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THE EFFECT OF DIFFERENT PHOSPHORUS DOSES ON SEED YIELD AND QUALITY PARAMETERS OF BLACK CUMIN (*Nigella* sp.)

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ABSTRACT

Phosphorus is an important element that affects the generative development, seed and fruit quality of plants. This study was carried out in the ecological conditions of Kahramanmaras province to determine the effects of different phosphorus doses on the vegetation, yield, and quality characteristics of black cumin. The experiment was carried out in the field of "Field Crops Research and Application Department of Kahramanmaras Sutcu Imam University Faculty of Agriculture" in the winter growing seasons of 2017-18 and 2019-20, according to the split plots in randomized blocks as 3 replications. Two *Nigella* genotypes, one of which is a registered variety (Cameli variety), and five different P doses (0, 3, 6, 9, 12 kg da^{-1}) were used in the study. According to the research findings, while phosphorus doses did not have a significant effect on plant characteristics such as number of branches, number of capsules, plant height, it was determined that it affected the number of seeds in the capsule and seed yield. The highest number of seeds per capsule (128.23 per capsule^{-1}) was obtained from the highest P (12 kg da^{-1}) application, and the highest seed yield (136.04 kg da^{-1}) was obtained from the 6 kg da^{-1} P application. Significant differences were observed in doses and genotype × dose interaction in terms of quality characteristics.

Keywords: Cameli variety, *Nigella sp*, Phosphorus dose, quality characteristics, yield

INTRODUCTION

Medicinal plants have been used for centuries for food, seasoning, medicine, and healing purposes (Bayram et al., 2010). *Nigella sativa* is an annual herbaceous plant of the Ranunculaceae family. There are 20-24 species of *Nigella* in the world and it is stated that 12 to 15 of them are found in the flora of Turkey (Baser, 2010; Ayhan, 2012). *Nigella* is one of the high value-added medicinal and aromatic plants that can be easily grown in the climatic conditions of Turkey, and is used in folk medicine, in kitchens as spices, odorants, and flavor enhancers, and as raw material in the food industry (Akgul, 1993; Ceylan, 1997). It has a hairy and upright structure, which can usually grow up to 35-70 cm in height. *Nigella* seeds are black in color and 2.5-4 mm in size (Baydar, 2013). Comprehensive studies have been carried out on *N. sativa* by many researchers and its antidiabetic, immunomodulatory, analgesic, antimicrobial, anti-inflammatory (Ramadan, 2015; Saleh et al., 2018), anticancer, spasmolytic, bronchodilator, renal protective, gastro-protective, antioxidant properties have been determined. It has been widely used for therapeutic purposes for its antihypertensive, digestive, liver tonics, diuretic, analgesic, antibacterial, antidiarrheal, appetizing, properties and in skin disorders (Ahmad et al., 2013). The purpose of commercial medicinal plant cultivation is to obtain high-seed, essential, and fixed oil yield per hectare. *N. sativa* seeds contain crude fiber (8.4%), protein (26%), ash (4.8%), and carbohydrates (25%). The World Health Organization (WHO) attaches importance to the research of medicinal plant species for the benefit of human health and systems. It has been reported that the effective use of *N. sativa* for therapeutic and commercial purposes will largely depend on yield (bioactive compounds-essential oil, seeds) and quality (Yimam et al., 2015). The basic condition for success in plant production is to obtain high yield and quality products. Adequate and balanced fertilization is one of the important cultural practices that affect yield and quality increase (Anonymous, 2016). Therefore, the amount of fertilizer needed by the plant, the application time of the fertilizer, and the application method should be determined by the studies for each plant species and the region where production will be made. Phosphorus is one of the most deficient elements after nitrogen for the soils of our country in increasing the yielding of plants (Turan, 2014). The P contents of the plants generally vary between 0.05% and 1.0% according to the dry matter principle. Plants contain much less phosphorus compared to nitrogen (N), magnesium (Mg), calcium (Ca), and potassium (K). Inorganic phosphorus compounds (Pi) entering the root are stored in the root or transported to the top organs of the plant. After various chemical reactions, inorganic P turns into various organic compounds, including enzymes, nucleic acids, and proteins. In addition to those called adenosine monophosphate (AMP), adenosine diphosphate (ADP) and adenosine triphosphate (ATP), other organic-phosphate groups play an important role in transferring the energy needed in metabolic events in plants. The importance of phosphorus in photosynthesis, carbon fixation, and assimilation is undeniable. Phosphorus plays an important role in the formation of genes and chromosomes in plants. Phosphorus plays a role in the transmission of genetic codes from one generation to the next. Phosphorus requirement is very high in meristematic tissues for cell division and growth. It has been determined that phosphorus significantly affects seed and fruit formation, and in the absence of sufficient phosphorus, seed and fruit quality decreases significantly (Kacar, 2015). Phosphorus (P) is among the most limiting nutrients needed for good plant growth and higher yield, and is stored in seeds (White and Veneklaas, 2012; Seyyedi et al., 2017). There is no standard definition of P that is suitable for plant in soil. For this reason, a wide variety of extraction methods are used in the estimation of P for the plant in the soil (Buczko et al., 2018). In plant production, more or less fertilization has negative effects on growth and yield. Black seed quality and production can be severely affected by P deficiencies in the soils (Seyyedi et al., 2017). Mohammed et al. (2000) reported that P and N fertilizers significantly improved growth parameters, yield and yield components as well as nutrient contents in *Nigella sativa.* It was reported that high phosphorus and nitrogen levels cause significant increases in fixed oil, essential oil, protein and phosphorus, and this increase may be because of the effect of phosphorus on root development, flower formation, seed and fruit development (Hammo, 2008). This study aims to determine the effects of different phosphorus doses on seed yield and quality characteristics of black cumin in Kahramanmaras conditions.

