Elevation Determines the Productivity of Large Cardamom (Amomum subulatum Roxb.) Cultivars in Sikkim Himalaya

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Abstract

Large cardamom (*Amomum subulatum* Roxb.) is an economically important cash crop that provides a livelihood option for the rural communities in the Khangchendzonga Landscape (KL), including Sikkim and supports a large value-chain of diverse stakeholders across the globe. This study explores the influence of elevation on yield-related traits of the large cardamom cultivars grown at different elevations in Sikkim. We evaluated twelve morphometric traits, including eight yield-related traits (number of capsules per spike, capsule length, capsule width, fresh capsule weight, dry capsule weight, number of seeds per locule, fresh seed weight, and dry seed weight) in five large cardamom cultivars (Dzongu Golsey, Sawney, Seremna, Ramsey, and Varlangey) from Sikkim, cultivated at 41 different locations with elevation ranging between 975–2069 m asl. The statistical analysis indicated a significant variability ($P < 0.05$) in morphometric traits including yield-related traits (except capsule length and width) in five large cardamom cultivars. The cultivars cultivated at an elevation below 1500 m, such as Dzongu Golsey, Sawney, and Seremna, had higher values for yield-related traits than those growing at elevations above 1500 m, and the yield-related traits were negatively correlated with the elevation. Likewise, Varlangey and Ramsey, cultivated above 1500 m elevation, performed better than the same cultivars grown below 1500 m of elevation and depicted a positive correlation between elevation and yield-related traits. The study revealed that the elevation determines the performance of the larger cardamom progression, and suggests cultivating the cultivars in their suitable elevation range for better productivity.

Introduction

Large cardamom (*Amomum subulatum* Roxb., family-Zingiberaceae) is one of the most ancient spices (Bhutia et al. 2018) and the third most expensive spice after saffron and vanilla[1]. It is native to the eastern Himalayan region and probably domesticated first by the indigenous Lepcha tribe of Sikkim in India, and later was passed on to the neighboring district of Darjeeling in West Bengal (India), southern Bhutan, and eastern Nepal[2]. The plant is a perennial shrub, which has several tillers consisting of pseudo-stems with leaves appearing on the upper part and an inflorescence (spike) arising from the rhizome. It is typically a cross-pollinated plant but is also capable of self-pollination. It grows well under agroforesty systems (*Alnus nepalensis* D. Don, *Terminalia myriocarpa* Van Heurck, and Mull. Arg., *Bucklandia populnea* R. Br. Ex Griff., *Macaranga indica* Wight, *Edgeworthia gardneri* (Wall.) Meisn., *Viburnum coriaceum* Blume, *Maesa chisia* D. Don, *and Symplocos ramosissima* Wall. ex G. Don)[2]. Its seeds are used to add flavor to various food and vegetable recipes, and contains 3% essential oil which is rich in cineole as well as possesses medicinal properties like a cardiac stimulant, diuretic, carminative, stomachic, and anthelmintic[3]. Because of being a high-value cash crop, it is often termed a "currency crop"[4].

The large cardamom is a major source of income generation for farmers in the eastern Himalayan region, including Sikkim and West Bengal in India; eastern Nepal; and Southern Bhutan[2, 5]. At present, India and Nepal possess a major stake in the production of large cardamom[6, 7]. In the context of India, Sikkim is the largest producer of large cardamom, which contributes to about 88% of the total production in the country[8, 9]. Approximately 22.7% (17735 ha; 2.49% of the total geographic area) of the total agricultural area in Sikkim is under the cultivation of large cardamom, which during 2017-18 produced approximately 4385 MT of large cardamom[10]. Nearly 14.34% of the total households in Sikkim cultivate large cardamom[8], in subtropical to temperate eco-climatic zone with an elevation ranging between 600–2000 m[2]. Recently, the production of this cash crop has declined sharply, affecting the income of cardamom-growing farmers in Sikkim and jeopardizing their livelihoods[6,11–13].

There are six cultivars of large cardamom identified from Sikkim (*viz.* Dzongu Golsey, Sawney, Seremna, Ramsey, Ramla, and Varlangey), and each cultivar is suitable within a specific elevational range[14, 15]. For example, Dzongu Golsey, Sawney, and Seremna are suitable at low to mid-elevation (600–1500 m), whereas Ramsey, Ramla, and Varlangey are suited for elevation above 1500 m[14, 15]. However, mostly in Sikkim and other parts of eastern Himalaya, all six large cardamom cultivars are grown randomly at different elevations ranging from 600–2500 m without giving due consideration to their suitable habitat.

