Research Article

Effect of Seed Rate and Variety on Yield and Yield Contributing Traits of Black Cumin (*Nigella sativa* L.) at Andracha Woreda, Southwestern Ethiopia

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Abstract | Black cumin is grown as one of Ethiopia's main seed spice crops. But its production and productivity are constrained by a shortage of improved varieties and poor cultural practices including seed rate. Therefore, studies were carried out in Andracha woreda of southwestern Ethiopia during the 2017 and 2018 major cropping period of year to identify the top-performing genotypes of black cumin (*Nigella sativa* L.) in response to seed rate. The experiment composed of four varieties (Dirshaye, Darbera, Aden, and local), and four levels of seed rate (10kg, 15kg, 20kg, and 25kg per ha) set out in a randomized complete block design and replicated three times. The findings of the statistical analysis exhibited that the majority of the response variables under consideration were significantly ($P<0.01$) influenced by seed rate, variety, and interaction of both factors except for days to maturity, plant height, and thousand seed weight. Based on the over-year combined analysis, the highest capsule number per plant (10.4), yield per plant (2.46), and total yield (703.9kg/ha) were noticed for the Darbera variety treated with a 15 kg/ha seed rate. The highest seed number per capsule (87.2) was also recorded for this treatment in the 2017 growing season. Essential oil (0.85 in 2017 and 0.65% in 2018) and oleoresin (29.4 in 2017 and 29.8% in 2018) content of this treatment met the international standard even though maximum recorded essential oil content was 0.92% in 2017 and oleoresin content was 33.8% in 2018. Therefore, concerning overall traits, it can be concluded that the Darbera variety combined with a 15kg/ha seed rate can be suggested for production in the research region.

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Introduction

Black cumin (*Nigella sativa* L.) is popular seed spices and medicinal plants in the family Ranunculaceae. The crop is a blooming annual herbaceous plant indigenous originated from the east Mediterranean, the Arabian Peninsula and India (Arshad, 2015; Thilakarathna *et al.*, 2018; Gharib-

Zahedi, 2010). It is one of Ethiopia's most important spice crops, used mostly to flavor meals, prepare oil for medical purposes and perfumes, as an income source, agricultural diversification, and export (Wubeshet and Dessalegn, 2019; Tiru *et al*., 2017). It is also used in the country to reduce the spiciness of pepper powder (Edwards *et al*., 2003). It is also the second exported spice next to ginger, with Arabic countries together with other mostly Muslim countries accounting for 98 percent of Ethiopia's exports in 2008 (Orgut, 2007).

The crop is grown as a rain-fed crop in Ethiopia's highlands, at elevations of 1500-2500 meters, with an average temperature of 12-20 degrees Celsius and a yearly rainfall of 120-400 mm which is ideal for blooming, fertilization, and fruit production. It grows well in most types of soil with a pH of 5-8 (Takruri and Dameh, 1998). Despite the fact that black cumin is a resilient spice plant that grows in a variety of soils (Jansen, 1981), it grows best in sandy loam soil with high microbial activity. It grows best on flat, well-drained soils in areas with moderate rainfall and sloppy soils in areas with excessive rainfall (Orgut, 2007).

In Ethiopia, black cumin is mainly grown in West Shoa, North Shoa, Bale, Jimma, Illubabor, and Arsi Zones of Oromya region; South Wollo and South Gonder, in Amhara Region; and Kaffa, Sheka, and Benchi-Maji, zones of the southern region within 'Woina Dega' dry areas (Minstry of Agriculture and Rural Developement, 2003). On 13,672.52 hectares of land, these regions produced 4,201.2 tons of black cumin seed (Ministry of Trade and Industry, 2010). In the previous production seasons, black cumin seed production climbed dramatically from 5887 ton during 1997-2001 years (Minstry of Agriculture and Rural Developement, 2003) to 18000 metric tons of seed produced in the 2014/15 season (Ethiopian Investment Agency, 2015).

Although its production and area coverage have increased, its national average productivity is 0.79 t/ha (Habtewold *et al*., 2017) which is very low as compared to 1.5-1.9 ton/ha the crop potential (Minstry of Agriculture and Rural Developement, 2006, 2009). According to Yosef (2008) and Zigyalew (2020), lack of recommended fertilizer rate, shortage of improved seed, a problem with postharvest management, lack of better agronomic practices and extension services, and marketing issues are the primary variables influencing black cumin production. The usage of contemporary and intensive agricultural technology such as improved seeds, row planting, and artificial fertilizer was also quite low in Ethiopia (Chanyalew *et al*., 2010). Thus, acceptance and use of latest agricultural technologies were recommended to enhance the productivity and benifit of commercial black cumin production (Abebe *et al*., 2020).