MATERIALS AND METHODS

In this study, black cumin seeds were sown in the winters of 2018 and 2020. Due to the unsuitable land and climatic conditions in the 2019 planting season, the second year of the experiment was carried out in the 2020 winter growing season.

Experimental Site and Conditions

The research was carried out in the Field Crops Research and Application land of Kahramanmaras Sutcu Imam University, Faculty of Agriculture. According to Table 1, the long-term average amount of precipitation was 650.80 mm. While the total precipitation in the vegetation period of 2017-18, in which the research was conducted, was 522.80 mm, which was below the long-term average of total precipitation, the total precipitation in the vegetation period of 2019-20, was above the long-term average of the total precipitation with a value of 652.30 mm. While the long-term average temperature was 12.60°C, the average temperature of the vegetation period of 2017-18, in which the study was conducted, was 14.74°C, and the average temperature of the vegetation period of 2019-20 was 13.25°C, which was above the long-term average. According to Table 1, the average temperature values in both years were higher than the long-term average temperature, and the average temperature was higher in the first year than in the second year. The average relative humidity in Kahramanmaras is 63.04% compared to the long-term average. Although the average relative humidity in the study period of 2017-18 was 59.98%, and the average relative humidity in the study period of 2019-20 was higher than the first year with 61.91%, it was seen that the average relative humidity values of both years in which the study was carried out were lower than the long-term average relative humidity value. Soil samples taken from 0-30 cm depth in the experimental field were analyzed at the University-Industry-Public Cooperation Development Application and Research Center (USKIM). Some physical and chemical properties of the soil are given in Table 2. Properties of the soil sample in 2018 and 2020 are as follows, clayed loamy (72.00 and 69.96), slightly alkaline (7.66 and 7.71), low salinity (0.86%) and salt-free (0.05%), moderately calcareous (3.91 and 6.09%), low in organic matter (1.66 and 1.58%), high in potassium (53.00 and 55.51 kg da^{-1}), moderately phosphorus (6.29 kg da^{-1}), and very low (2.84 kg da^{-1}), respectively.

Table 1. Precipitation temperature, and relative humidity values of experimental years and long-term growing seasons in Kahramanmaras Province (Anonymous 2020a)

		Months								
Climatic Factory	Year	November	December	January	February	March	April	May	June	Total or Avarage
Precipitation (mm)	2017-2018	89.60	33.70	149.90	63.10	47.40	71.60	28.10	39.40	522.80
	2019-2020	39.10	198.50	88.00	72.70	173.40	61.80	18.50	0.30	652.30
	Long years	87.50	116.60	125.40	108.30	93.40	69.80	41.20	8.40	650.80
Average Temperature (°C)	2017-2018	12.20	8.90	7.40	9.70	14.20	18.40	21.70	25.40	14.74
	2019-2020	13.50	8.40	6.30	6.10	12.50	15.90	15.90	24.50	13.25
	Long years	11.50	6.80	4.90	6.40	10.60	15.50	20.30	25.30	12.60
Relative humidity (%)	2017-2018	64.20	69.00	69.50	69.40	60.80	45.30	52.60	49.10	59.98
	2019-2020	56.20	81.90	69.30	68.30	67.30	58.20	47.20	46.90	61.91
	Long years	66.68	79.85	69.99	65.62	60.00	57.59	54.95	49.67	63.04

Table 2. Some chemical and physical properties of the study area soils (Anonymous 2020b)

Year	Texture class	Organic matter (%)	$CaCO_3$ (%)	EC (dS m-1)	pH	P_2O_5 (kg da-1)	K_2O (kg da-1)
2018	Clay (72)	1.66	3.91	0.86	7.66	6.29	53
2020	Clay-loam (69.96)	1.58	6.09	0.05	7.71	2.84	55.51

Experimental Material

In the study, *N. sativa* species (Genotype 1-G1) and registered Cameli variety (Genotype 2-G2) seeds obtained from the GAP Agricultural Research Institute Directorate and Eskisehir Transitional Zone Agricultural Research Institute, were used in the study as materials. In the study, Triple Super Phosphate (43-45%) fertilizer for phosphorus doses and Ammonium Nitrate fertilizer (33%) for N dose were used. In the experiment, 5 different doses of phosphorus, 0, 3, 6, 9, and 12 kg da^{-1} were applied. Nitrogen was calculated to be 6 kg pure N per decare, and a half was applied during planting and the remaining half was applied in spring during the bolting period.