The yield-attributing traits of the plants are significantly influenced by the climatic conditions exposed during different developmental stages[16]. Some of the plants are locally adapted to specific climatic conditions, beyond which their performance declines[17]. Such plants require an optimum elevation for biomass production, and the net photosynthetic rate and enzymatic activity decrease or increase when the optimum elevation is changed[18–20]. Elevation can significantly influence microclimatic conditions as it affects temperature, humidity, sunlight hours, UV-B radiation, water deficits, and other environmental factors[21]. For example, temperature decreases by a lapse rate of 0.52–0.65 C with every 100 m rise in elevation[22], while shortwave solar radiation increases with increasing elevations[23, 24]. Various environmental factors like air temperature, humidity, and solar radiation exposed to plants as well as water and nutrients absorbed by them differ at different elevations[25, 26]. Thus, plants alter their physiological and morphological characteristics in response to environmental conditions regulated by the elevational gradients[27, 28]. In large cardamom, a significant influence of elevation and plantation types on chlorophyll content and Normalised-Difference Vegetation Index (NDVI) has been observed[29]. However, studies on the influence of elevation on other biochemical, morphology, and yield-attributing traits are still scanty.

Different cultivars of the large cardamom in Sikkim and other parts of the Eastern Himalayas are thriving and producing yields beyond their suitable elevational range. But, whether there is a significant difference in the morphological and yield-related traits of the cultivars of large cardamom cultivated at and beyond their suitable elevational range is not been studied so far. This study aims to determine how elevation influences the morphology and yield-related traits in the cultivars of large cardamom. For this purpose, we analyzed twelve morphological traits, including eight yield-related traits, in each of the five cultivars (Dzongu Golsey, Sawney, Seremna, Ramsey, and Varlangey) grown in 41 different locations in Sikkim at varying elevations ranging from 975–2065 m (asl).

Results

Morphometric variability among large cardamom cultivars

Out of twelve morphometric traits evaluated in the study, eight were yield-related traits (number of capsules per spike, capsule length, capsule width, fresh capsule weight, dry capsule weight, number of seeds per locule, fresh seed weight, and dry seed weight). The one-way analysis of variance (ANOVA) revealed significant variability ($P < 0.05$) among cultivars for most of the morphological traits, except for the leaf length (Table 1). Among the twelve traits, the dry weight of seed, which ranged from 1.36 g – 32.16 g with an average of 9.85 g, had the maximum coefficient of variation (CV = 43.66%), and the capsule width, which ranged from 12.52 g – 21.96 g with an average of 16.92 g, had the minimum coefficient of variation (CV = 12.83%).
The twelve morphometric traits among all five cultivars of large cardamom were also compared (Table 2). The Varlangey was identified as the tallest among the large cardamom cultivars with an average plant height of 2.19 m bearing a maximum number of leaves (an average of 10). Whereas the Dzongu Golsey was identified as the shortest, with an average height of 1.45 m, bearing a minimum number of leaves (approximately 7). The Varlangey had the maximum value for the dry weight of the capsule (7.67 g), followed by Seremna (7.31 g), Dzongu Golsey (6.40 g), Ramsey (5.68 g), and Sawney (5.17 g). Likewise, the maximum value for dry seed weight was observed for Seremna (11.40 g), followed by Varlangey (10.23 g), Dzongu Golsey (9.67 g), Ramsey (9.59 g), and Sawney (7.28 g). The cultivar Varlangey had the maximum number of capsules per spike (average 13) and Ramsey had the minimum (average 11).

Morphometric variability among large cardamom grown at different elevations

The morphometric traits between the five cultivars grown at different elevations were compared (Table 3). The Seremna cultivar was found cultivated at the six plantation sites with an elevation ranging between 975 and 2069 m (Table 1). The morphometric traits (such as plant height, leaf length, leaf width, number of capsules per spike, number of seeds per locule, fresh seed weight, and dry seed weight) differed significantly ($P < 0.05$) among Seremna cultivated at different elevations. For the number of leaves per tiller, capsule length, capsule width, fresh capsule weight, and dry capsule weight, the difference was statistically insignificant ($P > 0.05$). We also performed a correlation analysis to determine the relationship between the morphometric traits of each cultivar of large cardamom and the elevation (Fig. 1). In the case of Seremna, the elevation had a significantly high negative correlation ($P < 0.05$) with the number of seeds per locule (R = -0.80) and fresh seed weight (-0.70), and a moderate negative correlation ($P < 0.05$) with plant height (-0.50), leaf width (-0.50), number of capsules per spike (-0.50), fresh capsule weight (-0.60), and dry seed weight (-0.60), respectively (Fig. 1).

Likewise, Dzongu Golsey was found growing in four plantation sites between an elevational range 1100–1842 m. Significant variability ($P < 0.05$) was observed for plant height, number of leaves per tiller, leaf width, fresh seed weight, and dry seed weight among Dzongu Golsey grown at four different elevations.

For the remaining traits, the differences were statistically insignificant ($P > 0.05$). The correlation analysis revealed a significantly high negative correlation ($P < 0.05$) between elevation and fresh seed weight (-0.70) and dry seed weight (-0.90), respectively (Fig. 1). Although a negative correlation existed between elevation and plant height, leaf length, leaf width, fresh capsule weight, dry capsule weight, and number of seeds per locule, the correlation was statistically insignificant ($P > 0.05$). Similarly, Sawney was recorded from five plantation sites located between the elevation range 1441–1926 m. A significant difference ($P < 0.05$) in morphometric traits among Swaney cultivars from five elevations was recorded only in the dry capsule weight. A significant negative correlation ($P < 0.05$) was observed between elevation and dry capsule weight (-0.80) and dry seed weight (-0.60), respectively (Fig. 1).

