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Research Paper

Plant population is crucial to yield enhancement of white cumin (*Trachyspermum ammi*) in northwestern Ethiopia

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ABSTRACT

A field experiment was conducted during August 2017 and January 2018 at Dembia district of Ethiopia, to determine the optimum plant population of white cumin [*Trachyspermum ammi* (L.) Sprague ex Turrill] by adjusting inter- and intra-row spacings. The experiment consisted of a complete randomized block design with 4 inter-row spacings (30, 40, 50 and 60 cm) and 3 intra-row spacings (10, 15 and 20 cm), replicated 3 times. The maximum mean days to flowering (92 days) were recorded in plant spacing of 50 cm × 20 cm. The highest numbers of primary and secondary branches were obtained in 60 cm × 20 cm spacing. The maximum numbers of umbels and umbellets were recorded in 40 cm × 20 cm spacing. The interaction effects of spacings on plant height, biological yield, seed yield, and harvest index were significant, while those on days to flowering and maturity, number of primary and secondary branches, number of umbels and umbellets, and 1,000-seed weight were non-significant. It is concluded that white cumin should be planted at the spacing of 40 cm × 10 cm in Dembia district and similar other agroecological areas of Ethiopia to achieve the maximum yield.

Key words: Plant population, Plant spacing, Productivity, Spices, White cumin or carom

White cumin or carom is an annual medicinal and aromatic spice plant belonging to the family Apiaceae (Tomar and Malik, 2014). Ethiopia is considered as a centre of diversity for white cumin. Here it is mainly cultivated around Amhara Region (Gondar, Bure, Mersa, Gojam, Shewa and Wolo) and Oromia Region (Bale). However, for own household consumption, it is grown in different parts of the country as well (Habtewold *et al*., 2017).

Ethiopia is a homeland for many spices including white cumin (ITC, 2010). Ethiopian people use spices to flavour bread, butter, meat, soups, and vegetables and they use them to make medicines and perfumes too (ITC, 2010).

Despite the importance and potential of the crop, little attention has been given to improve the productivity of white cumin. The average yield of this crop is low due to lack of superior varieties and scientific crop-production technologies. Suitable plant spacing can lead to optimum yield. The optimization of this factor can lead to a higher yield in the crop by favourably affecting the absorption of nutrients and exposure of the plant to the light. Maintenance of adequate plant population, among other improved agronomic practices, is an important component of crop-production technology. The plant population for any particular environment is primarily governed by seed amount and row spacing however, there is very little information on the effects of inter- and intra-row spacings on yield, yield attributes and profitability of white cumin. Obviously, for appropriate recommendations, the present research on inter- and intra-row spacing for maximum yield of the crop was conducted.

MATERIALS AND METHODS

This research was conducted at a farmer's field in Dembia district, about 42 km from Gondar, from August 2017 to January 2018, during the main rainy season of Central Gondar Administrative Zone, Amhara National Regional State of Ethiopia. It is located at 12º22'0''N, 37º 15'0''E and 1873 m above sea-level. The soil is Vertisols and the major portion of the annual rainfall received is between June and September. The area receives unevenly distributed average annual rainfall that varies from 760 to 1,000 mm. The maximum and minimum daily mean temperatures are 30ºC and 23ºC, respectively.

