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RESEARCH ARTICLE

South Western Ghats of India: A niche of clove (*Syzygium aromaticum* (L.) Merr. & Perry) diversity

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Abstract

The survey conducted across major clove (*Syzygium aromaticum* (L.) Merr. & Perry) growing regions of the South Western Ghats of India, especially in the states of Kerala and Tamil Nadu, identified thirty accessions with distinct characteristics and superior yield. Clove accessions were characterized based on twenty-one qualitative and twelve quantitative traits. Significant variations were observed among fifteen qualitative characters with predominant traits including elliptical canopy shape, semi-erect branching pattern, leaf lamina and its apex, mid-bud forming season, clustering pattern of flower, bud size, fruit and seed shape. The dendrogram constructed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) grouped thirty accessions into five major clusters at a genetic similarity of 73%, with Accession 19 identified as unique. Principal component analysis of twelve quantitative characters revealed three component groups, explaining 70.85% of the total variance. The score plot generated from the principal component loading grouped the accessions into eighteen clusters. A minimal dataset comprising four characters, namely plant height, canopy spread in East-West direction, number of inflorescences per square meter and mature bud length, was generated. Observations on both qualitative traits and the minimum data set facilitated the identification of ideotypes. The geographical location was not found to influence genetic diversity significantly.

Keywords

clove; cluster analysis; principal component analysis; South Western Ghats; *Syzygium aromaticum*; minimum data set

Introduction

Clove (*Syzygium aromaticum* (L.) Merr. & Perry), native to the Moluccas islands of Indonesia (1-6), is a valuable spice crop with historical significance as a food preservative and medicine. Cloves are aromatic plants belonging to the Myrtaceae family (1). The inflorescence is a terminal, trichotomous panicle, corymbose, shortly pedunculate and branched from the base and was highly variable in the number of flowers (7). The dried, unopened flower buds commonly used in the cuisines impart a distinct hot taste. Clove exhibits high antioxidant activity, making it a potential free radical scavenger (8). The analysis of the dichloromethane extract of clove bud oil identified the presence of carbohydrates, terpenoids, glycosides, steroids, sterols, tannins and phenolic compounds, revealing a complex and diverse chemical profile. This rich composition indicates that clove bud oil may hold potential for various biological activities and applications (9). Studies on clove essential oil composition revealed that eugenol is the primary component (10-13).

Another study also investigated the chemical composition of clove bud essential oil using Gas Chromatography-Mass Spectrometry (GC-MS) and identified eugenol, β-caryophyllene, caryophyllene oxide, eugenol acetate, α-selinene, cadinene, 2-pinene, among others (14).

The global production of cloves is estimated at 1,81,788 Metric Tonnes (15), with Indonesia being the leading producer. The domestic production of clove in India is relatively modest with 1,183 MT per annum (16), and the cultivation is limited to parts of the Western Ghats of Tamil Nadu, Kerala, Karnataka and the Andaman and Nicobar Islands. Clove is cultivated in the hilly terrain of the Western Ghats at higher elevations in Tamil Nadu and Karnataka and in the red soils of the midlands of Kerala. The clove population in India originated from a limited number of trees introduced, which contributed to a narrow genetic base (17). Moreover, the self-pollinating nature of the crop limits the scope for variability (18).

Plant characterization at the morphological level is a potential tool for the identification of clove diversity (5). The morphological diversity among various clove types might offer vital information needed for crop improvement (1, 5, 19, 20). Research works on the identification of clove accessions based on morphological markers are limited in India. Three distinctly different morphological variants in cloves were located during the surveys conducted in Tamil Nadu (21) and identified promising variants that offered great potential for utilising their diversity for crop improvement programs. A previous study reported a few variants based on morphological and flower bud characteristics in a survey conducted in the Keeriparai and Maramalai regions of Kanyakumari in Tamil Nadu (22). In general, differences in the shape of trees, bearing habits, cropping season, and variation in yield, colour, shape and the dimension of clove in India have been recorded. Thus, there is a critical need to explore and characterise morphological diversity among clove accessions to identify potential traits for crop improvement programs. This study investigated the morphological distinctiveness and genetic divergence of existing clove accessions in the South Western Ghats of India, a significant clove-growing region in the country.

Materials and Methods

A survey was carried out in major clove-growing areas of southern Kerala and the Kanyakumari district of Tamil Nadu to identify the extent of genetic divergence in the existing populations of clove during 2017-18 (Fig.1). From a survey of 1800 plants, thirty accessions with superior yield and distinct morphological characters were selected for further study. The plant accessions selected were from productive local trees aged over 25 years. All the selected accessions were subjected to morphological characterisation based on tree, leaf, bud, flower, fruit and seed character. Twenty-one qualitative and twelve quantitative characters were taken (Table 1).

Descriptors froscrwm *Garcinia mangostana*, as published by the International Plant Genetic Resources Institute (23) and minimal descriptors for *Syzigium cumini* (24) and *Myristica fragrans* (25) were utilised for characterization of the accessions. Descriptors were recorded visually or according to standard colour charts of the Royal Horticulture Society. Bud size was measured during harvesting when they turned slightly pink and were categorized as small, medium and large. The dry yield was recorded from the harvest from November to March of each year

Table 1. Qualitative and quantitative characters observed among the selected clove accessions

Sl. No.	Qualitative characters	Quantitative characters
1	Canopy shape	Plant height (m)
2	Branching pattern	Girth at 45 cm (cm)
3	Colour of young leaves	Canopy spread in North-South (NS) direction (m)
4	Colour of mature leaves	Canopy spread in East-West (EW) direction (m)
5	Leaf lamina shape	Number of branches
6	Leaf apex shape	Number of inflorescences per m^2
7	Leaf arrangement	Number of flower buds per inflorescence
8	Bud forming season	Single bud fresh weight (mg)
9	Bud clustering habit	Single bud dry weight (mg)
10	Bud size	Mature bud length (mm)
11	Position of flower	Mature bud diameter (mm)
12	Petal colour	Dry bud yield (kg)
13	Sepal colour	
14	Colour of stigma	
15	Colour of peduncle	
16	Colour of hypanthium	
17	Fruit shape	
18	Mature fruit colour	
19	Ripe fruit colour	
20	Seed shape	
21	Seed colour	