The cultivar Ramsey was found at ten plantation sites with elevations ranging from 1209–1783 m. There was a significant difference ($P < 0.05$) in plant height, capsule width, and fresh seed weight among Ramey cultivated at different elevations. For the rest of the traits, the difference was statistically insignificant. There was a significant moderate positive correlation ($P < 0.05$) between elevation and the number of capsules per spike (0.40), number of seeds per locule (0.60), dry capsule weight (0.50), and dry seed weight (0.60), respectively (Fig. 1). The cultivar Varlangey was found at sixteen sites between elevational range 1495–2069 m. Significant differences ($P < 0.05$) were observed in plant height, number of leaves per tiller, leaf length, number of capsules per spike, fresh capsule weight, fresh seed weight, and dry seed weight. There was a significant moderate positive correlation ($P < 0.05$) between elevation and leaf width (0.30), number of seeds per locule (0.60), fresh seed weight (0.40), and dry seed weight (0.60), respectively (Fig. 1).

Variability in yield-related traits at two elevational ranges

The Seremna, Dzongu Golsey, and Sawney cultivars of large cardamom are best suited at an elevation between 900 and 1500 m[14, 15], however, our observations showed that they are being grown at sites with an elevation of more than 1500 m. Likewise, Ramsey and Varlangey cultivars are preferred at elevations above 1500 m[14, 15], but this study showed that their cultivation has shifted to sites with an elevation of less than 1500 m. Therefore, we divided the cardamom plantation sites of each cultivar into two elevational ranges (below 1500 m and above 1500 m) and compared the yield-related traits for each cultivar grown at these two elevational ranges (Fig. 2).

In Seremna cultivar grown at sites below 1500 m, the average values for yield-related traits like the number of capsules per spike (12), fresh capsule weight (42.62 g), dry capsule weight (8.10 g), number of seeds per locule (20), fresh seed weight (30.79 g), and dry seed weight (13.28) were significantly higher ($P < 0.05$) than those grown at the sites above the 1500 m (Fig. 2). Although the values for capsule length (22.96 mm) and capsule width (18.16 mm) were slightly higher in the Seremna grown below 1500 m, the values were statistically insignificant (Fig. 2). In the Dzongu Golsey, the average values for the number of seeds per locule (21), fresh capsule weight (44.24 g), and dry seed weight (7.29 g) were significantly greater ($P < 0.05$) in the same plants grown at the sites below 1500 m than those grown above 1500 m (Fig. 2).

In the case of the Sawney, yield-related traits like the number of seeds per locule (19), fresh seed weight (32.33 g), and dry seed weight (11.59) were significantly higher ($P < 0.05$) for the cultivar grown at the sites below 1500 m compared to the that grown above it (Fig. 2). The Ramsey cultivar grown above 1500 m had significantly higher ($P < 0.05$) values for dry capsule weight (6.88 g), number of seeds per locule (13.73), and dry seed weight (11.06 g) than that grown below 1500 m (Fig. 2). Although yield-related traits like the number of capsules per spike (12), capsule length (22.97 mm), capsule width (16.04 mm), fresh capsule weight (38.91 g), and fresh seed weight (27.02 g) were slightly higher in the Ramsey grown above 1500 m than below 1500 m, the differences were statistically insignificant (Fig. 2). In this study, plantation sites for the Varlangey cultivar were located at their preferred elevation (i.e. above 1500 m).

Discussion

In this study, we found that the elevation of 41 large cardamom cultivation sites in Sikkim ranged from 975–2096 m. According to the large cardamom cultivation manual[14, 15], each cultivar of the large cardamom is suitable for a specific elevational range. But, this study revealed that the farmers in Sikkim are not considering the preferred elevational range of the respective cultivars while cultivating this cash crop. This is because the large cardamom is a high-value, low-volume, non-perishable perennial cash crop[29], thus, the farmers in Sikkim are transplanting the large cardamom plants on their agricultural land randomly, just to generate income and run their livelihood.

We observed a significant variability for the majority of morphometric traits in Seremna and Varlangey followed by Dzongu Golsey, Ramsey, and Sawney cultivars. This variability might have arisen due to the change in precipitation, temperature, and soil characteristics[30] along elevations. The previous study by Singh et al.[29] suggested that elevation and plantation types contribute significantly to the variability of chlorophyll content and NDVI in large cardamom. Similar studies on other crop plants like rice (*Oryza sativa* L.)[31], pea (*Pisum sativum* L.)[32], Cassava (*Manihot esculenta* Crantz)[33], mung bean (*Vigna radiata* (L.) R.Wilczek)[25], desho grass (*Pennisetum pedicellatum* Trin.)[34] and the plant like pink savory (*Satureja thymbra* L.)[26] suggested a significant influence of elevation on their biochemical constituents, nutritive value, plant height, grain yield, biological yields, and other morphological characteristics.

