Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Morphometric and biochemical trait-based assessment of genetic diversity in coriander (Coriandrum sativum L.) germplasm from Madhya Pradesh, India

Dinesh Semwal

dinesh.semwal@icar.org.in

ICAR-National Bureau Of Plant Genetic Resources

Monika Jha

ICAR-National Bureau Of Plant Genetic Resources

Praveen K. Singh

ICAR-National Bureau Of Plant Genetic Resources

OP Dhariwal

ICAR-National Bureau Of Plant Genetic Resources

RS Meena

National Research Centre on Seed Spices

MK Mahatama

National Research Centre on Seed Spices

Vinay Bhardwaj

National Research Centre on Seed Spices

Article

Keywords: Coriandrum sativum, genetic diversity, essential oil composition, GC-HS profiling, Multivariate analysis

Posted Date: July 27th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10380287/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Morphometric and biochemical trait-based assessment of genetic diversity in coriander (*Coriandrum sativum* L.) germplasm from Madhya Pradesh, India

DP Semwal[1*], Monika Jha[1], Praveen K. Singh[1*], OP Dhariwal[1], RS Meena[2], MK Mahatma[2] and Vinay Bhardwaj[2]

[1]ICAR- National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi-110012. India

[2]ICAR- NRC on Seed Spices, Tabiji, Ajmer, Rajasthan-305206, India

DP Semwal: dinesh.semwal@icar.org.in

Monika Jha: monika.jha@icar.org.in

Praveen K Singh: praveen.singh1@icar.org.in

OP Dhariwal: om.dhariwal@icar.org.in

RS Meena: rsm.nrcss@gmail.com

MK Mahatma: maheshmahatma@gmail.com

Vinay Bhardwaj: vinaycpri@gmail.com

To whom the correspondence should be addressed

DP Semwal

Email ID: dinesh.semwal@icar.org.in,

Praveen K Singh

Email ID: pksingh128@gmail.com

Abstract

Coriander (*Coriandrum sativum* L.) is an economically important seed spice cultivated worldwide for its aromatic seeds, which are extensively utilized in culinary, pharmaceutical and fragrance industries. Harnessing rich genetic diversity preserved in indigenous germplasm offers considerable opportunities for improving seed quality and essential oil composition; however, integrated morpho-biochemical evaluations of these genetic resources remain limited. In present study, we comprehensively characterized 30 indigenous coriander accessions collected from diverse agro-climatic regions of Madhya Pradesh, India, by integrating seed morphological traits, essential oil content, GC-HS-based volatile metabolite profiling, genetic variability estimates and multivariate statistical analyses. Significant ($P \leq 0.05$) variation was observed across all investigated traits, revealing extensive morpho-biochemical diversity within germplasm. Total oil content ranged from 6.45 to 13.85%, whereas linalool, the principal volatile constituent, varied from 67.11 to 94.58%. Significant variation was also observed for α-pinene (0.94–22.38%) and geranyl acetate (0.00–6.37%), facilitating identification of chemically distinct linalool- and α-pinene-rich chemotypes. High heritability accompanied by substantial genetic advance for essential oil content, α-pinene, geranyl acetate, 100-seed weight and seed length suggested predominance of additive gene action, highlighting these traits as promising targets for selection in coriander breeding. Hierarchical cluster analysis and principal component analysis (PCA) further divided accessions into genetically distinct groups, with first two principal components explaining 78.7% of total phenotypic variation. The elite accessions identified in this study, combining superior seed characteristics with desirable essential oil profiles, constitute valuable genetic resources for cultivar improvement. Collectively, these findings provide a comprehensive resource for conservation and utilization of indigenous coriander germplasm and establish a strong foundation for developing high-yielding cultivars with enhanced seed quality and tailored essential oil composition to meet increasing demands of food, pharmaceutical and fragrance industries.

Keywords: *Coriandrum sativum,* genetic diversity, essential oil composition, GC-HS profiling, Multivariate analysis

1. Introduction

Coriander (*Coriandrum sativum* L.), an annual herbaceous species belonging to the family *Apiaceae*, is believed to have originated in the Mediterranean region. The cultivation and utilization of coriander have been documented for approximately five millennia, underscoring its long-standing significance in human civilization. The cultivation of coriander is geographically widespread, encompassing major production regions in Asia, Europe and Americas. India dominates global coriander production and is recognized as the largest producer and consumer of the crop. Within the country, the principal coriander-growing regions include Rajasthan, Madhya Pradesh and Gujarat, where favourable agro-climatic conditions support large-scale cultivation.

The genus *Coriandrum* comprises two recognized species: the cultivated species, *C. sativum* and the wild species, *C. tordylium*, which is naturally distributed in regions of Lebanon and Turkey [1]. Based primarily on fruit size, *C. sativum* has traditionally been classified into two subspecies or varietal groups, namely *var. vulgare* and *var. microcarpum*. The latter is characterized by relatively small fruits measuring approximately 2–3 mm in diameter, whereas *var. vulgare* possesses larger fruits ranging from 4–5 mm in diameter [2,3]. Subsequent taxonomic investigations proposed additional refinements to this classification. For instance, Ivanova and Stoletova [4] recognized three subspecies—*sativum* (corresponding to the former *vulgare*), *microcarpum* and *indicum*. Later, Diederichsen and Hammer [5] expanded the taxonomic framework by recognizing ten distinct botanical varieties within the species.

Coriander is a versatile seed spice crop valued for both its culinary and industrial applications. Its seeds and fresh leaves are extensively utilized as flavouring and seasoning agents in a wide range of food preparations. The characteristic aroma and flavour of coriander are attributed to the presence of essential oils and diverse volatile compounds, including (+)-linalool, γ-terpinene, α-pinene, camphor, decanal, geranyl acetate, limonene and camphene. Owing to its rich phytochemical composition, coriander has gained considerable commercial importance beyond culinary use and serves as a valuable raw material in the food, pharmaceutical, cosmetic, and fragrance industries [6].

Despite its widespread cultivation and diverse applications, substantial variability exists among coriander accessions with respect to their biochemical composition and quality attributes. The concentration and profile of total oils and other bioactive constituents are known to vary considerably among genotypes, influencing both their nutritional and commercial value. Characterization of germplasm collections for these biochemical traits is therefore essential for identifying superior accessions and broadening the genetic base available for crop improvement.

Furthermore, evaluation of biochemical diversity provides valuable insights into genetic potential of available germplasm and facilitate selection of elite genotypes for breeding programs aimed at enhancing quality-related traits. Accordingly, present investigation aimed to characterize biochemical diversity in coriander germplasm collected from Madhya Pradesh and to identify accessions possessing favourable biochemical traits for potential utilization in breeding and crop improvement programs.

