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PERFORMANCE AND CHARACTERIZATION OF PROMISING CARDAMOM (*ELETTARIA CARDAMOMUM* MATON) ACCESSIONS AT HIGH AND LOW ALTITUDES OF SRI LANKA

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ABSTRACT

Promising accessions of Cardamom (*Elettaria cardamomum* Maton, family *Zingiberaceae*) belonging to Malabar (Ec 100, Ec 101, Ec 102 and Ec 103), Vashukka (Ec 104, Ec 200, Ec 201, Ec 300, Ec 301, Ec 400, Ec 401, Ec 403, Ec 405 and Ec 406) and Mysore types (Ec 302 and Ec 700) available in Sri Lanka were screened to compare their performance under different vegetation types (natural forest and *Hevea* rubber plantations), altitudes (1000 m and 50-150 m AMSL) and agro-climatic conditions (IU1 and WL1).

Overall better growth and reproductive (percentage of reproductive pseudostems per clump) performances were observed under natural forest conditions at high altitude than in rubber plantations in low altitude. Capsule size and shape, general panicle angle, inter-nodal length along the panicle and the texture of the under side of the leaflet could be used for differentiation of types or accessions both in high and low altitudes. Mysore and Vashukka types, accession Ec 201(2071 capsules/yr.), Ec 300 (1016 capsules/yr.), Ec 301(1183 capsules/yr.), Ec 401(1051 capsules/yr.), and Ec 700 (1061 capsules/yr.) performed best under high altitudinal conditions whereas Malabar type Ec 100 (534 capsules/yr.), Ec 101 (572 capsules/yr.) and Ec 102 (593 capsules/yr.) together with Vashukka type (Ec 400 (641 capsules/yr.) performed best in low altitude rubber plantations. The conversion factor of ovules into seeds of these accessions was over 80% in low altitude while it was over 75% in all the high altitude accessions. Size of the clump, colour of the leaflets and capsules, length of the panicle, number of flower stalks per cincinus and flowering frequency along the cincinus were also affected by environmental conditions.

Key words

Cardamom, *Elettaria cardamomum*, *Hevea*, Characterization

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INTRODUCTION

Cardamom (*Elettaria cardamomum* Maton; *Zingiberaceae*) is a tall herbaceous perennial with a branching subterranean rhizome. It is one of the major spice crops in Sri Lanka earning considerable foreign exchange (SL Rs. 21 million in 1998) for the country (Anon., 1998).

Two botanical varieties of Cardamom have been recognized, namely var. *major* Thw. and var. *minor* Walt. or var. *cardamom*. However, variety *major*, the native cardamom in Sri Lanka is now treated as a separate species (Sasikumar *et al.*, 1999), while Parry (1969) considered it to be a variety of the Malabar Cardamom. It grows wild in wet forests and is found especially in the Ratnapura District in Sri Lanka, but it is not cultivated commercially.

By 1800 A.D., cultivars of variety *minor* or *cardamom* were introduced to Sri Lanka from India for commercial cultivation. Information on these introduced cultivars, their time of introduction etc., are not known. In 1970s, the Department of Minor Export Crops introduced some accessions from India, but these accessions were also not properly characterized and documented so far.

Variety *minor* is cultivated under natural forests in the central hills (above 600 m; 4711 ha in 1999) of Sri Lanka (Anon., 1998). The average productivity of Cardamom in Sri Lanka is about 50 kg per hectare whereas that in Guatemala it is 250-300 kg/ha. In India, some varieties like PV-1 have yielded more than 500 kg/ha (Kuriakose and Sadhankumar, 1990). The most important reason for this low productivity in Sri Lanka is due to the lack of high yielding varieties suitable to the varying agro-climatic conditions, even though other reasons like size of the holding, land tenure, etc. may also contribute to the cause. Further, the forest cover in the high altitudes where the conditions are optimal for this crop is fast diminishing in Sri Lanka.

The Government's decision to terminate the cultivation of Cardamom in the Knuckles hill range (Gazette, 2000) has not only resulted in a limited scope for expansion but, has also greatly reduced the existing area suitable for cultivation of Cardamom. Therefore, the potential area for expansion of cardamom is restricted to either mid or low altitudes of the wet zone under tree crop plantations. Thus, it is important to find alternative lands to grow Cardamom in these non-traditional growing areas. It is also essential to identify suitable varieties that are adapted to the climate in these areas, together with a package of agronomic practices for the new environments, to expand Cardamom production in Sri Lanka.

The Department of Export Agriculture in Sri Lanka has carried out a preliminary study to evaluate the feasibility of inter-cropping Cardamom at low altitudes, mainly under rubber and to evaluate the adaptability of Cardamom germplasm for these conditions. More than 125,000 ha of mature rubber lands could be found in this region and even if 5% of these lands were intercropped with Cardamom varieties having about 50 g dry capsule/clump, this could lead to an increase of 100% of the total cardamom production.

Cardamom accessions, collected from different agro-climatic regions in Sri Lanka together with recent introductions are being routinely screened in the traditional growing areas to select those that could give a better yield and quality and also having resistance to major pests and diseases. These accessions need to be further developed through hybridization and other modern techniques for a sustainable industry.

The diversity of ecosystems in which Cardamom can be grown is limited. Most of the biodiversity in cardamoms come from varietal (genetic) diversity (Madhusoodasan *et al.*, 1994). Therefore, the present study was undertaken to identify the varietal diversity and characterize it under different agro-climatic conditions for future varietal improvement programmes, as well as to select the best performing accessions for high and low altitudes of Sri Lanka.

MATERIALS AND METHODS

Two sites were selected at high altitude. Site 1 was under the forest cover consisting of *Albizia moluccana, Macaranga* spp. *(Kenda), Erythrina* spp. *(Dadap), Toona* spp. etc., and Site 2 was under *Eucalyptus* spp. (Red gum) and *Macaranga* spp. *(Kenda),* both at Kellabokke estate in Kandy District (Table 1). Fifteen promising accessions of Cardamom (Ec 101, Ec 102 and Ec 103 from Malabar type, Ec 104, Ec 200, Ec 201, Ec 300, Ec 301, Ec 400, Ec 401, Ec 403, Ec 405 and Ec 406 from Vashukka type and Ec 302 and Ec 700 from Mysore type), collected from high altitude areas, were field planted (2.2 x 1.8 m spacing) in a Randomized Complete Block (RCB) Design.

Two other sites were selected at low altitude in Bulathsinhala (Site 3) in Kalutara District and in Debathgama (Site 4) in Kegalle District, both with mature rubber plants (7 years old, PB-86 clone), planted at 5.4 x 3.6 m spacing. Ten accessions of Cardamom (Ec 100, Ec 101 and Ec 102 from Malabar type, Ec 104, Ec 200, Ec 400, Ec 401, Ec 403 and Ec 405 from Vashukka type and Ec 700 from Mysore type) were field planted as one row of cardamom plants (2.2 m spacing) along the center line of two rubber rows in a RCB Design (Table 1).

