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Assessment of Phenotypic Diversity among Ethiopian Coriander Accessions (*Coriandrum sativum*) at Kulumsa, Southeastern Ethiopia

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ABSTRACT

A phenotypic diversity study was carried out under field conditions in the *meher* season ((July–November 2019 and 2020) at Kulumsa, Southeast Ethiopia to assess variables that directly affect seed yield, contribute to the total phenotypic variance, and classify coriander accessions. Twenty-five Ethiopian coriander accessions were laid out in a simple lattice design with two replications. Eight morphological parameters of the coriander accessions showed highly significant differences ($p \le 0.01$)) in the combined analysis of variance. Plant height, the number of umbellets umbel^{-1}, the number of seeds umbel^{-1}, and the seed yield plant^{-1} all had a positive and direct effect on the seed yield (t ha^{-1}). The first two principal components contributed 62.6% of the total phenotypic variation. Number of umbels plant^{-1}, number of umbellets umbel^{-1}, seed yield plant^{-1}, and seed yield (t ha^{-1}) were the characteristics with the highest loading effects in the first principle component, and plant height and seed yield (ha^{-1}) in the second. Six clusters of accessions were created. About 28% and 8% of the studied accessions were found in the largest cluster (I) and clusters (V and VI), respectively. The highest inter-cluster distances were observed between VI and III (D^2=159.21), IV and III (D^2=155.84), and VI and I (D^2=113.26) clusters. Crossing between accessions included in those clusters could produce highly heterotic responses and segregants. In general, this study demonstrated significant phenotypic diversity among the tested accessions and could be used in improvement programs to develop desirable coriander cultivars.

KEYWORDS: Cluster, coriander, direct effect, principal component

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1. INTRODUCTION

Coriander (*Coriandrum sativum* L.) is a diploid annual leafy vegetable and seed spice belonging to the Umbelliferae family (Hedburg, 2003). Coriander is cultivated on a wide range of soils between 1650 and 2400 m.a.s.l. in Ethiopia (Habetewold et al., 2017; Getachew et al., 2021). In Ethiopia, productivity varies according to agroecology and cultivar; the national average productivity is 0.25 t ha^{-1} (Habetewold et al., 2017; Gizaw et al., 2023). It is cultivated in Ethiopia primarily for income generation as well as local consumption and studied in order to increase its production and oil value (Miheretu, 2018). Coriander seeds are widely available and sold at high prices in every market in the country (Beemnet, 2018). It has various local names in Ethiopia, such as Dembilal (*Amharic*), debo, shucar (*Oromiffa*), tsagha, zagda (*Tigrignya*), and tibichota (*Konsonya*), reflecting its economic importance in the country's diverse cultures (Jansen, 1981; Goetsch et al., 1984).

The mature seeds and fresh green leaves are the most valuable parts of coriander from an economic standpoint (Sahib et al., 2013). The small fruit has medicinal and nutritional value and is used as a spice and seasoning (Arif et al., 2014; Bhat et al., 2014; Mandal and Mandal, 2015; Devi et al., 2020; Girma et al., 2022; Pal et al., 2023). In Ethiopia, mature seeds are often used as a spice, while fresh green leaves are also eaten as a green salad (Getachew et al., 2021). The leaves and immature fruits of coriander are used as an ingredient for the preparation of "data" in the southern parts of Ethiopia (Beemnet, 2018). Green coriander leaves are rich in vitamins, protein, and minerals and are used in vegetables and salads, while the seeds can be used as a spice, contain linalool-rich essential oils, and are used in cooking (Singh et al., 2005).

Ethiopia is regarded as a center of primary diversification for coriander (Jansen, 1981). This was also supported by different reports on existence of sufficient variability for agronomic and chemical traits, genetic, phenotypic, and biochemical diversity, variation in pheno-qualitative characters, and adaptation for Ethiopian coriander accessions (Beemnet et., 2010, Beemnet et al., 2011; Geremew et al., 2015; Geremew et al., 2016; Beemnet, 2018; Arega et al., 2021; Gizaw et al., 2023).

The study of genetic and phenotypic diversity in the gene pool has been carried out to contribute to promoting better recombination by selecting parents with maximum genetic differences, which are generally suitable for genetic improvement in crops (Arunachalam, 1981; Desalegn et al., 2019). Coriander is a highly cross-pollinated crop that is best enhanced by mass or recurrent selection (Moharana et al., 2023). However, limited studies have been reported on agronomic practices, evaluation, variability, heritability, genetic advance, correlation and path analysis, and genotypic diversity analysis among Ethiopian coriander accessions (Beemnet et al., 2013; Geremew et al., 2015; Geremew et al., 2016; Beemnet, 2018; Gizaw et al., 2023). The huge diversity of coriander in Ethiopia remains largely unexplored, incomplete, and inconclusive, posing a significant challenge (Anonymous, 2022; Gizaw et al., 2023). To enable breeders to use Ethiopian coriander accessions directly, it is essential to fully understand the key features that have contributed to the overall phenotypic variation, classification, and direct effect on seed yield. It is advantageous to exploit the richness of coriander diversity and fill existing knowledge and information gaps. Thus, the study aims to identify characters that have a direct effect on seed yield, contribute to total phenotypic variation, and classify coriander accessions.