2. Material and methods

2.1 Germplasm Collection and GIS Mapping

A total of 30 coriander (*Coriandrum sativum* L.) germplasm accessions were collected from Ashok Nagar, Guna, Gwalior and Shivpuri districts of Madhya Pradesh, India (24°34′–26°07′ N latitude and 77°03′–78°02′ E longitude) during March 1–9, 2019. The collection region, located at transitional zone between central and western India, is recognized as a significant centre of diversity for seed spice crops and serves as an important hotspot for genetic variation in coriander, cumin, fenugreek, ajwain and several other allied species. Geographic coordinates of collection sites were recorded and utilized for GIS-based mapping to document spatial distribution of germplasm accessions (Fig. 1). All collected germplasm accessions were conserved in the National Genebank (NGB), ICAR-NBPGR, New Delhi for long-term preservation. The National Identity (IC) numbers assigned to the collected germplasm accessions are presented in Table 1.

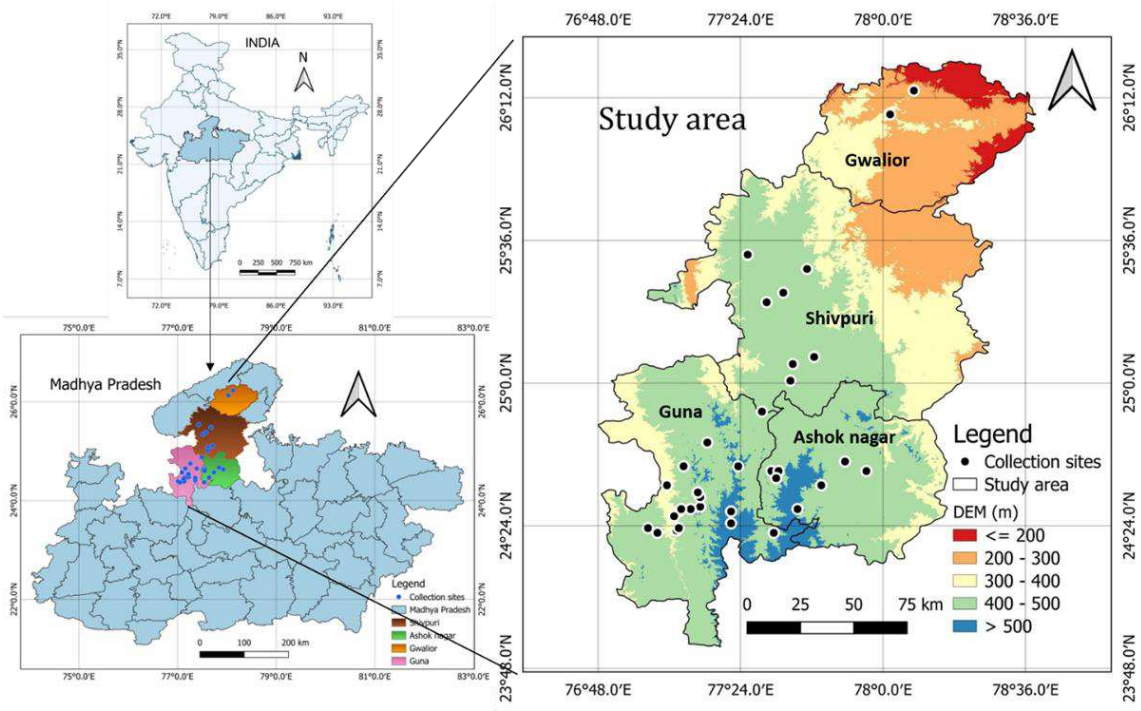


Fig. 1. Coriander germplasm collection sites in Madhya Pradesh, India.

Table 1. Passport data information of collected coriander (*Coriandrum sativum* L germplasm used in the study

S. No	Collector No.	IC No.	District	State	Latitude	Longitude
1	SDM-19/1	631401	Gwalior	Madhya Pradesh	26.13	78.03
2	SDM-19/3	631403	Shivpuri	Madhya Pradesh	25.38	77.58
3	SDM-19/4	631404	Shivpuri	Madhya Pradesh	25.38	77.58
4	SDM-19/9	631405	Shivpuri	Madhya Pradesh	25.54	77.43
5	SDM-19/16	631407	Shivpuri	Madhya Pradesh	25.08	77.62
6	SDM-19/19	631408	Shivpuri	Madhya Pradesh	25.01	77.61
7	SDM-19/20	631409	Shivpuri	Madhya Pradesh	25.01	77.61
8	SDM-19/22	631411	Guna	Madhya Pradesh	24.52	77.23
9	SDM-19/24	631413	Guna	Madhya Pradesh	24.38	77.13

10	SDM-19/25	631414	Guna	Madhya Pradesh	24.38	77.13
11	SDM-19/27	631416	Guna	Madhya Pradesh	24.37	77.05
12	SDM-19/28	631417	Guna	Madhya Pradesh	24.37	77.05
13	SDM-19/29	631418	Guna	Madhya Pradesh	24.37	77.05
14	SDM-19/32	631421	Guna	Madhya Pradesh	24.44	77.12
15	SDM-19/33	631422	Guna	Madhya Pradesh	24.44	77.12
16	SDM-19/34	631423	Guna	Madhya Pradesh	24.46	77.36
17	SDM-19/35	631424	Guna	Madhya Pradesh	24.41	77.36
18	SDM-19/38	631425	Guna	Madhya Pradesh	24.47	77.19
19	SDM-19/40	631426	Guna	Madhya Pradesh	24.46	77.14
20	SDM-19/41	631427	Guna	Madhya Pradesh	24.65	77.39
21	SDM-19/43	631428	Ashok Nagar	Madhya Pradesh	24.63	77.53
22	SDM-19/44	631429	Ashok Nagar	Madhya Pradesh	24.63	77.56
23	SDM-19/45	631430	Ashok Nagar	Madhya Pradesh	24.6	77.55
24	SDM-19/46	631431	Ashok Nagar	Madhya Pradesh	24.57	77.74
25	SDM-19/47	631432	Ashok Nagar	Madhya Pradesh	24.57	77.74
26	SDM-19/48	631433	Ashok Nagar	Madhya Pradesh	24.57	77.74
27	SDM-19/49	631434	Ashok Nagar	Madhya Pradesh	24.57	77.74
28	SDM-19/50	631435	Ashok Nagar	Madhya Pradesh	24.63	77.93
29	SDM-19/51	631436	Guna	Madhya Pradesh	24.65	77.16
30	SDM-19/52	631437	Guna	Madhya Pradesh	24.65	77.16

2.2 Morphological trait assessment

Physical attributes of the coriander seeds, including seed length and seed width, were measured using a digital Vernier calliper. 100 seed weight was recorded with an electronic weighing balance. Length to width (L/B ratio) was determined using the following formula:

$$L/B\ ratio = \frac{Seed\ Length\ (mm)}{Seed\ width\ (mm)}$$

2.3 Volatile profiling by Gas Chromatography Headspace (GC-HS)

The essential oils were profiled using Agilent Gas chromatography (7890A) equipped with Headspace (G1888) (GC-HS). Dry seeds (1 g) of Coriander was crushed and placed inside 20-ml crimp headspace vials. Vials were sealed with an aluminium-coated silicone rubber septum and placed in HS auto sampler. Samples were heated at 100°C for 7 min with continuous shaking to extract volatiles. Volatiles were released by piercing the septum of the vial through the sampling probe in transfer line and finally into the GC inlet port. The temperature of loop and transfer line was kept at 110°C and 120°C, respectively. A 100:1 split injection ratio was used to introduce volatiles into the GC instrument equipped with a HP5 MS column (30 m length, 0.25 mm internal diameter, 0.25 µm film thickness). Inlet temperature was kept at 250°C. An initial temperature of the oven was set at 60°C with a 2-minute hold. After that, the temperature was raised to 150°C at a rate of 5°C min^{-1}, and the rate was further adjusted to 10°C min^{-1} to 260°C. EO constituents were identified and quantified based on the retention time of standards (Sigma-Aldrich, Germany) and the % area of the compounds on the FID detector [7].