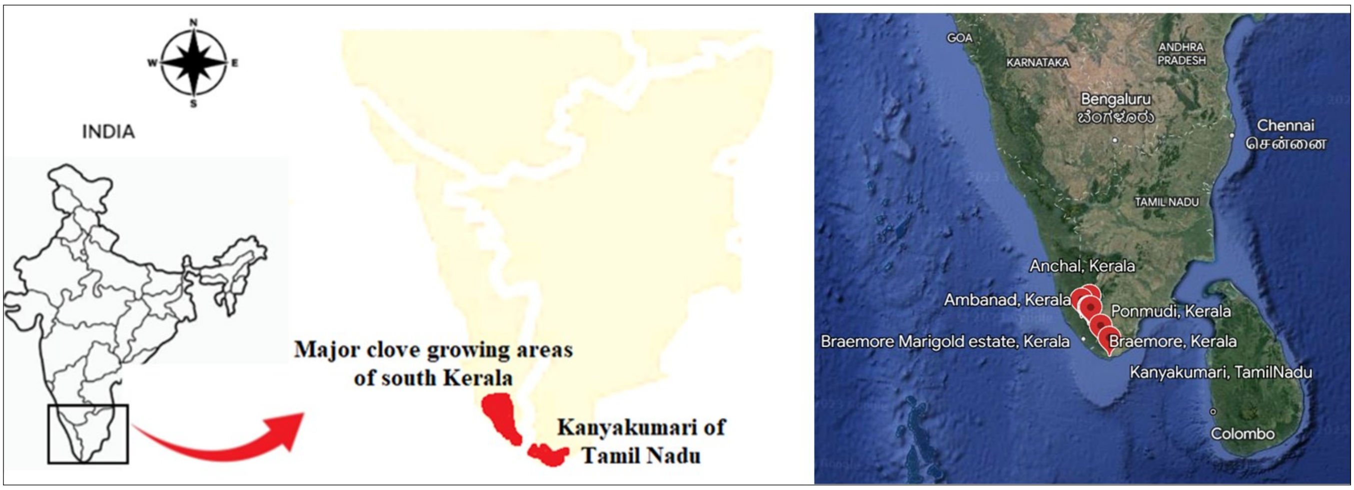

Fig. 1. Study locations.

and the pooled mean of data was collected and presented over five consecutive years, from 2016 to 2021.

The soil condition plays a significant role in the robust establishment of a plantation. Thus, soil parameters N, P, K, organic carbon and pH were recorded during the study period. The required nutrients were applied according to the package of practices recommended by Kerala Agricultural University based on the soil test data. For soil analysis, soil samples were collected from 1.8 to 2 m away from the base of the selected trees at a depth of 30 cm.

Qualitative data were utilized for cluster analysis using the NTSYS (Numerical Taxonomy System) package 2.2. Quantitative data were subjected to principal component analysis using KAU-GRAPES 1.0.0. Cluster analysis is done for quantitative data to validate clusters formed in the score plot by PCA analysis.

Results and Discussions

Morphological characterisation of clove accessions

The morphological characterisation of clove accessions revealed significant variation in several qualitative traits, while some traits exhibited uniformity across all accessions. Among the 21 qualitative characters observed, considerable variation was found in 15 of them. This indicated diverse morphological traits among the clove accessions (Fig. 2-5). However, uniformity occurred with leaf arrangement, the position of the flower, colour of the peduncle, mature fruit colour, ripe fruit colour and seed colour among all the accessions (Table 2). This uniformity suggests stability in these specific traits among different clove accessions. The canopy shapes observed in the accessions were elliptical, cylindrical, conical and pyramidal with elliptical shapes (Fig. 2A-D) being the most common (40%), followed by cylindrical, conical and pyramidal shapes. Canopy shapes associated with the branching pattern of a tree play a major role in capturing solar radiation (26). A majority of the clove accessions had semi-erect branching patterns (56.67%), followed by irregular (33.33%) and erect (10%). Mature leaves were predominantly dark green (66.67%), while young leaves showed variations in colour, including red-pink with a green tinge (90%), yellow-green (6.67%), or purple-red (3.33%). The predominant leaf shape was lanceolate with an acuminate apex

Fig. 2. Expressions for canopy shapes A. Elliptical B. Cylindrical C. Conical D. Pyramidical.