2. MATERIALS AND METHODS

2.1. Description of experimental site

The experiment was carried out during the 2019 and 2020 cropping seasons at Kulumsa Agricultural Research Center (KARC), located at 8° 00' to 8° 02'N latitude and 39° 07' to 39° 10'E longitude at an elevation of 2210 m. a.s.l. in Tiyo district, Arsi Administrative Zone of the Oromia Regional State, 167 km Southeast of Addis Ababa. KARC is located on a very gently undulating topography with a gradient of 0 to 10%. It has a low relief difference, with an altitude ranging from 1980 to 2230 meters (Abayneh et al., 2003). The agro-climatic condition of the area is wet, with 832 mm of mean annual rainfall and a uni-modal rainfall pattern with an extended rainy season from March to September. However, the peak season runs from July to August. The mean annual maximum and minimum temperatures are 23.2 and 10 °C, respectively (KARC metrological station, unpublished data). The coldest month is December, whereas March and May are the hottest months. KARC has three major soil types: Eutric Vertisol, Vertic Luvisol, and Vertic Cambisol (Abayneh et al., 2003).

2.2. Experimental material and design

The two coriander cultivars registered in Ethiopia, Denkinesh and Indium 01, which have varied yield potentials and oil contents, were chosen as standard checks for this experiment (Table 1).

One hundred fifty coriander accessions were originally obtained from the Ethiopian Biodiversity Institute and evaluated under observation nursery at Kulumsa Agricultural Research Center in 2017, and selected 23 accessions were advanced to preliminary variety trials in 2019 and 2020. The accessions and cultivars with their collection name (229714, 212115, 202734, 240546, 212830, 240574,

Table 1: Description of the registered coriander cultivars used as standard checks

Variety name	Released		Altitude (m.a.s.l)	Maturity (days)	Productivity (t ha^{-1})		^{a}Essential oil content
	Year	*Breeder			Research	Farmer	
Indium 01	2008	DZARC/EIAR	1600-2300	114-125	1.25	0.95	0.5
Denkinesh (Brazil)	2017	TNSRC and KARC/EIAR			1.8-2.6	1.5	0.6

Source: (Biruk and Sileshi, 2019; Anonymous, 2022); EIAR: Ethiopian Institute of Agricultural Research; KARC: Kulumsa Agricultural Research Center; DZARC: Debre Zeit Agricultural Research Center; TNSRC: Tepi National Spice Research Center; a: dry based

211471, 90305, 329702, Indium 01, 212225, 240547, 20662, 240577, 211568, 240552, 90309, 90451, 229716, 90444, 229811, 212950, 202518, Denkinesh, and X1) are ordered as serial numbers (1-25) shown in Dendrogram which were presented under the cluster analysis in the result and discussion part (Figure 6). The experiment was laid out in a 5×5 simple lattice design, with each accession replicated twice.

2.3. *Data collection and statistical analysis*

The analysis of variance (ANOVA) was performed on the data collected for the eight morphological parameters using R software (Anonymous, 2023), in accordance with the steps specified in Gomez and Gomez (1984). To determine the characteristics that directly influenced seed yield, the factors that contributed most to overall variation, and the grouping of Ethiopian coriander accessions, bivariate and multivariate analyses were carried out.

2.4. *Correlation and path coefficient analysis*

Simple correlation analysis was unable to adequately explain the association between yield and the other features. However, path coefficient analysis (PCA) is a more efficient method to explain the direct effect of independent variables on the dependent variable. Genotypic correlation coefficients were estimated according to Johanson et al. (1955), Miller et al. (1958), and Singh and Chandhury (1985). Path analysis was performed according to the procedure described by Dewey and Lu (1959). The direct and indirect effects at the genotypic level for the accessions were calculated using the path coefficient method suggested by Wright (1921) and Dewey and Lu (1959), and seed yield was the dependent variable.

2.5. *Principal component analysis*

To examine the relationships among the quantitative traits that were correlated with each other, principal component analysis was performed using a correlation matrix. This analysis was used to convert the correlated variables into uncorrelated components using R software (Anonymous, 2023).

2.6. *Clustering of accessions and Euclidean distance*

Based on eight quantitative variables, the genotypes were sorted into appropriate clusters using the ward linkage method. The number of clusters was calculated using the pseudo-F and pseudo-T values. To calculate the genetic distance between and within clusters, Mahalanobis' (1936) generalized distance statistics were used. The values calculated between cluster pairs were considered chi-square values and were tested for significance using "p" degrees of freedom, which represents the number of studied traits.

3. RESULTS AND DISCUSSION

3.1. *Analysis of variance*

The combined analysis of variance showed highly significant differences ($p \le 0.01$) in plant height, umbel number per plant, number of umbellets per umbel, number of seeds per umbel and umbellets, seed yield per plant, and hectare among the different coriander accessions studied (Table 2). Consistent with our findings, previous studies have also reported significant phenotypic differences in these traits among Ethiopian coriander accessions other than those included in this study (Beemnet and Getinet, 2010; Geremew et al., 2015; Beemnet, 2018; Gizaw et al., 2023). The results of this experiment were in line with the reports of Kumawat et al. (2022).