Seed rate is the key factor determining yield in any crop production system (Najmi *et al*., 2013). It is one of the cultural practices affecting black cumin production (Mahbuba *et al*., 2021; Koli, 2013); Ahmed and Haque, 1986). The establishment of optimum plant density in a field helps the plants to fully exploit the growth resources (water, air, light, soil) and minimizes intra-species and extra-species competitions therefore this leads to maximum yield (Alizadeh and Koucheki, 1995).

Former research showed that black cumin varieties significantly vary in their response to the density of the plant in the different growing environments (Gholinezhad and Abdolrahimi, 2014; Abdolrahimi *et al*., 2012; Ahmed and Haque, 1986). The optimum seed rates which ranged from 10kg/ha (Özlem and Süleyman, 2004) to 20-30 kg/ha in 25-40 cm rows (Weiss, 2002) were reported for different varieties at different locations. Similar variations in seed rate for different varieties were also reported at different environments for coriander (Katiyar *et al*., 2014) and Sesame (Naim *et al*., 2012; Lazim, 1973). In Ethiopia, the highest significant grain yield was reported at 20kg/ha seed rate for local varieties in northern Ethiopia (Yemisrach *et al*., 2008); while 5-7.5kg/ha (Minstry of Agriculture and Rural Developement, 2006) and 15-20kg/ha reported for released varieties (Minstry of Agriculture and Rural Developement, 2009). Variation in the adaptability of different varieties including the released one was also reported at different growing environments where maximum yield was observed for local varieties as compared to the released varieties at the Kafa zone of southwestern Ethiopia (Ermias *et al*., 2015); whereas the released varieties Dirshaye and Aden were recommended for west Hararghe zone mid highlands, eastern Ethiopia (Gezahegn and Sintayehu, 2016), Darbera variety performed best as compared to other released and local varieties at mid-altitude of Bale, southeastern Ethiopia (Asefa and Beriso, 2020), and the released variety Aden at 10kg/ha seed rate performed best at Burusa of Oromiya region (Mahbuba *et al*., 2021). These variations reported for different black cumin varieties under different seed rates and locations call for the importance of specific area research recommendations.

Despite the conducive agro-ecology and importance of the crop, farmers of the study area are not benefited due to a lack of information on improved varieties and suitable cultural practices including seed rate. To diversify its output and boost farmer income, evaluation of selected varieties combined with improved agronomic practices like seed rate was, therefore, one of the issue is easing the difficulties in getting the necessary varieties with improved cultural practices for which the finding of this study was likely to support and alert black cumin producers and processors. Thus, this research was designed to detect the suitable seed rate and variety for the study area.

Materials and Methods

Study area description

The study was carried out at Andracha Woreda (Getiba) of South-western Peoples Regional States during 2017 (from July 10 to december 17) and 2018 (July 18 to December 29) main cropping seasons under rain-fed conditions. Geographically, the study site is situated 712 km away from Addis Ababa to the southwest direction at 35.045595 longitudes, 7.056521 latitudes, and 1970 m.a.s.l. elevation. The soil type of the site is characterized by Acrisol (Berhane and Sahlemedhin, 2003). The area receives mean annual rainfall which ranges between 1800-2200 millimeters with a min. and max. temperature of 15.1 °C and 27.5°C, respectively (Tadesse and Masresha, 2007). In the study, the results of some chemical and physical analysis of the soils collected before conducting the experiments were existing in Table 1. Accordingly, both year trial soils were clay loam textured and slightly acidic; Their organic matter, organic carbon, and total nitrogen content as well as Cation Exchange Capacity (CEC) were medium; while, the available phosphorus content was shown to be "low" (Table 1).

Planting material

The experimental material consists of four varieties; three improved varieties (Aden, Dirshaye, and Derbera) obtained from Kulumsa agricultural research center and the local variety obtained from the neighboring farmers. The detailed descriptions of the tested varieties are presented in Table 2.