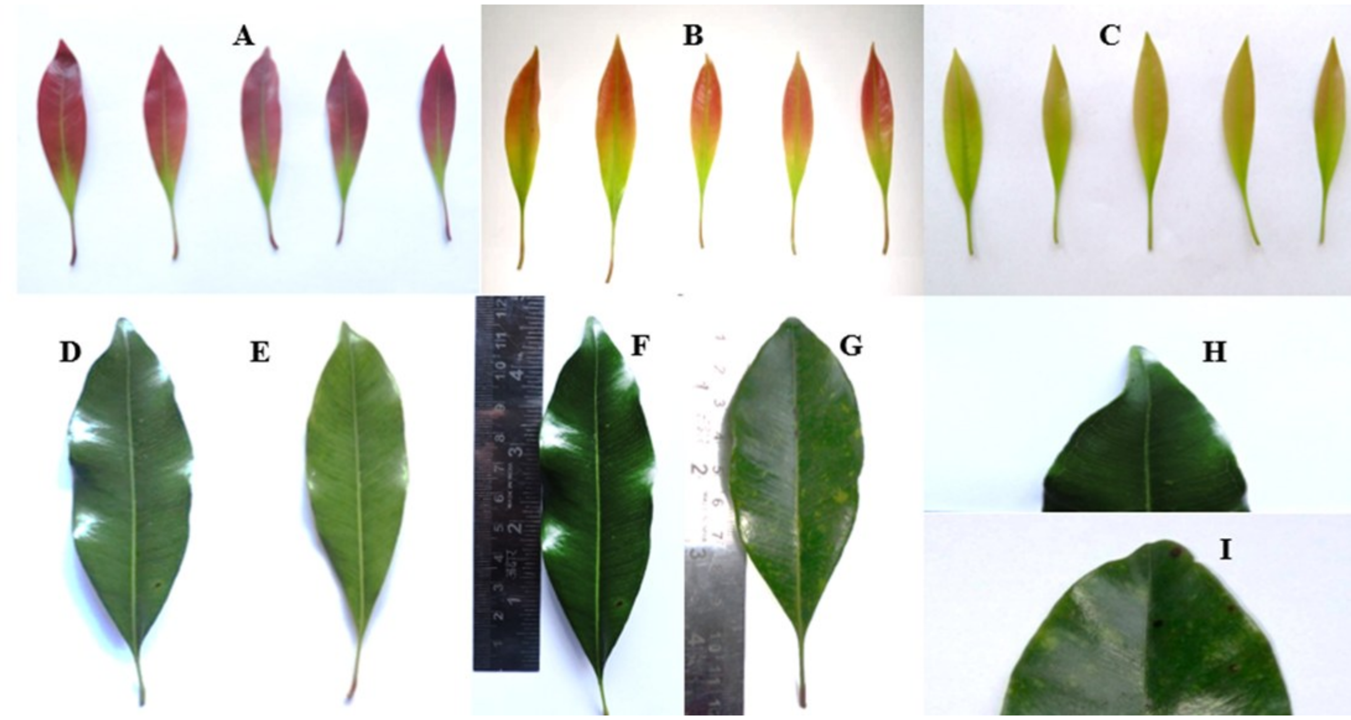

Fig. 3. Expressions for leaf characters A. Red pink with light green tinged young leaves (Code: 43 A, B) B. Purple red with light green young leaves (Code: N 57A) C. Yellow green with light green young leaves (Code: 149 A) D. Dark green mature leaf (Code: 134 A) E. Green mature leaf (Code: 130 A) F. Lanceolate shape G. Narrowly Elliptic shape H. Acuminate tip I. Acute tip.

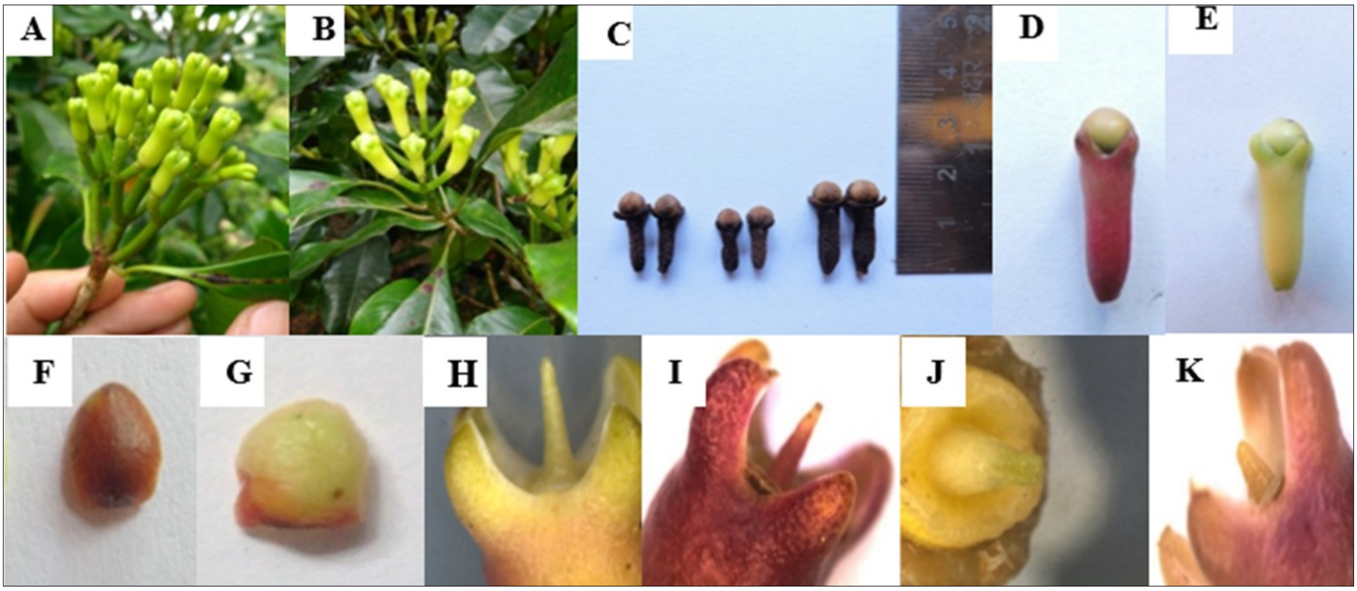

Fig. 4. Expressions for floral characters A. Combination of 1,2,3,4,5 flower buds per cluster B. Combination of 1,2,3 flower buds per cluster C. Expression of bud size (small, medium & large) D. Purple red hypanthium (59C) E. Light green hypanthium (N144A) F. Green brown (Code:152D) petal G. Light green Code (149D) petal H. Yellow green (Code:150A) sepal I. Dark purple red (Code:53B) sepal J. Medium yellow green (Code: 154B) K. Medium purple red (Code: 59D).

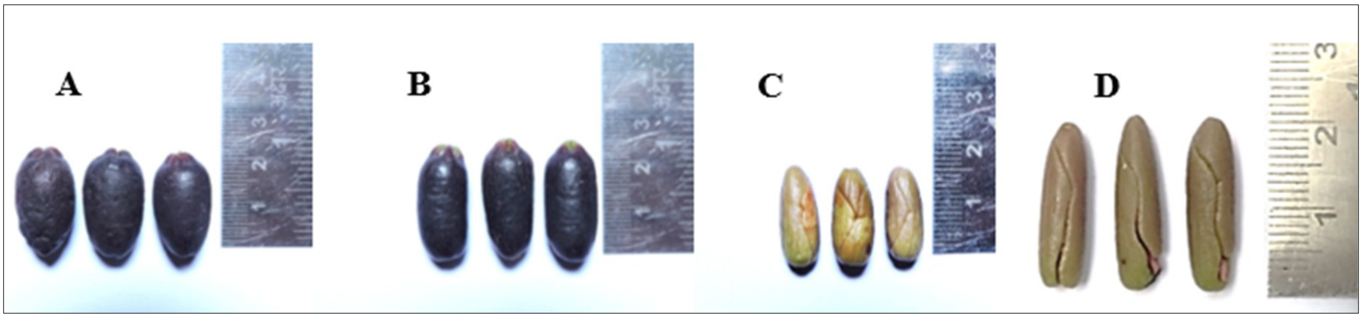

Fig. 5. Expressions for fruit and seed characters A. Elliptical fruit B. Oblong fruit C. Elliptical seed D. Oblong seed.