The observed high variation between the tested coriander accessions suggests that they could be used as a valuable source of genetic materials for further coriander breeding programs. We found a significant interaction between accessions and year, indicating that the accessions exhibited a differential response across the two years for traits such as umbel number per plant, number of umbellets per umbel, and thousand seed weight. These findings underscore the importance of selecting appropriate coriander accessions for specific breeding programs, taking into account potential variation across different growing conditions and environments.

3.2. *Correlation and path coefficient analysis*

Coriander seed yield was positively and significantly associated with plant height (r_g=0.6**), number of umbellets umbel^{-1} (r_g=0.43*), number of seeds umbel^{-1} (r_g=0.71**), and seed yield plant^{-1} (r_g=0.34*) (Table 3). A strong correlation of seed yield was reported by Beemnet et al. (2013) for

Table 2: Combined mean squares for quantitative traits of coriander accessions in 2019 and 2020 at Kulumsa

Traits	Rep (DF=1)	Block (Rep) (D=8)	Year (DF=1)	Source of variation					Means
				Acc (DF = 24)	Year ×Acc (DF = 24)	Error (DF=41)	CV (%)	R^2	
PH	154.77	63.72	18455.96**	936.77***	37.25ns	47.84	6.14	0.95	114.95
NUPP	134.33	14.21	4155.74**	513.06***	19.09**	7.35	5.36	0.98	54.82
NULTSPU	4.87	4.2	387.22**	33.14***	0.83**	1.16	11.47	0.94	11.37
NSPU	12.11	16.97	8.44ns	90.9***	4.25ns	9.12	12.62	0.82	25.7
NSPULTS	7.67	0.41	64.87**	1.48***	0.021ns	0.22	7.54	0.9	6.68
SYLDPP	24.21	6.29	234.28**	79.57***	2.19ns	5.32	17.02	0.89	13.88
TSW	8.3	2.18	43.91**	6.62***	0.137**	0.99	8.79	0.79	12.52
SYLDHA	0.19	0.21	9.76**	5.39***	0.078ns	0.058	8.96	0.97	3.24

Rep: replication; Block (Rep): block within replication; DF: degrees of freedom; Acc: accessions; CV: coefficient of variation; R^2: coefficient of determination; PH: Plant height at maturity (cm); NUPP: Umbels number per plant; NULTSPU: Umbellets number umbel^{-1}; NSPU: Number of seeds umbel^{-1}; NSPULTS: Number of seeds umbellet^{-1}; SYLDPP: Seed yield plant^{-1} (g); TSW: thousand seed weight (g); SYLDHA: Seed yield ha^{-1} (t ha^{-1}); ns: Non-significant difference at p>0.05; significance at *: p=0.05; **: p=0.01; ***: p=0.001

Table 3: Path coefficients of direct (main diagonal) and indirect effects of the quantitative characters of coriander studied at Kulumsa in 2019 and 2020; Residual=0.33

	PH	NULTSPU	NSPU	SYLDPP	rg
PH	0.5646688	0.0005835	0.0575311	-0.018683	0.6041**
NULTSPU	0.001694	0.1945155	0.1073604	0.1236301	0.4272*
NSPU	0.0978571	0.0629063	0.331974	0.0640625	0.7083**
SYLDPP	-0.061492	0.1401679	0.1239591	0.1715654	0.342*

PH: Plant height at maturity (cm); NULTSPU: Umbellets number umbel^{-1}; NSPU: Number of seeds umbel^{-1}; SYLDPP: Seed yield plant^{-1} (g); rg: Genotypic correlation coefficients; *: p=0.05; **: p=0.01

plant height (r_g=0.99**) and seed yield plant^{-1} (r_g=1**). The yield of seeds is influenced by a wide range of variables. However, assessing the direct and indirect contributions of each trait to seed yield requires a more sophisticated approach than simple correlation estimations, which do not fully capture the complex interrelationships between yield components and seed yield (Bhatt, 1973; Ram et al., 2017). Path coefficient analysis is a more suitable approach for determining the specific effects of different traits on seed yield and can provide valuable information for selecting the most promising components to improve seed yield.

We found that plant height, number of umbellets per umbel, number of seeds per umbel, and seed yield per plant had a positive direct effect on seed yield (Table 3). Among these parameters, plant height had the highest positive degree of favorable effect on seed yield (0.56), followed by the number of seeds per umbel (0.33) and the number of umbellets per umbel (0.19). In addition, the highest positive indirect effect was exerted by seed yield per plant, number of seeds per umbellet, and umbel. According to Geremew et al. (2015), there are both positive and negative associations between seed yield and the number of seeds umbel^{-1}, as well as between seed yield and plant height and the number of umbellets plant^{-1}. In contrast, we found that plant height and the number of umbellets in each umbel had a positive direct effect on seed yield. The results are in accordance with the findings of Beemnet et al. (2013), Geremew et al. (2015), and Kumawat et al. (2022). These findings imply that it may be advantageous to concentrate on traits that have a higher and positive association and direct effect on seed yields and to boost coriander production.

The magnitude of the residual effect (0.33) indicated that the parameters included in the path analysis explained 67% of the variation in seed yield, while 33% of the variation was due to other parameters that were not included in our research. Our findings suggest that primary components for improving seed yield include plant height, number of umbellets umbel^{-1}, number of seeds umbel^{-1}, and seed yield plant^{-1}, as indicated by both the correlation and path coefficient analysis. Characters other than those are secondary components that are relevant to yield improvement.