Table 1: *Some chemical and physical characteristics of the experimental site soils (0-30 cm).*

Soil characteristics	Year	
	2017	**2018**
pH water, 1:2.5	5.95	5.67
Organic carbon (%)	3.95%	3.25%
Organic Matter (%)	3.88%	3.38%
Cation exchange capacity (CEC)	22.29 meq/100g soil	22.22 meq/100g soil
Total nitrogen	0.20%	0.18%
Available phosphorus	9.15 ppm	8.59 ppm
Texture		
Clay	26.80%	25.70%
Silt	36%	35.40%
Sand	37.20%	38.90%

Table 2: *Descriptions of Black cumin varieties.*

Characters	Varieties			
	Darbera	**Dershaye**	**Aden**	**Local**
Altitude (m)	1650-2004	1800-2500	1800-2500	
Rainfall (mm)	120-400	1000-1200	1000-1200	
Plant height(cm)	57	54-62	54-64	-
Maturity day	155-173	134-153	134-150	-
Growth habit	Erect and condensed branching and leafy at head	Erect Annual profusely branching	Erect Annual profusely branching	-
Yield (ton/ha)	1.5-1.9	0.9-1.6	0.9-1.6	-
Year of release	2006	2009	2009	-
Breeder/ maintainer	SARC/ OARI	MARC/ EIAR	MARC/ EIAR	-
Source	MoARD, 2006	MoARD, 2009		

EIAR: Ethiopian Institute of Agricultural Research, MARC: Melkassa Agricultural Research Center, OARI: Oromia Agricultural Research Institute, SARC: Sinana Agricultural Research Center.

Experimental design and treatments

The study composed of a factorial combination of four varieties (Aden, Dirshaye, Derbera, and local) and four levels of seed rate (10kg, 15kg, 20kg, and 25kg per ha) which were set out in a Randomized Complete Block Design and replicated three times.

Cultural practices

The research field was tilled with oxen until the soil was finely loosened. Each plot had a width and length of 2.4m and 3m, respectively, and was subdivided into eight rows. The space between blocks and plots was retained at 1.5 m and 0.5 m, respectively. Drilling 30cm apart in rows was used to sow the seeds. Borders were defined as the outermost rows on both sides of plots. All management practices were carried out consistently. In both years, the experiment for the compressive suggestion was repeated using similar approaches.

Data collection

The six harvestable middle rows of individual plot were used to collect data for individual response variables. The individual plant was measured based on a randomly selected and tagged ten plants in the central rows.

Phonological and growth variables

Days to 50% emergence was counted from the date of planting until 50% of the seedlings emerged above the ground. The actual count of the days from emergence date to the date when nearly half of the plants developed flowers was registered as days to 50% flowering. The days to maturity were calculated from emergence date to the time when 90% of the capsules become yellow. The primary and secondary branch number after flowering were counted and averaged. A standard ruler was used to measure plant height (cm) from the plant's base to the tip of the capsule.

Yield variables

Capsules number per plant and number of seeds per capsule were computed from the average of ten sampled plants per plot and ten randomly taken capsules per plant, respectively. The average weight of seed yield from ten plants was used to calculate seed yield per plant (g). Total yield (kg/ha) was noted from the total seeds harvested from central rows and converted into kg/ha.

Quality variables

Thousand seeds weight (g): A sample of 1000 seeds per plot was taken and weighed.

Essential oils (%): The essential oil separation was done as per the ASTA (1997) method. A modified Clevenger method was used to determine the amount of volatile oil. 100gm of the milled sample was weighed and placed in a 500 mL round bottom flask. 1 L of distilled water was added to the flask holding the sample. Water was poured and filled into the trap. The system was connected to the condenser, which was then mounted on a pedestal on the heating mantle. The flask was brought to a boil, and the distillation was persistent until no change in oil content was detected in two successive readings taken at one-hour intervals. Each cycle of the distillation process took roughly 3-4 hours to complete. Then, the heat source was switched off, and the oil volume was measured. After that, the extracted oils were carefully separated from their hydrolytes. After drying each oil sample with anhydrous sodium sulphate (Na2SO4), the pure oils were recovered. The following calculation or formula was used to compute the % volatile oil content.

$$Oleorsine, w/w = \frac{weight\ of\ the\ residue\ (g)}{weight\ of\ the\ sample\ (g)}$$

Oleoresin% (Acetone extractable solutes): The thimble made of thick filter paper was filled within ground sample. In an oleoresin extraction chamber, the thimble was suspended above a bottle of solvent and beneath a condenser. The flask was heated to allow solvents to evaporate and flow up into the condenser, where the solvent vapors were transformed to a liquid, which then trickled into the sample-containing collection chamber. The required component was collected in the distillation flask after many cycles, and the extract was quantitatively shifted into a beaker. On a steam bath, the solvent was completely evaporated (Heidolph, rotary evaporator, Germany). The container was heated in a hot air oven at 110°±2°C until two successive weightings recorded at one and half hour intervals did not fluctuate above 1mg. The non-volatile oleoresin was determined from the dried residues (ASTA, 1997) using the following formula:

$$Oleorsine, \frac{w}{w} = \frac{Weight\ of\ the\ residue\ (g)}{Weight\ of\ the\ sample\ (g)} \times 100$$

Statistical analysis

Using the methods described by Montgomery (2013), the data was subjected to two-way analysis of variance. For response variables with non-significant error variances across years, combined analyses were conducted. however, for significant error variances response variables with across years, the findings were reported based on each year's analysis. The least significant difference values were used to compare treatment means when F values were shown to be significant at a 5% level of probability. SAS 9.2 statistical software was used to analyze the data (SAS, 2008).