Table 2. Non variable characters observed among the selected clove accessions

Sl. No.	Characters	Expression
1	Leaf arrangement	Opposite
2	Position of flower	Terminal
3	Colour of peduncle	Green
4	Mature fruit colour	Dark purple red
5	Ripe fruit colour	Bluish black
6	Seed colour	Green brown

(86.67%) followed by narrowly elliptical lamina with an acute apex (13.33%) (Fig. 3A-I). The bud-forming seasons in clove were categorized as early, mid and late. The early bud-forming season in South Western Ghats started from September to October, mid -season from November to December and the late season from January to February. Mid-season bud forming was predominant (70%) among the accessions surveyed. A group of forest cloves with a large canopy was found to bloom early as reported (3).

Clove inflorescences were paniculate cymes and consisted groups of three flowers each. Most accessions exhibited a clustering habit with a combination of 1, 2, or 3 flower buds per cluster (86.67%) and only 13.33% had a combination of 1,2,3,4,5 flower buds per cluster, which was a rare character. The majority of the accessions in our survey had medium-sized buds. An earlier study had reported three different types of clove flower buds viz., small, medium and big (22). The predominant hypanthium colour was light green with a unique accession (Acc.19) exhibiting purple and red colour. The majority had a petal colour of light green and a few green brown. Two types of sepal colouration were observed in the selected genotypes mainly yellow green (96.67%) and dark purple-red (3.33%). Medium yellow-green was the most common colour of the stigma, followed by medium purple-red (Fig. 4A-K). The oblong shape was predominant for both fruit and seed with a few exhibiting elliptical shapes. Another study also reported oblong-shaped seeds in clove (7). The shape of the seed of clove was dependent on the fruit shape and oblong fruit produced oblong seeds and elliptical fruit produced elliptical seeds (Fig. 5A -D). Morphological variations among local clove accessions may be due to genetic and environmental factors and external environmental factors have a significant impact on the variation in phenotype among the genotypes (5,27-30). Genotypes respond differently to changes in environmental conditions; thus, environmental stability is essential in genotype selection and trait improvement (31). In this study, the soil characteristics across all study sites were consistent and any variations in soil nutrient levels were minor and resolved with the recommended practices. Also, the climatic conditions, including temperature and rainfall patterns, were uniform across all study sites, as they are all located in the Southern Western Ghats with the same climate. Standardized cultivation practices were followed for all accessions, ensuring that external environmental factors were controlled as much as possible. Thus, genetic variability may be the only reason among the different genotypes as the primary factor contributing to the observed variations (32).

Diversity analysis of clove accessions

The diversity analysis of clove accessions was done using Jaccard's similarity coefficient and cluster analysis. The similarity coefficient ranged between 0.41 to 1.00 indicating that the clove accessions of the present study had a low level of genetic variation. The maximum similarity value of 1.00 was observed between Acc. 5 and Acc. 6 and between Acc. 13, Acc. 17 and Acc. 25, whereas Acc.19 was quite distinct from other accessions, as indicated by the low value of the similarity coefficient (0.41). The Unweighted Pair Group Method with Arithmetic Mean (UPGMA) based dendrogram clustered the thirty accessions into five major clusters at 73% genetic similarity (Fig. 6). Cluster analysis grouping is more influenced by the number of similar characters (5, 33-40). Cluster I contained 20 accessions with similar qualitative characters related to leaf color, hypanthium, petal, sepal, fruits and seeds, indicating a lack of significant diversity in these traits. Cluster II contained four accessions, Acc. 8, Acc. 20, Acc. 27 and Acc. 15, which showed similar characters except canopy shape, branching pattern and mature leaf colour. Cluster III contained two accessions, Acc. 29 and Acc. 30 differing only in bud forming season and bud size. Acc. 29 was mid-season bearer producing medium-sized buds while Acc. 30 was an early bearer producing small buds. The cluster IV contained three accessions, Acc. 3, Acc. 21 and Acc. 23, with similar characteristics except for canopy shape, branching pattern and bud-forming season. Cluster V had only one accession, Acc. 19, identified as a unique accession having a young leaf with purple red colour with a light green tinge, the dark purple red hypanthium, green brown petal, dark purple red sepal and medium yellow green stigma.

Principal Component Analysis (PCA) of clove accessions

Principal Component Analysis was conducted to reduce the dimensionality of the dataset and identify the principal components that explain the most variance. A multivariate analysis of twelve quantitative characters, including dry bud yield of selected clove accessions, was done (Table 3). The analysis of the data on the pooled mean of dry bud yield recorded for five years of selected clove accessions is presented in Table 4. Three principal component groups were selected based on Eigen values greater than 1 (Table 5, Fig. 7), indicating that these components explain more variability than a single

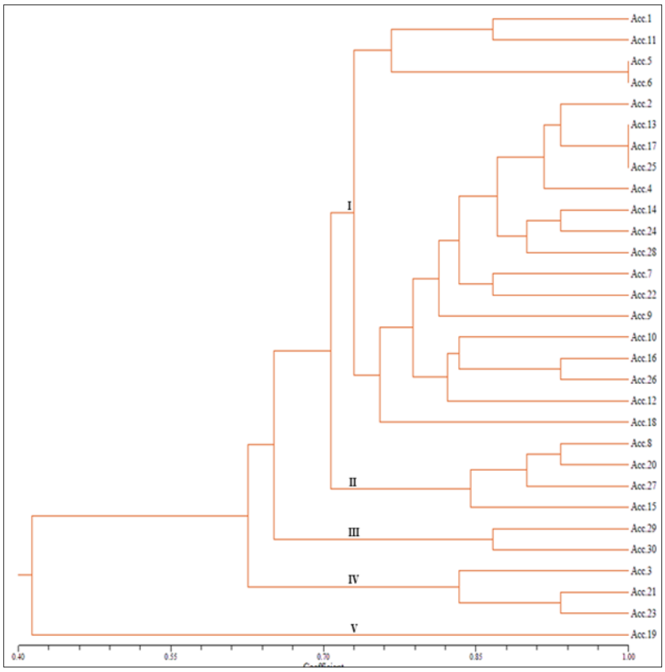

Fig. 6. Dendrogram constructed by UPGMA clustering method based on qualitative morphological traits of thirty clove accessions.