3.3. Principal component analysis

The first two principal components (PCs) within an eigenvalue greater than unity explained 63.5% of the total variation among the examined accessions (Figure 1). With eigenvalues of 3.5 and 1.58, respectively, the overall variances of the eight variables evaluated among the 25 accessions, 43.8% and 19.7% were contributed from PC1 and PC2, respectively. Similar to this, Lopez et al. (2008) identified four of the first four principal components that collectively accounted for 73.5% of the variation in the set of phenotypic variables and had eigenvalues greater than 1. The first, second, third, and fourth pcs contributed 45%, 13%, 9.6%, and 5.9% of the assemblage of phenotypic traits, biochemical, and molecular diversity in coriander germplasm in Ames, respectively.

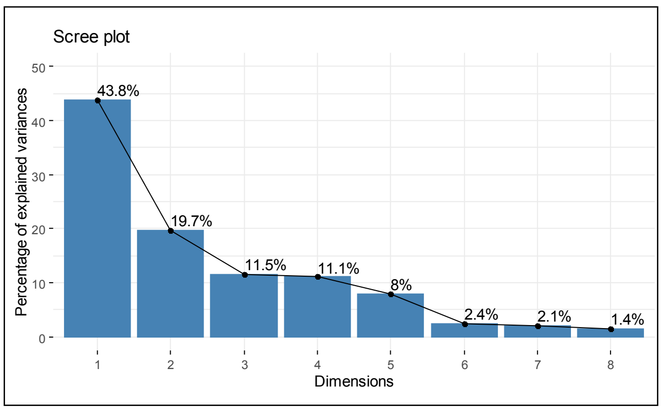

Figure 1: The scree plot

The number of umbels plant^{-1}, number of umbellets umbel^{-1}, and seed yield plant^{-1} were the main contributing features to higher loading effects in the pc1 and Plant height and seed yield (t ha^{-1}) are the highest contributors to the total variation in the pc 2 (See Figures 2 and 3). The maximum variability (variable PCA) was seen from parameters which are displayed in the right two quadrants (Figure 4) and accessions, which are extremes from the origin (PCA-Biplot), signify phenotypic diversity of the accessions compared with those near to the origin (Figure 5).

The higher and lower contributors of accessions for the total variation were 240546 and 329702, respectively (Figure 5) in the first two pcs.

In accordance with the current result, Singh et al. (2005) reported that plant height in the first vector and seed yield plant^{-1} in the second vector contributed the most towards the divergence of 70 coriander genotypes based on nine component traits in the canonical vector analysis. Similarly, the variation of the data for the subsequent components

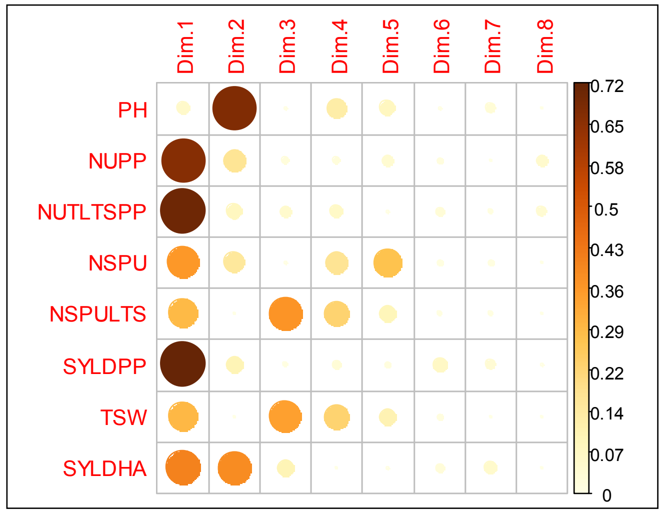

Figure 2: The contributors of the variables in the first two pcs with their correlation