2.4 Total Oil Content of Coriander

The total oil from coriander seeds was extracted using a Soxhlet apparatus [8]. A volume of 5 g of pulverised seed samples was weighed, placed into the thimble, and plugged with fat-free cotton wool. The thimble was placed in a Soxhlet apparatus for oil collection. The oil was extracted with the solvent *n*-hexane for 6 h continuously. After cooling, the oil was collected from the flask, and the content was measured.

2.5 Experimental Design and Statistical Analysis

The experiment was conducted using a Completely Randomized Design (CRD) with three replications. Data recorded for morphological and biochemical traits were subjected to one-way analysis of variance (ANOVA) to assess the significance of differences among coriander germplasm accessions. Mean comparisons were performed using Tukey's Honestly Significant Difference

(HSD) test at the 5% probability level. All statistical analyses were carried out using R software version 4.5.3 R [9].

Descriptive statistics, including measures of central tendency and dispersion, were computed for all studied traits. Genetic variability parameters, namely genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV), were estimated following the method of Burton and DeVane, [10] while broad-sense heritability (H^2bs), genetic advance (GA) and genetic advance as percentage of mean (GAM) were calculated according to the procedures described by Johnson et al. [11]. Pearson's correlation coefficients were estimated to assess the magnitude and direction of associations among morphological and biochemical traits. Principal component analysis (PCA) was performed to identify the major sources of variation and quantify the contribution of individual traits to the overall genetic diversity among accessions [12]. Genetic relationships among coriander accessions were further examined through hierarchical cluster analysis based on Euclidean distance matrices generated from standardized trait data.

3. Results and Discussion

3.1 Morphological characterization in coriander germplasm

Analysis of variance revealed significant differences ($P \leq 0.05$) among collected coriander accessions for all evaluated seed morphological traits, including 100-seed weight, seed length, seed width and length-to-width (L/B) ratio (Table 2; Fig. 2), demonstrating substantial phenotypic diversity within germplasm. The observed variation reflects broad genetic base indigenous coriander collections from Madhya Pradesh and underscores their potential for germplasm conservation, parent selection and crop improvement. The substantial phenotypic variability observed in the present study is consistent with earlier reports documenting considerable diversity in economically important morphological traits among coriander accessions [13, 14, 15]. The concordance of these findings across diverse germplasm collections reinforces the existence of a broad genetic base in coriander and emphasizes its potential for genetic improvement through targeted selection and breeding.

Among evaluated traits, 100-seed weight exhibited considerable variation, ranging from 1.05 to 1.62 g. Accessions IC 631414, IC 631405, IC 631407 and IC 631401 recorded highest seed weight, whereas IC631404, IC 631418 and IC 631431 possessed comparatively lighter seeds. Seed weight is an important yield-associated trait that also influenc es seed quality and market preference. The substantial variability observed among accessions indicates the availability of exploitable genetic variation for the development of high-yielding coriander cultivars. The substantial variation in 100-seed weight observed among evaluated coriander accessions

corroborates earlier findings reporting significant differences for this trait [16]. As one of key yield-contributing characteristics, 100-seed weight is of particular breeding importance due to its close association with seed vigour, productivity and market acceptability [17]. The wide range of variation recorded in present study therefore highlights potential of indigenous coriander germplasm as a valuable source of superior alleles for developing high-yielding and commercially desirable cultivars.

Significant variation was also observed in seed dimensional traits, with seed length ranging from 4.145 to 6.055 mm and seed width from 3.725 to 4.185 mm, resulting in marked differences in seed morphology among evaluated accessions. The corresponding length-to-width (L/W) ratio (1.10–1.58) further demonstrated presence of both elongated and relatively rounded seed morphotypes, reflecting substantial morphological diversity within indigenous germplasm. This variation is likely cumulative outcome of prolonged farmer-mediated selection acting in concert with adaptation to diverse agro-climatic conditions across Madhya Pradesh. During germplasm exploration, farmers from Ashok Nagar, Guna, Shivpuri and Kumbhraj consistently identified traditional landraces, including Kumbhraj, Mithi Dhana and Kudi Dhana, as preferred cultivars because of their early maturity and suitability for producing premium-quality green coriander seeds for regional beverage industry. Such sustained, location-specific selection for desirable agronomic and seed quality traits has likely facilitated maintenance of distinct seed morphotypes within indigenous coriander germplasm. Moreover, seed size and shape are economically important traits in coriander, influencing seed grading, handling efficiency, processing quality and consumer preference [18].

Overall, accessions IC 631414, IC 631405, IC 631422 and IC 631423 consistently exhibited superior performance across multiple seed morphological traits, suggesting that these genotypes constitute valuable genetic resources for coriander improvement. Their incorporation into breeding programmes may facilitate development of cultivars with improved seed quality, enhanced market value and greater industrial applicability.



Fig. 2. Variability in seed shape, size and colour of coriander germplasm collected from Guna and Shivpuri districts of Madhya Pradesh, India (Excerpt from Semwal et al. [19])

Table 2. Mean performance of coriander accessions for seed morphological traits

Accession	100-seed weight (g)	Seed length (mm)	Seed width (mm)	L/B ratio
IC 631401	1.585^{abc}	5.775^{a}	4.05	1.485^{abc}
IC 631403	1.300^{efghijkl}	4.760^{efg}	3.985	1.275^{abcd}
IC 631404	1.045^{m}	4.145^{i}	3.79	1.100^{d}
IC 631405	1.605^{ab}	6.000^{a}	3.985	1.580^{a}
IC 631407	1.605^{ab}	5.150^{bcd}	3.895	1.365^{abcd}
IC 631408	1.550^{abcd}	5.050^{cde}	3.815	1.335^{abcd}
IC 631409	1.520^{abcde}	5.395^{b}	3.885	1.460^{abc}
IC 631411	1.450^{abcdefgh}	5.255^{bc}	4.06	1.400^{abcd}
IC 631413	1.470^{abcdefg}	5.045^{cde}	3.835	1.355^{abcd}
IC 631414	1.615^{a}	6.040^{a}	4.185	1.500^{ab}
IC 631416	1.245^{ghijklm}	4.680^{fg}	3.915	1.270^{abcd}
IC 631417	1.370^{bcdefghij}	4.565^{gh}	3.725	1.270^{abcd}
IC 631418	1.055^{m}	4.220^{i}	3.79	1.155^{cd}
IC 631421	1.450^{abcdefgh}	5.315^{bc}	3.995	1.350^{abcd}
IC 631422	1.500^{abcdef}	6.055^{a}	4.145	1.495^{ab}
IC 631423	1.505^{abcdef}	5.985^{a}	4.17	1.490^{ab}
IC 631424	1.155^{jklm}	4.680^{fg}	3.805	1.290^{abcd}