Table 3. Quantitative characterization of selected clove accessions

Accessions ID	Plant height (m)	Girth at 45 cm	Canopy spread		No. of branches	No. of inflorescence/ m²	No. of flower buds/ inflorescence	Single bud weight (fresh) (mg)	Single bud weight (dry) (mg)	Mature bud length (mm)	Mature bud diameter (mm)
			NS	EW							
Acc.1	9.20	118.5	4.20	3.75	48	114	13.47	327.05	114	19.06	5.94
Acc.2	9.7	67.33	4.55	4.1	40	71	9.42	243.6	73	15.85	5.2
Acc.3	13.6	138.1	4.60	4.35	44	73.75	8.47	400.37	128.5	17.73	6.41
Acc.4	6.45	86.2	4.95	5.10	38	79.5	9.31	310.59	103	18.56	5.79
Acc.5	6.55	85.4	5.15	4.30	46	70.25	15.05	367.47	101.5	18.76	5.83
Acc.6	7.35	96	4.80	4.75	39	97.5	18.21	334.2	91.6	18.04	5.83
Acc.7	14.95	99.8	7.42	7.05	47	43.5	10.47	324.48	110	18.73	5.55
Acc.8	9.7	90.1	5.90	6.20	38	51	10.42	314.43	104	18.53	5.1
Acc.9	10.81	114	6.1	5.9	46	75.25	9.	328.4	94.8	17.27	6.04
Acc.10	8.16	103.5	5.5	4.28	43	71.5	10.48	253.81	81.5	17.81	6.47
Acc.11	9.83	122	4.06	3.77	39	86	14.52	276.25	83.4	16.73	5.49
Acc.12	7.36	108.3	4.4	3.65	42	94.75	10.74	324.16	107.7	18.54	5.81
Acc.13	12.1	134	6.1	7.52	48	73.25	10.62	358.52	108.8	18.70	5.84
Acc.14	9.15	110.6	5.1	4.42	37	79	9.10	317.75	102.3	18.56	5.78
Acc.15	7.49	73.2	4.9	4.63	32	74.75	9.44	354.22	98.5	17.93	5.53
Acc.16	9.62	120.2	4.6	4.07	52	68.5	7.25	337.18	78.6	16.26	5.83
Acc.17	8.7	102.4	5.4	4.51	45	73.25	11.81	274.3	112	18.70	5.54
Acc.18	7.68	97.4	4.83	4.62	38	75	10.36	341.84	98.2	17.65	5.85
Acc.19	5.6	53	3.25	2.90	31	48.5	7.47	237.04	76	15.99	4.9
Acc.20	7.35	76.55	4.23	3.65	49	114.25	9.31	305.58	81	18.38	5.32
Acc.21	6.85	102.5	6.15	7.00	41	87.75	7.1	358.3	99	18.03	5.2
Acc.22	6.50	85.9	4.30	4.00	38	92.5	9	253.96	75.5	15.26	5.18
Acc.23	5.15	68.2	3.45	3.55	41	99.5	9.57	337.59	89.5	18.18	5.63
Acc.24	5.30	69	4.35	3.90	48	113	10.47	326.32	92.5	17.89	5.39
Acc.25	7.85	82.9	5.05	5.8	43	79.5	12.1	332.35	94	17.97	5.9
Acc.26	10.30	92.5	5.0	5.8	44	69	7.47	348.5	108	17.94	5.94
Acc.27	5.9	65.8	4.25	4.05	36	100.5	12	330.5	94.5	18.77	5.27
Acc.28	15.25	97.3	4.10	4.30	33	85	10.94	281	80	16.25	5.18
Acc.29	7.15	55.3	3.15	3.40	31	24.75	6.68	274.53	82	15.68	5.19
Acc.30	6.80	44.1	3.1	2.95	26	36.25	6.05	216.27	66.5	14.94	4.92

Table 4. Dry bud yield of selected clove accessions

Accessions ID	Dry bud yield per tree (kg / tree)					
	2016-17	2017-18	2018-19	2019-20	2020-21	Pooled mean
Acc.1	7.3	6.7	7.5	6.54	5.1	6.63
Acc.2	7.89	3.1	2.64	4.97	3.89	4.50
Acc.3	7.12	3.1	3.32	5.98	3.98	4.7
Acc.4	3.89	7.06	3.99	2.9	5.12	4.59
Acc.5	5.46	6.12	8.04	5.45	5.97	6.21
Acc.6	6.12	4.87	6.89	5	5.87	5.75
Acc.7	8.98	3.1	7.3	6.7	3.1	5.84
Acc.8	6.2	3.5	5	3.8	5.43	4.79
Acc.9	6.93	3.2	4.9	4.2	3.0	4.45
Acc.10	2.8	4.6	3.8	2.6	4.1	3.64
Acc.11	4.7	3.6	4.9	6.8	4.03	4.81
Acc.12	2.7	5.6	8.07	2.9	6.05	5.06
Acc.13	3.2	6.01	3.5	3.8	6.5	4.60
Acc.14	6.9	2.1	6.5	4.8	4.2	4.90
Acc.15	3.2	3.7	5.02	2.1	6.23	4.05
Acc.16	7.12	2.4	4.1	3.2	4.2	4.20
Acc.17	3.9	7.3	3.01	2.6	5.1	5.28
Acc.18	1.9	8.01	3.9	4.78	6.01	4.92
Acc.19	3.02	1.9	2.9	2.1	3.3	2.64
Acc.20	6.7	4.8	5.1	7.25	5.09	5.79
Acc.21	3.0	5.5	5.9	3.1	4.2	4.34
Acc.22	6.12	8.2	2.9	3.9	2.6	4.74
Acc.23	3.5	5.3	3.6	4.3	3.9	4.12
Acc.24	4.7	4.5	3.4	4.8	2.7	4.02
Acc.25	4.5	3.2	3.2	3.5	2.4	3.36
Acc.26	6.02	4.6	5.2	5.7	3.6	5.02
Acc.27	6.89	5.46	2.6	4.5	3.7	5.02
Acc.28	2.01	1.34	2.1	1.23	1.0	1.54
Acc.29	3.8	2.6	2.5	2.9	5.8	3.52
Acc.30	1.66	3.9	5.76	1.03	5.89	3.65