We found that the large cardamom cultivars such as Dzongu Golsey, Sawney, and Seremna, cultivated at the sites below 1500 m had higher values for yield-related traits than the same cultivars grown at elevations above 1500 m. The negative correlation between elevation and their yield-related traits such as the number of capsules per spike, number of seeds per locule, capsule length, capsule width, fresh weight of capsule, and dry weight of capsule, further suggested that these three cultivars are suitable at low to mid-elevations (900–1500 m). A similar trend was observed in mung bean where thousand-grain weight and biological yield were reduced with increasing elevation[25]. The yield, effective panicles, and grain per spike of rice also decreased with increasing elevation[31]. This suggests that the yield-related traits of the crop species adapted to a low to mid-elevation decline with the increase in elevation. Such variation in morphological and phenological traits along the elevational gradient is common in plants[17].

Likewise, the cultivar Ramsey cultivated above 1500 m was found to perform better than the same cultivar grown below 1500 m in terms of yield-related traits. We found a positive correlation between elevation and its yield-related traits, suggesting that the cultivar Ramsey is suitable for cultivation at an elevation above 1500 m. The cultivar Varlangey was found at sites with an elevation of 1500 m and above. This cultivar had higher values for most of the traits analyzed in this study than the other cultivars. Abbasi et al.[32] also suggested yield-related traits such as the number of seeds per pod, fresh seed weight plant, fresh seed yield per hectare, fresh pod yield per plant, etc. of peas cultivated at higher elevations (2124 m asl) were significantly higher than the one cultivated at low to mid-elevation (1508 m and 1645 m). Similar to the pea, yield-related traits of Ramsey, Varlangey, and Ramla decrease with decreasing elevation.

Elevation affects the growth and development of plants[35]. The locally adapted plants produce more biomass in their local environment (i.e., lowland plants yield more biomass in the lowland and high-elevation plants yield more biomass at high elevation)[17]. The performance of locally adapted plants declines beyond their specific climatic zone[17]. Based on the result of this study, the large cardamom cultivars such as Dzongu Golsey, Seremna, and Sawney are locally adapted to low and mid-elevations (600–1500 m), whereas Ramsey and Varlangey are adapted to higher elevations than 1500 m. Our result supports the elevational range for each cultivar prescribed in the large cardamom manuals of Sikkim[14] and Bhutan[15]. Therefore, the cultivation of large cardamom cultivars without considering their specific elevational range might be one of the factors contributing to the decline in large cardamom production in Sikkim.

The observations of this study highlights that the yield-related traits of the different cultivars of the large cardamom are influenced by the elevation and each cultivar is suitable at a specified elevational range. Therefore, the study suggests to consider the suitable elevational range of each large cardamom for better yield and productivity. But, more detailed studies on the influence of edaphic, micro-climatic, and other environmental factors on the yield of the large cardamom along the elevational gradient are required to strengthen our observation. Nonetheless, the adaptability of large cardamom cultivars to a wide range of elevations (above and below the preferred elevations) indicates its resilience to the changing climate and can be explored in the future to develop it as a climate-resilient crop.

Materials And Methods

Study area

The Khangchendzonga Landscape (KL) extends from 40 m to 8,586 m asl (Mount Khangchendzonga) and spreads over eastern Nepal, western Bhutan, and Sikkim and northern West Bengal in India. Sikkim (27°N latitude and 88°E longitude) with a total geographical area of 7096 km^2 - is one of the small states of India which falls within the KL region (Fig. 3) and is also a part of the eastern Himalayas - one of the biodiversity hotspots of the world. The state is endowed with rich biodiversity and agriculture is the main source of livelihood for more than 64% of its population[36]. The present study was carried out in 41 large cardamom cultivation sites located at three districts of Sikkim (East, North, and South) with latitude, longitude, and elevation ranging between 27°14'00.2"N – 27°25'23.8"N, 88°22'32.4"E – 88°37'50.6", and 975 m – 2069 m asl. Sikkim was selected as the study area because large cardamom is the major cash crop in Sikkim and contributes significantly to the national large cardamom production.

Data collection

Extensive field surveys were performed in 41 large cardamom cultivation sites to collect the morphometric data from 122 plant samples of five large cardamom cultivars; *namely*, Varlangey (48), Ramsey (30), Seremna (18), Sawney (14), and Golsey (12) (Table S1) during the March to October months of the year 2020 and 2021. Data for twelve morphometric traits such as plant height, number of leaves per tiller, leaf length, leaf width, number of capsules per spike, capsule length, capsule width, fresh capsule weight (weight of 10 fresh capsules), dry capsule weight (weight of dry 10 capsules), number of seeds per locule, fresh seed weight (weight of 100 fresh seeds), and dry seed weight (weight of 100 dry seeds) were recorded from the field as per the descriptor[15]. For data scoring, we used a manual measuring and counting method as relevant for the traits. Measurements of plant height, leaf length, leaf width, etc., were performed in the field without harming/destroying the plant. For measuring the length, width, and weight of capsules and seeds, we collected the capsules of the large cardamom from the field following institutional, national, and international guidelines and legislation with proper consent/permission from the concerned land owner/farmers of the study sites.