Design and Cultural Practices

In the land where the soil preparation was made, the rows were opened with the help of a marker with a planting depth of 2-3 cm, and a spacing of 30 cm in 6 rows, and the genotypes were divided into the main plots, the phosphorus doses were placed in the sub-plots, and the plots were carried out in three replications according to the experimental design. The length of the plot was 3 m and the width was 1.80 m, the distance between the plots was 0.5 m and the distance between the blocks was 2.5 m. Plants were thinned so that the row spacing was 10 cm. Irrigation was done by the furrow method twice in both years and weed control was done by hand. The trial was established in November in both years. The thinning process of the plants was carried out in March, the weed control was carried out once in April with the thinning process. Irrigation was performed twice, in May and June (Table 3). No diseases or pests were detected during the vegetation period of the plants. After removing the edge effect of the plants which grew ripe (one row from the top and bottom, and 50 cm from the beginning and end of the plot), the plants were harvested by hand on 18 June 2018 and 25 June 2020. The following characteristics were measured in 10 randomly selected plants from the plots after harvest; the number of branches, plant height (cm) in a plant (piece plant^{-1}), the number of capsules in a plant (capsule plant^{-1}), the number of seeds in a capsule (piece capsule^{-1}), thousand-grain weight (g), seed yield (kg da^{-1}), protein ratio (%), essential oil content (%), essential oil yield (L da^{-1}), fixed oil content (%), and fixed oil yield (kg da^{-1}). After 25 g of seeds samples were ground, the hydro-distillation process was performed in Neo-Clevenger device for 3 hours, and then the essential oil content (%) was volumetrically determined. In addition, fixed oil content (%) was determined by extraction with petroleum ether for 6 hours in the Soxhlet apparatus in 5 g of ground seeds.

Table 3. Data on cultural activities and practice times

Years	Sowing date	Plant thinning	Weed control	Irrigation 1	Irrigation 2
2018	16 November 2018	20 March 2018	22 April 2018	15 May 2018	2 June 2018
2020	14 November 2020	15 March 2020	20 April 2020	28 May 2020	5 June 2020

Statistical Analyses

Statistical analyzes of the examined yield and quality-related characteristics were analyzed using the SAS 9.1 package program according to the split-plot trial design. The differences that were found to be significant were subjected to the LSD multiple comparison test ($P<0.05$ or $P<0.01$ according to the limit of probability found significant).

RESULTS AND DISCUSSION

In this study, the effects of phosphorus applications on yield, and quality characteristics in two different black cumin genotypes were investigated.

Plant height (cm)

While the difference between genotype, dose, and genotype × dose interaction was not found to be significant in terms of the effect of phosphorus application on plant height, the application years were found to be significant. The average plant height value was 75.35 cm in 2018 and 60.06 cm in 2020 (Table 4). Since the amount of precipitation in 2018 was higher than 2020 in April-May, which was the period of plant bolting, there was a difference in plant height between the years (Table 1). Kizil et al. (2008) reported that higher precipitation amount in the first year of the study contributed positively to number of branches, plant height, and capsules number per plant. Yimam et al. (2015) reported plant height as 45.7-72.5 cm, Tuncturk et al. (2011) as 30.7- 35.3 cm, Muhammad et al. (2017) as 50.02-53.51 cm, Shirmohammadi et al. (2014) as 23.0-32.1 cm, Kosar and Ozel (2018) reported plant height as 47.8-68.6 cm, Kilic and Arabaci (2016) 78.9 cm, and Abadi et al. (2015) as 19.04-23.43 cm. Kizil et al. (2008) reported plant height in the range of 50.5-59.0 cm in winter planting and that there was no difference between doses. Similarly, no differences were detected in plant height between doses in this study. The increased plant height may actually be because of the greater availability of nutrients in the soil in the cultivation area (Yimam et al., 2015). The ecology, soil, and agricultural practices in which the plant grows had important effects on plant height. The differences between the results of other studies in terms of plant height were because of soil, genotype, and ecological conditions.

Table 4. Two-year averages and LSD groupings of applied phosphorus doses on yield and vegetative properties in black cumin

		PH	NB	NC	NSC	TSW	SY
Genotype	G_1	68.66	8.43 a	16.95 a	120.49	2.58 b	125.31
	G_2	66.76	7.56 b	14.79 b	123.29	2.70 a	129.56
Doses (kg da^{-1})	0	67.77	7.87	15.59	119.86 bc	2.62	121.77 b
	3	67.90	7.80	16.42	116.04 c	2.61	128.46 ab
	6	66.23	7.91	16.13	122.78 b	2.64	136.04 a
	9	68.46	8.06	15.59	122.53 b	2.63	124.57 b
	12	68.18	8.30	15.64	128.23 a	2.69	126.34 b
Year	2018	75.35 a	9.76 a	18.76 a	111.63 b	2.67 a	154.34 a
	2020	60.06 b	6.23 b	12.98 b	132.15 a	2.61 b	100.54 b
Genotype x Doses (G × D)	$G_1 \times P_0$	68.26	8.13	16.98	120.62	2.53	116.91
	$G_1 \times P_3$	68.68	8.33	17.61	114.73	2.53	118.40
	$G_1 \times P_6$	66.67	8.20	16.86	121.52	2.56	138.23
	$G_1 \times P_9$	70.83	8.82	17.12	117.00	2.60	127.27
	$G_1 \times P_{12}$	68.87	8.67	16.21	128.60	2.69	125.76
	$G_2 \times P_0$	67.28	7.62	14.21	119.12	2.73	126.65
	$G_{2\times}$x P_3	67.12	7.28	15.24	117.35	2.70	138.54
	$G_2 \times P_6$	65.80	7.63	15.40	124.05	2.73	133.86
	$G_2 \times P_9$	66.10	7.32	14.07	128.07	2.67	121.88
	$G_2 \times P_{12}$	67.50	7.95	15.07	127.87	2.70	126.93
Mean		67.71	7.99	15.87	121.9	2.64	127.44
CV		5.89	6.8	7.9	4.77	3.00	7.24
LSD for years		2.09**	0.28**	0.66**	3.06**	0.04*	4.85**
LSD for genotype		ns	0.28**	0.66*	ns	0.04**	ns
LSD for doses		ns	ns	ns	4.83**	ns	7.67**
LSD for G × D		ns	ns	ns	ns	ns	ns