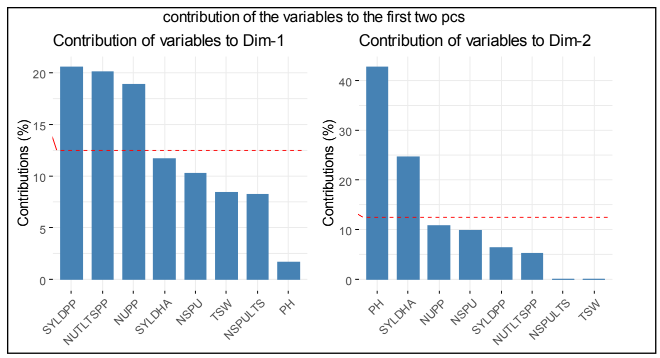

Figure 3: The contributors of the variables to the first two pcs

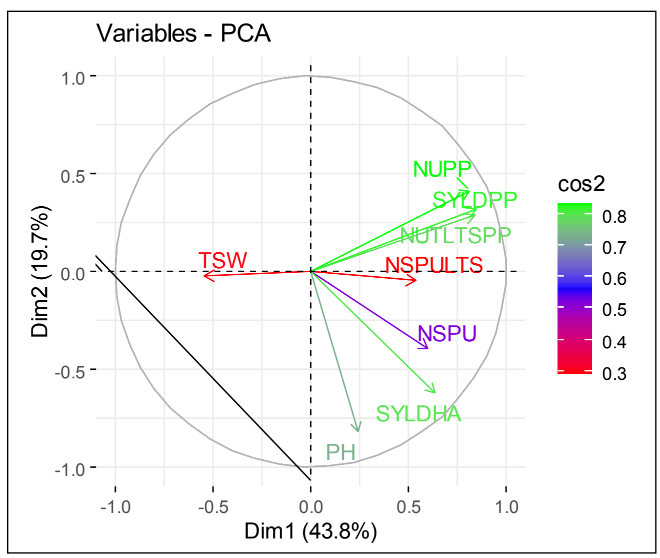

Figure 4: Total contribution of the variables

shows the independent effects of plant height, seed yield plant^{-1}, and seed yield h^{-1} of the total area as reported by Syafii et al. (2015) and Legesse et al. (2018) among maize and garden cress genotypes respectively. Higher coefficients (eigenvectors) for certain traits represent the relationship of that trait to the relevant PC axes (Sneath and Sokal, 1973).

Positive and negative correlations between components and variables were interpreted using positive and negative loading values. Components with the largest absolute values within the first PC exerted a stronger influence on the cluster than those with lower absolute values closer to zero (Chahal and Gosal, 2002). The loading plot demonstrated the extent of variance and relationships among the variables, indicating the extent of association among measured variables (Figures 2 and 5).

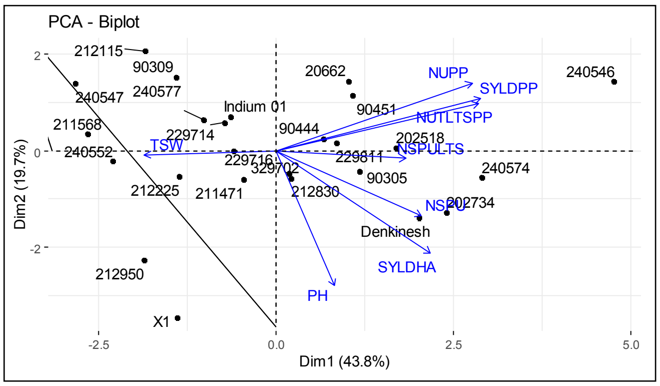

Figure 5: The PCA biplot of both the morphological characters and coriander accessions

The loading plot of PC 1 against PC 2 showed the relationships among variables based on the pooled performances of the coriander accessions across the two seasons. Similar relationships were observed among the variables for the biplot analysis, where the position of each accession was plotted . While all variables had positive values for the first component; they were roughly equally divided into positive and negative values for the second component.

The importance and relationship between variables within a component were determined by the magnitude and direction of factor loadings within a PC (Azeez et al., 2013). The sign of the loading indicates the direction of the relationship between the components and the variable. The greater the loading factors, the higher the contribution of the associated traits to the variance. Our analysis revealed relatively strong associations between plant height and seed yield (t ha^{-1}), seed yield plant^{-1}, number of umbellets umbel^{-1}, number of umbellets umbel^{-1}, and number of seeds umbel^{-1}, and umbellets. Moreover, there was a relatively strong association between the number of umbellets umbel^{-1} and seed yield (t ha^{-1}). In contrast, thousand seed weights had relatively weaker associations with the other parameters.

3.4. Cluster analysis

The genotypes were grouped based on similarities in their morphological characters, allowing representative accessions from a particular cluster to be chosen for hybridization programs. The accessions were grouped based on Euclidean distance, using the Ward linkage method into six clusters (Figure 6). The first, second, third, fourth, fifth, and sixth clusters, respectively, comprehend seven (1, 3, 6, 8, 13, 21, and 24), six (2, 5, 9, 10, 19, and 20), two (4 and 23), five (7, 11, 14, 17, and 18), three (12, 15, and 16), and two (22 and 25) accessions. In line with this result, Beemnet et al. (2011) found eight clusters among 49 Ethiopian coriander accessions. Geremew et al. (2016) and Beemnet (2018) also reported eight and seven clusters of 81 and 49 studied Ethiopian coriander accessions collected from different corners of the country, respectively.

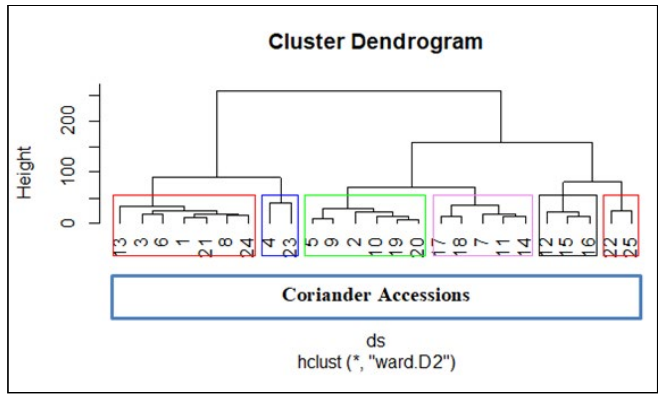

Figure 6: Dendrogram depicting genetic relationships among accessions using Ward's linkage method

The number of accessions per cluster varied from two genotypes in clusters III and VI to seven genotypes in cluster I. Cluster II, IV, and V consisted of six, five, and three accessions, respectively. The distribution pattern of all the genotypes into various clusters showed the presence of considerable genetic divergence among the genotypes for most of the parameters studied. Cluster one accommodates for 28% of the total genotypes and was characterized by a higher number of seeds per umbel and medium plant height, which were peculiar characteristics that distinguished these genotypes from the rest. Cluster III accounted for 8% of the total genotypes and exhibited a large difference in seed yield per hectare compared to other clusters. Cluster II included 24% of the total genotypes, and seed yield and the number of seeds per umbel had limited cluster mean values. Cluster IV accounted for 20% of the total genotypes, and the number of umbels per plant, number of umbellets per umbel, number of seeds per umbel per plant, and seed yield per plant had maximum cluster mean values, with lower thousand seed weight (Table 4).