Statistical analysis

The above-mentioned morphometric data sets acquired from the large cardamom cultivation sites were observed as non-normal data sets which were transformed to a normal distribution using arcsin transformation. The transformed data set with normal distribution was used for parametric tests like one-way analysis of variance (ANOVA), Tukey’s test, and correlation. All statistical analyses, such as descriptive statistics (minimum, maximum, average, standard error), coefficient of variation (CV), one-way ANOVA, and correlation were performed using the R program[37].

Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data used in the study is provided in supplementary information (Table S2).

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Tables

Table 1 Variability of twelve morphological traits in large cardamom cultivars of Sikkim.

Traits (unit)	Abv[a]	Min[b]	Max[c]	Mean	CV%[d]	Sig[e]
Plant height (m)	PH	0.46	3.50	1.98 ± 0.046	25.85	***
No. of leaves per tiller	NLpT	5.00	13.00	9.00 ± 0.142	17.28	***
Leaf length (cm)	LL	38.30	85.50	60.61 ± 0.749	13.65	ns
Leaf width (cm)	LW	6.11	12.17	8.64 ± 0.102	12.99	**
No. capsule per spike	NCpS	4.00	21.00	12.00 ± 0.294	27.21	**
Capsule length (mm)	CL	16.59	33.57	23.44 ± 0.302	14.25	**
Capsule width (mm)	CW	12.52	21.96	16.92 ± 0.196	12.83	*
Fresh weight of capsule (g)	FWC	18.94	88.48	46.04 ± 1.419	34.05	***
Dry weight of capsule (g)	DWC	1.56	12.90	6.72 ± 0.231	37.95	**
No. of seed per locule	NSpL	6.00	31.00	14.00 ± 0.472	36.08	**
Fresh seed weight (g)	FSW	10.38	79.44	28.96 ± 0.828	31.58	**
Dry seed weight (g)	DSW	1.36	32.16	9.85 ± 0.390	43.66	*

[a]Abbreviations of traits, [b]minimum, [c]maximum, [d]coefficient of variation, [e]significance based on one-way ANOVA, ± standard error, *significant at $P < 0.05$, **significant at $P < 0.01$, ***significant at $P < 0.001$, [ns]non-significant.

Table 2 Comparison of twelve morphological traits among five cultivars of large cardamom from Sikkim.

Traits[a]	Dzongu Golsey	Sawney	Seremna	Ramsey	Varlangey
	Mean ± SE[b]	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
PH (m)	1.45 ± 0.18	2.01 ± 0.05	1.81 ± 0.12	1.96 ± 0.06	2.19 ± 0.08
NLpT	7.00 ± 0.51	9.00 ± 0.30	8.00 ± 0.22	8.00 ± 0.25	10.00 ± 0.21
LL (cm)	57.14 ± 2.99	62.12 ± 1.68	62.08 ± 1.82	59.07 ± 1.10	61.44 ± 1.36
LW (cm)	8.46 ± 0.41	8.02 ± 0.26	9.34 ± 0.31	8.31 ± 0.15	8.81 ± 0.15
NCpS	12.00 ± 0.60	12.00 ± 1.03	11.00 ± 0.73	11.00 ± 0.50	13.00 ± 0.52
CL (mm)	21.35 ± 0.68	23.37 ± 0.84	22.57 ± 0.82	22.37 ± 0.50	24.98 ± 0.48
CW (mm)	17.10 ± 0.71	16.17 ± 0.44	17.18 ± 0.55	15.99 ± 0.30	17.57 ± 0.32
FCW (g)	38.46 ± 3.02	38.76 ± 1.61	38.54 ± 1.96	38.50 ± 1.66	57.59 ± 2.49
DWC (g)	6.40 ± 0.79	5.17 ±0.70	7.31 ± 0.40	5.68 ± 0.48	7.67 ± 0.33
NSpL	16.00 ± 2.29	16.00 ± 1.23	15.00 ± 1.41	11.00 ± 0.73	15.00 ± 0.63
FSW (g)	25.08 ± 1.79	26.81 ± 1.82	26.92 ± 1.57	25.86 ± 1.18	33.28 ± 1.58
DSW (g)	9.67 ± 1.23	7.28 ± 1.00	11.40 ± 0.80	9.59 ± 0.73	10.23 ± 0.68

[a]Abbreviation of traits are same as in Table 1, [b]standard error capsules per spike (-0.50), fresh capsule weight (-0.60), and dry seed weight (-0.60), respectively (Fig. 2).

