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Genetic diversity and conservation of cardamom (*Elettaria cardamomum* Maton.) in India

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Summary
Genetic diversity and conservation of cardamom (*Elettaria cardamomum* Maton.) in India
India is recognized as a rich source of genetic diversity for cardamom. Today, the conservation and use of the genetic resources of cardamom constitute one of the priority programmes adopted by the Indian Institute of Spices Research. Numerous exploration missions have been carried out leading to the collection of about 310 accessions. The collected germplasm accessions are conserved in *ex situ* and *in vitro* germplasm repositories (short and long term). Accessions with distinct morphological marker characters, such as compound panicle types, terminal panicle bearing, narrow leaf types, pink pseudostem types, dark green and bold capsules and high-yielding biotic-stress tolerant types, are conserved in the repository. Three-hundred-and-ten accessions of cardamom germplasm were evaluated for 16 characters. Nine of the characters showed high variability. Following non-hierarchical Euclidean cluster analysis all the genotypes were grouped into three clusters with a variable number of genotypes. Accessions of three cultivar groups often grouped together in the same cluster, suggesting some degree of ancestry between the three groups.

Key words: cardamom, cluster analysis, *Elettaria cardamomum*, disease resistance, germplasm characterization

Résumé
Diversité génétique et conservation de la cardamome (*Elettaria cardamomum* Maton.) en Inde
L'Inde est considérée comme une source très importante de diversité génétique de la cardamome. Actuellement, la conservation et l'utilisation des ressources génétiques de cardamome sont au cœur d'un des programmes prioritaires adoptés par l'Institut indien de recherche sur les épices (*Indian Institute of Spices Research*). De nombreuses missions d'exploration ont été entreprises et ont permis la collecte d'environ 310 échantillons. Les accessions de matériel génétique collectées sont conservées dans des banques de gènes *ex situ* et des systèmes de conservation *in vitro* (à court et à long terme). Les accessions présentant des marqueurs morphologiques distinctifs tels que panicule composé, panicules terminales, feuilles étroites, stipe rose, capsules vert sombre et très grandes, résistance aux stress biotiques associée à une productivité élevée, sont conservées dans les banques de gènes. Trois cent dix accessions de matériel génétique de cardamome ont été évaluées sur la base de 16 caractères. Neuf des caractères présentent une variabilité élevée. En utilisant une analyse de données par groupes euclidienne non hiérarchique, tous les génotypes ont été rassemblés en trois groupes constitués d'un nombre variable de génotypes. Les accessions de trois groupes de cultivars sont souvent présentes ensemble dans le même groupe, suggérant l'existence d'un ancêtre commun à ces trois groupes.

Resumen
Diversidad genética y conservación del cardamomo (*Elettaria cardamomum* Maton.) en la India
La India ha sido reconocida como una abundante fuente de diversidad genética del cardamomo. En la actualidad la conservación y empleo de los recursos genéticos del cardamomo constituye uno de los programas prioritarios del Instituto Indio de Investigaciones sobre las Especias. Se han llevado a cabo numerosas misiones de exploración que condujeron a la recolección de unas 310 accesiones. Las accesiones recogidas se conservan en campos de germoplasma *ex situ* y en repositorios *in vitro* (de corto y largo plazo). En los repositorios se conservan accesiones con diferentes caracteres morfológicos marcadores, por ejemplo tipos de panícula compuesta, tipos portadores de panícula terminal, tipos de hoja estrecha, tipos de seudotallo rosado, tipos de cápsula gruesa verde oscuro y tipos de alto rendimiento tolerantes al estrés biótico. Se evaluaron 16 caracteres para las trescientas diez accesiones de germoplasma de cardamomo. Nueve de estos caracteres mostraron una gran variabilidad. Aplicando baterías de análisis euclidianos no jerárquicos, todos los genotipos quedaron agruparon en tres aglomerados, cada uno con un número variable de genotipos. A menudo, las accesiones de tres grupos de cultivares se agrupaban juntas en el mismo aglomerado, lo que sugiere la existencia de cierto grado de linaje común a los tres grupos.