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White cumin variety 'Dembia 1' released by the Gondar Agricultural Research Centre in 2017, was used as planting material. Urea (46% N) and blended fertilizer NPSB (18.9% N, 37.7% P_2O_5, 6.95% S and 0.1% B) were used as sources of plant nutrients. The experiment was laid out in a randomized complete-block design with 3 replications. The treatments consisted of factorial combinations of 4 inter-row plant spacings (30, 40, 50 and 60 cm) and 3 intra-row spacings (10, 15 and 20 cm). Plot size was 3 m × 3 m, accommodating 10, 6, and 5 rows for 30, 50 and 60 cm inter-row spacings, respectively. However, a plot size of 2.8 m × 3 m was used for 40 cm inter-row spacing by cutting out 20 cm from length which had accommodated 7 rows per plot. A distance of 1 m between plots and 2 m between blocks was maintained. Sowing was done on 8 August, 2017 using the recommended seed rate of 5 kg/ha by drilling seeds in soil of each plot. Fertilizers were applied at the rates of 86 kg/ha urea and 65 kg/ha NPSB. The NPSB was applied at planting, while urea was applied in splits, half at planting and the remaining amount was topdressed after thinning. The experimental field was handweeded 3 times during the growing season. Thinning was done 45 days after sowing, as the crop is highly branched.

Data were collected on number of days to 50% flowering, and days to 90% maturity; growth attributes such as plant height, number of primary and secondary branches per plant; yield and yield components such as the number of umbels per plant and umbellets per umbel, biological yield (kg/ha), seed yield (kg/ha), 1,000-seed weight (g) and harvest index, i.e. the ratio of economic yield to biological yield expressed in percentage. The recorded data were subjected to the analysis of variance (ANOVA) using SAS statistical software version 9.0. For treatments, which showed significant difference, means were separated using least significant difference test.

RESULTS AND DISCUSSION

Crop phenology

Days to 50% flowering: The main effect of inter- and intra-row spacing on days to 50% flowering was significant ($P<0.05$); however, the interaction effect of these treatments did not show significant difference (Table 1). The minimum number of days to 50% flowering was recorded for the closer spacing of 30 cm × 10 cm, while the maximum number of days taken to 50% flowering were recorded for the wider spacing of 50 cm × 20 cm but these values were not statistically different from that of 60 cm × 20 cm spacing. These results confirm the findings of Sharma (2013). Significant improvement in days to flowering due to increase in spacing or reduction in plant population/unit area could be ascribed to the availability of more space/plant which implied that individual plant at wider spacing received higher growth inputs, i.e. sunlight, water and nutrients, with least competition as compared to the plants grown under closer spacing. Thus, greater inputs under wider spacing resulted in profuse branching which, in turn, might have helped larger canopy development and delayed plants to attain reproductive phase (Garima *et al*., 2018).

Days to 90% maturity: Neither the inter-row spacing nor the intra-row spacing and nor their interaction significantly influenced the days to 90% maturity (Table 1). Our results are in line with those of Nath *et al*. (2008).

Growth attributes

Effect of spacing on plant height: Interaction effects of inter- and intra-row spacings resulted in a highly significant ($P< 0.01$) effect on plant height (Table 1). The tallest plants were recorded at 40 × 10 cm spacing, whereas the widest inter- and intra-row spacings (50 cm × 20 cm and 60 cm × 20 cm) resulted in shorter plants as compared to the narrow inter- and intra-row spacing (Table 4). The interaction effect of inter- and intra-row spacings showed continuous decline in height of plants along spacing combinations, except at 30 cm inter-row spacing. The present result confirms the findings of Muvel *et al*. (2015), who stated that white cumin under inter-row spacing of 45 cm attained higher plant height as compared to other row spacings (30

Table 1. Analysis of variance (ANOVA) showing mean square values for days to flowering (DF), days to maturity (DM), plant height (PH), number of primary branches (NPB), number of secondary branches (NSB), number of umbels (NUM) and number of umbellets (NUL) in white cumin

Source of variation	Mean squares							
	df	DF	DM	PH	NPB	NSB	NUM	NUL
Inter-row spacing (A)	3	12.99*	13.4NS	68.24**	22.77**	395.45**	4407.74**	34.03**
Intra-row spacing (B)	2	14.11*	15.19NS	84.93**	12.72**	332.33**	624.43*	4.59*
A × B	6	1.51NS	1.6NS	32.35*	0.18NS	3.13NS	231.16NS	1.88NS
Error	22	2.75	4.93	9.73	2.02	36.99	158.51	1.26

NS, Non-significant; *significant ($P<0.05$); **highly significant ($P<0.01$)

cm and 60 cm). Similarly, Naruka *et al*. (2012) also reported that the highest plant height was recorded at narrow (45 cm × 10 cm) spacing than those of wider (45 cm × 20 cm and 45 cm × 30 cm) row spacings in white cumin. Higher plant height under closer spacing may be attributed to more competition for light amongst plants. Significant increase in plant height at early stage of crop growth under closer spacings seems to be due to mutual shading because of dense population.