Table 3 Variability of twelve morphological traits within each large cardamom cultivar cultivated at different elevations.

Traits[a]	Dzongu Golsey		Sawney		Seremna		Ramsey		Varlangey	
	P-value	Sig.[b]	*P*-value	Sig.	*P*-value	Sig.	*P*-value	Sig.	*P*-value	Sig.
PH	0.011	*	0.982	ns	0.000	***	0.833	ns	0.027	*
NLpT	0.023	*	0.154	ns	0.234	ns	0.939	ns	0.001	**
LL	0.120	ns	0.404	ns	0.011	*	0.225	ns	0.018	*
LW	0.015	*	0.672	ns	0.001	**	0.610	ns	0.107	ns
NCpS	0.144	ns	0.347	ns	0.022	*	0.107	ns	0.017	*
CL	0.346	ns	0.461	ns	0.127	ns	0.212	ns	0.055	ns
CW	0.271	ns	0.233	ns	0.133	ns	0.825	ns	0.064	ns
FCW	0.212	ns	0.266	ns	0.217	ns	0.716	ns	0.002	**
DWC	0.581	ns	0.001	******	0.162	ns	0.009	**	0.067	ns
NSpL	0.100	ns	0.082	ns	0.002	**	0.002	**	0.055	ns
FSW	0.007	**	0.053	ns	0.000	***	0.457	ns	0.000	***
DSW	0.001	**	0.161	ns	0.015	*	0.022	*	0.000	***

[a]Abbreviation of traits are same as in Table 1, [b]significance, [ns]non-significant, *significant at the 0.05 level, **significant at the 0.01 level, ***significant at the 0.01 level.