IC 631425	1.190^{ijklm}	4.885^{def}	3.955	1.275^{abcd}
IC 631426	1.270^{fghijklm}	4.300^{hi}	3.95	1.155^{cd}
IC 631427	1.315^{defghijkl}	5.050^{cde}	4.02	1.310^{abcd}
IC 631428	1.420^{abcdefghi}	5.165^{bcd}	4.085	1.320^{abcd}
IC 631429	1.125^{klm}	5.050^{cde}	3.795	1.360^{abcd}
IC 631430	1.360^{cdefghijk}	5.270^{bc}	3.97	1.395^{abcd}
IC 631431	1.055^{m}	4.150^{i}	3.785	1.305^{abcd}
IC 631432	1.220^{hijklm}	4.265^{hi}	3.83	1.170^{bcd}
IC 631433	1.405^{abcdefghi}	5.165^{bcd}	3.975	1.375^{abcd}
IC 631434	1.105^{lm}	4.275^{hi}	3.78	1.180^{bcd}
IC 631435	1.360^{cdefghijk}	5.170^{bcd}	3.92	1.360^{abcd}
IC 631436	1.370^{bcdefghij}	4.815^{efg}	4.07	1.265^{abcd}
IC 631437	1.315^{defghijkl}	4.785^{efg}	4.01	1.280^{abcd}

Values followed by different superscript letters within a column are significantly different according to Tukey's HSD test ($P \leq 0.05$).

3.2 Total oil content

The oil content of coriander accessions exhibited substantial variation, ranging from 6.45 ± 0.07% to 13.85 ± 0.07%, indicating considerable diversity among evaluated germplasm. The highest oil content was observed in accession IC 631404, collected from Shivpuri, with a mean value of 13.85 ± 0.07%. This was followed by IC 631434 (11.60 ± 0.14%), IC 631432 (10.90 ± 0.14%) from Ashok Nagar, and IC 631416 (10.70 ± 0.14%) from Guna. In contrast, lowest oil content (6.45 ± 0.07%) was recorded in accessions IC 631411 from Guna and IC 631405 from Shivpuri, highlighting pronounced accession-specific variation in essential oil accumulation across studied populations.

The total oil of coriander seeds is highly valued because of its exceptionally high content of petroselinic acid, a rare monounsaturated omega-12 fatty acid and a positional isomer of oleic acid, distinguished by the location of its double bond at the Δ6 position rather than the Δ9 position. Petroselinic acid typically constitutes 65–85% of the total fatty acids in coriander seed oil, imparting unique physicochemical properties that confer significant industrial, nutritional, and pharmacological value [20].

3.3 Volatile oil composition in coriander germplasm

GC-HS analysis revealed substantial genotypic variation in total oil profile of coriander accessions. A total of 14 volatile compounds were identified across evaluated germplasm, and one-way ANOVA revealed highly significant differences ($P < 0.001$) among accessions for total oil content and principal volatile constituents. Given their importance to coriander aroma and quality, linalool, α-pinene and geranyl acetate were selected for detailed evaluation (Table 3). Analysis of volatile oil composition revealed linalool as predominant volatile constituent across all evaluated coriander accessions, accounting for 67.11–94.58% of volatile oil. This observation is consistent with previous reports identifying linalool as the principal component of coriander seed total oil, although wide range observed in the present study further confirms existence of substantial chemotypic diversity within indigenous coriander germplasm [20]. The high linalool content recorded in accessions IC 631433, IC 631421, IC 631436, IC 631422, IC 631403 and IC 631430 highlights their potential as valuable genetic resources for breeding cultivars with superior aroma and enhanced total oil quality.

In addition to linalool, considerable variation was observed for α-pinene (0.94–22.38%) and geranyl acetate (0.00–6.37%), indicating substantial diversity in composition of bioactive volatile constituents among evaluated accessions. These volatile terpenes are key determinants of sensory and commercial quality of coriander total oil and therefore play an important role in its industrial grading and market value. α-Pinene imparts a characteristic fresh, woody, pine-like aroma, whereas geranyl acetate contributes pleasant floral and fruity notes that enhance fragrance profile of oil [21]. Consequently, variation in relative abundance of these compounds is of considerable commercial significance, particularly for flavour, fragrance, cosmetic and perfumery industries, where specific volatile profiles are highly desirable.

Overall, observed variation in total oil content and three major volatile constituents highlights broad biochemical diversity within coriander germplasm. Accessions IC 631430 and IC 631436 combined high linalool content (>91%) with favourable oil yield, whereas IC 631404 exhibited highest oil content. Distinct α-pinene-rich (IC 631429, IC 631437, IC 631405) and geranyl acetate-rich (IC 631413, IC 631431) chemotypes were also identified. Indigenous accessions accumulating α-pinene at levels exceeding total terpenoid fraction reported previously [20]. This finding indicates existence of distinct α-pinene-rich chemotypes within Madhya Pradesh germplasm and highlights their potential for developing coriander cultivars with specialized aroma profiles for flavour and fragrance industries.

Table 3. Total oil content and relative abundance (% peak area) of major volatile compounds in coriander accessions determined by GC–MS