This might have decreased the availability of light to the plants. The reduced light intensity at the base of the plant stem tends to accelerate the elongation of lower internodes resulting in greater plant height (Garima *et al*., 2018).

Effect of spacing on primary and secondary branches: The main effect of inter- and intra-row spacings showed highly significant ($P < 0.01$) effect on the number of primary branches, while their interaction effect was not significant (Tables 1,4). The maximum number of primary branches were recorded with the wider inter- and intra-row (60 and 20 cm, respectively) spacings, while the lowest numbers were recorded with the narrow spacing (30 cm × 10 cm). Widening of inter-row spacing from 30 cm to 60 cm increased the number of primary branches. Similarly, increasing of intra-row spacing from 10 to 20 cm also increased the number of primary branches significantly. The current result supports the results of Barde (2009), who reported greater number of primary branches due to wider inter- and intra-row spacings.

As for the secondary branches, the main effect of inter- and intra-row spacing also showed a highly significant ($P < 0.01$) effect on the production of secondary branches too. However, the interaction of inter- and intra-row spacings did not show any significant effect (Tables 1, 2). Thus, the maximum numbers of secondary branches were recorded under wider inter-row and intra-row (60 and 20 cm) spacings, while the lowest numbers of secondary branches were recorded under narrow spacing (30 cm × 10 cm). Accordingly, widening of inter-row spacing from 30 cm to 60 cm increased number of secondary branches. Similarly, increasing of intra-row spacing from 10 cm to 20 cm increased the number of branches significantly. Our results support the findings of Muvel *et al*. (2015) and Waskela *et al*. (2017). The increase in number of branches may be attributed to more space per plant available under wider spacings. The larger canopy development associated with profuse branching might have increased the interception, absorption and utilization of solar energy.

Yield and yield attributes

Plant spacing versus formation of umbels and umbellets: The analysis of variance indicated that the main effect of inter-row spacing had a highly significant ($P<0.01$) but the main effect of this treatment had only a significant ($P<0.05$) effect on the number of umbels/plant, while their interaction effect was not significant (Tables 1, 2). The highest mean number of umbels were counted on plants grown at 40 cm inter-row spacing, but was statistically similar to that of 50 cm inter-row spacing. The reason why the inter-row spacing above 50 cm increased vegetative growth rather than increased number of umbellets because above 50 cm there was only increase in the number of umbels. Similarly, the highest numbers of umbels were recorded at 20 cm intra-row spacing but statistically similar to that of 15 cm intra-row spacing. The lowest number of umbels was obtained at 30 cm × 10 cm spacing. Increasing the row spacing from 30 cm × 10 cm to 30 cm × 20 cm

Table 2. Main effects of inter- and intra-row spacings on days to 50% flowering, number of primary and secondary branches, number of umbels and umbellets in white cumin