The fourth cluster had the highest mean values of 1000 seed weights. Maximum plant height was one of the unusual characteristics of the accessions clustered in cluster VI, which accounted for 8% of the total genotypes. Therefore, accessions grouped in this cluster took longer to grow

Table 4: Cluster wise mean values of characters of coriander accessions, studied in 2019 and 2020 cropping season

Traits	Clusters					
	I	II	III	IV	V	VI
PH	113.4	104	128.61	115.01	97.15	149.45
NUPP	51.13	62.16	65.8	85.19	40.58	39.15
NULTSPU	11.55	12.13	13.67	17.46	7.12	7.17
NSPU	27.58	21.52	27.63	31.13	22.77	24.53
NSPULTS	6.62	6.79	6.87	7.16	6.46	6.49
SYLDPP	13.17	14.78	16.11	28.79	10.44	8.47
TSW	12.2	13.02	11.81	11.44	13.59	13.19
SYLDHA	3.15	2.68	4.42	4.01	2	4.21

PH: plant height (cm), NUPP: No. of umbels plant^{-1}, NULTSPU: No. of umbellets umbel^{-1}, NPU: Number of seeds umbel^{-1}, NSPULTS: No. of seeds umbellets^{-1}, SYLDPP: Seed yield plant^{-1} (g); TSW: Thousand seed weight (g), SYLDHA: seed yield (t ha^{-1})

and were affected by the lodging and shattering of seeds. Among the clusters, clusters II and V had the lowest mean performance in yields and other important characteristics. This indicates that the opportunity to obtain high-yielding segregating individuals is limited by crossing with other clusters. In general, the mean values of each parameter in each cluster indicated that accessions could be selected for different breeding purposes. Hence, genotypes grouped under clusters III, IV, and VI were found to be high-yielders based on their mean values for seed yield per hectare and other important characteristics. These clusters could be targeted for further breeding programs to develop high-yielding coriander varieties.

3.5. Estimation of inter and intra cluster distances

Divergence analysis is often performed using Mahalanobis` D^2 technique to classify different genotypes for hybridization purposes (Mahalanobis, 1936). Genetic improvement through crossing and selection depends on the level of genetic diversity between the parents. The paired D^2 value was calculated based on the pooled average of the accessions. Cluster-wise t-tests showed that there were statistically significant differences between paired clusters (Table 5). The chi-square (X^2) tests for the six clusters indicate that there are statistically significant differences between all the clusters. The highest inter-cluster distance was recorded between cluster VI and cluster III (D^2=159.21), followed by between cluster V and cluster III (D^2=155.84), between cluster I and cluster VI (D^2=113.26), between clusters III and IV (D^2=112.5), and between clusters I and V (D^2=106.08). These results revealed that these groups were more genetically distinct from each other (Table 5). Beemnet et al. (2011) and Geremew et al. (2016) stated ranges of inter cluster-distances of 24.3 to 480.5 and 3.2 to 329.85, respectively.

Table 5: Intra (bold diagonal) and inter-cluster distance (off-diagonal) in coriander

Clusters						
	I	II	III	IV	V	VI
I	13.23					
II	32.86**	11.15				
III	50.23**	82.52**	19.99			
IV	63.30**	30.83**	112.50**	13.56		
V	106.08**	73.57**	155.84**	43.99**	10.60	
VI	113.26**	83.60**	159.21**	60.18**	51.09**	11.84

X^2 (0.05): 15.51; X^2 (0.01): 20.09

Crosses involving parents from the most divergent groups will exhibit maximum heterosis and higher variability in genetic architecture (Sing et al., 1987). In the present study, clusters with the highest inter-cluster distances were the most dissimilar. However, the chances of obtaining segregants with higher yields are quite limited when one of the clusters has a very low yield level (Samal et al., 1989). Therefore, in breeding programs, it is important to consider not only the genetic distance between clusters but also their mean performance for important agronomic traits to maximize the chances of obtaining superior progenies. The selection of parents for hybridization should also consider the specific advantages of each cluster and each accession within the cluster, depending on the specific goals of the breeding program (Chahal and Gosal, 2002). Therefore, based on the present results, it can be proposed that crosses involving cluster III with clusters VI, V, and III exhibit high heterosis and may lead to segregation with respect to coriander genotypes. The present study revealed significant genetic and phenotypic diversity among the accessions tested, suggesting opportunities to improve seed yield through the crossbreeding of accessions from different clusters and subsequent selection from segregating and advanced generations. To increase the chance of producing high heterotic hybrids and a broad spectrum of diversity in segregating generations, more genetically varied parents must be employed in the hybridization procedure (Arunachalam, 1981; Desalegn et al., 2019). Furthermore, according to reports of Marker and Krupakar (2009), the most successful hybrids may include high-producing parents that have a wide range of genetic variations.

