of the plant height figures, there were differences at the 1% significance level between the genotypes, years, and replications. In contrast, the year × genotype interaction was not statistically significant. While the thousand seed weight of the genotypes varied between 1.8-2.9 g (experimental mean 2.4 g) in 2018, 1.9-3.3 g (mean 2.7 g) in 2019, and 2.0-3.0 g according to the combined analysis results of the two years (experimental mean 2.6 cm), line 19 (material taken from the stock market) was the black cumin genotype with the highest thousand seed weight (Table 4). 11 black cumin genotypes reached a higher per thousand weight than Çameli variety (test mean 2.6 cm), and 14 genotypes reached higher than trial average. The values of the genotypes in the experiment in terms of thousand seed weight were within the limits of the values (2.00-3.00 g) reported by Kalçın (2003) (1.59-2.06 g), Özel et al. (2009) (2.07-2.40 g), Ghamarnia et al. (2010)'nın (2.2-2.4 g), Akgören (2011) (1.21-2.62 g), Arslan et al. (2011) (1.97-2.01 g), Kulan et al. (2012) (2.22-2.69 g), Taqi (2013) (2.57-2.78 g), Tavas et al. (2014) (2.34-2.73 g), Baytöre and Yaver (2014) (1.97-2.30 g), Tektaş (2015) (2.40-2.90 g), Ertaş (2016) (2.47-2.67 g), Mehmood et al. (2018) (1.55-2.84 g), Kamçı (2019) (2.12-2.76 g) and higher. It is believed that the statistical difference that emerged as a result of the study resulted from the genetic effects of the genotypes and climatic and environmental conditions, especially the (*Cuscuta* spp.) problem. Damage to the capsules by heavy rain near the harvest time and the sudden overpressing temperature caused the generative cycle to shorten and not fill the pod.

Number of seeds in capsule

Regarding the number of seeds in the capsule, statistically significant differences were found at the 1% probability limit regarding the genotypes used in the experiment in both years. According to the results of the variance analysis performed by combining the years, there were 1% statistically significant differences in terms of genotypes and years. In contrast, the year × genotype interaction was not statistically significant. The number of seeds in the capsule belonging to the genotypes was 31.3-84.1 seeds capsule^{-1} in 2018 (experimental mean 55.0 seeds capsule^{-1}), in 2019 25.7-56.7 seeds capsule^{-1} (mean 41.3 seeds capsule^{-1}), and according to the combined analysis results of the two years, it was 28.5-69.6 seeds capsule^{-1} (experimental mean 48.1 seeds capsule^{-1}), line 23 (Eskişehir) was the black cumin genotype with the highest number of grains in the capsule (Table 4). It was observed that 14 genotypes taken to study had the number of grains in the capsule above the standard. The values of the genotypes included in the experiment in terms of the number of seeds in the capsule (28.5-69.6 seeds capsule^{-1}) were similar to the values declared by Kalçın (2003) (91.90-104.05 seeds capsule^{-1}), Ghamarnia et al. (2010) (52.46-64.42 seeds capsule^{-1}), Safaei et al. (2014) (58.73-61.48 seeds capsule^{-1}), and Kamçı (2019) (71.87-102.90 seeds capsule^{-1}). The values reported by Özel et al. (2009) (53.07-89.40 seeds capsule^{-1}), Akgören (2011) (60.5-94.2 seeds capsule^{-1}), and Mehmood et al. (2018) (53.38-106.58 seeds capsule^{-1}) were within the limits and low. It is thought that the difference between the years is due to the precipitation, cold, and dodder grass damage sustained by the plant in different developmental periods.