Results and Discussion

Phenological variables

Days to 50% emergence: Based on over year combined data the variety main effect on days to 50% Emergence was highly significant ($P<0.01$), while seed rate main effect, and seed rate with variety interaction effect were non-significant (Table 3). As a result, Aden and Dirshaye varieties (14.83days) followed by Darbera emerged earlier than the local variety (16.62 days) which showed longer days to emerge (Table 4). The significant differences observed in the number of days required for 50% of the seeds to emerge from the soil may be attributed to genetic variations that may exist among the cultivars. Adam (2006) also reported considerable differences between black cumin varieties concerning days to 50 % emergence. Amdie and Teshome (2021) also obtained significant variation between black cumin varieties in relation to days to 50% emergence which extended from 25.11 to 31.22 days.

Days to 50% flowering: Investigation of variance of the two years combined data revealed that varieties had highly significant ($P<0.01$) difference for days to 50% flowering. Variation among seed rate and the interaction effect, on the other hand, were non-significant (Table 3). From this result, the local variety took the shortest days to flower (80.83 days) as compared to other improved varieties. Variety Aden showed the maximum date (95.54 days) to flower (Table 2); while derbera and Dirshaye varieties showed medium and statistically similar days to flower. This outcome is consistent with the finding of Gezahegn and Sintayehu (2016) who also described shortest days to 50% flowering in local variety as compared to Aden variety. In contrast to these findings, Ermias *et al*. (2015) reported local check took longer days to blossom than the improved varieties. Significant variety effect on flower initiation of black cumin was also stated by Mahbuba *et al*. (2021) and Miheretu (2018). The flowering date of black cumin genotypes was ranged from 84 up to 93 days in the experiments conducted at Bale, Southeastern Ethiopia (Miheretu, 2018). This might result from genetic difference between the varieties.

Table 3: *Mean values of combined analysis of the main effect of seed rate and variety on phonological variables of Black cumin (Nigela sativa L.) at Andracha during 2017and 2018 growing seasons.*

Variety	Days to 50% emergence	Days to 50% flowering	Days to maturity
Aden	14.83 [c]	95.54 [a]	155.08
Darbera	15.5 [b]	87.46 [b]	155.08
Dirshaye	14.83 [c]	88.21 [b]	155.50
Local	16.62 [a]	80.83 [c]	154.75
$LSD_{(5\%)}$	0.597	1.647	1.795
P-value	<0.001**	<0.001**	0.865 [ns]
CV (%)	4.6	2.2	1.4
Seed rate			
10	17.75	13.67	155.67
15	17.00	13.42	155.21
20	17.42	13.58	154.04
25	17	13.75	155.5
$LSD_{(5\%)}$	0.733	0.96	1.795
P-value	0.389 [ns]	0.838 [ns]	0.264 [ns]
CV (%)	5.1	8.5	1.4

*At a 5% level of significance, means having with the same letters in the same column are nonsignificantly different from each other, CV: Coefficient of Variation, LSD: Least Significant Difference, [ns] : non-significant, **: Significant at 1% level.*

Days to maturity: The investigation of variance of the two years' combined data showed that non-significant variations were observed between varieties, seed rate, and interaction of both factors with respect to days to maturity (Table 3). This result is similar with the report of Fekadu *et al*. (2021) in which they found a non-significant effect of inter-row spacing and seed rate on days to maturity in Arsi highlands. However, in contrast to this study, significant variations in terms of days to maturity among black cumin genotypes at different locations were reported by Adam (2006), and Ermias *et al*. (2015). Adam (2006) reported 135 -149 days at Adet, and 99 to122 days range of maturity at Woreta location. Ermias *et al*. (2015) also reported 132.5-146 days at Keyakela and 160-168.4 days range of maturity at Alarigata locations of southwestern Ethiopia, indicating the presence of variation among black cumin genotypes in response to the days to maturity at different environmental conditions.