Table 1

Agro-climatic parameters and soil characteristics of the experimental sites

Agro climatic	High altitude		Low altitude	
Parameter	Site 1	Site 2	Site 3	Site 4
Location	Kellabokke	Kellabokke	Bulathsinhala	Kegalle
Agro-ecological region	IU1	IU1	WL1	WL1
Altitude (m-AMSL)	1000	1000	50	150
Annual Rainfall (mm)	>2500	>2500	>2500	>2500
Soil type	Red Yellow-Podzolic	Red Yellow-Podzolic	Red Yellow-Podzolic	Red Yellow-Podzolic
Soil pH	4.02	4.26	4.8	5.3
Soil fertility				
- N (%)	0.51	0.44	0.24	0.18
- P (ppm)	3.46	2.98	2.18	2.06
- K (ppm)	141	158	84	55
- Organic Carbon	4.8	4.2	2.12	2.36
Shade type	Forest cover	Forest cover	Rubber	Rubber
Phosynthetically - Active Radiation ($\mu E/m^2/s$)	245-281	261-310	285-328	319-342
Day temperature (^0C)	22-26	22-26	28-32	28-32

Agronomic practices for Cardamom plants were carried out according to the recommendations published by the Department of Export Agriculture (Anon., 1996) and for Rubber, as per the advisory circulars published by the Sri Lanka Rubber Research Institute (Anon., 1994).

Three years after field planting, cardamom plants were fully mature and their vegetative and reproductive characteristics were recorded for another three years at monthly intervals.

The number of pseudostems, height of the bush, diameter of a well-developed pseudostem at the base and at 10 cm above the ground level, diameter of the bush base and the canopy spread were measured in each clump. The leaflet number, length and width of the 6th leaflet from the distal end of a well-developed pseudostem were measured while giving scores for the colour and texture of the under surface of the leaflets. Further, randomly selected bushes were uprooted and the inter-nodal length, the diameter of the developed rhizomes as well as the general rooting depth and their spread were recorded.

With respect to reproductive characteristics, the number of sexually reproductive pseudostems per clump, the number of panicles per clump and per pseudostem were recorded. General angles of the panicles to the ground surface were calculated using the 'Pythagoras Theorem'. Lengths of the longest panicle, number of cincinni in the first 20 cm of the panicles were recorded only at the end of the fruiting season. The total number of flower-stalks of the fully mature cincinni was counted. The number of mature capsules in a cincinus was counted after harvesting. Six hundred flower buds and six hundred mature capsules were brought into the laboratory and the number of ovules per flower and the number of seeds per capsule of each accession was counted. The length and width of the capsules were also measured while giving scores to their colour (1-for light green to 10 for dark green) and the shape (1-round, 2-long, 3-triangular). Another sixty samples of capsules from each accession were weighed before and after oven drying (55^{0}C for 36 hours.). The total number of capsules harvested from the tagged cincinni, panicles and the whole clump were also recorded. The amount of rainfall, total number of rainy days, maximum and minimum temperature, relative humidity and available light levels were recorded at each of the experimental sites. The data gathered were analyzed using the 'SAS' software computer package.

RESULTS

Vegetative characteristics

In the higher altitude (1000 m AMSL), where the conditions were optimum for growth of Cardamom, the accessions exhibited a range of vegetative and reproductive characteristics. Accession Ec 201 (Vashukka type) performed best under the high altitude conditions. It had 44 pseudostems per clump while the next best accession Ec 700 had 41 (Table 2). The percentage of the

reproductive pseudostems in a clump was over 64% in all the accessions except in Ec 102 (55%) and Ec 103 (57%). More than 78% pseudostems in a clump produced fruits in accessions Ec 200, Ec 201, Ec 300, Ec 301, Ec 401 and Ec 700 at high altitude. Ec 201 and Ec 700 had the largest diameters of the pseudostem bases (more than 4 cm) while all the others ranged between 3 and 4 cm. The tallest plants were observed in the accession Ec 700 (408 cm), while Ec 200, Ec 201 and Ec 400 also maintained better heights. The best rhizome spread (clump base diameter) was also observed in Ec 201 (94 cm) and accessions Ec 101, Ec 405 and Ec 700 spread over an area greater than 80 cm diameter. The largest canopy spread was in accession Ec 700 (328 cm) and the lowest in accession Ec 103 (267 cm).

Table 2

Clump characteristics of different types and accessions of Cardamom grown at high altitude sites 1 and 2.

Types and Accessions	Pseudostem				Clump Diameter	
	No. per clump	Reproductive (%)	Diameter (cm)	Height (cm)	Base (cm)	Canopy (cm)
Malabar						
Ec 101	27^{ghi}	70^{b}	3.5^{d}	334^{h}	81^{e}	314^{b}
Ec 102	23^{j}	55^{e}	3.2^{e}	325^{i}	43^{h}	287^{cd}
Ec 103	15^{l}	57^{e}	3.3^{e}	261^{m}	49^{g}	267^{d}
Vashukka						
Ec 201	44^{a}	79^{a}	4.6^{a}	399^{b}	94^{a}	317^{b}
Ec 200	39^{c}	79^{a}	3.6^{cd}	373^{d}	69^{d}	311^{b}
Ec 401	37^{cd}	78^{a}	3.7^{cd}	280^{k}	63^{e}	303^{bc}
Ec 406	35^{d}	68^{bc}	3.8^{c}	364^{e}	50^{g}	288^{c}
Ec 400	32^{e}	71^{b}	3.8^{c}	381^{c}	72^{d}	312^{b}
Ec 403	31^{ef}	74^{b}	3.6^{d}	352^{f}	56^{f}	299^{bc}
Ec 300	29^{fg}	78^{a}	3.3^{e}	271^{l}	54^{f}	305^{bc}
Ec 301	26^{hi}	78^{a}	3.6^{d}	294^{j}	63^{e}	275^{cd}
Ec 405	25^{ij}	67^{bc}	3.3^{e}	365^{e}	84^{c}	291^{c}
Ec 104	20^{k}	64^{bc}	3.2^{e}	337^{h}	47^{g}	309^{bc}
Mysore						
Ec 700	41^{b}	79^{a}	4.3^{b}	408^{a}	89^{b}	328^{a}
Ec 302	28^{gh}	67^{bc}	3.9^{c}	341^{g}	62^{e}	306^{bc}

Means of the same letter are not significantly different at 5% level

At low altitude (50-150 m AMSL), only accession Ec 102 had about 35 pseudostems per clump while accession Ec 104 produced 27 pseudostems (Table 3). All the other accessions had between 30-35 pseudostems per clump. Of the total pseudostems per clump, the proportion of reproductive pseudostems was over 70 % in accession Ec 100 and less than 50 % in accessions Ec 104 and Ec 401. The tallest accession was Ec 405 (319 cm) and the shortest was Ec 100 (211 cm). The rhizome spread (58-67 cm) and the pseudostem diameter (2.8-3.2 cm) had little variation among the accessions. The largest canopy spread was in Ec 101 (305 cm) and the smallest in accession Ec 102 (215 cm).