Introduction
Cardamom, 'Queen of Spices', is the dried fruit of the perennial rhizomatous herb, *Elettaria cardamomum* Maton, which belongs to the family Zingiberaceae. It is one of the most ancient and valuable spice crops. This crop is indigenous to South India and Sri Lanka (Purseglove 1981). The natural habitat of *E. cardamomum* is in the evergreen rainforests of the Western Ghats of South India at altitudes between 600 and 1500 masl. Cardamom is generally cross-pollinated and propagated by seedlings and suckers; occasionally selfing also occurs. Considerable variation is encountered in seedling progenies of cardamom (Padmini et al. 2000).

The present cardamom-growing area in India (Figure 1) is concentrated mainly in those regions that are the natural habitat of the species: between 8°30′ and 14°30′N latitude and longitude 75–70′E. This area is an elongated tract from north to south extending over 2000 km, from Sirsi of Karnataka to Thirunelvelli of Tamil Nadu. East to west, it is a narrow belt of land distributed over the Western Ghats (Madhusoodanan et al. 1994). The important areas of cultivation are:

- Kerala State—Nelliampathy, Wynad and Idukki in the Travancore Cochin (Malabar) region;
- Karnataka—Uttar Kannada, Shimoga, Hassan and Chickmagalur, and the hills of Kodagu (Coorg);
- Tamil Nadu—Northern and Southern foot hills of Nilgiris, Madurai, Salem and Tirunelveli, Anamalai and parts of Coimbatore districts.

Table 1. Characteristic features of cardamom cultivar groups

Characters	Malabar	Mysore	Vazhukka (natural cross between Malabar and Mysore)
Adaptability	Lower altitudes 600–900 m asl	Higher altitudes 900–1200 m asl	Wide range
Areas of cultivation	Karnataka	Kerala and parts of Tamil Nadu	Kerala
Plant growth	Medium	Robust	Robust
Panicles	Prostrate (Figure a)	Erect (Figure 2b)	Semi-erect (Figure 2c)
Capsules	Round to oblong	Round or oblong	Bold, elongated
Leaf petiole	Short	Long	Long
Capsule colour at maturity	Pale/golden/yellow	Green	Green

Elettaria is a small genus with 3–4 species in East and Southeast Asia. Two botanical varieties were distinguished by earlier researchers, one for the wild taxon and one for the cultivated forms (Wardini and Thomas 1999). *E. cardamomum* var. *major* Thwaites consists of wild cardamoms that are particularly common in Sri Lanka and Southern India. *E. cardamomum* var. *cardamomum* (syn var. *minor* Watt. var. *minuscula* Burkill) consists of the cultivated cardamoms, which however could better be classified and named as cultivar groups. Usually, the cultivars are grouped as 'Malabar' (prostrate panicle—see Figure 2(a)), 'Mysore' (erect panicle—see Figure 2(b)) and 'Vazhukka' (semi erect panicle—see Figure 2(c)). The characteristic features of these cultivar groups are given in Table 1.

Six research organizations are at present engaged in research on improvement of cardamom. Regular surveys for germplasm collection are being undertaken by these institutes for collecting the available natural variants and are conserved in respective repositories (see Appendix 1 [online]). Detailed documentation of cardamom genetic resources were reported by Mayne (1951), Abraham and Tulasidas (1958) and Sudharshan et al. (1991).

It is essential that sufficient variability for economic traits exists in the germplasm for profitable utilization in breeding programmes. The genetic diversity of selected plants is not always based on factors such as geographical diversity or place of release (Bhat 1970). Hence, characterization of genetic divergence for selection of suitable and diverse genotypes should be based on sound statistical procedures, such as D^2 statistics and nonhierarchical Euclidean cluster analysis (Mehalanobis 1936; Spark 1973). These procedures characterize genetic divergence using the criterion of similarity or dissimilarity based on the aggregate effect of a number of economically important characters. In view of these, cardamom genotypes were evaluated in this study to determine the magnitude of variability in the population for yield and yield components, to determine the grouping pattern of genotypes in different clusters.