Growth variables

Plant height: The analysis of variance of the two years combined data shows that non-significant variations were observed between varieties, seed rate, and interaction of both factors with respect to plant height (Table 4). Similar results were reported by Gholinezhad and Abdolrahimi (2014), and Mahbuba *et al.* (2021) in their experiments of variety with plant density effect on black cumin. Whereas, contrasting results were reported from the experiments conducted at different sites of kaffa zone of south western Ethiopia (Ermias *et al*., 2015), visa vis, significant effect at one (Kaya kela) testing location with the local check showed the maximum plant height; on the other hand non-significant effect at other (Alarigata) testing site, indicating variation in response of varieties at different growing ecologies.

Number of primary branches per plant: There was highly significant ($p<0.01$) difference between the treatments due to the seed rate and variety interaction effect on the number of primary branches per plant (Table 4). Averaged over years, statistically similar and highest values were observed for Aden (3.4) and Darbera (3.4) varieties sown with 10kg/ha seed rate and Darbera (3.28) variety treated with 15kg/ha seed rate. On the contrary, the lowest primary branch number per plant was counted in local varieties treated with a 20kg/ha seed rate (2.078) (Table 4). This could be caused by genetic hetrogenity among varieties in response to different seed rates. This result is corroborated with the reports of Koli (2013) who observed highly significant variety by spacing interaction effect on primary branch number per plant of black cumin. Similarly, Mahbuba *et al.* (2021) reported a significant variety by seed rate interaction effect on the branches number per plant of black cumin. They observed the maximum number of branches per plant (5.3) for the variety Dirshaye at the seeding rate of 10kg/ha. Fekadu *et al.* (2021) also found that low seed rates (5 and 15 kg/ha) increased branch number per plant as compared to the 20kg/ha seed rate for Aden variety. This is probably due to less competition for resources under a low seed rate.

Table 4: *Mean values of combined analysis of interaction effect of seed rate and variety on some growth and yield variables of Black cumin (Nigela sativa L.) at Andracha during 2017and 2018 growing seasons.*

Variety	Seed Rate	Plant height	Number of primary branches	Capsule number/ plant	Seed yield per plant(g)	Total seed yield(kg/ha)	Thousand seed weight(g)
Aden	10	45.63	3.4 a	9.85 ab	1.126 fg	649 bc	2.397
	15	47.98	3.033 b	9.25 b	2.35 ab	656.6 b	2.293
	20	50.6	2.6 c	5.95 ef	1.107 fg	596.7 de	2.477
	25	41.82	2.333 de	4.68 g	1.001 fgh	584.6 def	2.233
Darbera	10	51.92	3.4 a	8.33c	2.254 b	616.9 cd	2.177
	15	49.12	3.283 a	10.4 a	2.463 a	703.9 a	2.183
	20	41.18	2.358 de	5.58 f	1.086 fg	548.1 g	2.003
	25	42.97	2.483 cd	5.53 f	0.906 h	554.5 fg	2.060
Dirshaye	10	44.17	2.6 c	8.25 c	2.242 b	603.8 d	2.477
	15	43.42	2.383 de	5.45 f	1.327 de	535.2 gh	2.163
	20	44.07	2.333 de	5.35 f	1.875 c	614.2 d	2.270
	25	39.57	2.083 f	4.62 g	1.501 d	512.6 h	2.183
Local	10	44.17	2.4 d	6.23 e	1.126 fg	613.6 d	2.183
	15	42.08	2.2 ef	5.48 f	1.363 d	585.7 def	2.273
	20	43.14	2.078 f	6.41 e	0.98 gh	565 efg	2.487
	25	46.98	2.117 f	7.53 d	1.113 fg	553.8fg	2.213
$LSD_{(5\%)}$		16.683	0.197	0.641	0.175	34.65	0.4499
P-value		0.095ns	<0.001**	<0.001**	<0.001**	<0.001**	0.861ns
CV (%)		10.1	4.6	5.6	7.1	7.1	12.0

*At a 5% level of significance, means having with the same letters in the same column are nonsignificantly different from each other, ns: non-significant, **: Significant at 1% level, CV: Coefficient of Variation, LSD: Least Significant Difference.*