Number of branches

While the difference between genotypes was at the level of 5% in 2018 in the number of branches in the plant, no statistical difference was detected in 2019. According to the analysis of variance performed by combining the years, 5% significant differences were found between genotypes and 1% in terms of year × genotype interaction between years. In 2018, the number of branches of the genotypes was 2-4.4 pieces plant^{-1} (experimental mean 3.2 pieces plant^{-1}), in 2019, it was 1.8-3.1 pieces plant^{-1} (mean 2.1 pieces plant^{-1}), and according to the combined analysis results of the two years, 2.0-3.4 pieces plant^{-1}. While the number of branches varied across the plants (experimental mean 2.6 pieces plant^{-1}), line 4 (Burdur) was the black cumin genotype with the highest number of branches (Table 4). According to the results of the combined analysis, it was found that more than half of the trial material (16 genotypes) reached the number of branches in a single plant above the standard. The values (2.00-3.4 pieces plant^{-1}) of the genotypes in terms of the number of branches, included in the experiment were higher than the values reported by Tavas et al. (2014) (2.96 pieces plant^{-1}); yet close and lower than the values reported by Kalçın (2003) (5.42-6.90 pieces plant^{-1}), Ertaş (2016) (4.15-5.27 pieces plant^{-1}), Özel et al. (2009) (2.30-4.43 pieces plant^{-1}), Akgören (2011) (3.1-4.6 pieces plant^{-1}), Arslan et al. (2011) (1.3-3.5 pieces plant^{-1}), Baytöre and Yaver (2014) (3.45-4.42 pieces plant^{-1}), Koşar and Özel (2018) (2.77-4.63 pieces plant^{-1}), Kamçı (2019) (4.41-5.64 pieces plant^{-1}). Almost all of the experiment was affected by precipitation and weeds in 2019. Still, there was a statistically significant difference at the level of 5% between the 2018 genotypes due to the intense damage caused by the climate only in the populations in some parts of the experiment in 2018. It has been reported in previous studies that the number of branches, one of the yield criteria, can change depending on the genotype, precipitation, and cultural practices [3,4].

Number of capsules

No statistical difference was found between the genotypes used in the experimental in 2019 in terms of the number of capsules and the combined analysis. In 2018, statistically significant differences were found between the genotypes at the 1% probability limit, between the recurrences at the 5% probability limit, and according to the results of the variance analysis performed by combining the locations, statistically significant differences were found between the years compared to the 1% level. Again in the combined analysis, a statistically significant difference at the 1% probability limit was found in year × genotype interaction on the number of capsules in the plant. The number of capsules belonging to the genotypes varied between 1.6-3.7 capsule plant^{-1} in 2018, 1.5-3.3 capsule plant^{-1} in 2019, and 1.8-2.9 capsule plant^{-1} in the combined analysis. The average of years was 2.7, 2 and combined 2.4 capsule plant^{-1}, respectively. The black cumin of Line 4 (Burdur) was the genotype with the highest number of branches (Table 4). It was determined that 12 genotypes had more capsules than both Çameli variety and average. The values (1.8-2.9 capsule plant^{-1}) of the genotypes in the experiment in terms of the number of capsules were lower than the values reported by Özel et al. (2009) (2.27-15.97 capsule plant^{-1}), Ghamarnia et al. (2010) (17.52 to 24.24 capsule plant^{-1}), Akgören (2011) (5.6-9.2 capsule plant^{-1}), Arslan et al. (2011) (2.26-5.60 capsule plant^{-1}), Kulan et al. (2012) (2.93-11.05 capsule plant^{-1}), Şahin(2013) (1.1-9.0 capsule plant^{-1}), Baytöre and Yaver (2014) (5.70-7.23 capsule plant^{-1}), Safaei et al. (2014) (5.6-6.1 capsule plant^{-1}), Tavas et al. (2014) (7.62-8.55 capsule plant^{-1}), Ertaş (2016) (7.91-9.44 capsule plant^{-1}), Koşar and Özel (2018) (4.03-7.63 capsule plant^{-1}), Mehmood et al. (2018) (28.47-39.38 capsule plant^{-1}), Kamçı (2019) (8.11-11.53 capsule plant^{-1}). There is a close relationship between the number of capsules and the number of branches, another parameter of the yield criteria. For this reason, the low figures in our branch number results due to climate and weeds were also proportionally low in the number of capsules, and the major genotype was the number 4 genotype, just like the number of branches.

Seed yield

In seed yield per decare, statistically significant differences were found between genotypes at the 1% probability limit in both years and 1% between replications in 2018. According to the results of the combined analysis of variance of the years, statistically significant differences were found between the genotypes, years, and year × genotype interaction at the 1% significance level and between the recurrences at the 5% probability limit. The seed yield of the genotypes ranged between 126.8-544.8 kg ha^{-1} (experimental mean 289.3 kg ha^{-1}) in 2018, 188.2-624.4 kg ha^{-1} (experimental mean 378.9 kg ha^{-1}) in 2019, and 194.5-505.9 kg ha^{-1} according to the combined analysis results of the two years, the experimental (average 334.1 kg ha^{-1}) number 1 (Denizli) black cumin line was the most fertile black cumin genotype (Table 4). The annual average (334.1 kg ha-1) of 14 genotypes resulted with higher seed yield compared to Çameli variety (328.1 kg ha-1) with the number 16.