Accession	Total oil content (%)	α-Pinene (%)	Linalool (%)	Geranyl acetate (%)
IC 631401	$8.00^{h} \pm 0.00$	$3.33^{no} \pm 0.16$	$90.23^{e} \pm 0.15$	$0.22^{mn} \pm 0.01$
IC 631403	$8.65^{fg} \pm 0.07$	$2.71^{pq} \pm 0.09$	$92.21^{c} \pm 0.13$	$1.79^{kl} \pm 0.06$
IC 631404	$13.85^{a} \pm 0.07$	$8.69^{g} \pm 0.09$	$84.07^{j} \pm 0.17$	$2.27^{hij} \pm 0.07$
IC 631405	$6.45^{n} \pm 0.07$	$19.10^{b} \pm 0.18$	$67.11^{q} \pm 0.16$	$4.87^{c} \pm 0.12$
IC 631407	$7.25^{jk} \pm 0.07$	$6.11^{kl} \pm 0.11$	$88.62^{g} \pm 0.17$	$1.51^{l} \pm 0.04$
IC 631408	$7.95^{h} \pm 0.07$	$7.14^{i} \pm 0.08$	$84.44^{j} \pm 0.16$	$3.11^{f} \pm 0.05$
IC 631409	$6.95^{klm} \pm 0.07$	$6.06^{kl} \pm 0.12$	$84.20^{j} \pm 0.15$	$4.63^{c} \pm 0.06$
IC 631411	$6.45^{n} \pm 0.07$	$10.44^{e} \pm 0.16$	$82.95^{k} \pm 0.13$	$2.57^{gh} \pm 0.08$
IC 631413	$7.90^{h} \pm 0.14$	$2.30^{qr} \pm 0.08$	$89.45^{f} \pm 0.15$	$6.37^{a} \pm 0.12$
IC 631414	$6.55^{mn} \pm 0.07$	$8.05^{h} \pm 0.14$	$79.25^{n} \pm 0.18$	$5.54^{b} \pm 0.08$
IC 631416	$10.70^{d} \pm 0.14$	$0.94^{s} \pm 0.06$	$89.95^{ef} \pm 0.10$	$5.48^{b} \pm 0.13$
IC 631417	$6.90^{klm} \pm 0.14$	$5.73^{l} \pm 0.07$	$85.6^{1i} \pm 0.18$	$4.23^{d} \pm 0.15$
IC 631418	$6.45^{n} \pm 0.07$	$3.12^{nop} \pm 0.09$	$89.46^{f} \pm 0.13$	$3.78^{e} \pm 0.08$
IC 631421	$7.95^{h} \pm 0.07$	$3.12^{nop} \pm 0.09$	$93.12^{b} \pm 0.13$	$3.84^{e} \pm 0.10$
IC 631422	$7.40^{ij} \pm 0.14$	$3.02^{nop} \pm 0.08$	$92.53^{bc} \pm 0.16$	$2.37^{hi} \pm 0.08$
IC 631423	$7.75^{hi} \pm 0.07$	$10.84^{e} \pm 0.15$	$80.63^{m} \pm 0.16$	$3.80^{e} \pm 0.13$
IC 631424	$8.05^{h} \pm 0.07$	$3.47^{n} \pm 0.07$	$88.61^{g} \pm 0.13$	$2.40^{h} \pm 0.09$
IC 631425	$6.55^{mn} \pm 0.07$	$13.79^{c} \pm 0.13$	$73.21^{o} \pm 0.12$	$2.93^{fg} \pm 0.08$
IC 631426	$8.85^{fg} \pm 0.07$	$6.55^{jk} \pm 0.11$	$86.84^{h} \pm 0.15$	$3.06^{f} \pm 0.09$
IC 631427	$8.80^{fg} \pm 0.14$	$9.60^{f} \pm 0.12$	$79.68^{n} \pm 0.19$	$2.34^{hi} \pm 0.10$
IC 631428	$6.60^{mn} \pm 0.14$	$4.87^{m} \pm 0.12$	$89.37^{f} \pm 0.14$	$2.03^{ijk} \pm 0.06$
IC 631429	$7.70^{hi} \pm 0.14$	$22.38^{a} \pm 0.24$	$69.78^{p} \pm 0.15$	$2.42^{h} \pm 0.09$
IC 631430	$10.10^{e} \pm 0.14$	$3.09^{nop} \pm 0.09$	$92.01^{c} \pm 0.17$	$0.51^{m} \pm 0.02$
IC 631431	$7.10^{jkl} \pm 0.07$	$2.67^{pq} \pm 0.07$	$90.27^{e} \pm 0.16$	$5.70^{b} \pm 0.18$
IC 631432	$10.90^{d} \pm 0.14$	$11.57^{d} \pm 0.18$	$82.79^{k} \pm 0.18$	$0.00^{n} \pm 0.00$
IC 631433	$7.94^{h} \pm 0.14$	$1.83^{r} \pm 0.09$	$94.58^{a} \pm 0.16$	$3.59^{e} \pm 0.06$
IC 631434	$11.60^{c} \pm 0.14$	$10.63^{e} \pm 0.15$	$79.17^{n} \pm 0.16$	$3.86^{e} \pm 0.08$
IC 631435	$8.55^{g} \pm 0.07$	$6.91^{ij} \pm 0.06$	$86.21^{hi} \pm 0.13$	$1.92^{jk} \pm 0.03$

IC 631436	$6.75^{lmn} \pm 0.07$	$2.85^{op} \pm 0.10$	$92.95^{b} \pm 0.09$	$1.78^{kl} \pm 0.04$
IC 631437	$9.05^{f} \pm 0.07$	$22.35^{a} \pm 0.19$	$69.73^{p} \pm 0.23$	$2.43^{h} \pm 0.10$

Values represent mean ± SD (n = 2). Different superscript letters within a column indicate significant differences among accessions according to Tukey's HSD test ($P \leq 0.05$).

3.4 Genetic heritability, genetic advance and variability

Estimates of the genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), broad-sense heritability (H^2), genetic advance (GA) and genetic advance as a percentage of the mean (GAM) are fundamental genetic parameters for assessing extent of variability and predicting effectiveness of selection in crop improvement programmes [22]. In present study, these parameters were estimated for seed morphological and biochemical traits (Table 4). Considerable variability was observed across all evaluated traits, indicating presence of ample genetic diversity within indigenous coriander germplasm and providing a strong foundation for identification and selection of superior genotypes in breeding programmes.

Considerable genetic variability was observed among evaluated traits. Among biochemical traits, α-pinene exhibited highest genotypic and phenotypic variability (GCV = 77.51%; PCV = 77.53%), followed by geranyl acetate (GCV = 52.63%; PCV = 52.71%), indicating substantial genetic diversity for these economically important volatile constituents. In contrast, total oil content showed moderate variability (GCV = 21.32%; PCV = 21.36%), whereas linalool, despite being the predominant constituent of coriander total oil, displayed comparatively low variation (GCV = PCV = 8.74%), suggesting a relatively conserved accumulation pattern across evaluated accessions. Among seed traits, 100-seed weight exhibited highest genetic variability (GCV = 12.64%), which was considerably greater than variability previously reported for 1000-seed weight in coriander (GCV = 2.85%; PCV = 4.65%) [23], indicating presence of a broader genetic base for seed weight in indigenous germplasm examined in present study. Seed length also showed appreciable variability (GCV = 11.32%), whereas length-to-width ratio exhibited moderate variation (GCV = 8.21%; PCV = 9.08%). In contrast, seed width displayed lowest level of genetic variability (GCV = 2.05%; PCV = 4.06%), suggesting limited scope for selection based on this trait.

Broad-sense heritability (h^2) varied markedly among the evaluated traits, ranging from 25.66% for seed width to 99.96% for linalool. Exceptionally high heritability estimates were recorded for linalool (99.96%), α-pinene (99.95%), geranyl acetate (99.70%), total oil content (99.68%), seed length (98.29%), and 100-seed weight (89.76%), indicating that the observed phenotypic

variation for these traits was predominantly attributable to genetic factors. Such high heritability suggests that these traits are likely to respond effectively to phenotypic selection and therefore represent promising targets for genetic improvement programmes [24]. In contrast, seed width exhibited relatively low heritability (25.66%), implying a greater influence of environmental factors and/or non-additive genetic effects on its expression. Nevertheless, heritability estimates should be interpreted with caution, as they are population- and environment-specific and cannot be extrapolated across different coriander germplasm [25].