Comparison of the performance of accessions at low and high altitude showed that accession Ec 700 had the highest variation. In this accession the variations at high and low altitudes in pseudostem number was 41 and 30, reproductive pseudostems per clump was 79% and 51%, pseudostem diameter at

the base was 4.3 and 3 cm, clump height was 408 and 294 cm, diameter at clump base was 89 and 59 cm and canopy diameter was 328 and 268 cm, respectively.

Table 3

Clump characteristics of different types and accessions of Cardamom grown at low altitude sites 3 and 4.

Types and Accessions	Pseudostem				Clump Diameter	
	No. per clump	Reproductive (%)	Diameter (cm)	Height (cm)	Base (cm)	Canopy (cm)
Malabar						
Ec 102	35^{a}	60^{ab}	2.9^{ab}	248^{e}	66^{ab}	215^{h}
Ec 100	33^{ab}	72^{a}	2.8^{b}	211^{f}	61^{ab}	221^{g}
Ec 101	30^{bc}	64^{ab}	2.8^{b}	259^{d}	67^{a}	305^{a}
Vashukka						
Ec 200	33^{ab}	57^{b}	2.9^{ab}	293^{b}	67^{a}	244^{f}
Ec 403	32^{ab}	57^{b}	2.9^{ab}	293^{b}	67^{a}	244^{f}
Ec 401	32^{ab}	48^{b}	3.0^{ab}	270^{c}	61^{ab}	254^{e}
Ec 400	31^{b}	61^{ab}	3.2^{a}	248^{e}	63^{ab}	290^{b}
Ec 405	31^{b}	58^{ab}	3.0^{ab}	319^{a}	60^{ab}	260^{d}
Ec 104	27^{c}	47^{b}	2.9^{ab}	246^{e}	58^{b}	239^{f}
Mysore						
Ec 700	30^{bc}	51^{b}	3.0^{ab}	294^{b}	59^{ab}	268^{c}

Means of the same letter are not significantly different at 5% level

The leaflet number per pseudostem was directly related to the height of the pseudostem. At the high altitude sites, Ec 700 had the highest number (23) of leaflets while Ec 201 had the second highest (22) (Table 4). Length of leaflets was higher in Ec 201 (74 cm) while it was 71 cm in Ec 700. Ec 201 and Ec 300 had the broadest leaflets of about 20 cm and narrowest in Ec 103 and Ec 405 (14 cm). Dark green leaflets were observed in Ec 405 and Ec 406. Leaflets with more silky textured under sides, were in Ec 103 and Ec 102. Accessions Ec 101, Ec 300 and Ec 405 had slight silky texture. Longest inter-nodes of the rhizome were in Ec 300 and Ec 301 (4.1 cm) while shortest inter-nodes were in Ec 103 and Ec 400 (2.6 cm). Largest rhizomes with more than 3 cm diameter were observed in Ec 102, Ec104, Ec 302 and Ec 400 accessions. With respect to the rooting zone, a rooting depth of about 20 cm was observed in Ec 103, Ec 104 and Ec 405. Shallow rooting depths (about 14 cm) were recorded in Ec 201, Ec 300 and Ec301. The most widespread rooting zone was in Ec 405 (84 cm) followed by that in Ec 406 (77 cm) (Table 4).

At the low altitude sites, Ec 700 and Ec 200 had the highest number of leaflets (19-20) per pseudostem (Table 5). Leaflet length was highest in Ec 200 (69 cm) and lowest in Ec 401 (52 cm). Ec 200 had the broadest leaflets of about 19 cm and Ec 401 the narrowest (9 cm). Ec 403 (7.8) and Ec 405 (7.9) had dark green leaflets. The silkiest texture of the under side of the leaflet was in Ec 100 (3). Longest inter-nodes of the rhizome were in Ec 401 (4 cm) and the shortest in Ec 102 (2.1 cm). The largest rhizomes with 2.8 cm in diameter were observed in Ec 104. The most widespread rooting zone was in Ec 200 (78.6 cm).

Table 4

Leaflet, rhizome and root characteristics of different types and accessions of Cardamom grown at high altitude sites 1 and 2.

Types and Accessions	Leaflets					Rhizome		Roots	
	Number per Pseu.	Length (cm)	Width (cm)	Colour Score[1]	Texture Score[2]	Inter-nodal length(cm)	Diameter (cm)	Depth (cm)	Spread (cm)
Malabar									
Ec 103	20^{abc}	59^{g}	14^{e}	6.9^{c}	2.7^{a}	2.6^{e}	2.1^{h}	20^{a}	72^{cd}
Ec 101	18^{c}	67^{cde}	16^{bc}	6.6^{c}	1.0^{cd}	2.8^{de}	2.6^{de}	17^{bcd}	66^{e}
Ec 102	17^{c}	60^{fg}	15^{cde}	6.8^{c}	2.0^{b}	2.8^{de}	3.3^{a}	16^{de}	55^{g}
Vashukka									
Ec 201	22^{ab}	74^{a}	20^{a}	7.8^{b}	0.0^{f}	3.4^{bc}	2.5^{def}	14^{e}	64^{ef}
Ec 300	20^{abc}	67^{bcd}	20^{a}	7.0^{c}	1.1^{c}	4.1^{a}	2.6^{de}	14^{e}	71^{d}
Ec 401	20^{abc}	63^{efg}	16^{bcd}	6.5^{c}	0.5^{fe}	3.8^{ab}	2.5^{efg}	15^{de}	54^{g}
Ec 405	20^{abc}	62^{fg}	14^{de}	8.6^{a}	1.4^{c}	2.7^{de}	2.7^{cd}	21^{a}	84^{a}
Ec 403	19^{c}	68^{bc}	16^{bcd}	8.1^{ab}	0.0^{f}	3.1^{cd}	2.3^{gh}	17^{bcd}	66^{e}
Ec 200	19^{c}	66^{cde}	15^{cde}	6.9^{c}	0.3^{ef}	3.3^{bc}	2.6^{de}	19^{ab}	73^{cd}
Ec 400	19^{c}	64^{def}	17^{b}	8.4^{ab}	0.6^{be}	2.6^{e}	3.1^{a}	15^{de}	71^{d}
Ec 301	19^{c}	62^{fg}	16^{bcd}	6.9^{c}	0.4^{ef}	4.1^{a}	2.9^{bc}	14^{e}	70^{d}
Ec 406	19^{c}	60^{fg}	17^{b}	8.6^{a}	0.2^{f}	2.9^{cde}	2.3^{gh}	18^{abc}	77^{b}
Ec 104	18^{c}	62^{fg}	16^{bcd}	6.8^{c}	0.0^{f}	2.7^{de}	3.1^{a}	20^{a}	75^{bc}
Mysore									
Ec 700	23^{a}	71^{ab}	16^{bcd}	8.1^{ab}	0.3^{ef}	3.2^{cd}	2.9^{ab}	15^{e}	56^{g}
Ec 302	19^{c}	63^{efg}	15^{cde}	6.8^{c}	0.0^{f}	2.8^{de}	3.1^{a}	16^{de}	62^{f}

[1]Colour score (1-10) 1-Very light green to 10 - Very dark green
[2]Texture of the under side of the leaflets - (0-3), 0-Rough, 3-silky
Means of the same letter are not significantly different at 5% level

Table 5

Leaflet, rhizome and root characteristics of different types and accessions of Cardamom grown at low altitude sites 3 and 4.