Our yield values in the experiment were found to be within the limits of the values reported by (194.5-505.9 kg ha^{-1}) Ertuğrul (1986) (273 kg ha^{-1}), Özel and Demirbilek (2000) (358.6-439.5 kg ha^{-1}), Özel et al. (2001) (336.7-416.7 kg ha^{-1}), Baytöre and Yaver (2014) (284-435 kg ha^{-1}), Ertaş (2016) (301-538 kg ha^{-1}) and high. Also, they were lower than the reported values by Kalçın (2003), (683.9-770.1 kg ha^{-1}), Özel et al. (2009) (1406.3-2482.3 kg ha^{-1}), Akgören (2011) (905-1883 kg ha^{-1}), Kulan et al. (2012) (676.6-903.3 kg ha^{-1}), Taqi (2013) (829-1270 kg ha^{-1}), Tavas et al. (2014) (557.7-689.1 kg ha^{-1}), Tektaş (2015) (719-1188 kg ha^{-1}) and Gülhan and Taner (2020) (623 kg ha^{-1}).

It is thought that the yield values obtained in the research are lower than in some studies due to the adverse weather conditions experienced in both years and the intense dodger weed damage.

Fixed oil ratio

Regarding fixed oil ratio, statistically significant differences were found at the 1% probability limit in genotypes in both years and 1% in terms of recurrences only in 2019. According to the results of the variance analysis performed by combining the years, there were 1% differences in genotypes between years and year × genotype interaction and 5% between replications. While the fixed oil ratio of genotypes was 21.8%-40.2% (experimental mean 28.3%) in 2018, 27.8%-40.6% (mean 34.8%) in 2019, and according to the combined analysis results of the two years, it ranged between 27.2% and 35.3% (experimental mean 31.5%), line 28 (Kırıkkale) was the black cumin genotype with the highest fixed oil content (Table 4). According to the combined analysis of the materials in the experiment, it was determined that 2/3 (20 genotypes) had a higher fixed oil content than Çameli variety. In terms of fixed oil ratio, the values (27.2-35.3%) of the genotypes in the experiment were similar and higher than the values reported by D'Antuono et al. (2002) (13-19.7-22.9%), Arslan et al.(2011) (21.70-31.50%), Akgören (2011) (19.51-26.34%), Baytöre and Yaver (2014) (16.71-30.08%), Kamçı (2019) (29.58-32.42%). It was found close and low compared to the values reported by Kızıl et al. (2008) (30.2 to 37.9%), Matthaus and Özcan (2011) (28.0- 36.4%), Kulan et al. (2012) (38.91-40.58%), Şahin (2013) (26.90-44.00%), Gharby et al. (2015) (27-37%), Tavas et al. (2014) (36.09-36.37%), Ertaş (2016) (37.5-37.6%), Gülhan and Taner (2020) (two-year average values 26.8%-37.3%). Although similar results were obtained in terms of fixed oil ratio in both years, it is thought that the difference between the lines is due to the genetic structure of the populations.

Fixed fatty acid composition

In the component analysis of fixed oil of the black cumin genotypes in 2018 and 2019, it was determined that the main components were linoleic, oleic, palmitic, and stearic acids. Their rates are respectively 45.45-55.62%, 18.83-25.01%, 6.95-11.72%, and 3.50-4.77%. The highest value in linoleic acid was number 18, and line number 11 in oleic acid was the Burdur line (Table 3).

In previous studies, the main components and ratios of black cumin oil were determined by Kızıl et al. (2008) linoleic acid 43.34%-51.50%, Şahin (2013) linoleic 54.6%, oleic 27.7% and palmitic acid 13.4%, stearic acid 3.46%, Tavas et al. (2014) linoleic acid 57.92%, oleic acid 23.07%, Ertaş (2016) linoleic 57.98%, oleic 24.50% and palmitic acid 12.31%. Safaei et al. (2017) determined linoleic acid as 55.71% in autumn sowing, 55.5% in spring planting, Kamçı (2019) linoleic as 52.47%-55.48%, oleic as 20.57-28.32%, palmitic acid as 12.20-12.63% and stearic acid as 2.99-3.53%. When the results obtained from the research were compared with the previous studies, it was determined that while there were similar figures, there were also positive differences in terms of the main components. These differences are thought to be due to genetic differences.