Materials and methods

The experimental material consisted of 310 accessions collected from cardamom-growing regions of South India such as Waynad, Anamalais, Manjoli Hills, Nelliampathy, Lower Pulneys, Meghamalai and Cardamom Hills. These accessions were evaluated at the Indian Institute of Spices Research, Cardamom Research Centre, which is located in a heavy rainfall region (2500–3500 mm per annum) at an elevation of 1000 m asl. The trial was planted with a spacing of 2 m × 2 m with 10 experimental plants per accession. Recommended crop-growing practices were followed. Data on 16 characters were recorded during the 2001 crop season from 10 plants and the average was taken for analysis. The mean and coefficient of variation were calculated as per the standard statistical procedures. A nonhierarchical Euclidean cluster analysis (Spark 1973) was conducted to estimate the intra- and inter-cluster distances and to group the genotypes into different clusters.

Results and discussion

Natural populations of cardamom, being cross-pollinated, exhibit a great degree of variability for quantitative and qualitative characters. Genetic variation exists for precocity of bearing, panicle emergence, length, position and branching of panicles, number of panicles per tiller, size of tiller, number of capsules per raceme, size, shape and colour of mature capsules, essential oil content and resistance to disease. The estimates of mean and coefficient of variation are given in Table 2.

Variability in 'Malabar' type

The highest variability was recorded for yield per plant (CV 92.80%) followed by number of panicles per plant (78.76) and capsule width (69.77). Seeds per capsule and leaf length showed low variability of 9.69 and 15.74, respectively. The high variability for yield per plant is apparent from the stand of the crop where absolutely non-yielding to high yielding (3223.00 g) types were observed. The maximum number of panicles per plant (139.33) and maximum panicle length (90.12 cm) were recorded in Acc.75 and Acc.52, respectively. In cardamom usually two panicles per tiller emerge at a time. The variation for this character was observed in a few accessions where there were three or four panicles per