Types and Accessions	Leaflets					Rhizome		Roots	
	Number per Pseu.	Length (cm)	Width (cm)	Colour Score[1]	Texture Score[2]	Inter-nodal length(cm)	Diameter (cm)	Depth (cm)	Spread (cm)
Malabar									
Ec 101	16^{d}	63^{bc}	13^{ab}	6.4^{de}	1.5^{c}	2.5^{c}	2.4^{c}	15.4^{a}	60.5^{c}
Ec 100	14^{f}	57^{cd}	18^{a}	6.1^{e}	3.0^{a}	2.5^{c}	2.1^{e}	14.4^{a}	49.1^{d}
Ec 102	14^{f}	57^{cd}	13^{ab}	6.4^{de}	2.1^{b}	2.1^{d}	2.0^{f}	16.9^{a}	51.9^{d}
Vashukka									
Ec 200	19^{b}	69^{a}	19^{a}	7.3^{bc}	0.0^{f}	2.8^{bc}	2.5^{b}	14.5^{a}	78.6^{a}
Ec 400	18^{c}	64^{ab}	18^{a}	7.0^{c}	0.6^{de}	3.0^{b}	2.5^{b}	14.8^{a}	63.9^{bc}
Ec 403	16^{d}	61^{bc}	15^{ab}	7.9^{a}	0.3^{ef}	3.1^{b}	2.3^{d}	15.4^{a}	66.6^{b}
Ec 104	16^{d}	57^{cd}	18^{a}	6.1^{e}	0.0^{f}	2.2^{d}	2.8^{a}	16.5^{a}	61.4^{bc}
Ec 405	15^{e}	54^{d}	15^{ab}	7.8^{ab}	0.3^{ef}	3.2^{b}	2.3^{d}	14.4^{a}	53.5^{d}
Ec 401	13^{g}	52^{d}	9^{b}	6.9^{cd}	0.8^{d}	4.0^{a}	2.3^{d}	14.4^{a}	4.4^{bc}
Mysore									
Ec 700	20^{a}	60^{bc}	15^{ab}	6.9^{cd}	0.0^{f}	2.3^{d}	2.5^{b}	16.1^{a}	61.6^{bc}

[1]Colour score (1-10) 1-Very light green to 10 - Very dark green
[2]Texture of the under side of the leaflets - (0-3), 0-Rough, 3-silky
Means of the same letter are not significantly different at 5% level

Reproductive characteristics

The general angle of the panicle to the ground surface is the major criterion widely used to differentiate the types of Cardamom. Generally, the panicle is horizontal in the Malabar type, vertical in the Mysore type and intermediate in the Vashukka type (Table 6). In this study however, a wider variation of the panicle angle was observed among them. At high altitude, on average the Mysore types had about 30 panicles per clump; Malabar types had the lowest number of panicles per clump (25), longest panicles (98 cm), the lowest number of cincinni in the first 20 cm of the panicle and least number of flower stalks (15) per cincinus. All three types had a maximum of 4 panicles per pseudostem, 17-18 ovules per ovary and 14-15 seeds per capsule.

Considering the individual accessions, Ec 700 had 37 panicles per clump and Ec 103 had less than 20 (Table 6). Panicle length in Ec 201 was greater than 110 cm and less than 70 cm in Ec 200 and Ec 403. Ec 403 and Ec 300 had the shortest inter-nodes (more than 10 nodes in first 20 cm length) along the panicle whereas Ec 103 and Ec 104 had the longest inter-nodes (less than 4 nodes in first 20 cm length). The highest number of flower stalks per cincinus was observed in Ec 201 and Ec 300 (20-21). The number of ovules per ovary were 20 and 19 in the accessions Ec 201 and Ec 104 respectively, and the number of seeds per capsule was 17 in these two accessions.

Table 6

Panicle and capsule characteristics of different types and accessions of Cardamom grown at high altitude sites 1 and 2.

Type	Panicles					Flower stalks No. per cincinus	Capsules No/cincinus (After-harvesting)	Ovules Number/ ovary	Seed Number/ capsule
	Angle to the ground	Number per clump	Number per pseu.-dostem	Length (cm)	Cincinni (No.in first 20 cm)				
Mysore	79^{a}	30^{a}	4^{a}	89^{b}	6.4^{a}	17^{a}	3.5^{a}	18^{a}	15^{a}
Vashukka	62^{b}	27^{b}	4^{a}	91^{b}	6.6^{a}	16^{a}	3.5^{a}	17^{a}	15^{a}
Malabar	08^{c}	25^{c}	4^{a}	98^{a}	5.7^{b}	15^{b}	3.6^{a}	18^{a}	14^{a}
Accessions									
Malabar									
Ec 101	20^{j}	32^{b}	4^{a}	105^{ab}	5.5^{def}	18^{abc}	3.6^{bc}	18^{ab}	14^{bc}
Ec 102	09^{k}	23^{def}	4^{a}	101^{ab}	8.2^{b}	17^{bcd}	4.0^{ab}	18^{ab}	15^{abc}
Ec 103	03^{l}	19^{f}	4^{a}	86^{c}	3.6^{f}	12^{f}	3.4^{cd}	17^{abc}	14^{bc}
Vashukka									
Ec 300	67^{c}	25^{cd}	4^{a}	97^{abc}	11.3^{a}	21^{a}	3.1^{d}	17^{abc}	15^{abc}
Ec 301	66^{c}	28^{c}	4^{a}	99^{ab}	5.6^{de}	13^{ef}	4.0^{ab}	17^{abc}	15^{abc}
Ec 200	64^{d}	26^{cd}	4^{a}	65^{d}	6.1^{cd}	15^{cde}	3.9^{ab}	17^{abc}	15^{abc}
Ec 104	61^{e}	21^{ef}	4^{a}	103^{ab}	2.3^{g}	17^{bcd}	4.0^{ab}	19^{a}	17^{a}
Ec 201	59^{f}	32^{b}	4^{a}	110^{a}	4.6^{ef}	20^{a}	3.1^{d}	20^{a}	17^{a}
Ec 403	59^{f}	26^{cd}	4^{a}	67^{d}	12.1^{a}	19^{ab}	4.2^{a}	16^{c}	12^{c}
Ec 405	56^{g}	34^{b}	4^{a}	100^{ab}	12.8^{a}	13^{ef}	3.3^{cd}	18^{ab}	16^{ab}
Ec 401	56^{g}	26^{cd}	4^{a}	103^{ab}	5.8^{cde}	14^{def}	4.0^{ab}	13^{d}	14^{bc}
Ec 406	55^{g}	24^{cde}	4^{a}	72^{d}	5.3^{de}	14^{def}	4.2^{a}	18^{ab}	16^{ab}
Ec 400	48^{h}	28^{c}	4^{a}	101^{ab}	8.3^{b}	17^{bcd}	4.0^{ab}	18^{ab}	16^{ab}
Mysore									
Ec 700	85^{a}	37^{a}	4^{a}	105^{ab}	6.0^{cd}	17^{bcd}	3.9^{ab}	17^{abc}	16^{ab}
Ec 302	74^{b}	23^{def}	4^{a}	73^{d}	7.2^{c}	15^{cde}	3.3^{cd}	18^{ab}	15^{abc}