Table 5. Eigen values, percentage of variance and cumulative percentage of variance of Principal Components

Principal component	Eigen value	Percentage of variance	Cumulative percentage of variance
PC1	5.371	44.755	44.755
PC2	2.041	17.01	61.765
PC3	1.09	9.085	70.85
PC4	0.861	7.172	78.022
PC5	0.703	5.858	83.88
PC6	0.626	5.216	89.096
PC7	0.472	3.932	93.028
PC8	0.295	2.462	95.489
PC9	0.252	2.098	97.587
PC10	0.145	1.211	98.799
PC11	0.082	0.682	99.481
PC12	0.062	0.519	100

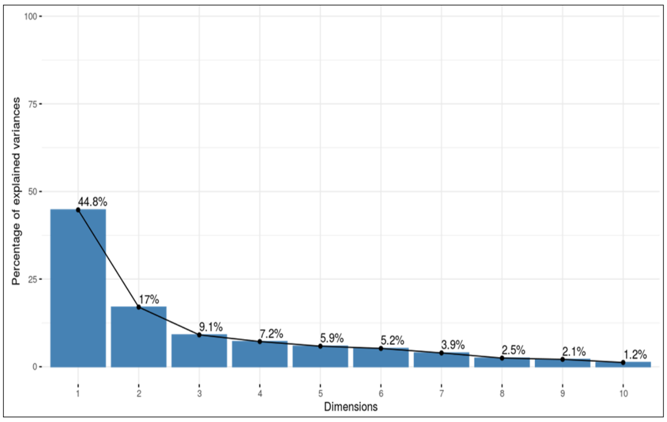

Fig. 7. Scree plot of eigen values.

variable. The three principal components collectively explained 70.85% of the total variance in the dataset. This suggests that the selected principal components effectively summarize the variability in the twelve quantitative characters.

Principal component analysis can address more relevant variables by grouping suitable traits into different components (41). Principal component 1 contributed the most to the variance (44.75%) and was positively influenced by variables such as single bud dry weight, mature bud length, single bud fresh weight, girth at 45cm and canopy spread in the North-South (NS) direction. Principal component 2 contributed 17.01% of the variance and was primarily influenced by the number of inflorescences per m^2, plant height and canopy spread in the East-West (EW) direction. Principal component 3 contributed to the remaining variance and was positively associated with girth at 45cm height, mature bud diameter, and plant height. Based on the data from principal component loadings (Table 6), a score plot and biplot were formed to better understand the results. The score plot developed from PC1 and PC2 revealed relationships between the thirty clove accessions based on their values for the variables (Fig. 8). Eighteen clusters were formed, indicating similarities among certain accessions regarding their characteristics. Samples to the right in the score plot have high values for variables.

The biplot generated from PC1 and PC2 illustrated the variables that contributed the most to the variability in the dataset. Variables such as the number of inflorescences per m^2, mature bud length, single bud fresh and dry weight, girth at 45cm, canopy spread (NS and EW) and plant height were identified as significant contributors to variability (Fig. 9).

Table 6. Component loadings and percentage contribution of each variable to three principal components

Variables	Characters	Component loadings			Percentage contribution of variables		
		PC1	PC2	PC3	PC1	PC2	PC3
X1	Plant height (m)	-0.178	**0.464**	**0.385**	3.169	**21.553**	**14.794**
X2	Girth at 45 (cm)	**-0.332**	0.136	**0.47**	**11.047**	1.842	**22.071**
X3	Canopy spread (NS)	**-0.318**	0.314	-0.272	**10.14**	9.849	7.402
X4	Canopy spread (EW)	-0.278	**0.384**	-0.341	7.713	**14.775**	11.623
X5	Number of branches	-0.308	-0.098	0.205	10.04	0.958	4.185
X6	Number of inflorescence (m^2)	-0.147	**-0.508**	0.193	2.147	**25.778**	3.706
X7	Number of flower buds per inflorescence	-0.184	-0.35	0.07	3.394	12.245	0.494
X8	Single bud weight fresh (mg)	**-0.334**	-0.052	-0.109	**11.18**	0.275	1.198
X9	Single bud weight dry (mg)	**-0.358**	0.033	-0.161	**12.789**	0.107	2.586
X10	Mature bud length (mm)	**-0.348**	-0.2	-0.336	**12.123**	4.001	11.292
X11	Mature bud diameter (mm)	-0.303	-0.04	**0.396**	9.186	0.159	**15.717**
X12	dry bud yield (kg / tree)	-0.264	-0.291	-0.222	6.975	8.457	4.933