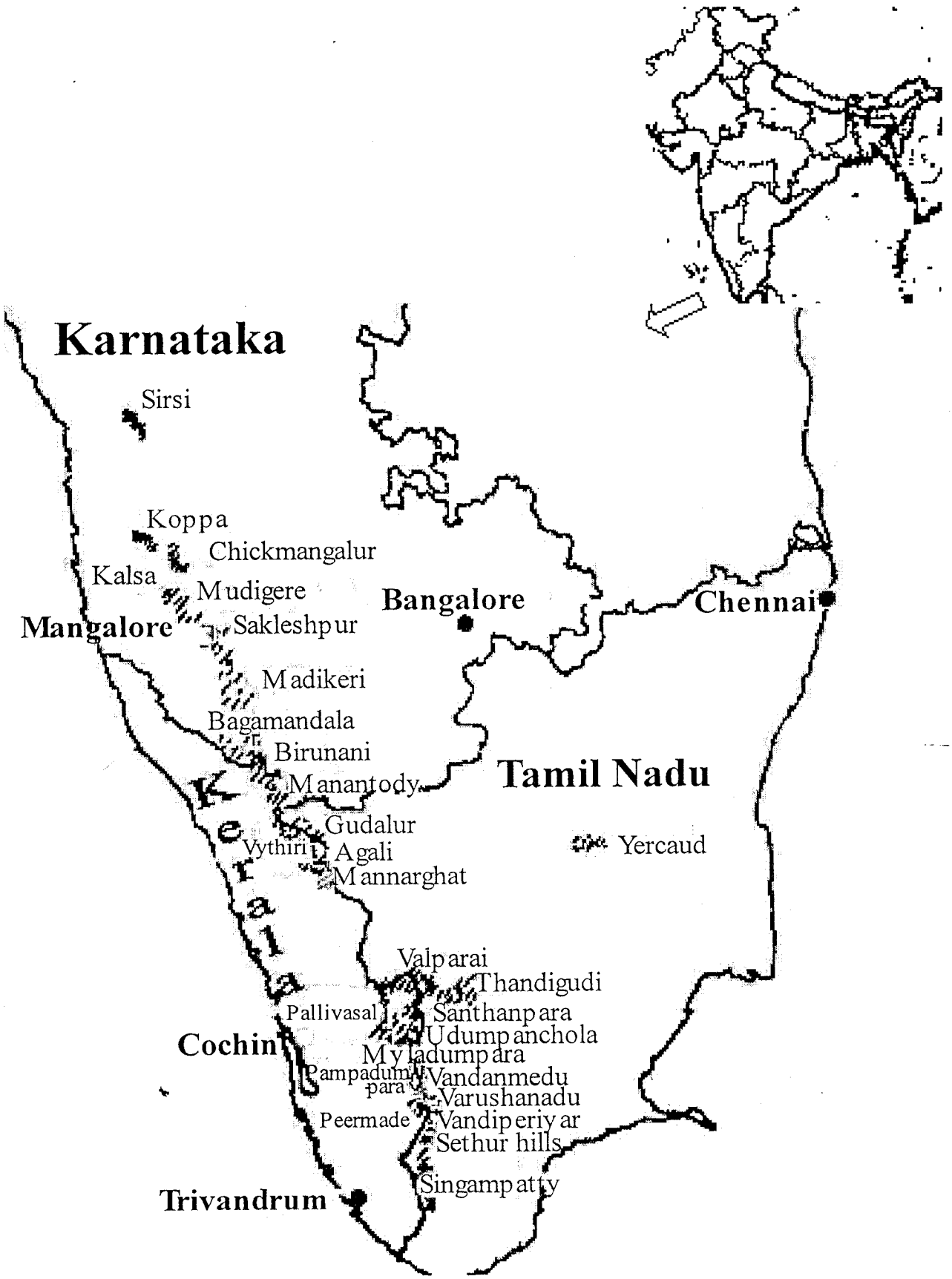

Figure 1. Cardamom growing regions of India.