PH: Plant height (cm), NB: Number of branches (branch plant^{-1}), NC: Number of capsules (capsule plant^{-1}), NSC; Number of seeds per capsule (seed capsule^{-1}), TSW: Thousand seeds weight (g), SY: Seed yield (kg da^{-1}), ns: No significant, *$P<0.05$; **$P<0.01$

Number of branches per plant (number per plant^{-1})

Genotypes were significant at a level of 1% in terms of the number of branches in the plant, while the interaction between dose and genotype × dose was found to be insignificant. While the number of branches was 8.43 per plant^{-1} in genotype 1 (G1), it was 7.56 per plant^{-1} in genotype 2 (G2) (Table 4). The difference between years was significant and the average number of branches was 9.76 in the first year, while it was 6.23 in the second year (Table 4). Tuncturk et al. (2011) reported the number of branches per plant as 3.76 to 4.10, and Kizil et al. (2008) as 5.1 to 6.2 in winter sowing period. Faizy (2019) determined the number of branches as 7.18-7.88 branch plant^{-1}. Kizil et al. (2008) reported that more rainfall in the first year of the trial contributed positively to number of branches, plant height, and number of capsules per plant. Similarly, in the second year of the study, plant growth was weaker, and therefore, the number of branching decreased in the second year because of the fact that the precipitation in March and April, which is the plant development period, was less than in the first year (Table 1). The response of the plant to phosphate fertilizer can be highly variable from one year to the next because of many factors affecting P availability and crop growth (Kizil et al., 2008). This may cause differences in the data of the plant observations in different years.

Number of capsules per plant (capsule plant^{-1})

While genotypes were significant at the 5% level in terms of the number of capsules in the plant, no difference was observed in the interaction of genotype x doses. Genotype 1 (16.95 capsule plant^{-1}) has a lower value than genotype 2 (17.79 capsule plant^{-1}) in terms of the number of capsules. While the number of capsules per plant was 18.76 capsule plant^{-1} in the first year, it was determined as 12.98 capsule plant^{-1} in the second year (Table 4). The fact that Geren et al. (1997) did not find a difference between doses in the February sowing in the second year supports our study. Kizil et al. (2008) determined the number of capsules per plant in winter sowing as 12.4-15.5 capsules per plant^{-1} and did not find any difference between doses and years. Yimam et al. (2015) determined the number of capsules per plant as 21.5-45.9 (60/40 N/P), Datta (2004) obtained the highest number of capsules at 20 and 40 kg ha^{-1} phosphorus (5.68-5.61), the lowest number of capsules (4.68) in the control group. Tuncturk et al. (2011) reported 4.68-5.68 capsules per plant^{-1}, Faizy (2019) 34.40-38.46 capsules per plant^{-1}, Kosar and Ozel (2018) 4.03-7.63

capsules per plant^{-1}, Kilic and Arabaci (2016) 16.17 capsules per plant^{-1}.

Number of seeds per capsule (piece capsule^{-1})

While it was found that the effect of phosphorus doses on the number of seeds in the capsule was at a significance level of 1%, the interaction between genotype and genotype × dose was not significant. While the average number of seeds per capsule in G1 was 120.49 per capsule, it was determined as 123.29 in G2. In terms of doses, the highest value was obtained from the 12 kg da^{-1} application with 128.23 seeds per capsule at, while the lowest value was determined as 119.86 and 116.04 seeds per capsule from 0 kg da^{-1} and 3 kg da^{-1} applications, respectively. While the number of seeds in a capsule was 111.63 seeds per capsule in the first year, it was determined as 132.15 seeds per capsule in the second year (Table 4). Yimam et al. (2015) determined the number of seeds per capsule in the range of 55.1-91.6, Tuncturk et al. (2011) determined the number of seeds in a capsule in the range of 52.2-56.2 seeds per capsule^{-1} and reported that there was no statistical difference between the doses. Rana et al. (2012) reported that there were significant differences between the varieties in terms of the number of capsules per plant (29.53-30.30) and the number of seeds per capsule (58.47-60.33), and increasing fertilizer doses increased these values at significant level. This increase may be because of the increased nutrient uptake by the root system after the fertilizer, increased chlorophyll content, and increased protein and photosynthesis (Rana et al., 2012). It was reported that there are significant differences between the concentrations on the number of seeds in the capsule in black cumin (Ali et al., 2015b), and this may be because of the higher enzymatic activity and increased metabolite levels (Shah and Samiullah, 2007).