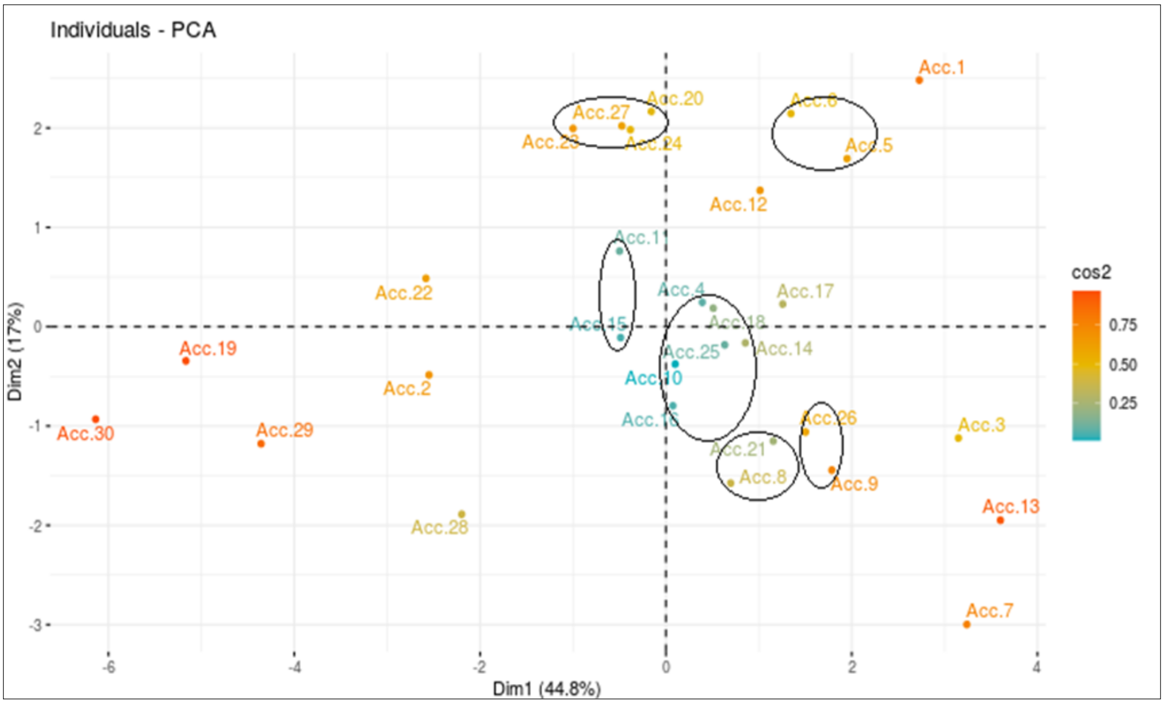

Fig. 8. Clustering of accessions based on score plot.

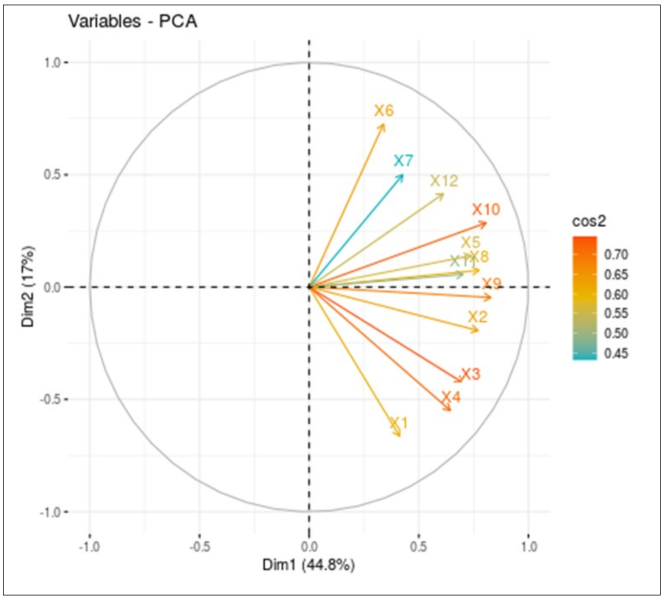

Fig. 9. Biplot generated based on first two principal components.

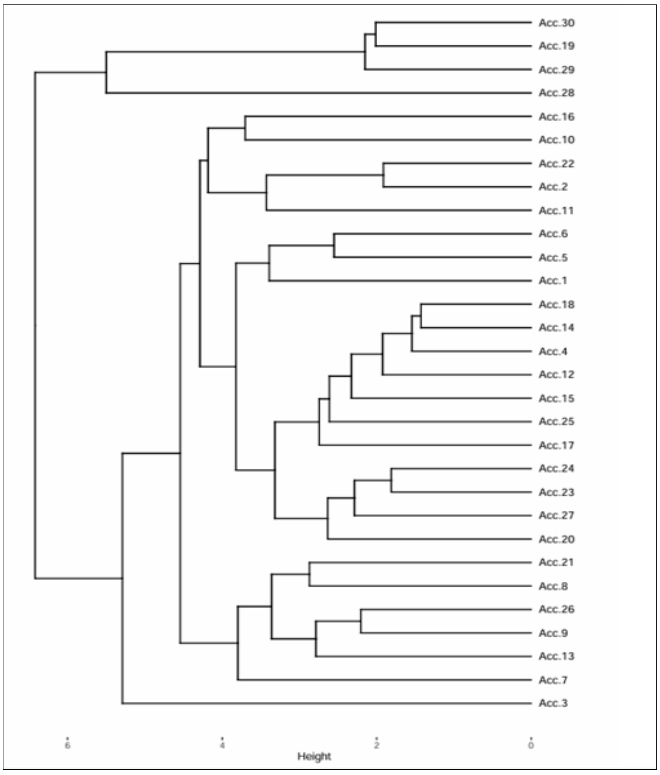

Fig. 10. Clustering based on quantitative traits.