4. CONCLUSION

Seed yield (t ha^{-1}) was directly affected by plant height, number of umbellets umbel^{-1}, number of seeds umbel^{-1}, and seed yield plant^{-1}. Plant height, number of umbels plant^{-1}, number of umbellets umbel^{-1}, seed yield plant^{-1}, and seed yield (t ha^{-1}) were major contributing traits and accounted for 62.6% of the total variation in the first two Pcs. The highest and lowest inter-cluster distances were observed between clusters III and VI and I and II, respectively, in six clusters.

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7. REFERENCES

Abayneh, E., Demeke, T., Gebeyehu, B., Kebede, A., 2003. Soil of Kulumsa Agricultural Research Center. National Soil Research Center (NSRC), Soil survey and land evaluation, Technical Paper No.76.

Anonymous, 2022. Plant variety release, protection and seed quality control directorate. MoA (Ministry of Agriculture), 2022; Crop Variety Register, Issue No. 25. Addis Ababa, Ethiopia.

Anonymous, 2023. R Core Team, 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Arega, A., Solomon, T., Beriso, W., 2021. Adaptation trial of coriander (*Coriandrum sativum* L.) varieties in the mid land areas of Guji zone, Southern Ethiopia. South Asian Journal of Agricultural Sciences 1(2), 17–20.

Arif, M.U., Khurshid, H.A., Khan, S., 2014. Genetic structure and green leaf performance evaluation of geographically diverse population of coriander (*Coriandrum sativum* L.). European Academic Research 2(3), 3269–85.

Arunachalam, V., 1981. Genetic distance in plant. Indian Journal of Genetics and Plant Breeding 41, 226–236.

Azeez, M.A., Aremu, C.O., Olaniyan, O.O., 2013. Assessment of genetic variation in accessions of sesame (*Sesamum indicum* L.) and its crosses by seed protein electrophoresis. Journal of Agroalimentary Processes and Technologies 19(4), 383–391.

Beemnet, M., Getinet A., 2010. Variability in Ethiopian coriander accessions for agronomic and quality traits. African Crop Science Journal 18(2), 43–49.

Beemnet, M., Getinet, A., Bizuayehu, T., 2011. Genetic divergence in Ethiopian coriander accessions and its implication in breeding of desired plant types. African Crop Science Journal 19(1), 39–47.

Beemnet, M.K., 2018. Variation in phenol-qualitative characteristics of Ethiopian coriander (*Coriandrum sativum* L.). Academic Research Journal of Agricultural Science and Research 6(9), 531–538.

Beemnet, M.K., Getinet, A., Bizuayehu, T., 2013. Correlation and path coefficient analysis for seed yield and yield components in Ethiopian coriander accessions. African Crop Science Journal 21(1), 51–59.

Bhat, S., Kaushal, P., Kaur, M., Sharma, H.K., 2014. Coriander (*Coriandrum sativum* L.): Processing, nutritional and functional aspects. African Journal of Plant Science 8(1), 25–33.

Bhatt, G.M., 1973. Significance of path coefficient analysis in determining the nature of character association. Euphytica 22(2), 338–343.

Biruk, H., Sileshi, A., 2019. Chemical composition of essential oils from released coriander variety (*Coriandrum sativum* L.) grown in Ethiopia. Chemistry and Materials Research 11(9), 1–5.

Chahal, G.S., Gosal, S.S., 2002. Principles and procedures of plant breeding: biotechnological and conventional approaches. Narosa Publishing House, New Delhi.

Desalegn, D.S., Kebede, T.M., Amand, St., Bernardo, P., Bai, A., Perumal, G.R., Bashir, E., 2019. Genetic diversity, population structure, and linkage disequilibrium of pearl millet. The Plant Genome 12(3), 1–12.

Devi, S., Gupta, E., Sahu, M., Mishra, P., 2020. Proven health benefits and uses of coriander (*Coriandrum sativum* L.). In Ethno pharmacological investigation of Indian spices, pp. 197–204. IGI Global.

Dewey, D.I., Lu, K.H., 1959. A correlation and path-coefficient analysis of components of crested wheatgrass seed production. Agronomy Journal 51(9), 515–518.

Geremew, A., Firew, M., Amsalu, A., 2016. Genetic diversity analysis of Ethiopian coriander (*Coriandrum sativum* L.) genotypes for seed yield and oil content. Journal of Experimental Agriculture International 14(6), 1–8.

Geremew, A., Firew, M., Amsalu, A., 2015. Variability, heritability and genetic advance for some yield and yield related traits and oil content in Ethiopian coriander (*Coriandrum sativum* L.) genotypes. International Journal of Plant Breeding and Genetics 9(3), 116–125.

Getachew, A., Mohammed, B., Gemmachu, I., 2021. Registration of "Gadisa" newly released coriander variety. In Regional Review Workshop on Completed Research Activities, p. 31.

Girma, H., Abukiya, G., Behailu, M., 2022. Research achievements and recommendations in crop management for enhancing the productivity of spices: A review. African Journal of Agricultural Research 18(6), 428–441.

Gizaw, W.T., Dasta, T.G., Fekadu, G.N., Demis, F.L., Awoke, A.Z., Nimona, F.H., 2023. Estimation of variability, heritability, and genetic advance among Ethiopian coriander (*Coriandrum sativum* L.) accessions. International Journal of Bio-resource and Stress Management 14(9), 1225–1233.