Thousand-seed weight (g)

It was observed that *Nigella* genotypes were significant at the level of 1% in terms of thousand-seed weight, but the effect of dose and genotype × dose interaction was not significant. The thousand-seed weight of G2 (2.70 g) was higher than that of G1 (2.58 g). The thousand-seed weight was determined as 2.67 g in the first year, and as 2.61 in the second year (Table 4). Yimam et al. (2015) reported that although there was a numerical difference (2.10-2.30 g) in the thousand-seed weight, it was insignificant, Ali et al. (2015a) reported that thousand-seed weight was an important indicator of yield and that fertilizer levels in *Nigella* genotypes were not very important in thousand-seed weight. Tuncturk et al. (2011) reported the thousand-seed weight as between 2.28-2.48 g and found it significant. Kosar and Ozel (2018) determined the thousand-seed weight as 1.81-3.16 g. Tuncturk et al. (2011) and Yimam et al. (2015) reported that a wide variety of factors such as variety, climatic factors, soil properties, and growing conditions affect thousand-seed weight. Yimam et al. (2015) reported that the P and N interaction was very important ($p<0.01$) in the yield parameters and growth parameters other than the thousand-seed weight of black cumin.

Seed yield (kg da^{-1})

Considering the effect of increasing phosphorus doses on seed yield, it was seen that the effects of genotype and genotype × dose interaction were not significant, while the doses were significant at the level of 1%. Since genotypes were mainly formed from the same species (*N. sativa*), although there was a numerical difference between the values in terms of seed yield, the difference was found to be statistically insignificant. According to Table 4, the seed yield of G1 was 125.31 kg da^{-1}, while the seed yield of G2 was determined as 129.56 kg da^{-1}. while the highest seed yield was obtained from the 6 kg da^{-1} application, the lowest seed yield was obtained from the 0 kg da^{-1} (121.77 kg da^{-1}), 9 kg da^{-1} (124.57 kg da^{-1}), and 12 kg da^{-1} (126.34 kg da^{-1}). The difference between years was significant. The seed yield was determined as 154.34 kg da^{-1} in the first year and 100.54 kg da^{-1} in the second year. According to Geren et al. (1997), although the seed yield of the P dose of 0 kg da^{-1} (12.6 kg da^{-1}) was statistically significant in the same group as 8 kg da^{-1} dose (11.8 kg da^{-1}) in February sowing in the second year, the control dose was found to be higher than the 8 kg da^{-1} dose in numerical value. Kizil et al. (2008) reported that the highest seed yield in winter sowing was obtained from the P application of 120 kg ha^{-1} with a value of 1534 kg ha^{-1}. Yimam et al. (2015) reported that the seed yield was in the range of 639.6-1336.7 kg ha^{-1} and the highest value was obtained from the 60/40 kg ha^{-1} (N/P) application. Tuncturk et al. (2011) obtained a seed yield value of 507-568 kg ha^{-1} in the first year, and a value of 549-626 kg ha^{-1} in the second year, and the highest yield from the P application of 40 kg ha^{-1}. It was reported that the difference between the years may be due to different precipitation regimes and differences in temperature. On the other hand, Ozguven and Sekeroglu (2007) applied 0, 3, 6 and 9 kg da^{-1} N and 0, 3 and 6 kg da^{-1} P doses to *Nigella* in Cukurova conditions, and reported that the highest seed yield (100.6 kg da^{-1}) was obtained from 6 kg N da^{-1} and 6 kg P da^{-1} fertilizer applications and that fertilizer doses did not significantly affect the oil content in the seed. While Turan (2014) obtained the highest seed yield as 96.64 kg da^{-1} in Cameli variety, and the highest seed yield at 2 kg P_2O_5 da^{-1} dose (111 kg da^{-1}). In this study, a higher seed yield was obtained from the Cameli variety with a value of 129.56 kg da^{-1} and the highest seed yield was obtained from 6 kg da^{-1} P application (136.04 kg da^{-1}). According to literature data, seed yields obtained as a result of P doses applied to *Nigella* vary. Accordingly; Tuncturk et al. (2011) from the 4 kg da^{-1} P application with a value of 62.6 kg da^{-1}, Shirmohammadi et al. (2014) obtained the lowest seed yield from the control group (451 kg ha^{-1}), and the highest seed yield (735 kg ha^{-1}) from biological phosphate + 40 kg ha^{-1} phosphorus application. Geren et al. (1997) from the 8 kg da^{-1} P application with a value of 60 kg da^{-1} and Kizil et al. (2008) from the 12 kg da^{-1} P application with a value of 1534 kg ha^{-1}. Turan (2014) reported that the highest seed yield at different phosphorus doses was closely related to climate and genotypic effects. Phosphorus for the plant is a nutrient element of great importance because it increases resistance to diseases and pests, ensures root development, plant maturation, early seed formation, and fertilization