The high estimates of genetic variability observed for several traits were further supported by genetic advance parameters. Genetic advance (GA) as a percentage of mean (GAM) ranged from 2.14% for seed width to 159.63% for α-pinene. Highest GAM values were recorded for α-pinene (159.63%), followed by geranyl acetate (108.26%), total oil content (43.85%), 100-seed weight (24.68%), seed length (23.12%), linalool (17.99%) and length-to-width ratio (15.28%), whereas seed width exhibited the lowest GA (0.08) and GAM (2.14%). High heritability coupled with high genetic advance is widely regarded as an indicator of predominately additive gene action and predicts an effective response to phenotypic selection [26]. Accordingly, high heritability and GAM estimates observed for α-pinene, geranyl acetate, total oil content, 100-seed weight and seed length suggest that these traits can be improved efficiently through direct selection, whereas the low genetic advance associated with seed width indicates comparatively limited potential for genetic improvement through simple phenotypic selection.

Table 4. Estimates of genetic diversity for biochemical and morphological traits in coriander germplasm

Trait	Mean	GCV (%)	PCV (%)	Heritability (%)	GA	GAM (%)
α-Pinene	7.44	77.51	77.53	99.95	11.88	159.63
Linalool	84.97	8.74	8.74	99.96	15.29	17.99
Geranyl acetate	3.05	52.63	52.71	99.7	3.3	108.26
Total oil	8.19	21.32	21.36	99.68	3.59	43.85
100-seed weight (g)	1.35	12.64	13.35	89.76	0.33	24.68
Seed length (mm)	5.02	11.32	11.42	98.29	1.16	23.12
Seed width (mm)	3.94	2.05	4.06	25.66	0.08	2.14
Length: width ratio	1.33	8.21	9.08	81.60	0.20	15.28

GCV = Genotypic coefficient of variation; PCV = Phenotypic coefficient of variation; GA = Genetic advance; GAM = Genetic advance as percent of mean.

3.5 Cluster analysis

The identification of genetically divergent groups is a fundamental prerequisite for effective selection of complementary parental lines in crop improvement programmes [27]. In the present study, hierarchical cluster analysis was employed to characterize underlying morpho-biochemical diversity among 30 indigenous coriander accessions based on their combined seed morphological traits and total oil composition. The analysis resolved the germplasm into four distinct clusters (Fig. 3), reflecting substantial divergence among evaluated accessions. Cluster-wise mean values for all investigated traits are presented in Table 5, providing a comprehensive overview of characteristic features associated with each cluster.

Cluster 1 (n = 18) represented the largest group and was characterized by highest mean linalool content (88.64%) and lowest α-pinene concentration (4.94%). Accessions in this cluster exhibited moderate total oil content (7.76%) together with intermediate seed morphological traits. Predominant linalool-rich genotypes in this cluster suggests for conventional coriander chemotype preferred for flavour and aroma.

In contrast, Cluster 2 (n = 8) was distinguished by highest mean total oil content (9.68%), although it comprised relatively small-seeded accessions with lowest 100-seed weight (1.09 g) and shortest seed length (4.29 mm). Thereby, identifies this group as a valuable source for improving oil yield.

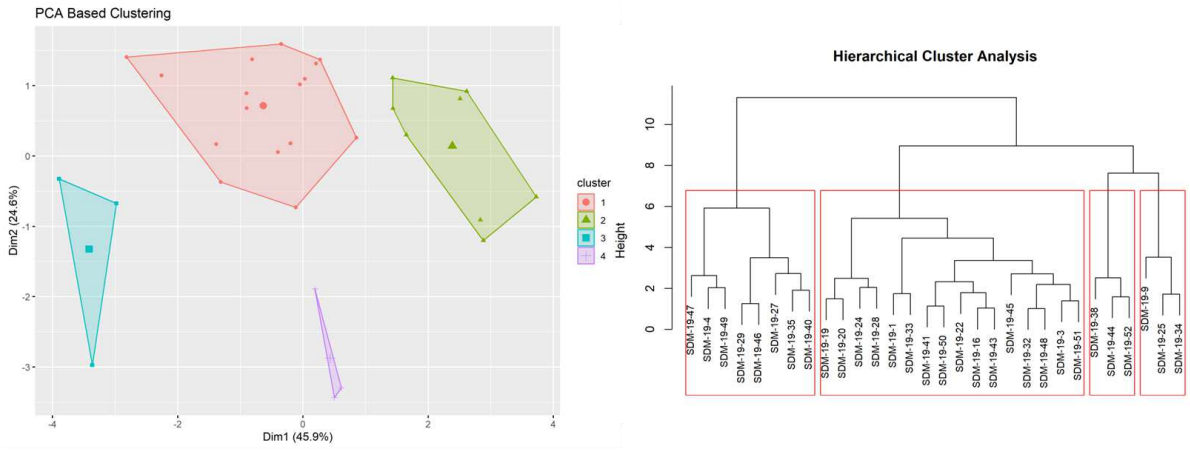
Cluster 3 (n = 3) included large-seeded accessions, recording highest mean 100-seed weight (1.57 g), greatest seed length (6.06 mm) and maximum length-to-width ratio (1.49). However, this cluster exhibited lowest total oil content (6.92%) and comparatively lower linalool concentration (75.66%).

Cluster 4 (n = 3) formed a distinct α-pinene-rich chemotype, exhibiting highest mean α-pinene content (19.51%) and lowest linalool concentration (70.91%). Total oil content (7.77%) and seed morphological traits in this cluster remained intermediate relative to the other groups. Therefore, genotypes of this cluster possess potential applications in the flavour and fragrance industries.

Overall, clustering analysis revealed clear differentiation among coriander accessions based on integrated seed morphology and total oil composition, highlighting presence of distinct morpho-biochemical groups within evaluated germplasm.

Table 5. Cluster-wise mean variation in total oil composition and seed morphological traits of coriander accessions

Cluster	n	Total oil content (%)	α-Pinene (%)	Linalool (%)	Geranyl acetate (%)	100-seed weight (g)	Seed length (mm)	Seed width (mm)	L:B ratio
1	18	7.76	4.94	88.64	2.68	1.42	5.16	3.88	1.33
2	8	9.68	5.96	86.4	3.32	1.09	4.3	3.76	1.14
3	3	6.92	12.66	75.66	4.74	1.57	6.06	4.05	1.49
4	3	7.77	19.51	70.91	2.59	1.18	4.86	3.81	1.27



a. **b.**

Fig. 3. Multivariate clustering of 30 coriander accessions based on quantitative traits. **a.** Principal Component Analysis (PCA) score plot; **b.** Neighbor-Joining (NJ) dendrogram constructed via Euclidean distance.

3.6 Correlation of biochemical traits with morphological traits of coriander seeds

Understanding the relationships among morphological and biochemical traits is essential for improving selection efficiency and accelerating genetic gain in crop breeding programmes [28]. Therefore, correlation analysis was performed to elucidate interrelationships among evaluated seed morphological and biochemical traits in indigenous coriander germplasm, providing insights into trait associations that can facilitate simultaneous improvement of multiple economically important traits.