Means of the same letter are not significantly different at 5% level

At the low altitude sites, on average, the Malabar types had about 26 panicles per clump, panicle length more than 90 cm, about 16 flower stalks per cincinus, 18 ovules per ovary and 15 seeds per capsule (Table 7). The corresponding values were less in the other two types. All three types had a mean number of 3-3.5 panicles per clump and 6.1-6.8 cincinni in first 20 cm of the panicle.

Considering the individual accessions, Ec 400 and Ec 102 had 28 or more panicles per clump while Ec 200, Ec 403 and Ec 405 had less than 20 (Table 7). Panicle length in accessions Ec 100, Ec 101, Ec 102 and Ec 400 was greater than 85 cm whereas that of Ec 401 and Ec 700 was less than 55 cm. Highest number of flower stalks per cincinus was observed in Ec 100 (17). The number of ovules per ovary was high (17-18) in all the accessions except Ec 104 and Ec 401; less than 10 seeds per capsule were observed in accessions Ec 200, Ec 401, Ec 405 and Ec 700.

Table 7

Panicle and capsule characteristics of different types and accessions of Cardamom grown at low altitude sites 3 and 4.

Type	Panicles					Flower stalks No. per cincinus	Capsules No/cincinus (After-harvesting)	Ovules Number/ovary	Seed Number/capsule
	Angle to the ground	Number per clump	Number per pseu-dostem	Length (cm)	Cincinni (No.in first 20 cm)				
Mysore	82^{a}	21^{b}	3^{b}	52^{c}	6.1^{a}	12^{b}	1.8^{a}	17^{b}	9^{b}
Vashukka	57^{b}	20^{b}	3.5^{a}	61^{b}	6.5^{a}	12^{b}	2.2^{a}	17^{b}	10^{b}
Malabar	10^{c}	26^{a}	3.5^{a}	93^{a}	6.8^{a}	16^{a}	2.5^{a}	18^{a}	15^{a}
Accessions									
Malabar									
Ec 101	16^{g}	25^{abc}	3.8^{ab}	95^{a}	5.6^{cd}	16^{a}	2.8^{a}	18^{a}	15^{a}
Ec 102	11^{h}	28^{a}	3.6^{ab}	98^{a}	9.8^{b}	15^{a}	2.6^{a}	18^{a}	16^{a}
Ec 100	03^{i}	26^{ab}	3.4^{bc}	85^{a}	3.8^{ef}	17^{a}	2.4^{a}	18^{a}	14^{b}
Vashukka									
Ec 405	63^{b}	17^{d}	3.4^{bc}	55^{b}	13^{a}	11^{c}	1.8^{a}	17^{b}	9^{c}
Ec 401	59^{bc}	21^{cd}	3.5^{ab}	54^{b}	5.5^{cd}	12^{bc}	2.6^{a}	16^{b}	9^{c}
Ec 200	59^{bc}	18^{d}	3.3^{bc}	49^{b}	5^{de}	11^{c}	2.1^{a}	18^{a}	10^{c}
Ec 104	56^{c}	20^{cd}	3.4^{bc}	60^{b}	2.8^{f}	11^{c}	1.9^{a}	16^{b}	11^{c}
Ec 403	56^{c}	19^{d}	3.4^{bc}	61^{b}	11.6^{a}	12^{bc}	2.1^{a}	17^{b}	12^{c}
Ec 400	50^{d}	29^{a}	4^{a}	87^{a}	4.5^{de}	15^{a}	2.6^{a}	18^{a}	15^{a}
Mysore									
Ec 700	82^{a}	22^{bc}	3.0^{c}	52^{b}	6.7^{c}	12^{bc}	1.8^{a}	17^{b}	9^{c}

Means of the same letter are not significantly different at 5% level

In the Vashukka and Mysore types longer capsules were observed at high altitude (Table 8, 9 and 10). Malabar types, on the other hand, had short capsules (9 mm) at both altitudes. The broadest capsules at low altitude was observed in Vashukka type (10.1 mm) and at the high altitude in the Mysore type. Capsule shape in each type did not change with altitude. In general, capsules were round in the Malabar types, long in the Vashukka types and triangular in the Mysore types.

Lighter green capsules were observed in low altitude. Capsules in Malabar types were lighter green compared to that of the other two types. Wet and dry weights of a capsule were high at high altitude. In the Vashukka type, the wet weights of capsules were similar (0.8 g) at both altitudes but their dry weights were higher at high altitude. The total number of harvested capsules per clump per year at high altitudes was below 800 in Malabar types and greater than 950 in the other two types. At low altitude, it was above 550 in Malabar type and below 275 in the other two types. Conversion factor of ovules to seed at high altitude was above 80 % in Mysore and Vashukka types and below 80% in the Malabar types whereas at low altitude, it was above 80% in the Malabar type and below 60% in the other two types (Tables 8 and 9).

Table 8

Capsule characteristics, yield and ovules: seed conversion factor of different types and accessions of Cardamom grown at high altitude sites 1 and 2.