(Bilen and Sezen, 1993). Yield components such as capsules and the number of branches affect the seed yield in field crops directly (Ozguven and Sekeroglu, 2007). Yimam et al. (2015) the application of P and N doses together in black cumin causes an increase in plant development, number of leaves and photosynthesis rate. Accordingly, an increase in the number of capsules may lead to an increase in seed yield. Seyyedi et al. (2015) reported that soils that contained high amounts of calcium carbonate affect the phosphorus uptake of the plant negatively, which will also negatively affect the phosphorus uptake in black cumin. Differences in seed yield in similar studies can be explained by the difference in soil structure and phosphorus content in the trial soils of the mentioned studies. According to the study that was conducted by Kacar and Katkat (2009), it was reported that phosphorus has positive effects on the reproductive period and seed maturity in cultivated plants.

Fixed oil content (%)

While there was no difference between genotypes in terms of fixed oil content, it was seen that the doses were significant at the 5% level and the genotype ×dose interaction at the 1% level. While the fixed oil content of genotype 1 was 37.33%, genotype 2 was 35.71%. The highest fixed oil content was obtained from the phosphorus doses of 6 kg da^{-1} (37.63%) and 9 kg da^{-1} (37.54%), which were statistically significant in the same group, while the lowest fixed oil content was obtained from the 12 kg da^{-1} (35.27%) dose. Kizil et al. (2008) obtained the maximum fixed oil content (37.4%) from the 16 kg da^{-1} P winter application, which was in the same statistical group as the 12 kg da^{-1} P application. Kara et al. (2015) reported the fixed oil content as 29.5%- 28.4% in the first and second year. Mamun and Absar (2018) reported fixed oil content as 25% and oleic acid content as 11.7%, Muhammad et al. (2017) as 21.92-22.95%, Faizy (2019) as 35.74-38.46%, Kosar and Ozel (2018) as 36.42-40.17%, Kilic and Arabaci (2016) as 38.17% in black cumin. According to Figure 1A, the highest fixed oil content was observed at the 3 kg da^{-1} (G1×P3) dose of genotype 1, and the lowest fixed oil content at the 3 kg da^{-1} (G2×P3) dose of G2. When compared by years, while the fixed oil content was 34.16% in the first year, it was 38.88% in the second year (Table 5). Aytac et al. (2017) determined that the fixed fat ratio was higher in the first year (43.2%) than in the second year (32.6%). Acetyl-CoA is a starting material for the formation of fatty acids. The glucose that is produced by photosynthesis is firstly converted into pyruvic acid and then into Acetyl-CoA in pyruvic acid. The oils are accumulated in the storage cells that are called oleasomes in the endosperm after the formation of the ovule after the fertilization in the plant. Oils are mostly accumulated in seeds in annual plants (Baydar and Erbas, 2014). Some responses may be associated with the role of phosphorus as a component of phosphatidylcholine, a biosynthetic intermediate and a carrier of acyl chains in plant seeds (Bates et al., 2013). Previous studies reported that P deprivation can lead to low phosphatidylcholine levels (Okazaki et al., 2013). Fredeen et al. (1990) reported that proper P nutrition could improve the photosynthetic process that would allow increased carbon fixation in the production of carbohydrates and lipids. It was reported that phosphorus affects the fixed oil rate and its components because it is found in the structure of many important enzymes such as nucleic acids, coenzymes, nucleotides, phytates, phospholipids, and sugar phosphates in plants playing active roles in photosynthesis.

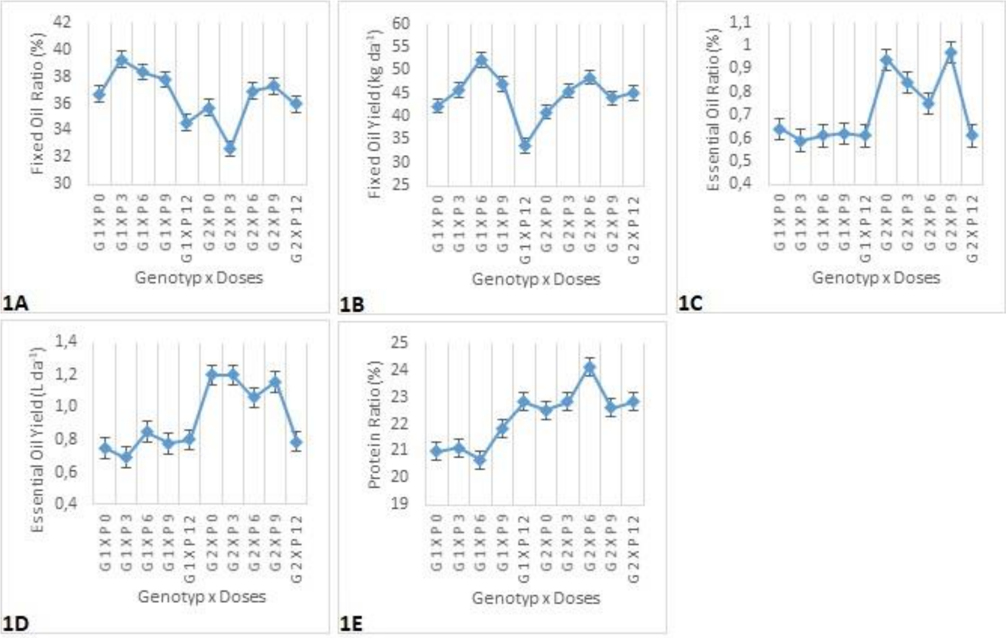

Figure 1. Two-year average values of genotype × dose interaction, which is statistically significant in the investigated characteristics