Correlation analysis revealed a moderate negative association between total oil content and seed morphological traits, including 100-seed weight ($r = -0.47$), seed length ($r = -0.45$), seed width ($r = -0.34$) and length-to-width ratio ($r = -0.44$), indicating that accessions with larger seeds generally exhibited lower total oil content (Fig. 4). In contrast, major volatile constituents (α-pinene, linalool and geranyl acetate) showed only weak correlations with seed morphological

traits (|r| < 0.15), suggesting that variation in volatile composition was largely independent of seed size and shape characteristics.

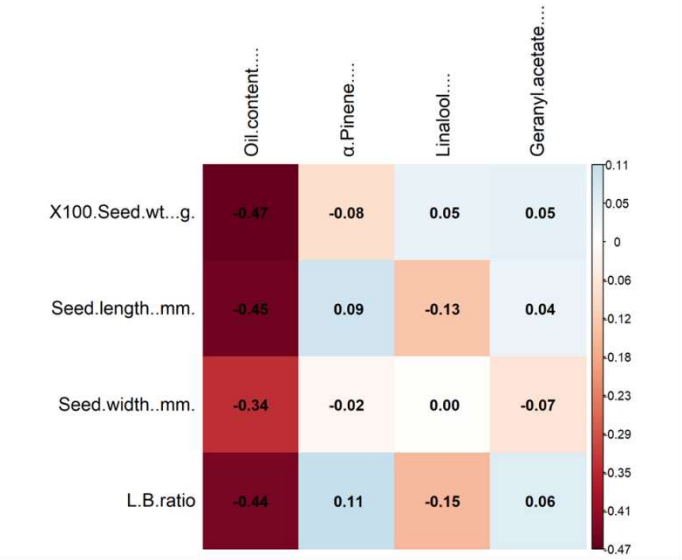


Fig. 4. Pearson correlation matrix between morphological and biochemical traits in 30 coriander germplasm accession.

3.7 Principal component analysis

Principal component analysis (PCA) is a powerful multivariate approach for identifying traits that contribute most to genetic divergence and for visualizing relationships among germplasm accessions [29].

In the present study, PCA revealed pronounced multivariate differentiation among indigenous coriander accessions (Fig. 5). The first two principal components accounted for 78.7% of total variation (PC1 = 49.4% and PC2 = 29.3%), indicating that majority of observed diversity was effectively captured by these two axes, whereas PC3 explained an additional 20.7% of variation. The strong contribution of seed morphological traits to PC1 demonstrates that seed size and shape are primary determinants of phenotypic divergence within evaluated germplasm. In contrast, opposing loading of total oil content on same axis suggests a negative association between seed size and oil accumulation, indicating that these traits may be regulated independently and should be considered simultaneously during selection. PC2 was predominantly influenced by major volatile constituents, with α-pinene and linalool exhibiting contrasting loadings, reflecting marked chemotypic variation in total oil composition among accessions.

The PCA biplot further resolved the accessions into distinct groups according to their seed morphological and biochemical characteristics, separating large-seeded genotypes from high total oil -producing accessions and distinguishing linalool- and α-pinene-rich chemotypes. These findings are consistent with hierarchical cluster analysis, confirming that seed morphology and total oil composition are the principal sources of diversity within indigenous coriander germplasm. Overall, PCA provides a robust framework for identifying genetically divergent accessions and selecting complementary parental combinations for simultaneous improvement of seed characteristics and total oil quality in coriander breeding programmes.

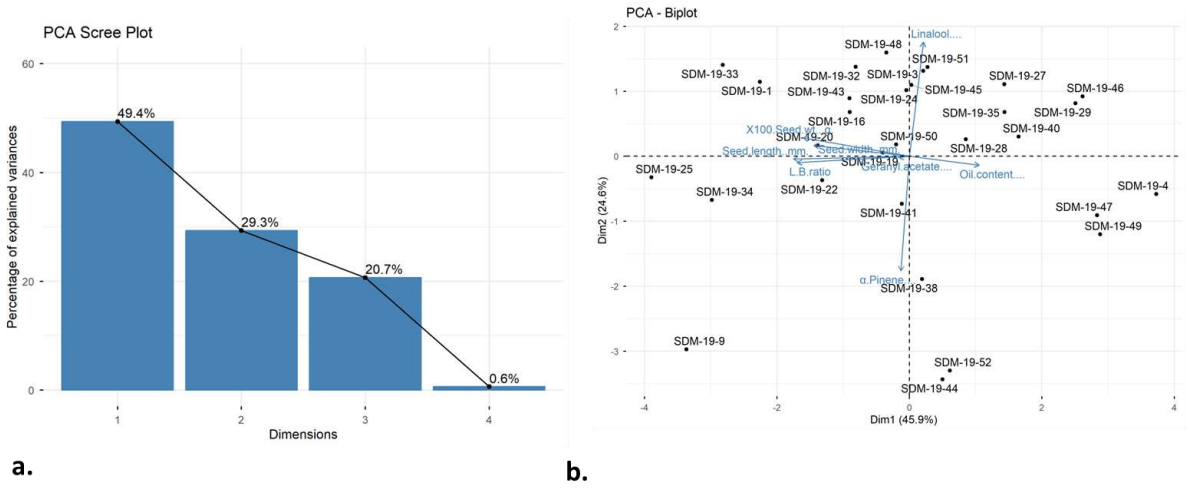


Fig. 5. Principal component analysis for physio-chemical traits in coriander germplasm. **(a)** Contribution of the dimensions explaining the variance of significant ($p \leq 0.05$) in the cluster analysis. **(b)** correlation of the traits and the dimension 1 & dimension 2.

4. Conclusion

This study provides a comprehensive morpho-biochemical characterization of indigenous coriander germplasm collected from diverse agro-climatic regions of Madhya Pradesh, revealing extensive variation in seed morphology, total oil content and volatile composition. The identification of distinct linalool-, α-pinene-, and geranyl acetate-rich chemotypes, together with significant variability observed for seed morphological traits, demonstrates considerable genetic potential preserved within these indigenous landraces. High heritability coupled with substantial genetic advance for key biochemical and seed traits indicates that these characteristics are amenable to effective phenotypic selection, whereas multivariate analyses further confirmed the existence of genetically divergent morpho-biochemical groups suitable for parental selection. The identified elite accessions possessing superior total oil content, desirable volatile profiles, and favourable seed characteristics represent valuable genetic resources for development of

improved coriander cultivars tailored to both domestic and industrial requirements. Overall, findings highlight importance of conserving indigenous coriander germplasm and provide a robust foundation for future breeding programmes aimed at enhancing seed quality, total oil yield and aroma composition.