Type	Capsules							Ovules
	Length (mm)	Width (mm)	Shape (Score)[1]	Colour (Score)[2]	Harvested number/ Clump/yr.	Wet weight g/capsule	Dry weight g/capsule	seed conversion factor
Mysore	12.7^{a}	10.1^{a}	2.4^{a}	7.8^{a}	954^{a}	0.8^{b}	0.15^{b}	84^{a}
Vashukka	12.1^{a}	9.9^{a}	2.0^{b}	7.7^{a}	1050^{a}	0.8^{a}	0.18^{a}	86^{a}
Malabar	09.3^{b}	9.0^{b}	1.9^{b}	6.6^{b}	791^{b}	0.7^{b}	0.15^{b}	78^{b}
Accessions								
Malabar								
Ec 101	14^{a}	11^{a}	3.0^{a}	7.2^{de}	860^{c}	0.88^{cde}	0.143^{gh}	75^{e}
Ec 102	11^{bc}	09^{cd}	1.3^{c}	6.4^{f}	857^{c}	0.66^{i}	0.157^{fg}	79^{cde}
Ec 103	11^{bc}	09^{cd}	1.3^{c}	6.4^{f}	697^{d}	0.5^{e}	0.124^{h}	80^{bcd}
Vashukka								
Ec 201	15^{a}	11^{a}	2.3^{b}	7.4^{cde}	2071^{a}	1.04^{a}	0.233^{a}	87^{abc}
Ec 200	13^{ab}	9^{cd}	1.3^{c}	7.7^{bcd}	616^{de}	0.84^{def}	0.179^{cde}	87^{abc}
Ec 300	13^{ab}	10^{ab}	2.0^{b}	8.6^{a}	1016^{b}	0.94^{bc}	0.199^{bc}	84^{bcd}
Ec 406	13^{ab}	09^{cd}	2.3^{b}	7.0^{ef}	853^{c}	0.92^{cd}	0.173^{def}	90^{a}
Ec 104	13^{ab}	11^{b}	2.0^{b}	7.5^{bcd}	757^{d}	0.80^{efg}	0.157^{fg}	89^{a}
Ec 403	13^{ab}	11^{a}	2.8^{a}	8.1^{ab}	687^{d}	0.73^{ghi}	0.158^{efg}	79^{de}
Ec 400	13^{ab}	11^{a}	2.1^{b}	7.5^{bcd}	756^{d}	0.85^{cde}	0.154^{fg}	86^{abc}
Ec 301	13^{ab}	11^{a}	1.9^{b}	7.1^{de}	1183^{b}	0.73^{ghi}	0.154^{fg}	84^{bcd}
Ec 405	12^{b}	10^{ab}	2.0^{b}	7.3^{de}	687^{d}	0.97^{ab}	0.216^{ab}	88^{ab}
Ec 401	12^{b}	09^{cd}	2.0^{b}	8.5^{a}	1051^{b}	0.76^{fgh}	0.158^{efg}	87^{abc}
Mysore								
Ec 700	14^{a}	10^{ab}	2.9^{a}	7.3^{de}	1062^{b}	0.83^{def}	0.174^{def}	87^{abc}
Ec 302	10^{c}	9^{cd}	2.0^{b}	8.1^{a}	829^{c}	0.67^{hi}	0.127^{h}	80^{cde}

[1]Shape of the capsule:1- round, 2-long, 3-triangular

[2]Colour of the capsule: from 1-Very light green to 10-very dark green

Means of the same letter are not significantly different at 5% level

Table 9

Capsule characteristics, yield and ovules: seed conversion factor of different types and accessions of Cardamom grown at low altitude sites 3 and 4.

Type	Capsules							Ovules
	Length (mm)	Width (mm)	Shape (Score)[1]	Colour (Score)[2]	Harvested number/ Clump/yr.	Wet weight g/capsule	Dry weight g/capsule	seed conversion factor
Mysore	9.1^{b}	9.0^{b}	1.7^{c}	5.5^{b}	564^{a}	0.6^{b}	0.13^{b}	86^{a}
Vashukka	11.4^{a}	8.8^{b}	2.9^{a}	6.3^{a}	172^{e}	0.7^{a}	0.14^{b}	55^{b}
Malabar	10.7^{a}	10.1^{a}	2.0^{b}	6.4^{a}	273^{b}	0.8^{a}	0.16^{a}	57^{b}
Accessions								
Malabar								
Ec 101	13^{a}	10^{b}	3.0^{a}	6.3^{b}	572^{a}	0.66^{cde}	0.132^{cd}	87^{a}
Ec 102	11^{b}	9^{b}	1^{c}	5.1^{e}	593^{a}	0.66^{cde}	0.117^{d}	89^{a}
Ec 100	10^{c}	9^{b}	1.1^{c}	5.1^{e}	534^{b}	0.5^{de}	0.124^{cd}	82^{a}
Vashukka								
Ec 104	13^{a}	11^{a}	1.9^{b}	6.4^{b}	286^{e}	0.6^{cde}	0.104^{d}	50^{b}
Ec 400	13^{a}	10^{b}	2.1^{b}	6.0^{b}	641^{a}	1.0^{b}	0.202^{a}	85^{a}
Ec 405	12^{ab}	10^{b}	3.0^{a}	6.4^{b}	120^{ef}	1.1^{a}	0.222^{a}	54^{b}
Ec 401	12^{ab}	10^{b}	2.1^{b}	7.1^{a}	208^{d}	0.7^{cd}	0.087^{de}	53^{b}
Ec 403	12^{ab}	09^{b}	1.9^{b}	6.4^{b}	91^{f}	0.69^{cde}	0.175^{b}	48^{b}
Ec 200	12^{ab}	09^{b}	1.3^{c}	6.1^{b}	168de	1.1^{a}	0.142^{cd}	49^{b}
Mysore								
Ec 700	13^{a}	11^{a}	2.9^{a}	6.3^{b}	173de	0.8^{c}	0.168^{c}	55^{b}

[1]Shape of the capsule:1- round, 2-long, 3-triangular

[2]Colour of the capsule: from 1-Very light green to 10-very dark green

Means of the same letter are not significantly different at 5% level

Longest capsules at high altitude were observed in accessions Ec 201 (15mm) and Ec 101 (14mm) whereas at low altitude it was 13 mm in Ec 101, Ec 104 and Ec 700 (Table 7, 8 and 10). Capsule width varied between 9 and 11 mm of all the accessions irrespective of altitude. Capsule shape was a distinct character for an accession and did not vary with altitude. Accessions Ec 100, Ec 102, Ec 103 and Ec 200 had round capsule shape, accessions Ec 104, Ec 201, Ec 300, Ec 301, Ec 302, Ec 400, Ec 401,Ec 405 and Ec 406 had longer shape and accessions Ec 101, Ec 403 and Ec 700 had triangular shape.

Dark green bigger capsules were observed at high altitude. Accessions Ec 300, Ec 302, Ec 401 and Ec 403 had darker green capsules compared to the others. Accession Ec 201 had 1.0 g/capsule of wet weight and 0.23 g/capsule of dry weight. Ec 300, 406 and Ec 405 also had more than 0.9 g/capsule wet weight and 0.199, 0.174 and 0.216 g/capsule dry weight in high altitude. At low altitude, Ec 200, Ec 400 and Ec 405 had more than 1 g/capsule wet weight and Ec 400 and Ec 405 had more than 0.2 g/capsule dry weight.

At high altitude all the tested accessions yielded over 600 capsules per clump per year whereas at low altitude only Ec 400 yielded over 600 and accessions Ec 100, Ec 101 and Ec 102 yielded over 500 capsules per clump (Tables 8 and 9). The best yielding accession at high altitude was Ec 201 (2071 number of capsules/year). Other better yielding accessions were Ec 301 (1183 /yr.), Ec 401 (1051 /yr.) and Ec 700 (1061 /yr.). Conversion factor of ovules into seeds at high altitude was over 75 % in all the accessions while at low altitude it was above 80 % only in Ec 100, Ec 101, Ec 102 and Ec 400.