Number of secondary branches per plant: The variety by seed rate interaction effect on the number of secondary branches per plant was shown to be highly significant (P<0.01) using analysis of variance in both years 2017 and 2018 (Table 5). Accordingly, statistically similar and highest values were observed for Darbera and Dirshaye varieties with 10 kg/ha (8.36) which is followed by Darbera variety sown with 15kg/ha seed rate (7.7) in the 2017 growing season. On the other hand, statistically similar and maximum values were observed for Dirshaye (4.93) and Darbera (4.6) varieties treated with 15kg/ha in the 2018 growing season. The lowest values for secondary branches per plant were recorded in Aden (1.8) and Dirshaye (2.13) varieties combined with 25kg/ha seed rate treatments in 2017 and 2018 growing seasons, respectively (Table 5). This result is similar to the reports of Koli (2013) in which he found a highly significant effect of variety by spacing interaction on secondary branches number of black cumin. Mahbuba *et al*. (2021) also reported significant effect of seed rate by variety on number of branch per plant. Hammo (2008) indicated significant reduction in the number of branches per plant at increased plant population,which was confirmed in our study for released varieties in 2017 trial season. In general, the number of secondary branches per plant reduced in 2018 as compared to 2017 in most studied treatment combinations probably due to difference in climatic situations of the two seasons.

Yield variables

Number of capsules per plant: The effect of interaction of variety and seed rate on the number of capsules per plant was found to cause a very highly significant (*P*<0.01) variation (Table 4). Averaged over years, the highest and statistically similar value of the capsules number per plant was recorded from Darbera in 15kg/ha (10.4) and Aden in 10 kg/ha (9.85). The treatment Dirshaye treated with 25kg/ha (4.62) produced statistically the lowest capsules number per plant (Table 4). This variation might be argued to the varieties' genetic hetrogenety in response to varying seed rates and environmental circumstances during pollination at the initial stage of seed set, which determines the number of capsules per plant (Salgueiro *et al*., 2010). This result is in agreement with the finding of Mahbuba *et al*. (2021) where they found a significant variety and seeding rate interaction effect on the capsule number per plant. They reported the highest value at seed rate 10 kg/ha for variety Aden. Significant effect of interaction of spacing by variety on capsules number per plant was also observed by Koli (2013) and Gholinezhad and Abdolrahimi (2014). According to Kafi (1990), the number of umbrellas per plant ranged from 18.9 to 31.3 at various plant densities. The largest number of capsules per plant (10.2) was recorded from 10 kg/ha, according to Özlem and Süleyman (2004).

Table 5: *Mean values of the Interaction effect of seed rate and variety on Number of secondary branches per plant and seed number per capsule of black cumin(Nigela sativa L.) at Andracha during 2017and 2018 growing seasons.*

Variety	Seed rate	Secondary branch number/plant		Seed number / capsule	
		2017	2018	2017	2018
Aden	10	7.5 b	4.06 abc	76.17 cd	66.17
	15	7.4 b	3.8 bcd	86.6 a	76.6
	20	2.93 gh	4.4 abc	78.67 c	68.67
	25	1.8 i	4.13 abc	78.1 c	68.1
Darbera	10	8.36 a	4.16 abc	80.2 bc	70.2
	15	7.7 b	4.6 ab	87.2 a	72.87
	20	3.567 f	3.56 cde	80.07 bc	70.07
	25	3.1 g	2.73 efg	75.73 cd	61.3
Dirshaye	10	8.36 a	3.8 bcd	77.9 c	67.1
	15	3.03 gh	4.93 a	77.1 c	67.1
	20	2.66 h	4.26 abc	71.3 d	65.73
	25	2.8 gh	2.13 g	89.07 a	79.07
Local	10	4.56e	4.06 abc	86.07 a	76.6
	15	5.83 d	4.15 abc	85.13 ab	75.13
	20	3.83 f	3.8 bcd	89.67 a	79.67
	25	4.86 e	4.13 abc	75.93 cd	65.93
$LSD_{(5\%)}$		0.37	0.88	5.619	22.85
P-value		<0.001**	<0.001**	<0.001**	0.798ns
CV (%)		4.7	14.1	4.2	19.4

*At a 5% level of significance, means having with the same letters in the same column are nonsignificantly different from each other, CV: Coefficient of Variation; LSD: Least Significant Difference; ns: non significant, **: Significant at 1% level.*

Number of seeds per capsule: A highly significant (*P*<0.01) variation was shown between varieties, seed rate, and interaction of both factors in relations to the seeds number per capsule in the 2017growing season (Table 5). As a result, the highest value (89.67) was registered in the local variety sown with a 20kg/ha seed rate. This value was statistically similar with Dirshaye sown at 25kg/ha (89.07), Darbera sown at 15 kg/ha (87.2), Aden sown at 15 kg/ha (86.6), and local variety sown at 10 kg/ha (86.07). This difference in the number of seeds per capsule between varieties observed might be due to the difference in response of varieties to different seed rates for this variable. This result is consistent with Mahbuba *et al.* (2021) findings, which indicated a significant interaction effect between variety and seeding rate on the seed number per capsule. They reported the highest value for the Aden variety at a 10 kg/ha seed rate. However, there was no significant difference between treatments in numbers of seeds per capsule in the 2018 growing season (Table 5). A comparable result was described by Fekadu *et al.* (2021) where they found a non-significant effect of seed rate on this variable.