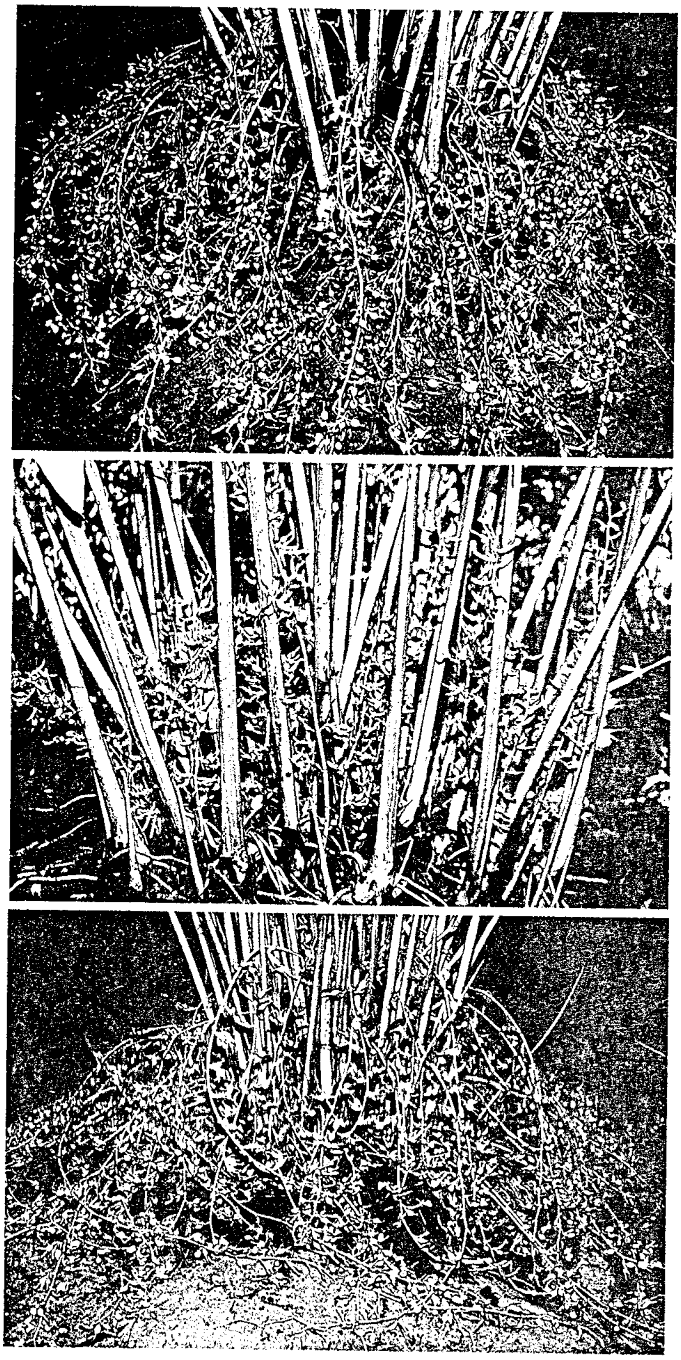

Figure 2. (a) Malabar (prostrate panicles); (b) Mysore (erect panicles); (c) Vazhukka (semi erect panicles).

tiller. The internodal length was minimal (1.00 cm) in Acc.60 resulting in a compact bearing panicle. Panicles generally were unbranched, but a few accessions had different types of branching pattern, viz. basal branching (Acc.298), terminal branching (Acc.260), profuse branching throughout the length and secondary as well as tertiary branching (Acc.248) (Figure 3). The secondary and tertiary-branched panicles were short and had less internodal length. The colour of capsules at physiological maturity varied from light to dark green. Dark green capsules, which fetch a premium price in the market, were recorded in a few accessions (Acc.298, Acc.263, Acc.273 and Acc.297), which retained their green colour even after processing.

Table 2. Variability in 310 accessions of cardamom

Characters	Cultivar group								
	Malabar			Mysore			Vazhukka		
	Mean	Range	CV %	Mean	Range	CV %	Mean	Range	CV %
Plant height (m)	1.67	0.58–2.19	20.96	1.73	0.91–2.28	18.60	1.80	1.38–2.20	13.25
Total tillers/plant	28.92	0.66–61.33	39.49	31.78	13.66–67.90	30.28	31.65	16.33–42.33	23.19
Bearing tillers/plant	8.65	0.0–27.00	56.30	9.58	5.15–11.00	36.01	9.90	1.33–33.00	62.32
Pseudostem dia. (cm)	1.08	0.32–1.99	23.15	1.26	0.83–1.81	19.84	1.30	1.05–1.56	12.31
No. of leaves/plant	208.93	10.00–411.80	43.64	250.08	45.80–421.70	32.83	246.49	115.00–409.00	28.46
Leaf length (cm)	46.96	15.74–64.00	15.74	49.16	35.00–61.00	14.87	49.26	42.00–57.67	9.28
Leaf width (cm)	7.64	11.33–17.80	17.80	8.44	5.15–11.00	17.06	8.06	6.33–11.33	14.76
No. of panicles/plant	42.65	4.5- 139.33	78.76	40.18	1.0–135.60	74.81	37.25	2.00–138.70	74.50
Panicle length (cm)	35.18	9.55-90.12	43.69	41.73	21.30–87.80	28.80	44.71	28.63–87.50	25.27
No. of nodes/panicle	16.71	8.0- 29.00	36.39	20.18	7.33–30.67	25.07	20.74	11.50–27.33	24.30
Internode length (cm)	3.05	1.0- 5.13	32.79	3.78	1.30–4.63	69.31	3.46	1.90–4.67	18.21
Capsule length (cm)	0.69	0.35–3.00	42.03	0.83	0.30–1.43	36.14	0.86	0.46–1.37	30.23
Capsule width (cm)	0.43	0.26–3.20	69.77	0.47	0.20–1.05	40.43	0.47	0.30–0.73	23.40
Seeds/capsule	16.63	8.00–23.20	9.69	16.91	10.50–24.50	11.62	16.35	9.70–23.0	9.03
Yield/plant (g)	872.05	0.0–3223.00	92.80	511.11	0.0–1123.30	98.11	608.06	0.0–865.30	89.71
100-capsules dry weight (g)	25.25	13.08–38.12	13.11	22.25	17.56–25.68	17.11	26.06	18.96–40.40	10.28