Figures

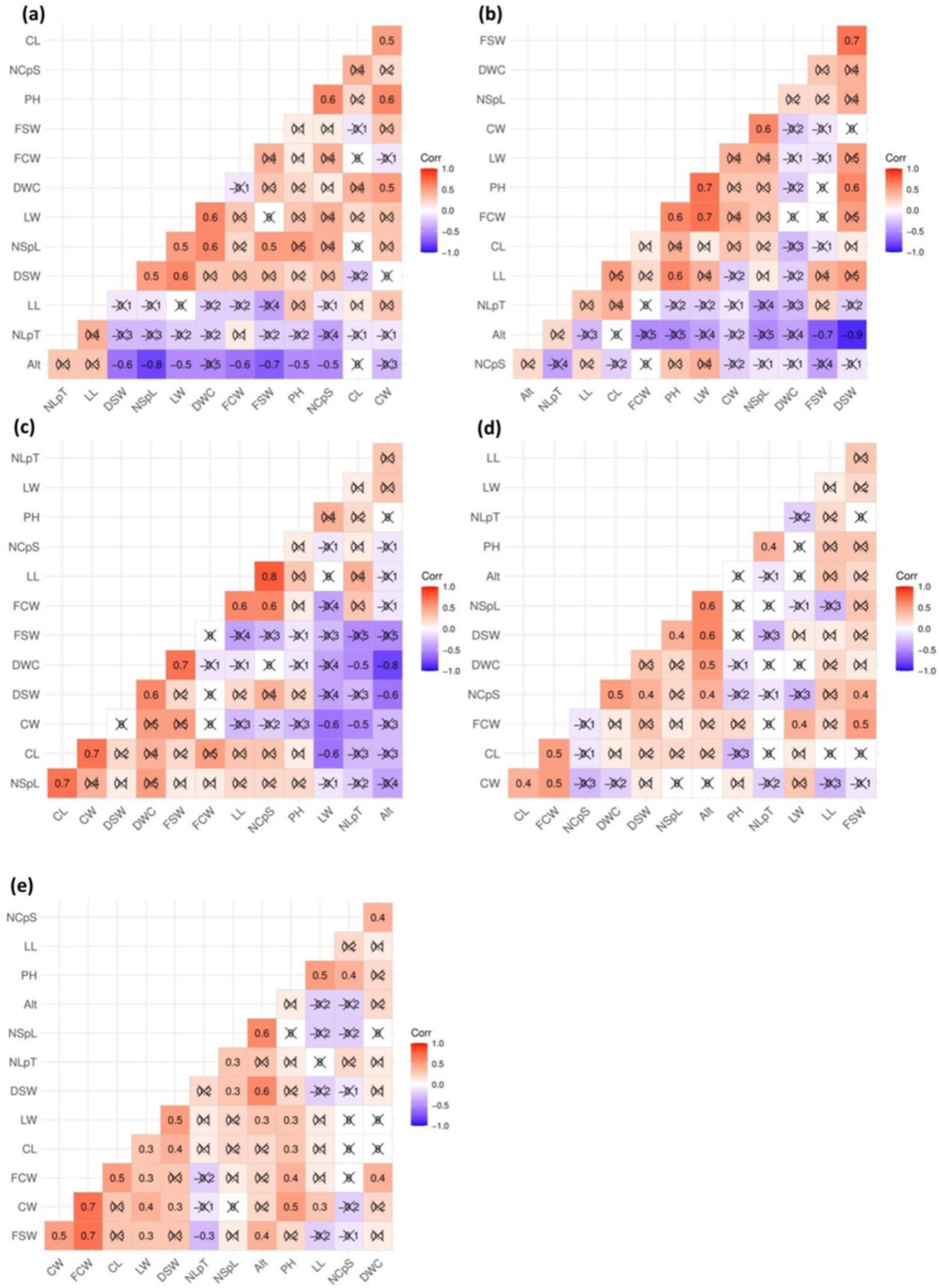

Figure 1

Correlation between twelve morphometric traits and elevation in five cultivars of the large cardamom. **(a)** Seremna **(b)** Dzongu Golsey **(c)** Sawney **(d)** Ramsey **(e)** Varlangey. *Note: Alt = elevation/elevation, PH = plant height, NLpT = number of leaves per tiller, LL = leaf length, LW = leaf width, NCpS = number of capsules per spike, CL = capsule length, CW = capsule width, FCW = fresh capsule weight, DCW = dry capsule weight, NSpL = number of seeds per locule, FSW = fresh seed weight, DWC = dry seed weight.*