Treatment	Days to 50% flowering	Primary branches	Secondary branches	Umbels	Umbellets/ umbel
Inter-row spacing (cm)					
30	89.22 ^{b}	13.65 ^{c}	45.21 ^{c}	147.82 ^{c}	13.27 ^{c}
40	90.77^{ab}	15.36 ^{b}	52.25^{b}	195.65 ^{a}	17.5 ^{a}
50	92.00 ^{a}	16.42^{ab}	57.3^{ab}	192.28^{a}	17.16 ^{a}
60	91.44 ^{a}	17.36 ^{a}	60.38 ^{a}	170.95 ^{b}	15.32 ^{b}
CD (P=0.05)	1.62*	*1.39***	*5.94***	*12.3***	*1.09***
Intra-row spacing (cm)					
10	89.75 ^{b}	14.69 ^{b}	48.4 ^{b}	168.41 ^{b}	15.1 ^{b}
15	90.91^{ab}	15.66^{ab}	54.03 ^{a}	179.9 ^{a}	16.09 ^{a}
20	91.91 ^{a}	16.75 ^{a}	58.92 ^{a}	181.71^{a}	16.25^{a}
SEm±	1.35	1.16	4.97	10.28	0.92
CD (P=0.05)	1.40*	1.2**	5.14**	10.66*	0.95*
CV (%)	1.82	9.06	11.3	7.12	7.11

Means followed by the same letter within a column are not statistically different from each other at 5% level of probability; *significant (P<0.05; **highly significant (P < 0.01) and 30 cm × 30 cm, the numbers of umbels also increased from 138 to 151 and 152, respectively. Garima *et al*. (2018) reported that successive increase in spacing from 30 cm × 10 cm to 50 cm × 10 cm significantly improved the number of umbels per plant. Similarly, these results are also in line with the findings of Nath (2008) and Muvel *et al*. (2015).

Like umbels, the main effect of inter-row spacing had a highly significant (P<0.01) and the main effect of intra-row spacing had only a significant (P<0.05) effect on the number of umbellets per umbel. However, the interaction effect of inter- and intra-row spacing was not significant (Tables 1,2). The maximum mean numbers of umbellets were recorded in 40 and 50 cm inter-row spacing, respectively; whereas the minimum numbers of umbellets were recorded in 30 cm inter-row. Similarly, the highest numbers of umbellets were obtained in 15 and 20 cm intra-row spacing, respectively, and the lowest numbers of umbellets were recorded under narrow intra-row spacing. These results are in line with those of Barde (2009), Naruka *et al*. (2012), Muvel *et al*. (2015) and Waskale *et al*. (2017). The highest numbers of umbels and umbellets per plant at the widest inter- and intra-row spacing were due probably to the proper adjustment of plants in the field which facilitated more aeration and penetration of light. At the wider inter- and intra-row spacing, however, the growth factors (nutrient, moisture and light) for individual plant were easily accessible thus, support the development of lateral branches. This might be owing to the increased number of branches which were higher under wider row spacing.

Plant spacing versus seed size: The intra-row and inter-row spacings and their interaction did not significantly affect 1,000-seed weight, i.e. representative of seed size (Table 3). The result confirms the findings of Naruka *et al*. (2012). Sedigheh *et al*. (2009) also found that the effect of sowing date and plant density on 1,000-seed weight was not significant in black cumin.

Plant spacing versus biological yield: There was a highly significant (P<0.01) interaction effect of inter- and intra-row spacings on biological yield (Tables 3, 4). Higher biomass yield was obtained at 40 cm × 10 cm spacing. This primarily occurred due to higher plant population recorded at narrow inter- and intra-row spacing of 40 cm × 10 cm and hence, greater dry-matter production. The lower biomass yield was found at plant spacing of 40 cm × 20 cm and 60 cm × 20 cm. These results support the findings of Waskale *et al*. (2017).

Plant spacing versus seed yield: The analysis of variance revealed that interaction of inter- and intra-row spacings had highly significant (P<0.01) effect on seed yield (Table 3). Statistically, the maximum seed yield was recorded in 40 cm × 10 cm spacing that was closely followed by spacing of 30 cm × 10 cm (Table 4). The increased seed yield with 40 cm row-spacing might be owing to higher values of yield attributes. The lowest seed yield was recorded from 60 cm × 20 cm plant spacing. The narrow inter-row spacing of 40 cm and 30 cm brought higher seed yield per hectare as compared to that of 50 and 60 cm inter-row spacings. Yield declined significantly from 2,118 to 1,416 kg/ha with the widening of plant spacing from 40 cm × 10 cm up to 60 cm × 10 cm. Moreover, when intra-row spacing became wider from 10 to 20 cm, the seed yield decreased from 1,745 down to 1,275 kg/ha.