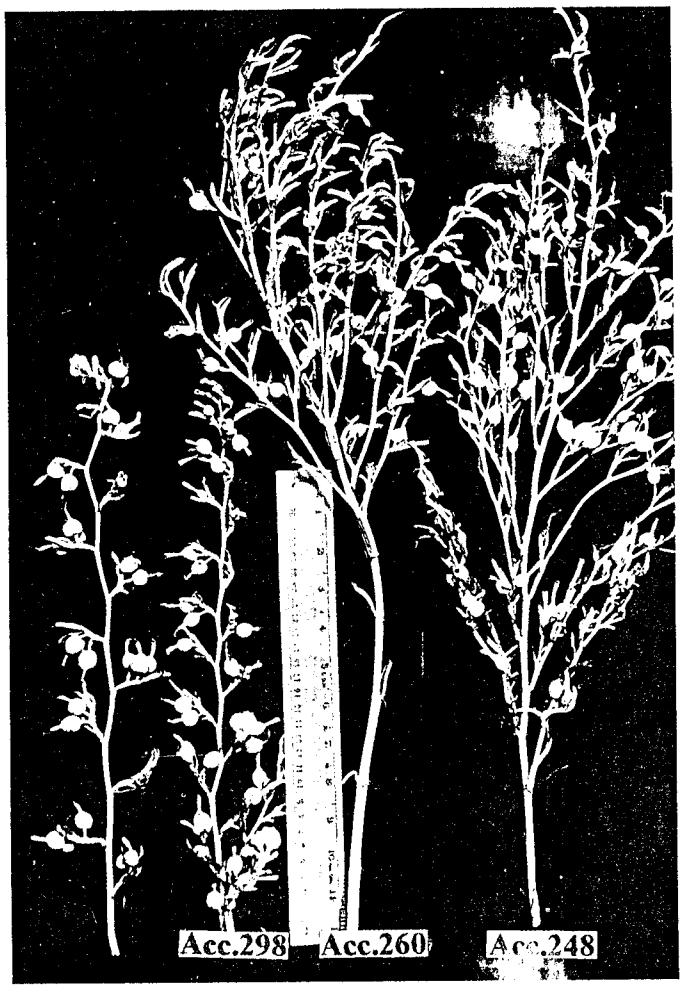

Figure 3. Variability for panicle branching in cardamom accessions (298, 260 and 248).