Table 3. Average fatty acid composition of *Nigella sativa* genotypes in the experiment (%)

Genotypes	Oleic Acid (C18:1n9c)	Linoleic Acid (C18:2n6c)	Palmitic Acid (C16:0)	Stearic Acid (C18:0)
1	23.88	54.15	11.03	4.26
2	22.71	54.30	11.16	4.33
3	22.96	52.73	10.56	4.31
4	23.41	52.79	10.89	4.55
5	22.75	54.26	10.83	4.14
6	23.83	51.46	10.82	4.21
7	22.41	53.53	10.80	4.23
8	23.89	50.93	10.54	4.25
9	21.28	55.19	11.08	4.16
10	22.92	52.89	10.75	4.03
11	25.01	48.54	6.95	4.77
12	22.20	54.21	11.22	4.21
13	21.93	54.13	11.31	4.08
14	21.44	55.11	11.68	4.14
15	22.62	54.17	11.32	4.01
16	20.45	53.96	11.00	4.31
17	22.45	55.28	11.37	4.18
18	22.10	55.62	11.34	4.19
19	22.62	53.69	11.17	4.18
20	18.83	45.45	9.39	3.50
21	22.74	54.59	11.49	3.94
22	22.34	54.11	11.42	4.09
23	21.96	54.82	11.72	4.10
24	22.45	53.65	11.37	4.09
25	22.36	53.62	11.26	4.11
26	23.77	54.34	11.43	3.96
27	22.06	54.24	11.22	4.05
28	21.79	53.90	11.19	4.19
29	22.70	54.27	11.19	3.93
30	22.69	55.12	11.23	3.89
Çameli	23.08	53.73	10.89	4.16
Mean	22.50	53.51	10.96	4.15

Table 4. Average figures of yield and yield components of *Nigella sativa* genotypes in experiments

G	Plant Height (cm)		Seed Yield (kg ha^{-1})		First Capsule Height (cm)		Thousand Seed Weight (g)		Number of Branches (pieces plant^{-1})		Number of Capsules (capsules plant^{-1})		Number of Seeds in Capsule (seeds capsule^{-1})		Emergence Time (day)		Maturation Time (day)		Fixed Oil Ratio (%)	
1	30.1	a-f	505.9	a	23.5	a-c	2.6	a-j	2.8	a-f	2.7	a-d	56.3	b-d	28.0	d-g	136.5	e	31.7	c-g
2	29.1	b-g	398.3	a-f	22.8	a-e	2.7	a-h	2.7	b-f	2.4	a-f	51.7	b-h	29.2	a-f	137.5	b-e	33.1	a-e
3	30.1	a-e	440.9	a-c	24.4	a-c	2.8	a-h	2.7	b-f	2.6	a-e	53.7	b-e	29.2	a-f	136.5	e	32.5	b-f
4	26.4	e-ı	490.3	a	22.0	b-e	2.5	e-k	3.4	a	2.9	a	53.6	b-f	28.7	b-g	137.3	c-e	33.3	a-d
5	22.3	ı-m	215.6	k-l	17.1	f-ı	2.9	a-e	2.7	b-f	2.6	a-e	43.6	e-k	30.2	a-b	137.2	c-e	30.8	e-k
6	24.8	h-l	282.5	g-l	19.1	d-g	2.9	a-f	3.0	a-d	2.9	a-b	49.1	b-ı	29.3	a-e	137.2	c-e	31.1	d-j
7	20.2	m-o	329.6	d-j	14.9	h-j	2.8	a-g	2.3	e-g	2.0	e-f	38.5	ı-l	29.3	a-e	137.7	b-e	29.7	g-k
8	19.9	m-o	298.4	f-l	13.0	ı-j	2.9	a-f	2.7	b-f	2.3	a-f	38.6	ı-l	29.8	a-c	137.7	b-e	31.9	c-g
9	32.2	a-c	406.5	a-f	24.8	a-c	2.4	g-l	2.7	a-f	2.5	a-f	58.1	b	28.2	c-g	137.8	b-e	33.2	a-d
10	30.2	a-e	415.5	a-d	23.9	a-c	2.0	m	2.6	b-g	2.4	a-f	57.4	b	27.7	e-g	136.5	e	33.7	a-c
11	17.7	n-o	283.6	g-l	11.8	j	3.0	a-b	2.0	g	1.8	f	35.5	k-l	29.9	a-c	137.6	b-e	27.2	l
12	26.1	e-j	366.2	b-g	21.7	b-e	2.3	ı-m	2.4	d-g	2.4	a-f	50.0	b-h	27.5	f-g	136.5	e	30.5	f-k
13	28.8	c-h	356.2	c-g	23.8	a-c	2.0	l-m	2.5	c-g	2.1	d-f	54.1	b-e	27.2	g	136.5	e	31.0	d-k
14	26.6	e-h	349.3	c-h	21.5	b-e	2.0	l-m	2.5	b-g	2.2	c-f	52.5	b-h	27.7	e-g	137.3	c-e	28.8	ı-l
15	22.0	j-n	338.1	c-ı	15.6	g-j	2.6	a-j	2.4	d-g	2.3	a-f	42.7	g-k	29.3	a-e	137.5	b-e	28.7	k-l
16	20.9	l-o	276.2	g-l	14.7	h-j	2.6	a-j	2.9	a-e	2.5	a-f	46.5	c-j	28.7	b-g	137.7	b-e	29.3	h-l
17	21.0	k-o	465.3	a-b	15.2	g-j	2.8	a-g	2.5	c-g	2.3	a-f	42.4	g-k	28.5	b-g	137.5	b-e	28.8	ı-l
18	19.4	m-o	246.9	h-l	13.0	ı-j	2.9	a-d	2.4	d-g	2.0	e-f	42.8	f-k	30.2	a-b	138.2	b-e	28.7	j-l
19	17.1	o	226.5	j-l	11.6	j	3.0	a	2.1	f-g	1.9	e-f	36.0	j-l	29.7	a-d	137.8	b-e	30.4	f-k