Seed yield per plant: The effect of interaction of variety and seed rate resulted highly significant (P<0.01) variation on seed yield per plant (g) (Table 4). The two years average data indicated that the highest yield of seeds per plant was recorded in Darbera variety sown with a 15Kg/ha seed rate (2.46g) which was statistically similar with Aden variety treated with 15Kg/ha seed rate (2.35g). The lowest weight of seeds per plant (0.906 g) was noted in the Darbera variety treated with a 25Kg/ha seed rate (Table 4). This might be due to the highest value of both primary and secondary branch numbers observed for this treatment which contributed to the increased number of leaves for photosynthesis, and the highest capsules number per plant and seeds per capsules observed in this experiment for this treatment. This result is in agreement with the works of Abdolrahimi *et al.* (2012) and Kafi (2003) where they reported seed yield per plant significantly varied for different varieties under varying plant densities. Mahbuba *et al.* (2021) also found a significant interaction effect of seed rate and variety on yield per plant of black cumin, and they reported maximum value for Aden variety when sawn at 10kg/ha.

Total seed yield (kg/ha): A highly significant (P<0.01) variation was observed due to the interaction effect of seed rate and variety on total seed yield (Table 4). Averaged over years, statistically, the maximum seed yield was recorded in the Darbera variety combined with a 15kg/ha seed rate (703.9kg/ha). The minimum seed yield was recorded from the Dirshaye variety combined with a 25kg/ha seed rate (512.6kg/ha) (Table 4). This result agreed with the results of Koli (2013), who reported a significant interaction effect of plant spacing with variety on black cumin yield. Similar variation in black cumin seed yield due to interaction effect of seed rate and variety was also shown by Mahbuba *et al.* (2021). The highest yield observed for the Darbera variety in this study might be due to its genetic capacity to give the highest yield than the other two released varieties as shown in the variety description presented in Table 1. Similarly, Asefa and Beriso (2020) also reported a higher yield for Darbera variety as compared to Dirshaye, Aden, and local varieties in their experiments of variety evaluation at Bale mid-altitude, southeastern Ethiopia. Maximum yield found at 15kg/ha seed rate, which is relatively wider spaced plants as compared to 20 and 25kg/ha might be due to the availability of more space to the plant at which plant could spread more and could produce more branches resulting in more number of capsules per plant which contributed to more yield as reported by Katiyar *et al.* (2014) in their similar experiments of coriander. Due to the existence of positive and highly significant correlation of seed yield of black cumin with primary and secondary branches number per plant (Zigyalew *et al.*, 2020), the highest value in the number of primary and secondary branches per plant observed for Darbera variety at 15kg/ha seed rate contributed to the maximum yield of this variable in this experiment. Inconsistent with this study, a 15kg/ha seed rate was also recommended for black cumin production in the Arsi highlands of Ethiopia (Fekadu *et al.*, 2021).

Thousand seeds weight (g): The analysis of variance of the two years combined data shows that non-significant variations were observed between varieties, seed rate, and interaction of both factors with respect to thousand seeds weight (Table 4). A similar non-significant spacing and variety effect on thousand seeds weight were observed on black cumin (Abdlrahimi *et al.*, 2012), and on coriander (Kızıl, 2002).

Quality variables

Essential oil content (%): Interaction of seed rate by variety showed a highly significant effect (P<0.01) on essential oil content in both years (Table 6). The highest and statistically similar value was observed for the Dirshaye variety combined with10, 15, and 20 kg/ha seed rate, and Aden variety combined with 10 and 15kg/ha seed rate in both 2017 and 2018 growing seasons. It ranged from 0.71 to 0.92, and from 0.49 to 0.72 in the 2017 and 2018 growing seasons, respectively. The highest value observed in this study was within the range of 0.7-1.3 reported for dershaye variety and 0.6-1.2 reported for Aden variety (Ministry of Agriculture and Rural Development, 2009). It is higher than the value reported for Darbera (0.47) and Dirshaye (0.6) (Ermias *et al*., 2015), and Darbera 0.21 (Ministry of Agriculture and Rural Development, 2006). This variation of essential oil content might be caused by difference in the genetic make-up of varieties, location, and season as reported by Weiss (2002). A similar interaction effect of variety and seed rate on essential oil yield was reported by Kızıl (2002) in his experiments of coriander.