Table 10

Ranking summery of the vegetative ad reproductive characteristics of different types and accessions of Cardamom at high and low altitudes (eg: 1 for highest value)

Character	Type						Malabar type					Vazhukka type																	Mysore		
	Malabar		Vazhukka		Mysore		Ec 100	Ec 101		Ec102		Ec 103	Ec 104		Ec 200		Ec 201	Ec 300	Ec 301		Ec 400		Ec 401		Ec 403		Ec 405		Ec 406	Ec 302	Ec 700	
Altitude (H-High, L-Low)	H	L	H	L	H	L	L	H	L	H	L	H	L	H	L	H	H	H	H	H	L	H	L	H	L	H	L	H	H	H	L
Pseudostem																															
Number per clump	3	1	2	2	1	2	1	7	2	9	1	11	3	10	1	3	1	6	8	5	2	3	1	5	1	9	2	4	6	2	2
No. of reproductive pseudostems	2	1	1	1	1	2	1	2	1	3	1	3	2	2	2	1	1	1	1	2	1	1	2	2	2	2	1	2	2	1	2
Base diameter	3	1	2	1	1	1	2	4	2	5	1	5	1	5	1	1	1	5	4	3	1	3	1	4	1	5	1	3	3	2	1
Height	3	3	2	2	1	1	6	8	4	9	5	13	5	8	2	4	2	12	10	3	5	11	3	6	2	5	1	5	7	1	2
Clump																															
Base diameter	2	1	1	1	1	1	1	3	1	8	1	7	2	7	1	4	1	6	5	4	1	5	1	6	1	3	1	7	5	2	1
Canopy diameter	3	3	2	2	1	1	7	2	1	3	8	4	6	2	6	2	2	2	3	2	2	2	5	2	6	3	4	3	2	1	3
Leaflet																															
Number per pseudostem	2	3	1	2	1	1	6	3	4	3	6	1	4	3	2	3	1	1	3	3	3	1	7	3	4	1	5	3	3	1	1
Length	3	1	2	1	1	1	3	7	2	3	3	6	3	6	1	3	1	2	6	4	1	5	4	2	2	6	4	6	5	1	2
Width	2	1	1	1	2	1	1	5	1	2	1	3	1	2	1	3	1	1	2	2	1	2	2	2	1	4	1	2	3	2	1
Colour (Strength of the greenness)	2	2	1	1	1	1	5	3	4	3	4	3	5	3	2	3	2	3	3	1	3	3	3	1	1	1	1	1	3	1	3
Hairiness of the underside of the leaf	1	1	2	2	3	3	1	1	3	3	2	2	6	6	6	5	6	3	5	4	4	6	4	6	5	3	5	6	6	5	6
Rhizome																															
Inter-nodal length	2	2	1	1	1	2	3	4	3	3	4	3	4	3	2	2	2	1	1	5	2	1	1	3	2	4	2	3	4	3	4
Diameter	3	2	2	1	1	1	5	8	3	4	6	1	1	1	2	4	4	4	2	1	2	5	4	7	4	3	4	7	1	1	2
Roots																															
Depth	1	1	1	1	1	1	1	1	1	2	1	4	1	1	1	4	5	5	5	4	1	4	1	2	1	1	1	1	4	5	1
Spread	2	2	1	1	3	1	4	3	3	5	4	7	2	2	1	3	5	3	3	3	2	7	2	5	2	1	4	2	6	7	2
Panicles																															
Angle to the ground	3	3	2	2	1	1	9	10	7	1	8	12	3	3	2	4	6	3	3	8	4	7	2	6	5	7	2	7	2	1	1
Number per clump	3	1	2	2	1	2	1	2	1	4	1	6	3	5	4	3	2	3	3	3	1	3	3	3	4	4	4	3	4	1	2
Length	1	1	2	2	2	3	1	1	1	1	1	3	2	1	2	4	1	1	1	1	1	1	2	4	2	1	2	4	4	1	2
Cincinni number per first 20 cm	2	1	1	1	1	1	5	4	3	2	2	6	6	7	4	3	5	1	4	2	4	3	3	1	1	1	1	4	3	3	3
Flower stalks number per cincinus	2	1	1	2	2	2	1	1	1	2	1	6	3	2	3	3	1	1	5	2	1	4	2	1	2	5	3	4	3	2	2
Capsule																															
Length	2	2	1	1	1	1	3	1	1	2	2	2	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1	1	3	1	1
Width	2	2	1	1	1	2	2	1	2	3	2	3	1	4	2	3	1	1	1	1	2	3	2	1	2	1	2	3	3	1	1
Shape	2	3	2	2	1	1	3	1	1	3	3	3	2	2	3	3	2	2	2	2	2	2	2	1	2	2	1	2	2	1	1
Colour (Strength of the greenness)	2	2	1	1	1	1	3	4	2	6	3	6	2	2	2	2	3	1	4	2	2	1	1	1	2	4	2	5	1	4	2
Wet weight	2	2	1	1	2	1	4	3	3	9	3	5	3	5	1	4	1	2	7	3	2	6	3	7	3	1	1	3	8	4	3
Dry weight	2	2	1	1	2	2	3	7	3	6	4	8	4	6	3	3	1	2	6	6	1	5	4	5	2	1	1	4	8	4	3
Seeds number/capsule	1	1	1	2	1	2	2	2	1	1	1	2	3	1	3	1	1	1	1	1	1	1	3	3	3	1	3	1	1	1	3
Total harvested number/clump	2	1	1	2	1	3	2	2	1	2	1	3	3	3	4	2	1	2	2	3	1	2	4	3	6	2	5	2	2	2	4
Ovules : seed conversion factor	2	1	1	2	1	2	1	5	1	3	1	2	2	1	2	1	1	2	2	1	1	1	2	4	2	1	2	1	3	1	2

DISCUSSION

Results reveal that some accessions of Cardamom could be grown satisfactorily at low altitudes (50-150 m AMSL) even under higher day temperatures (>30^{0}C). However, significant morphological differences were observed with respect to height and the diameter of the pseudostems and the base and the canopy diameters of a clump of different Cardamom accessions when grown under low and high altitude conditions.

Based on the vegetative and reproductive characteristics studied, the Mysore and Vashukka types are the best for high altitude areas (1000 m AMSL) whereas Malabar type is the best type for low altitude (50-150 m AMSL). In high altitude, accession Ec 201 (Vashukka type) and Ec 700 (Mysore type) had 40 or more pseudostems with the highest proportion (79%) of reproductive pseudostems per clump. Accessions of the Malabar type have the least numbers (21) of pseudostems and also the percentage of reproductive pseudostems per clump. At low altitude, the total number of pseudostems was more than 27 in all the accessions evaluated and 62% were reproductive pseudostems in Malabar type and less than 55% in the other two types. According to Attygalle (1988), in *E. cardamomum* variety *major* in low altitude, had 43-82% reproductive pseudostems per clump.