*: $P<0.05$, **: $P<0.01$, Y: Year, G: Genotypes, R: Recurrences, NS: Not Significant

Table 4 (Continue.) Average figures of yield and yield components of *Nigella sativa* genotypes in experiments

G	Plant Height (cm)		Seed Yield (kg ha^{-1})		First Capsule Height (cm)		Thousand Seed Weight (g)		Number of Branches (pieces plant^{-1})		Number of Capsules (capsules plant^{-1})		Number of Seeds in Capsule (seeds capsule^{-1})		Emergence Time (day)		Maturation Time (day)		Fixed Oil Ratio (%)	
20	19.8	m-o	194.7	l	15.5	g-j	2.6	a-j	2.6	b-g	2.2	b-f	38.8	ı-l	29.8	a-c	138.5	b-d	31.1	d-ı
21	33.3	a-b	231.0	ı-l	26.4	a	2.1	k-m	2.8	a-e	2.5	a-f	56.5	b-c	28.5	b-g	141.3	a	30.5	f-k
22	26.6	e-h	405.6	a-f	21.2	c-f	2.5	d-j	2.5	c-g	2.2	c-f	49.4	b-ı	29.2	a-f	137.7	b-e	32.1	c-f
23	32.0	a-d	333.4	c-j	26.5	a	2.4	g-l	3.2	a-b	2.8	a-c	69.6	a	30.7	a	141.7	a	33.5	a-c
24	30.3	a-e	318.1	d-k	24.8	a-c	2.5	f-k	2.3	e-g	2.2	c-f	53.2	b-g	28.3	c-g	138.0	b-e	33.4	a-d
25	25.2	g-k	288.5	g-l	18.8	e-h	2.6	a-j	2.9	a-e	2.4	a-f	45.6	d-k	29.7	a-d	137.3	c-e	31.5	c-h
26	25.9	f-j	311.5	d-k	21.3	b-e	2.5	c-j	3.1	a-c	2.7	a-d	49.0	b-ı	28.2	c-g	139.2	b	34.9	a-b
27	29.9	a-f	300.3	e-l	25.4	a-b	2.2	j-m	2.5	c-g	2.3	a-f	52.6	b-h	27.3	g	137.3	c-e	32.7	b-f
28	33.5	a	407.7	a-e	26.6	a	2.4	h-m	3.0	a-d	2.7	a-d	54.2	b-e	29.3	a-e	138.8	b-c	35.3	a
29	27.9	d-h	350.9	c-h	23.0	a-d	2.6	b-j	2.7	a-f	2.4	a-f	41.9	h-k	28.2	c-g	136.8	d-e	34.9	a-b
30	18.8	m-o	194.5	l	12.6	j	2.9	a-c	2.5	c-g	2.2	a-f	28.5	l	30.2	a-b	137.5	b-e	32.4	c-f
Ç	28.2	c-h	328.1	d-j	22.8	a-e	2.6	a-ı	2.6	b-g	2.4	a-f	49.9	b-h	28.8	b-g	138.5	b-d	30.6	f-k
Mean	**25.7**		**334.1**		**20.0**		**2.6**		**2.6**		**2.4**		**48.1**		**28.9**		**137.8**		**31.5**	
F Value	**		**		**		**		*		NS		**		**		**		**	
CV	14.5		28.5		18.2		14.3		21.9		24.1		19.7		5.3		1.1		6.7	
R	**		*		NS		**		NS		NS		NS		NS		**		*	
Y	**		**		**		**		**		**		**		**		**		**	
Y X G	**		**		**		NS		**		**		NS		NS		NS		**	