Goetsch, E., Engels, J., Demissie, A., 1984. Crop diversity in Konso agriculture. PGRC/E - ILCA Germplasm Newsletter 7, 18–26.

Gomez, K.A., Gomez, A.A., 1984. Statistical procedures for agricultural research. John wiley and sons.

Habetewold, K., Demes, F., Tewodros, L., Dejene, B., Haimanot, M., Wakjira, G., 2017. Seed spices production guideline: Ethiopian Institute of Agricultural Research: http://www.ublication.eiar.gov.et

Hedburg, I., Hedburg, O., 2003. Flora of Ethiopia and eritrea apiaceae to dipsacaceae. Hedeger, I., Edwards, S., Nemomsa, S. (Eds.), 4(Part 1), p.16.

Jansen, P.C.M., 1981. Spices, condiments and medicinal plants in Ethiopia; their taxonomy and agricultural significance. Center for Agricultural Publishing and Documentation, Wageningen, Netherlands, 294.

Johnson, H.W., Robinson, H.F., Comstooc, R.E., 1955. Estimates of genetic and environmental variability in soybeans. Agronomy Journal 47, 314–318.

Kumawat, R., Singh, D., Kumawat, K.R., Kumawat, S., Choudhary, M., 2022. Character association and path coefficient analysis in coriander under normal and limited moisture conditions. Electronic Journal of Plant Breeding 13(4), 1380–1386.

Legesse, T., Firew, M., Adugna, W., Zerihun, T., 2018. Genetic diversity in the Ethiopian garden cress (*Lepidium sativum* L.) using microsatellite markers. Current Plant Biology 16, 32–40.

López, P.A., Widrlechner, M.P., Simon, P.W., Rai, S., Boylston, T.D., Isbell, T.A., Bailey, T.B., Gardner, C.A., Wilson, L.A., 2008. Assessing phenotypic, biochemical, and molecular diversity in coriander (*Coriandrum sativum* L.) germplasm. Genetic Resources and Crop Evolution 55, 247–275.

Mahalanobis, P.C., 1936. On the generalized distance in statistics. National Institute of Science of India.

Mandal, S., Mandal, M., 2015. Coriander (*Coriandrum sativum* L.) essential oil: Chemistry and biological activity. Asian Pacific Journal of Tropical Biomedicine 5(6), 421–428.

Marker, S., Krupakar, A., 2009. Genetic divergence in exotic maize germplasm (*Zea mays* L.). Journal of Agricultural and Biological Science 4(4), 44–47.

Miheretu, F., 2018. Variation of yield components in some coriander accessions (*Coriandrum sativam* L.) of Ethiopia. Advances in Crop Science and Technology 6(3), 1–2.

Miller, P.A., Williams, J.C., Comstock, H.F., 1958. Estimation of genetic and environmental variance in upland cotton and their implications in selection. Agronomy Journal 50, 126–131.

Moharana, S.K., Bala, M., Ankita, A.C., Manasa, V., Naveen, Y.K.V., Malaviya, A.V., 2023. Analysis of variability and genetic divergence for seed yield in coriander (*Coriandrum sativum* L.). Electronic Journal of Plant Breeding 14(1), 69–78.

Pal, R., Kumar, R., Tripathi, A., Chaudhary, S., Singh, V., 2023. Perspective analysis of the physical and engineering properties of coriander seed at different moisture contents. International Journal of Plant and Soil Science 35(21), 11–22.

Ram, H., Khna, M.M., Pandey, V.P., Dwivedi, D.K., 2017. Correlation coefficient and path analysis in Coriander (*Coriandrum sativum* L.) genotypes. International Journal of Current Microbiology Applied Sciences 6(6), 418–422.

Sahib, N.G., Anwar, F., Gilani, A.H., Hamid, A.A., Saari, N., Alkharfy, K.M., 2013. Coriander (*Coriandrum sativum* L.): A potential source of high-value components for functional foods and nutraceuticals-A review. Phytotherapy Research 27(10), 1439–1456.

Samal, K.M., Jagadev, P.N., Lenka, D., 1989. Genetic divergence in chickpea. International Chickpea Newsletter 21, 5–6.

Singh, R.K., Chandhury, B.D., 1985. Biometrical methods in quantitative genetic analysis. Kalyni Publishers, New Delhi, India, 318pp.

Singh, R.P., Singh, D.P., Chaudhury, B.D., 1987. Morphological variation in Indian mustard. Annals of Applied Biology 3(1), 26–31.

Singh, S.P., Katiyar, R.S., Rai, S.K., Triphathi, S.M., Srivastva, J.P., 2005. Genetic divergence and its implication in breeding of desired plant types in coriander (*Coriandrum sativum* L.). Genetika 37, 155–163.

Sneath, P.H., Sokal, R.R., 1973. Numerical taxonomy. The principles and practice of numerical classification.

Syafii, M., Cartika, I., Ruswandi, D., 2015. Multivariate analysis of genetic diversity among some maize genotypes under maize-albizia cropping system in Indonesia. Asian Journal of Crop Science 7(4), 244.

Wright, S., 1921. Correlation and causation. Journal of Agricultural Science 20, 557–587.