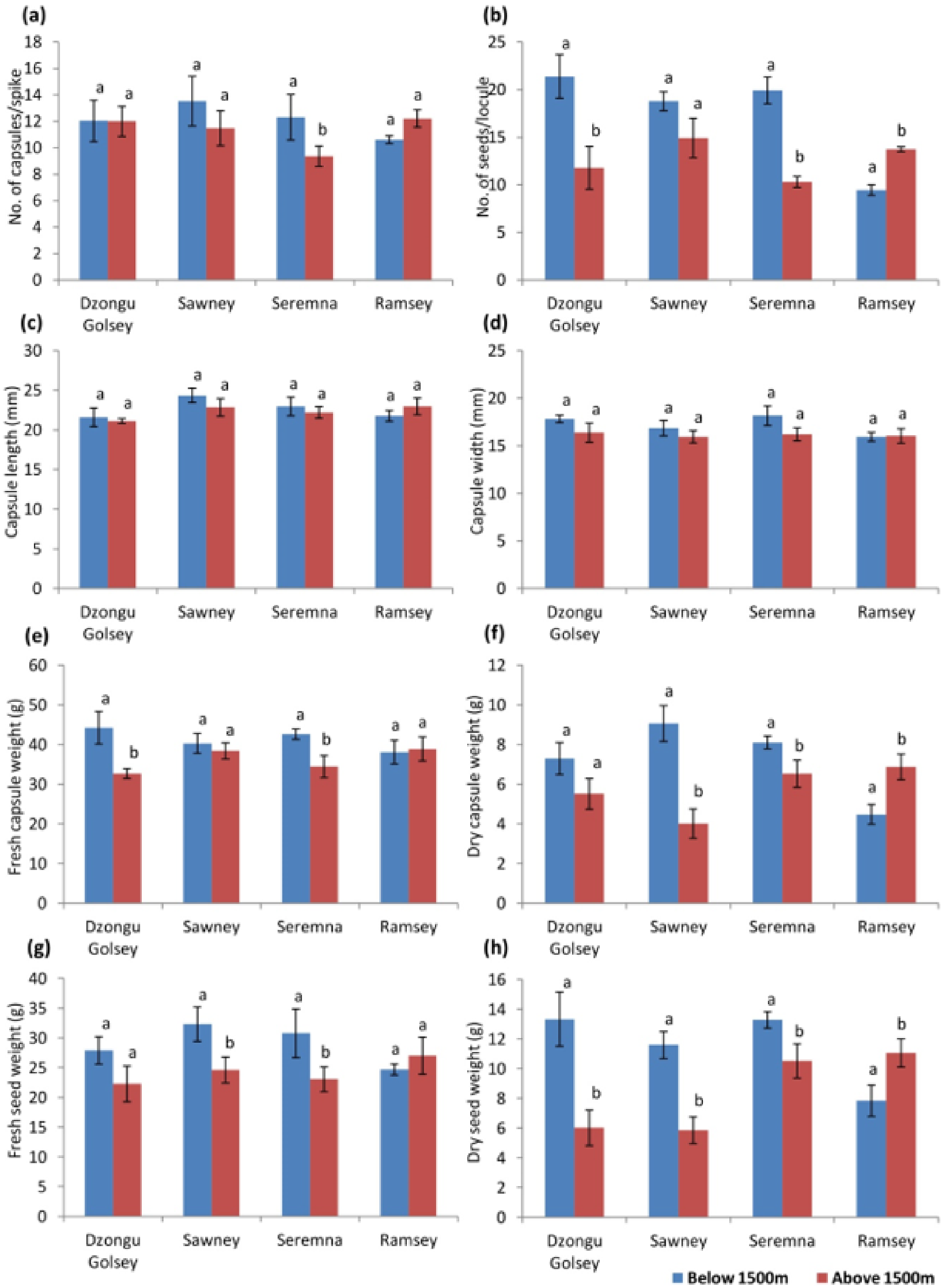

Figure 2

Comparison of yield-related traits within large cardamom cultivars cultivated at two elevational ranges (i.e., below 1500 m and above 1500 m) **(a)** Number of capsules per spike **(b)** Number of seeds per locule **(c)**Capsule length **(d)** Capsule width **(e)** Fresh capsule weight **(f)** Dry capsule weight **(g)** Fresh seed weight **(h)** Dry seed weight. *Note: the same alphabet on top of the graph means no significant difference and a different alphabet means a significant difference in trait.*

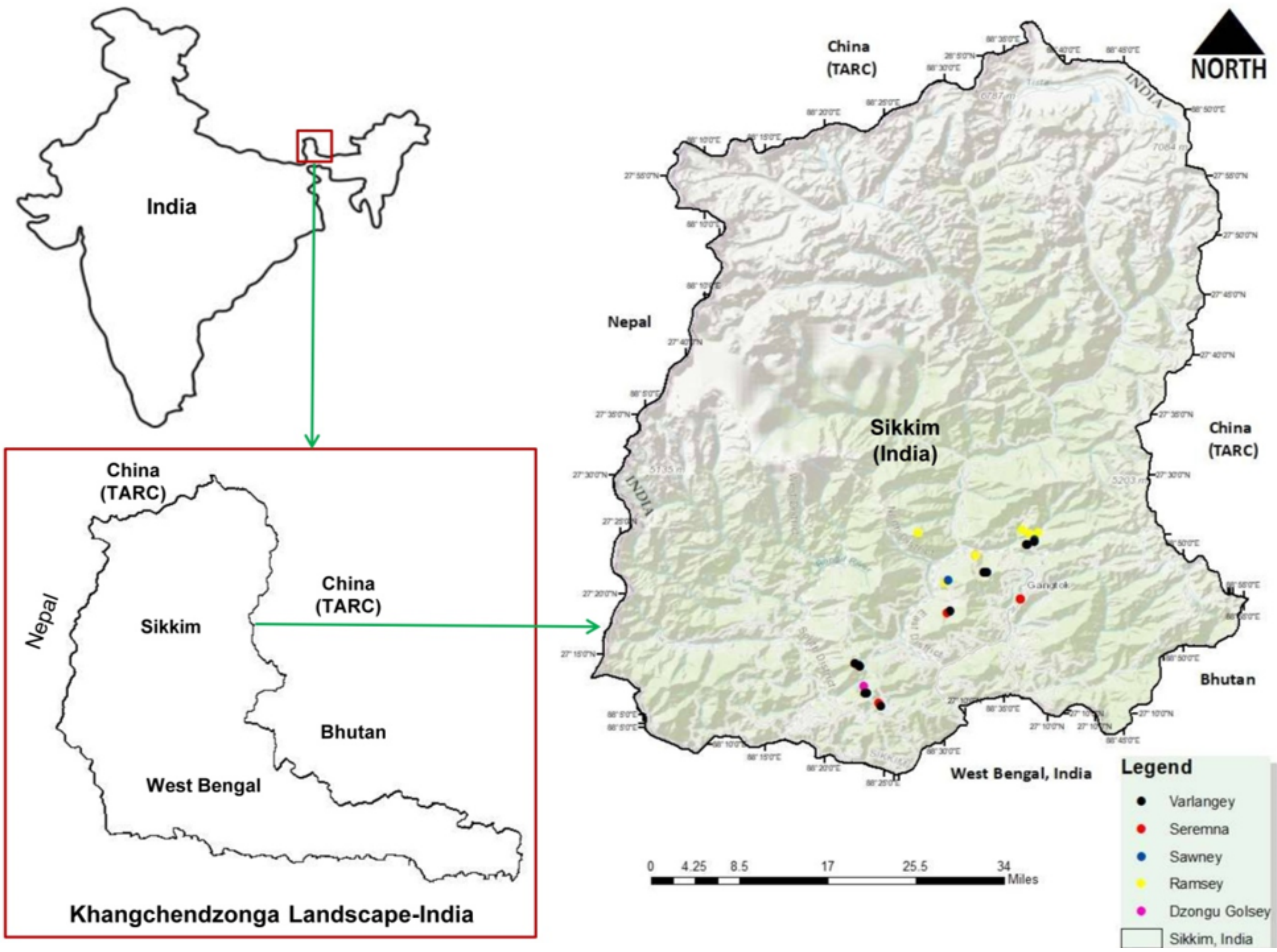

Figure 3

Study area under KL-India depicting plantation sites of five cultivars of large cardamom (Dzongy Golsey, Sawney, Seremna, Ramsey, and Varlangey) in three districts of Sikkim (East, South, and North).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryTable.xlsx