Our results agree with the findings of Barde (2009), Naruka *et al*. (2012), Muvel *et al*. (2015). These results amply justify that overcrowding of plants at closer spacing significantly reduces growth and yield attributes of the crop but compensates the yield to a certain level owing to more plants per unit area. However, under wider spacing reduced plant population, though improved overall growth of crop and increased crop yield components but failed to record the highest yield due to less number of plants/ha. Under closer spacing, growth and development of yield components and number of plants positively interacted with each other that might be due to increased biomass, resulting in higher seed yield (Naruka *et al*., 2012). Although data on the number of primary and secondary branches, number of umbels and umbellets were greater owing to wider spacing than those observed at narrow spacing (40 cm × 10 cm), seed yield/ha was the highest for the closest spacing

Table 3. Analysis of variance showing mean square values of biological yield (BY), seed yield (SY), thousand-seed weight (TSW) and harvest index (HI) in white cumin

Source of variation	df	Mean squares			
		BY	SY	TSW	HI
Inter-row spacing (A)	3	1094598.61*	300577.18**	0.01ns	73.86**
Intra-row spacing (B)	2	7187449.48**	665643.3**	0.01ns	10.23*
A × B	6	1010069.84*	42100.91**	0.001ns	12.18*
Error	22	310119.29	9940.68	0.005	2.63

NS, Non-significant; *significant (P<0.05); **highly significant (P<0.01)

(Tables 2, 4). This might have occurred owing to higher plant population at narrow spacings that could have resulted in higher seed yield.

Plant spacing versus harvest index: The interaction of inter- and intra-row spacings had a highly significant (P<0.01) effect on harvest index (Table 3), resulting in the highest harvest index of 28.55% recorded at a spacing of 40 cm × 10 cm (Table 4). This might be owing to the higher seed yield obtained at the plant spacing mentioned above and the lowest harvest index (19.65%) recorded from the spacing interaction of 60 cm × 10 cm. Similarly, a spacing of 40 cm × 15 cm and 40 cm × 20 cm had statistically similar results (27.87% and 28%, respectively).

The results showed that the mean values of inter-row spacings had more variation than those of intra-row spacings. These results are in line with those of Sharma (2013) and Muvel *et al*. (2015) who reported that white cumin exhibited the highest harvest index at a spacing of 45 cm × 30 cm than those of 30 cm × 30 cm and 60 cm × 30 cm spacings.

Correlation analysis: Correlations between growth parameters, yield and yield-related traits are given in Table 5.

Table 4. Interaction effects of inter- and intra-row spacings on plant height, biological yield, seed yield and harvest index in white cumin