Table 6: *Interaction effect of Seed rate and variety on essential oil and oleoresin content of Black cumin(Nigela sativa L.) at Andracha during 2017and 2018 growing seasons.*

Variety	Seed rate	**Essential oil (%)**		Oleoresin (%)	
		2017	2018	2017	**2018**
Aden	10	0.92 a	0.71 a	33.2 a	33.8 a
	15	0.92 a	0.72 a	28.9 d	29.03 cd
	20	0.85 b	0.64 bc	29.1 d	29.83 bc
	25	0.71 d	0.50 e	22.2 j	22.73 i
Darbera	10	0.71 d	0.50 e	27.3 f	28.03 ef
	15	0.85 b	0.65 bc	29.4 c	29.8 bc
	20	0.71 d	0.50 e	26.2 h	25.9 h
	25	0.78 c	0.57 d	25.4 i	25.8 h
Dirshaye	10	0.92 a	0.71 a	28.5 e	28.63 de
	15	0.92 a	0.72 a	26.8 g	26.67 gh
	20	0.92 a	0.72 a	29.4 c	29.8 bc
	25	0.85 b	0.65 b	30 b	30.67 b
Local	10	0.71 d	0.5 e	27 q	27.47 fg
	15	0.71 d	0.49 e	18 k	18.27 j
	20	0.78 c	0.56 d	26.9 q	27.1 fg
	25	0.85 b	0.62 c	26.3 h	25.9 h
$LSD_{(5\%)}$		0.0278	0.0085	0.2278	0.9777
P-value		<0.001**	<0.001**	<0.001**	<0.001**
CV (%)		2.7	0.6	0.5	2.1

*At a 5% level of significance, means having with the same letters in the same column are nonsignificantly different from each other, LSD: Least Significant Difference; CV: Coefficient of Variation ,^{ns}: non significant; **: Significant at 1% level.*

Oleoresin content (%): A highly significant (P<0.01) variety by seed rate interaction was observed for Oleoresin content (Table 6). The highest Oleoresin content was recorded for variety Aden treated with 10 kg/ha seed rate in both 2017 (33.2%), and 2018 (33.8) growing seasons. However, the lowest values were recorded for local variety treated with a 15 kg/ha seed rate in both 2017 (18%) and 2018 (18.27%) growing seasons. The results obtained in this experiment (Table 6) meets the national recommendations for Aden (27.2-32.4) and Dirshaye (26.3-30.6) variety except for the treatment Aden treated with 25 kg/ha seed rate (22%) (Ministry of Agriculture and Rural development, 2009). The highest values were observed as compared to the findings of Ermias *et al*. (2015) who reported 24.79, 28.4, and 28.31% for Dirshaye, Aden, and Darbera, respectively. According to research findings, both genetic and environmental variables influence the chemical constituent of black cumin (Arslan *et al*., 2012; Ertaş, 2016).

Conclusions and Recommendations

The results of this study indicated the existence of variations between seed rate and variety interaction effect on growth, yield, and quality of most of the characters considered except for plant height, days to maturity, and thousand seed weight which exhibited non-significant variation. On the otherhand, the main effects of variety on days to 50% emergence and flowering showed significant variation; whereas the interaction effect for these variables was non-signficant. As a result, the main effects of variety indicated Aden and Dirshaye varieties took significantly shorter days to emerge followed by Darbera, but Aden took longer days to flower followed by Dirshaye and Darbera. Concerning growth and yield variables, combined analysis of 2017 and 2018 years showed that the highest value of the number of primary branches per plant, number of capsule per plant, yield per plant, and total yield were recorded for Darbera variety treated with 15kg/ha. This treatment also exhibited the highest number of secondary branches per plant in 2018 and the maximum seed number per capsule in 2017 growing seasons in individual year analysis. This treatment also met the international standard of essential oil and oleoresin content of black cumin even though maximum essential oil content was recorded for Aden variety treated with 10 and 15kg/ha seed rate, and Dirshaye variety treated with 10, 15, and 20kg/ha in 2017 and 2018 growing seasons, and highest oleoresin content was recorded for Aden variety sown with 10kg/ha in 2018growing season. Therefore, it can be concluded that concerning overall traits variety Darbera combined with a 15kg/ha seed rate can be suggested for production in the study area.

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Novelty Statement

This study presented that, the Darbera variety sown at a 15 kg/ha seed rate was found to be the best for black cumin production in the Andracha area.

Author's Contribution

TB and AHG: Designed the experiments, conducted the experiments, measured the observations, analyzed and interpreted the data and wrote the paper.

Conflict of interest

The authors have declared no conflict of interest.

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