Hierarchical cluster analysis based on quantitative traits

A cluster analysis used quantitative data (Fig. 10) to compare the clusters formed through PCA. The PCA score plot represents the distribution of accessions in a 2D space based on the first two principal components (Dim1 and Dim2), which capture the maximum variance in the data. Accessions closer together in the plot are more similar. Hierarchical cluster analysis grouped genotypes based on their shared characteristics, ensuring that those with similar attributes were categorized within the same cluster (42). The clustering from the dendrogram and PCA score plot is mainly consistent, indicating that both methods capture similar relationships between the accessions. Clusters identified in the PCA are supported by the hierarchical relationships shown in the dendrogram. In both the dendrogram and PCA, accessions such as Acc.27, Acc.20, Acc.24 and Acc. 23 seem to cluster together. In the PCA score plot, they are very close in the upper central area, forming a tight cluster, corresponding to them being part of the same branch in the dendrogram. Accessions 9 and 26 are grouped closely in the PCA plot, indicated by their position in the lower right. The dendrogram also reflects this, as these accessions are part of a cluster before merging. Acc. 5 and Acc. 6 appear in the upper right quadrant of the PCA plot, forming a small cluster. The dendrogram shows them grouped as well, validating the clustering consistency. In some cases, such as with Acc.22 and Acc.2, the PCA shows them relatively close, but they may be more distinct in the dendrogram, highlighting different aspects of the data captured by the two methods.

Development of minimum data set (MDS) indicators for clove

Minimum data set (MDS) indicators for clove plants were selected based on certain quantitative characteristics. Based on the Principal Component Analysis (PCA)/correlation coefficient analysis approach, eight variables with the highest percentage contribution in the principal component (PC) groups PC1, PC2 and PC3 were considered. Only highly weighted factors within each principal component (PC) were retained to develop the minimum data set (43). The characters were X1- plant height, X2- girth at 45 cm, X3- canopy spread (NS), X4- canopy spread (EW), X6-number of inflorescences, X8- single bud weight fresh, X9- single bud weight dry and X10- mature bud length. A correlation matrix for the twelve quantitative characters was worked out (Table 7). When the correlation value was less than 0.6, both the variables were selected whereas when the correlation value was more than 0.6, the highly weighted variables based on the percentage contribution of variables on principal components PC1, PC2 and PC3 were selected. From the eleven quantitative characters contributing to yield, four characters namely, plant height, canopy spread (EW), number of inflorescences per $m^{2,}$ and mature bud length were selected as an MDS for clove. The quantitative data showed that Acc. 1, Acc. 5, Acc. 6, Acc. 7 and Acc. 20 are the high-yielding ones wherein Acc.1 had the highest value for single bud dry weight and mature bud length. Acc. 5 had the highest value for single bud fresh weight, Acc. 6 had the highest number of flower buds/ inflorescence, Acc. 7 had the highest value for canopy spread (NS) and Acc. 20 had the highest value for the number of inflorescences per m^2.

Developing ideotype in clove accessions

The process of developing an ideotype for clove accessions involves identifying desirable traits and characteristics in clove trees. The first step is to identify a clove tree with a desirable set of qualitative (observable traits) and quantitative (measurable characteristics) traits. Quantitative characteristics are mapped accordingly. Minimum data set characters are the essential traits or characteristics that need to be observed and recorded during the bearing season. The minimum data set characters that can be taken into consideration were set as plant height (m), canopy spread (EW), number of inflorescences per $m^{2,}$ and mature bud length (mm). Thus, observing the qualitative characters and the minimum data set characters in the bearing season, one can optimally sort out the ideotype clove accessions. In this study, we have not explicitly selected a single accession as the ideotype for cloves. However, accession 7 can be considered as ideotypes with high plant height (14.95 m), canopy spread in EW direction (7.05 m) and mature bud length of 18.73 mm, but the number of inflorescences per m^2 is less.

Conclusion

Clove is grown mainly in the Southern Western Ghats, and the present study identified thirty accessions with superior yield and distinct characteristics, offering valuable information for future crop improvement programs. Clove accessions characterized based on twenty-one qualitative and twelve quantitative traits grouped the accessions into five major clusters based on genetic similarity. PCA identified three principal component groups explaining 70.85% of the total variance. A minimal dataset comprising four characters was developed. Ideotypes for clove accessions were identified based on qualitative traits and the minimum dataset. The study showed limited genetic variation among the clove accessions studied, with some distinct accessions and clusters showing differences in specific traits. However, molecular analysis will provide additional insights into the genetic basis of these traits. Future work should focus on genotyping the accessions using molecular markers, which will enable the identification of markers associated with desirable

Table 7. Correlation matrix of the quantitative characters

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
X1	1	0.602***	0.464**	0.456*	0.238	-0.224	0.018	0.178	0.334	0.036	0.257	-0.044
X2	0.602***	1	0.517**	0.438*	0.581***	0.23	0.267	0.494**	0.582***	0.378*	0.667***	0.318
X3	0.464**	0.517**	1	0.881***	0.494**	-0.072	0.166	0.419*	0.523**	0.539**	0.361*	0.345
X4	0.456*	0.438*	0.881***	1	0.354	-0.117	0.05	0.481**	0.488**	0.441*	0.228	0.165
X5	0.238	0.581***	0.494**	0.354	1	0.42*	0.238	0.496**	0.419*	0.507**	0.55**	0.517**
X6	-0.224	0.23	-0.072	-0.117	0.42*	1	0.44*	0.311	0.14	0.415*	0.212	0.309
X7	0.018	0.267	0.166	0.05	0.238	0.44*	1	0.208	0.221	0.447*	0.278	0.446*
X8	0.178	0.494**	0.419*	0.481**	0.496**	0.311	0.208	1	0.733***	0.653***	0.544**	0.389*
X9	0.334	0.582***	0.523**	0.488**	0.419*	0.14	0.221	0.733***	1	0.772***	0.546**	0.508**
X10	0.036	0.378*	0.539**	0.441*	0.507**	0.415*	0.447*	0.653***	0.772***	1	0.469**	0.585***
X11	0.257	0.667***	0.361*	0.228	0.55**	0.212	0.278	0.544**	0.546**	0.469**	1	0.308
X12	-0.044	0.318	0.345	0.165	0.517**	0.309	0.446*	0.389*	0.508**	0.585***	0.308	1

traits. This molecular information can then be used to develop breeding strategies to improve clove varieties. Additionally, further field trials and replications across different environments will be necessary to validate the performance of the identified ideotypes under various conditions.

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Authors' contributions

SGS- planned the experiment and carried out the experiment

AM, RJB, AT- carried out the experiment

RP and NJ- wrote the manuscript

Compliance with ethical standards

Conflict of interest: The authors have no conflict of interest.

Ethical issues: None

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