Inter-row spacing (cm)	Plant height (cm)			
	Intra-row spacing (cm)			
	10	15	20	Mean
30	55.23[cde]	61.43[ab]	58.46[cbd]	58.37
40	65.3[a]	62.36[ab]	54.36[ed]	60.67
50	57.2[cbd]	54.26[ed]	51.23[e]	54.23
60	59.8[bc]	55.86[cde]	53.5[ed]	56.38
Mean	58.65	59.21	54.39	
SEm±	2.55			
CD (P=0.05)	*5.28***			
CV (%)	5.43			
	Biological yield (kg/ha)			
30	7,083.7[abc]	6,097.8[de]	6,443.3[bcd]	6,541.6
40	7,440.8[a]	6,196.6[cde]	4,835.4[f]	6,157.6
50	6,925.5[abcd]	6,512.0[abcd]	6,434.6[bcd]	6,624.03
60	7,210.3[ab]	5,428.2[ef]	4,984.5[f]	5,874.33
Mean	7,165.07	6,058.68	5,674.45	
SEm±	454.69			
CD (P=0.05)	*942.98***			
CV (%)	8.84			
	Seed yield (kg/ha)			
30	1,816.96[b]	1,423.54[ef]	1,328.07[ef]	1,522.86
40	2,118.94[a]	1,719.83[bc]	1,350.46[ef]	1,729.74
50	1,628.79[cd]	1,468.01[de]	1,285.06[fg]	1,460.62
60	1,416.36[ef]	1,306.11[efg]	1,138.76[g]	1,287.08
Mean	1,745.26	1,479.37	1,275.58	
SEm±	81.41			
CD (P=0.05)	168.83**			
CV (%)	6.64			
	Harvest index (%)			
30	25.76[bc]	23.51[cd]	20.58[efg]	23.28
40	28.55[a]	27.87[ab]	28.00[ab]	28.14
50	23.61[cd]	22.58[def]	20.00[fg]	22.06
60	19.65[g]	24.08[cd]	22.85[de]	21.52
Mean	24.39	24.01	22.85	
SEm±	1.32			
CD (P=0.05)	2.74**			
CV (%)	6.78			

Means followed by the same letter within a column all through from top to bottom for all the plant traits separately, are not statistically different from each other at 5% level of probability.

Table 5. Linear correlation coefficients (r) among growth; yield and yield-related traits in white cumin

	DF	PH	NPB	NSB	NUM	NUL	BY	SY	HI
DF	1.0	-0.4*	0.39*	0.43**	0.45**	0.42**	-0.48**	-0.47**	-0.08
PH		1.0	-0.38*	-0. 42*	-0.04	-0.06	0.49**	0.58**	0.21
NPB			1.0	0.63**	0.36*	0.38*	-0.44**	-0.52**	-0.18
NSB				1.0	0.46**	0.41*	-0.36*	-0.45**	-0.17
NUM					1.0	0.85**	-0.16	0.1	0.21
NUL						1.0	-0.12	0.3	0.2
BY							1.0	0.65**	-0.22
SY								1.0	0.57**
HI									1.0

*P<0.05; **P<0.01; DF, Days to 50% flowering; PH, plant height; NPB, number of primary branches; NSB, number of secondary branches; NUM, number of umbels; NUL, number of umbellets; BY, biological yield; SY, seed yield and HI, harvest index

Days to 50% flowering was positively and significantly but weakly correlated with the number of primary branches, secondary branches, number of umbels, number of umbellets and seed size (1,000-seed weight). However, this trait was negatively and significantly correlated with plant height and seed yield. Plant height was also positively and significantly correlated with biological yield and seed yield, but negatively correlated with primary and secondary branches. Similarly, number of primary branches, secondary branches, number of umbels and umbellets were positively and significantly correlated with each other. Therefore, number of primary branches correlated with the number of secondary branches, number of umbels and number of umbellets. Biological yield was significantly correlated with seed yield and seed yield was significantly correlated with harvest index. The current results are compatible with the previous studies made by Dalkani *et al*. (2012), who reported that the number of branches was positively and moderately correlated with the number of umbels. Significant and positive linear correlations were found between biological yield and plant height and between the numbers of umbels and umbellets. Seed yield was not significantly but positively correlated with the number of umbels (r=0.1) and the number of umbellets (r=0.3). This situation has happened due to variable plant densities wherein these yield attributes were lower at higher plant densities (at narrow plant spacings) and reduction in these attributes compensated for greater final plant stand at narrow spacing.

In conclusion from the results of this study, 40 cm × 10 cm plant spacing is recommended in order to have a plant population of 2.5×10^5/ha to increase the productivity of white cumin in the study area as well as those in other similar agro-ecologies. However, further studies to be conducted across locations and seasons are suggested.

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