Table 5. Two-year averages and LSD groupings of applied phosphorus doses for properties examined in black cumin

		FOC (%)		FOY (kg da^{-1})		EOC (%)		EOY (L da^{-1})		PC (%)	
Genotype	G1	37.33		44.18		0.61	b	0.77	b	21.48	b
	G2	35.71		44.78		0.82	a	1.08	a	22.97	a
Doses (kg da^{-1})	0	36.21	ba	41.58	c	0.78	a	0.97	a	21.73	d
	3	35.96	ba	45.63	b	0.71	b	0.94	a	21.96	cd
	6	37.63	a	50.36	a	0.68	b	0.95	a	22.41	b
	9	37.54	a	45.49	b	0.79	a	0.96	a	22.22	cb
	12	35.27	b	39.37	c	0.61	c	0.79	b	22.82	a
Year	2018	34.16	b	50.02	a	0.77	a	1.19	a	22.37	a
	2020	38.88	a	38.95	b	0.66	b	0.66	b	22.08	b
Genotyp × Doses (G×D)	$G_1 \times P_0$	36.71	a-c	42.23	ab	0.64	de	0.75	bc	20.97	de
	$G_1 \times P_3$	39.27	a	45.77	a	0.59	e	0.69	c	21.12	de
	$G_1 \times P_6$	38.34	ab	52.29	a	0.61	e	0.85	b	20.68	e
	$G_1 \times P_9$	37.79	ab	47.06	a	0.62	e	0.78	bc	21.84	cd
	$G_1 \times P_{12}$	34.58	bc	33.60	b	0.61	e	0.80	bc	22.82	b
	$G_2 \times P_0$	35.72	a-c	40.95	ab	0.94	ab	1.20	a	22.50	bc
	$G_2 \times P_3$	32.66	c	45.49	a	0.84	bc	1.20	a	22.81	b
	$G_2 \times P_6$	36.93	a-c	48.43	a	0.75	cd	1.06	a	24.14	a
	$G_2 \times P_9$	37.29	a-c	43.93	a	0.97	a	1.16	a	22.61	b
	$G_2 \times P_{12}$	35.97	a-c	45.14	a	0.61	e	0.79	bc	22.83	b
Mean		36.52		44.48		0.71		0.92		22.23	
CV		5.50		8.86		5.88		6.33		1.54	
LSD for years		1.05**		2.07**		0.02**		0.03**		0.18**	
LSD for genotype		ns		ns		0.02**		0.03**		0.18**	
LSD for doses		1.67*		3.28**		0.03**		0.04**		0.28**	
LSD for G x D		7.89**		15.49**		0.16**		0.23**		1.34**	

FOC: Fatty oil content, FOY: Fatty oil yield, EOC: Essential oil content, EOY: Essential oil yield, PC: Protein content, ns: No significant, *P<0.05; **P<0.01

Fixed oil yield (kg da^{-1})

While there was no difference between genotypes for fixed oil yield, it was observed that dose and genotype × dose interaction were significant at the 1% level (Table 5). The fixed oil yield was determined as 44.18 kg da^{-1} in G1 and 44.78 kg da^{-1} in G2. The highest fixed oil yield was observed in the 6 kg da^{-1} P application (50.36 kg da^{-1}), while the lowest was found in the 0 kg da^{-1} P (41.58 kg da^{-1}) and 12 kg da^{-1} P (39.37 kg da^{-1}) doses, which were statistically significant in the same group. According to Figure 1B, the lowest fixed oil yield was observed at 12 kg da^{-1} P dose of genotype 1 (33.60 kg da^{-1}), while the highest was observed at 0 kg da^{-1} and 12 kg da^{-1} P doses of G1, and at the doses, which were statistically significant in the same group as those of G2 except for the 0 kg da^{-1} P dose. In terms of years, the fixed oil yield was determined as 50.02 kg da^{-1} in the first year and 38.95 kg da^{-1} in the second year (Table 5). Akgoren (2011) reported the fixed oil yield between 18.85-41.08 kg da^{-1}. Telci (1995) determined the average fixed oil yield as 44.70-49.81 kg da^{-1}, which is consistent with the fixed oil yield values in the study. According to Turan (2014), the highest oil yield in the Bilecik population was obtained from 4 kg P_2O_5 da^{-1} application (42.97 kg da^{-1}), while the highest oil yield (46.34 kg da^{-1}) in Cameli variety was obtained from 2 kg P_2O_5 da^{-1} application. In this study, the fixed oil yield of the Cameli variety (Genotype 2) was statistically significant in the same group at all doses except for the control dose. Phosphorus is an important element playing roles in cell division, increasing the resistance of plants by promoting the uptake of potassium by plants, root development and maturation (Brohi and Aydeniz, 1994). With the increasing root development after phosphorus applications, the contact surface of the root in the soil expands, and the rate of utilization of other nutrients by plants increases (Marschner, 1995). Phosphorus fertilizers are very important in increasing the seed quality as well as the seed yield. Climatic conditions such as suitable temperature and sufficient precipitation are very important in black seed cultivation. Also, better root development, branching, and flowering (Bilen and Sezen, 1993), as well as increased number of capsules and the amount of seeds are observed (Seyyedi et al., 2017) with the administration of appropriate phosphorus doses. The effect of phosphorus on seed yield and fixed oil ratio directly affects fixed oil yield because fixed oil yield is calculated by using fixed oil ratio (%) and seed yield (kg da^{-1}) values.