Table 3. Distribution pattern of accessions into three clusters and estimate of average inter- and intra-cluster distances

Cluster no.	1	2	3	No. of genotypes
1	3.213			39
2	4.322	3.284		169
3	3.461	3.463	3.375	102

Table 4. Resistance of 10 selected cardamom accessions to rhizome rot

Disease index range (%)	Classification	Accessions
0–5	Highly resistant	none
6–10	Resistant	298, 341
11–25	Moderately susceptible	221, 134, 296, 244
26–50	Susceptible	132, 223, 248
>50	Highly susceptible	242

Variability in 'Mysore' type

High variability was exhibited for yield, number of panicles per plant and internodal length. Leaf length and width exhibited low variability. Leaf width varied from 3 to 11.00 cm, the minimum was recorded in Acc. 129. Although the panicle is usually produced at the collar region of the tiller, 'Alfred clone' (Acc.128) was unique in producing both basal and terminal panicles. The number of panicles per plant ranged from 7.33 to 135.60, with Acc. 98 having the most. Internodal length varied from 1.30 (Acc.109) to 4.63 cm (Acc.98). Capsule length and width exhibited moderate variability. Yield per plant varied from 0.0 to 1123.3 g and exhibited the highest variability. Variability for the character of seeds per capsule was least among the characters studied.

Variability in 'Vazhukka' type

High variability was recorded for characters such as yield, panicles and tiller bearing per plant. In general, the pseudostem was pale green to green in colour. Variation for this character was observed in Acc.130 (pink) and Acc.257 (dark green). The number of panicles per plant ranged from 2.0 to 138.70, with Acc.138 having the most. Moderate variability existed for panicle length, nodes per panicle, capsule length and width. The 100-capsules dry weight varied from 18.96 to 40.40 g: Acc. 257 was the heaviest. The results match those found in other studies of cardamom accessions from South India (George et al. 1981; Sudharshan et al. 1989; Prasath et al. 2001).

Clustering and relationships

The accessions in this study clustered into 39, 169 and 102 accessions in the first, second and third clusters (Table 3). Accessions from the same cultivar group were scattered in different clusters. There is no definite clustering of accessions for Malabar, Mysore and Vazhukka. This indicates the possibilities of a common ancestral and close relationship of the genotypes of these three groups and also that geographical origin is not the single factor for genetic divergence in cardamom. The maximum inter-cluster distance existed between cluster 1 and 2 (4.32) followed by that between 2 and 3 (3.463). The inter-cluster distances were greater than intra-cluster distances, revealing considerable amount of genetic diversity among genotypes.

Resistance to cardamom mosaic virus

Cardamom mosaic virus (Car MV) or *Katte* disease is a serious viral disease in cardamom plantations. In mono-cropping, the infection on bearing plants reduces the yield up to 69% in the third year of infection and total decline of plants occurs after 3–5 years of infection (Venugopal 1999). Testing of promising collections in four hot spots and also against natural infection confirmed the resistant nature of 17 collections.

Resistance to rhizome rot

Rhizome rot of cardamom is caused by combined infection of *Pythium vexans* and *Rhizoctonia solani*. Based on the field

reaction of cardamom accessions to rhizome rot, 10 entries were shortlisted as resistant sources and further testing yielded two resistant sources (Table 4).

Essential oil

The most commercially desirable item in cardamom is its volatile oil. The oil content in cardamom varies from 6.5 to 10.5%. The major chemical constituents which impart sweet flavour to the oil are terpinyl acetate, linalyl acetate and linalool. 'Mysore' possesses more terpinyl acetate than 'Malabar', while the later possesses more 1,8-cineole which imparts a harsh camphor-like note to the oil (Sarathkumara et al. 1985). Evaluation of germplasm has also led to the identification of two accessions (Acc.221 and Acc.218), that contained 7.8% essential oil content consistently for three years. This oil had a high concentration of aroma-bearing constituents of ethers such as alpha terpinyl and linalyl acetate and a low concentration of 1,8-cineole.

The results indicate that the accessions collected in South India and conserved at the Indian Institute of Spices Research are an important genetic reservoir of variability. The collected germplasm accessions are now conserved in *ex situ* and *in vitro* genebanks.

Acknowledgements

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Appendix 1—Cardamom germplasm repositories in India—is available online: http://www.ipgri.cgiar.org/pgrnewsletter/last.asp.