*: P<0.05, **: P<0.01, Y: Year, G: Genotypes, R: Recurrences, NS: Not Significant, Ç: Çameli

Conclusion

Black cumin seeds, fixed and essential oil have been used in spices, food, cosmetics, and medical fields since ancient times, so they are versatile medicinal plants whose value is increasing every year. For this reason, as in other medicinal plants, quality rather than yield comes to the fore in black cumin as well. Fertilizers and herbicides used pose a risk in terms of food and drugs. This study aimed to increase the black seed cultivation area and production by identifying the genotypes grown in accordance without fertilizers and pesticides, high quality, productive, machine harvested, and suitable for the region. This study tried to identify the yield and yield criteria of different advanced black cumin (*Nigella sativa* L.) lines grown in the ecological conditions of Ankara. According to the results of two years, the average values yield 334.1 kg ha^{-1}, plant height 25.7 cm, number of capsules 2.4 capsule plant^{-1}, the height of the first pod 20 cm, thousand seed weight 2.6 g, number of branches 2.7 pieces plant^{-1}, number of seeds in capsule 48.1 seeds capsule^{-1}, emergence time 28.9 days, maturation time 137.8 days, oil rate 31.5 %, fatty acid components linoleic acid 53.51%, oleic acid 22.50%, palmitic acid 10.96% and stearic acid 4.15%. The obtained values are consistent with many works of literature where fertilization practices are applied. It is thought that the statistical differences between the lines, years, and recurrences may be caused by the adverse and untimely climatic conditions observed during the two years, the genetic differences of the materials, and the difference in the genotypes to these conditions. Nigella sativa is a plant that is planted for both its seeds and the fixed oil extracted from these seeds. For this reason, the main purpose of cultivation is to have both characteristics higher and superior to the existing varieties. It has been determined as the result of the study that, out of 31 genotypes examined, black cumin genotypes with the number 1 (Denizli), 4 (Burdur), 17 (Borsa) and 3 (Burdur) respectively became prominent in terms of seed yield and black cumin genotypes with the number 28 (Kırıkkale), 29 (Ankara) and 26 (Egypt) became prominent in terms of essential oil ratio and that they are the genotypes that can be suggested for breeding studies to be continued for the region. In addition, while the genotypes with the number 28 (Kırıkkale)-21 (Borsa)-9 (Denizli) showed maximum performance and took the first three place in terms of plant height, those with the number 28 (Kırıkkale)-23 (Eskişehir)-21(Borsa) took the first three place in terms of capsule height, genotypes with the number 19 (Borsa)-11 (Burdur)-30 (Ankara) took the first three place in terms of weight per thousand, genotypes with the number 4 (Burdur)-23 (Eskişehir)-26 (Egypt) took the first three place in terms of number of branches on the plant, genotypes with the number 4 (Burdur)-6 (Syria)-23 (Eskişehir) took the first three place in terms of number of capsules on a plant, genotypes with the number 23 (Eskişehir)-9 (Denizli)-10 (Burdur) took the first three place in terms of number of grains per capsule, genotypes with the number 13 (Konya)-27 (Burdur)-12 (Konya) had the earliest emergence time and genotypes with the number 1 (Denizli)-3 (Burdur)-10 (Burdur) had the earliest harvest maturation time. In terms of the fixed fatty acids, black cumin genotype with the highest oleic acid ratio was measured in Burdur genotype with the number 11 (25.01%), and the highest linoleic fatty acid was measured in black cumin genotype (55.62%) with the number 18, which was obtained from Borsa. There seems to be promise for the genotypes that stood out in our study in the studies to come in future cultivar development studies.

Abbreviations

Y: Year; G: Genotypes; R: Recurrences; NS: Not Significant; Ç: Çameli; TARM: Central Research Institute of Field Crops.

Availability of data and material

Please contact the corresponding author for any data request.

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