Essential oil content (%)

Genotype, dose, and genotype × dose interaction were significant at the 1% level for essential oil content (Table 5). While the essential oil content of G1 was 0.61% and G2 was 0.82%. While the maximum essential oil content was obtained from 0 kg da^{-1} P and 9 kg da^{-1} P doses, which were statistically significant in the same group, the lowest was obtained from the 12 kg da^{-1} P dose. Considering the genotype × dose interaction according to figure 1C, it is seen that the maximum essential oil content was obtained from the 9 kg da^{-1} P dose of genotype 2, while the lowest content was obtained from the doses of genotype 1 except for the 0 kg da^{-1} P dose, which was in the same group as the 12 kg da^{-1} P dose of genotype 2 (Table 5). According to years, it was found to be 0.77% in the first year and 0.66% in the second year. Kizil et al. (2008) obtained the maximum essential oil content (0.60%) from the control dose (0 kg ha^{-1} P), which is similar to our results. Kara et al. (2015) determined the average essential oil content as 0.34% in the first year and 0.29% in the second year. Faizy (2019) determined the essential oil ratio in the range of 0.79-0.82%. Essential oil amount could be varied due to extraction methods applied and ecological factors such as fertilization, irrigation, seed type and climatic conditions etc (Aksu et al., 2021). As reported by Salem et al. (2020), fertilization has an important role in the growth, flowering, fruit, seed and oil yields of plants as well as in their biochemical components.

Essential oil yield (L da^{-1})

Genotype, dose, and genotype × dose interaction were found to be significant at the 1% level in terms of essential oil yield (Table 5). While the essential oil yield was 0.77 L da^{-1} in genotype 1, it was determined as 1.08 L da^{-1} in genotype 2. When the doses were examined in terms of essential oil yield, it was seen that the lowest essential oil ratio was obtained from the 12 kg da^{-1} P application and that all other doses were statistically significant in the same group (Table 5). According to figure 1D, while the highest essential oil yield was observed at the doses of genotype 2 other than 12 kg da^{-1} P dose, the lowest value was observed at 3 kg da^{-1} P dose of genotype 1. Looking at the years, it was determined as 1.19 L da^{-1} in the first year and 0.66 L da^{-1} in the second year.

Protein content (%)

According to Table 5, genotype, dose, and genotype × dose interaction are significant at the 1% level in terms of protein content. The protein content was found to be higher in genotype 2 (22.97%) than in genotype 1 (21.48%). Considering the doses, the highest protein content was obtained from the 12 kg da^{-1} P application (22.82%), while the lowest protein content was obtained from the control application (21.73%). According to figure 1E, the maximum protein content was obtained from the 9 kg da^{-1} P application of genotype 2, while the lowest protein content was obtained from the 9 kg da^{-1} P dose of genotype 1. While the protein content was 22.37% in the first year, it was 22.08% in the second year. According to Rana et al. (2012), the protein content in the applied fertilizer doses was between 15.42% and 23.18%, and the highest value (23.18%) was obtained from the 60/120 kg ha^{-1} N/P application, which was the highest dose. Takruri and Dameh (1998) found a protein content between 19.9-24.1% and obtained the highest value from the Indian source. Kabir et al. (2019) determined the protein content as 20.3%. The values in this study are seen to be compatible with the literature data.

CONCLUSION

This study was carried out in Kahramanmaras ecological conditions in 2018-2020 to determine the effect of increasing phosphorus doses in black cumin on yield and quality characteristics. Increasing phosphorus doses were found to be significant for the number of seeds in the capsule, seed yield, fixed oil content, fixed oil yield, essential oil content, essential oil yield, and protein content. The highest seed yield was obtained from the 6 kg da^{-1} P application (136.04 kg da^{-1}). While the seed yield increased up to the 6 kg da^{-1} P application, the 9 kg da^{-1} P and 12 kg da^{-1} P applications were in the same statistical group as the control. The fixed oil content, fixed oil yield, and essential oil yield, in a similar way, reached the highest value with the 6 kg da^{-1} P application, while the highest essential oil content was obtained from the 9 kg da^{-1} P application, and the highest protein content was obtained from the 12 kg da^{-1} P application. As a result, the difference between phosphorus doses on number of capsules per plant, plant height, number of branches per plant, and thousand-seed weight was found to be insignificant, and the phosphorus dose coming forward for seed yield and quality properties was 6 kg da^{-1}.

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