References

1. Hedge, I. C. & Lamond, J. M. *Coriandrum* L. In *Flora of Turkey and the East Aegean Islands* (ed. Davis, P. H.) Vol. 4, 330–331 (Edinburgh University Press, Edinburgh, 1972).
2. de Candolle, A. P. *Prodromus Systematis Naturalis Regni Vegetabilis*. Vol. 16 (Treuttel & Würtz, Paris, 1830).
3. Alefeld, F. *Landwirthschaftliche Flora* (Wiegandt & Hempel, Berlin, 1866).
4. Ivanova, K. & Stoletova, E. The history of culture and intraspecific taxonomy of *Coriandrum sativum* L. *Russ. Eng. Bot. Genisel* **133**, 26–40 (1990).
5. Diederichsen, A. & Hammer, K. The infraspecific taxa of coriander (*Coriandrum sativum* L.). *Genet. Resour. Crop Evol.* **50**, 33–63 (2003).
6. Gholizadeh, A., Dehghani, H., Khodadadi, M. & Gulick, P. J. Genetic combining ability of coriander genotypes for agronomic and phytochemical traits in response to contrasting irrigation regimes. *PLoS One* **13**, e0199630 (2018).
7. Lal S, Mahatma MK, Saxena SN, Jangir CK, Aishwath OP, Bhardwaj V, Choudhary M. (2026) Influence of Drying Methods on Preservation of Colour and Quality Attributes in Celery (*Apium graveolens* L.) and Dill (Anethum graveolens L.) Leaves. Applied Food Research. 15:101694.
8. Clevenger, J. F. Apparatus for the determination of volatile oil. *J. Am. Pharm. Assoc.* **17**, 345–349 (1928). https://doi.org/10.1002/jps.3080170407
9. R Core Team. *R: A Language and Environment for Statistical Computing* (R Foundation for Statistical Computing, Vienna, Austria, 2025). Available at: https://www.r-project.org/
10. Burton, G. W. & DeVane, E. H. Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material. *Agron. J.* **45**, 478–481 (1953).
11. Johnson, H. W., Robinson, H. F. & Comstock, R. E. Estimates of genetic and environmental variability in soybean. *Agron. J.* **47**, 314–318 (1955).
12. Jha, M., Pandey, C. D., Arya, L., Yadav, P., Bajpai, A., Abhishek, G. J., Sureja, A. K., Singh, A. K., Archak, S., Verma, M. & Riar, A. Deciphering morpho-molecular diversity and population structure in ridge gourd (*Luffa acutangula* (L.) Roxb.) germplasm for breeding applications. *S. Afr. J. Bot.* **193**, 15–23 (2026).
13. 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. Assessing phenotypic, biochemical, and molecular diversity in coriander (*Coriandrum sativum* L.) germplasm. *Genet. Resour. Crop Evol.* **55**, 247–275 (2008).

14. Meena, R. S., Lal, G. & Meena, N. K. Estimates of genetic diversity for morphological and yield contributing traits in coriander genotypes. *Indian J. Hortic.* **75**, 446–450 (2018).
15. Lokesh, N. V., Hegde, N., Maheswarappa, H., Chittapur, R. B., Bhuvaneshwari, G. & Reddi, S. Studies on genetic variability, heritability and genetic advance in coriander (*Coriandrum sativum* L.) genotypes under the Northern Dry Zone of Karnataka. *Int. J. Adv. Biochem. Res.* **10**, 478–480 (2026).
16. Mortazavian, S. M. M., Zare, S., Mousavi, S. E. & Khodadadi, M. Agro-morphological variation and inter-simple sequence repeat (ISSR)-based genetic diversity in coriander (*Coriandrum sativum* L.) germplasm. *Genet. Resour. Crop Evol.* **73**, 203 (2026).
17. Sharma, M., Vasisth, P., Dhanasekaran, G., Meena, M. L., Limbalkar, O. M., Sahoo, B. C., Kumar, N., Nanjundan, J., Singh, R., Avtar, R. & Watts, A. Breeding *Brassica juncea* hybrids with higher seed weight and oil content: Defining criteria for selection of parents. *Heliyon* **10** (2024).
18. Coşkuner, Y. & Karababa, E. Physical properties of coriander seeds (*Coriandrum sativum* L.). *J. Food Eng.* **80**, 408–416 (2007).
19. Semwal, D. P., Dhariwal, O. P., Ahlawat, S. P., Pandey, A., Bhatt, K. C. & Meena, R. S. Post-harvest method for coriander (*Coriandrum sativum* L.) in Madhya Pradesh. *ICAR News* **25**, 22–23 (2019).
20. Saxena, S. N., Meena, R. S., Vishal, M. K., John, S., Sharma, L. K., Mishra, B. K. & Agarwal, D. Variation in essential oil constituents of coriander (*Coriandrum sativum* L.) germplasm across coriander-growing regions in India. *J. Essent. Oil Res.* **34**, 173–180 (2022).
21. Zeb, A. Coriander (*Coriandrum sativum*) oils. In *Essential Oils in Food Preservation, Flavor and Safety* 359–364 (Academic Press, 2016).
22. Rasheed, A., Ilyas, M., Khan, T. N., Mahmood, A., Riaz, U., Chattha, M. B., Al Kashgry, N. A. T., Binothman, N., Hassan, M. U., Wu, Z. & Qari, S. H. Study of genetic variability, heritability, and genetic advance for yield-related traits in tomato (*Solanum lycopersicum* Mill.). *Front. Genet.* **13**, 1030309 (2023).
23. Aastha, S. L., Gupta, P., Anish, A. & Phaugat, M. Genetic variability, heritability, correlation and path coefficient analysis in coriander (*Coriandrum sativum* L.). *Int. J. Adv. Biochem. Res.* **10** (Suppl. 5), 853–861 (2026).
24. Schmidt, P., Hartung, J., Bennewitz, J. & Piepho, H. P. Heritability in plant breeding on a genotype-difference basis. *Genetics* **212**, 991–1008 (2019).

25. Karavolias, N. G., Greenberg, A. J., Barrero, L. S., Maron, L. G., Shi, Y., Monteverde, E., Piñeros, M. A. & McCouch, S. R. Low additive genetic variation in a trait under selection in domesticated rice. *G3 (Bethesda)* **10**, 2435–2443 (2020).
26. Cholin, S. & Raghavendra, S. Assessment of genetic variability in tomato (*Solanum lycopersicum* L.) for yield and yield-attributing traits. *Pharm. Innov. J.* **10**, 399–403 (2021).
27. Peeters, J. P. & Martinelli, J. A. Hierarchical cluster analysis as a tool to manage variation in germplasm collections. *Theor. Appl. Genet.* **78**, 42–48 (1989).
28. Neyhart, J. L., Lorenz, A. J. & Smith, K. P. Multi-trait improvement by predicting genetic correlations in breeding crosses. *G3 (Bethesda)* **9**, 3153–3165 (2019).
29. Sharma, J. R. *Statistical and Biometrical Techniques in Plant Breeding* (New Age International, New Delhi, 2006).

Acknowledgment

The authors are highly thankful to director, ICAR-NBPGR, New Delhi for providing resources.

Funding Statement

The present work is funded by the institute fund (ICAR-NBPGR, New Delhi).

Authors contribution

DPS, PKS and OPD conceived and designed study. DPS, OPD, MJ, RSM, MKM contributed to data collection and curation. MJ conducted data analysis and interpretation. MJ original manuscript draft and edited final version. DPS, PKS, VB, DKY, RSM and MKM critically reviewed the manuscript. PKS, DPS and DKY provided financial support. All authors read and approved final version of manuscript prior to submission.

Declaration of Interests

The author(s) declare no competing interests.

Data availability

All data generated or analysed during this study are included in this article.