Malabar type accessions have thinner pseudostems compared to the other accessions at both low and high altitudes. Pseudostem diameter has positive correlation with the yield, only at high altitude. Although, Sasikumar *et al.* (1999) reported that the Malabar type are medium size plants, accessions Ec 101 and Ec 102 (Malabar type) were taller than some of the Vashukka type accessions studied at high altitude; but at low altitude, Malabar type plants were the shortest.

Diameters at clump base of the accessions varied without any pattern or relationship; but diameters of clump canopy of Vashukka and Mysore types were higher than that of Malabar type at all locations. Therefore, plant spacing for Malabar type accessions could be reduced to maintain the yield.

The leaflet characteristics are useful to differentiate accessions. The highest number of leaflets are in Ec 700. This is positively related with the height of the pseudostem (0.54) irrespective of altitude (Table 4 and 5). Length (0.59) and width (0.63) of the leaflets were also positively related with the yield of Cardamom. Liyanarachcige *et al.* (1991) also reported that the length of the leaflet is highly associated with yield. At high altitude light green leaflets were observed only in Malabar type, whereas in low altitude lighter green leaflets were observed in all the accessions. Though, the silky texture of the leaflet (under surface) is a general character of Malabar type (Anon., 1996), accession Ec 101 has less silkiness like some Vashukka accessions (Ec 300 and Ec 405). It shows that silkiness of leaflet under surface is not a distinguishing characteristic for the Malabar type. However, the length, width, colour and texture of leaflets could play an important role when selecting Cardamom accessions for yield improvement programs.

It is difficult to measure the rhizome and root characteristics, because of the high variability (Table 4 and 5). Though, the results of rhizome inter-nodal length and diameter were presented, it is difficult to assume these characters as genetically inherited from the results of this study alone. Rooting depth and spread are correlated with plant height (0.67) and higher values were observed at high altitude where the shoot growth was highest, irrespective of the accession.

Panicle orientation is the major criterion to differentiate types of Cardamom (Anon., 1996); but it is also difficult to measure the panicle angles from the ground. At initiation of panicles they seem to be horizontal, and then with maturation they gradually change their gradient to the ground. Accessions Ec 100 and Ec 103 (Malabar type) have prostrate panicles, running almost on the surface of the ground (Table 6 and 7). Other Malabar type accessions have below 20^0 angles to the ground irrespective of the altitude. Similarly, it is difficult to differentiate Mysore and Vashukka type accessions at the early stages of panicle development, but with maturation the panicles grow erect in the Mysore type or remain intermediate in the Vashukka type. Erect or intermediate type, longer panicles have some tendency to bend to the ground. However, the general panicle angle of an accession did not significantly change with altitude.

Panicle number per clump is also highly correlated with yield. The correlation coefficient is 0.66 according to Liyanarachchige *et al.* (1991) and it is 0.645 according to Patil *et al.* (1998). But at low altitude, the number of panicles per clump was 17-22 was in Mysore and Vashukka type accessions (except in Ec 400), yielding below 286 capsules/clump/yr., compared to 25-29 in Malabar type (Ec 100, Ec 101 and Ec 102) and Vashukka type (Ec 400) accessions yielding over 534 capsules/clump/yr. (Table 6, 7 and 9). Therefore, the number of panicles per clump is not a good criterion to select Cardamom accessions for low altitude.

In each of the clumps in all accessions studied at high altitude and at low altitude Ec 400 alone had at least some pseudostems with 4 panicles each, (Table 6 and 7). This character could be taken as a yield component to select accessions for low altitude.

Length of the panicle is positively correlated with yield. The correlation coefficient is 0.64 according to Liyanarachchige *et al.* (1991), and it is 0.559, according to Patil *et al.* (1998). At high altitude, longer panicles were observed compared to that at low altitude in all accessions. However, the correlation between the panicle length and yield is not true for all the accessions, because some accessions (*eg*: Ec 403) had short and compact panicles (<70 cm), which gave more than 600 capsules/clump/yr. Therefore, panicle length appears to be a result of the gene - environment interaction (Table 6 and 7).

Cincinni number in first 20 cm length of the panicle is an indicator of the inter-nodal length. Ec 300, Ec 403 and Ec 405 had the shortest inter-nodal length whereas Ec 103 and Ec 104 (Malabar type) had the longest. The panicle internodal length appears to be a strong hereditary character that could be used to differentiate the accessions.

Flower stalk number per cincinus has very high correlation (0.87) with yield of accessions at high altitude, but at low altitude this correlation is less (0.46) (Table 6, 7, 8 and 9). This may be because all the accessions for this study were selected from the high altitude areas.

Number of capsules per cincinus after harvesting at high altitude ranged from 3.1 to 4.2 in all accessions and between 1.8 to 2.8 at low altitude (Tables 7 and 8). This indicates that a longer time is taken to open the adjacent flower buds along a cincinus at low altitude than that at high altitude. The time taken to mature the capsules also differs with the accessions and the environment.

Number of ovules per ovary acts as an inherited character of an accession and does not significantly vary with the environment. Therefore, the ovule to seed conversion factor is very high (>75%) in all accessions studied at high altitude whereas at low altitude it is high (>80%) only in some accessions (Ec 100, Ec 101, Ec 102 and Ec 400) (Tables 6 - 9). Though, George and Jayasankar (1983) reported that each capsule contains 15-20 seeds at high altitude; however, this varies with altitude and it may be that under low altitude conditions, some ovules of some accessions (Ec 401, Ec 405, Ec 700) having low number of seeds (9 seeds/capsule) may not have been fertilized.

All the capsule characteristics studied which did not differ significantly with the environmental changes, may be strongly inherited. Length, width, fresh weight and dry weight of capsules showed small increments at high altitude, the climate favorable for Cardamom (Tables 8 and 9). According to Patil *et al.* (1998), a negative correlation was observed between fresh yield/clump and dry capsules per kg (-0.486). Accessions Ec 200, Ec 201, Ec 400 and Ec 405 gave more than 1 g per fresh capsule and accessions Ec 201, Ec 300, Ec 400 and Ec 405 gave more than 0.2 g dry weight per capsule. Therefore, the accessions could be differentiated according to the size and weight of capsules.

Capsule shape also behaves as an inherited character that can be used for differentiation of accessions, but the capsule colour changes with the environmental factors. In the experimental sites at low altitude, lighter green capsules could be observed compared to that at high altitude.

Accessions Ec 201 was the best accession for high altitude. It gave more than 2000 capsules per clump per year. Other better yielding accessions were Ec 300 (1016 capsules/yr.), Ec 301 (1183 /yr.), Ec 401 (1051 /yr.) and Ec 700 (1061 /yr.). The best accession at low altitude was Ec 400, which yielded over 600 capsules per clump per year and the other promising accessions were Ec 100, Ec 101 and EC 102 that yielded over 500 capsules. These accessions could be recommended to grow under the respective agro-ecological conditions.

Ranking positions of the studied characteristics of all the Cardamom accessions studied under high and low altitudes are summarized in the table 10 and their values are given in tables 2-9. Therefore, the information gathered in

this study could be used as a guide to differentiate the accessions of cardamom with respect to their suitability for different altitudes.

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