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DIVERSITY ANALYSIS AND RELATIONSHIPS AMONG GINGER LANDRACES

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Abstract

Ginger (*Zingiber officinale*) is a valuable spice and aromatic crop having medicinal significance. To have insight into variability pattern and relationships among ginger landraces, the current study was undertaken at University of Tsukuba, Japan using 32 morphological traits. The germplasm revealed high variance for plant height, rhizome weight, rhizome thickness, sheath length, tillers plant^{-1} and leaf length. Principal component analysis explained 80% and 90% of the total variation by the first four PCs during the year 2005 and 2006, respectively. The representative accessions acquired from the genebank remained dispersed in the three clusters during both the years displaying variability among accessions. The ginger accessions collected from local markets were found interspersed among all the clusters. Positive and significant correlation among different quantitative traits was observed. Plant height, leaves tillers^{-1}, and tiller thickness appeared to be of prime importance as they directly influence rhizome yield, and provide a good indication for future's emphasis in crop improvement in ginger. No relationship between distribution pattern and acquisition source was observed in this study. The different approaches used to analyze different aspects of ginger provided a deep insight and indicated existence of considerable variability and diverse base which has been prioritized for crop improvement.

Introduction

Ginger (*Zingiber officinale* Rosc.) is one of the most important species of the family Zingiberaceae and widely used spice around the globe. It has a long history of cultivation in India and China, and believed to be originated from Southeast Asia (Ravindran & Nirmal-Babu, 2005). It is found cultivated and not known in a wild state (Purseglove, 1981).

Ginger is one of the species that is prone to sexual-reproduction constraints, and the predominant mode of propagation is through vegetative means. The sexual-reproduction constraint in gingers, thus, restricts its improvement mainly to clonal selection. In such circumstances a high variability and broad genetic base become imperative to have sound basis for worth full selection (Siddiqui *et al.,* 2010; Nisar & Ghafoor 2011). However, for the meaningful breeding, conservation and sustainable utilization of the genetic resources, the foremost step is to know existing state of diversity of those particular taxa (Jan *et al.,* 2011).

Studies on genetic variability for yield and associated characters in ginger from India indicated the existence of only moderate to high variability in ginger. Characterization of gingers for morphological, yield and quality parameters displayed moderate diversity in the germplasm assayed (Ravindran *et al.,* 1994). Pandey & Dobhal (1993) highlighted a wide range of variability in ginger for various morphological traits. Sasikumar (1992) also investigated 100 ginger accessions and found considerable diversity coupled with significant correlations among different traits.

The literature pertaining to variability studies in gingers is mainly from India, China, Thailand and Malaysia. However, no such study on gingers from Myanmar is reported so far. Myanmar's topographic diversity and wide range of ecological niches constitutes rich spot for plant genetic resources (San-San-Yi *et al.,* 2008). Several studies have also documented high diversity profile in different crops from Myanmar like mango-ginger (Jatoi *et al.,* 2010), tomato (San-San-Yi *et al.,* 2008), banana (Wan *et al.,* 2005) and rice (Yamanaka *et al.,* 2004). Ginger types are classified according to plant stature and yield into three groups: (1) small-sized plants with many tillers and a small rhizome, (2) medium-sized plants with an intermediate number of tillers and a medium-sized rhizome, and (3) large-sized plants with fewer tillers and larger rhizomes. The long period of domestication might have played a major role in the evolution of this crop that is sterile and propagated solely vegetatively (Ravindran *et al.,* 2005).

The lack of study on gingers from Myanmar advocated the need to characterize diversity profile of this crop. The current study was initiated to determine patterns of germplasm variation in the ginger germplasm for diverse morphological characters and to identify groups of accessions using different multivariate statistical methods. Moreover, to see variability trend in Myanmar-ginger that was acquired from three sources viz., genebank, farm and market. In addition a comparative analysis was also made to study variability in Myanmar-ginger compared with ginger from other Asian countries.

Materials and Methods

Plant material: The source material consisted of 19 accessions of *Z. officinale*, of which 13 were acquired from Myanmar (Table 1). Among 13 accessions from Myanmar, 5 were acquired from genebank, 2 from farmers' collection and 6 from local markets. The collection was made mainly from central Myanmar (Shan State and Mandalay division) which is the major growing region of ginger, and it represented landraces and local cultivars. Six accessions from different Asian countries namely Japan, Pakistan, Malaysia and Bangladesh representing market samples were also included in this study.

Germplasm characterization: The study was conducted at Institute of Life and Environmental Sciences, University of Tsukuba, Japan (36º6'0 N latitude and

140º6’0 E longitude) during the year 2005 and 2006. The work reported here was carried out from March to December of the respective year. Mean maximum temperature at Tsukuba ranges from 30.9ºC (August) to 9.1ºC (December) and the mean minimum temperature varies from -3.8ºC (January) to -2.8ºC (December). This cold situation prolongs and even some time during April night temperature reaches freezing level. Ginger is basically long duration crop and remains in the field from April/May to Dec/Jan depending upon the agro-ecological conditions. In the current study rhizomes were sown in small pots under glasshouse conditions in the mid March and transplanted into large pots and shifted in the open field during mid of May 2005 and 2006.

The rhizome bits (approximately 15 g each) of 19 genotypes were transplanted in pots with 30 cm diameter and 45 cm height. The first layer of 2-3 cm soil at the bottom of pot consisted of big-granular soil (aka dame churyu, Katou Sangyo Co., Japan) to ensure better drainage of excessive water. Pre-mix soil (Hana to yasai no Baiyo do, Katou Sangyo Co., Japan) was, then, added partly prior to mixing of fertilizers. For fertilizers the recommended package of Anon., (1993) was followed. The experiment was laid out as non-replicated and 5 plants for each accession were planted. Partial shading over the gingers was managed by using shading net and it was removed in September.

Table 1. List of ginger (*Z. officinale*) germplasm accessions, their collection origin and collection source used in the present study.

Code	Accession	Source
1.	ZO4-1	Myanmar (Genebank)[1]
2.	ZO12-1	Myanmar (Genebank)
3.	ZO14-1	Myanmar (Genebank)
4.	ZO19-1	Myanmar (Genebank)
5.	ZO28-1	Myanmar (Local farm)
6.	ZO31-1	Myanmar (Local farm)
7.	ZO50	Myanmar (Market)
8.	ZO52	Myanmar (Market)
9.	ZO56	Myanmar (Market)
10.	ZO58	Myanmar (Market)
11.	ZO72-1	Malaysia (Market)
12.	ZO73-1	Japan (Market)
13.	ZO75-1	Myanmar (Genebank)
14.	ZO79	Bangladesh (Market)
15.	ZO81	Pakistan (Market)
16.	ZO84	Pakistan (Market)
17.	ZO85	Pakistan (Market)
18.	ZO87	Myanmar (Market)
19.	ZO88	Myanmar (Market)

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Ginger germplasm was characterized for 33 morphological traits (Table 2). Descriptive characters were recorded during the phase of active growth of gingers, whereas quantitative characters were recorded 6-7 months after plantation. Data for rhizome based characters were recorded after harvesting of ginger rhizomes. Observations for leaf characters were recorded for 3 leaves tiller^{-1}, 5 tillers plant^{-1} and 5 plants accession^{-1}. For sheath length and width 3 tillers plant^{-1} were used. Plant height was measured from soil surface to the highest point of the plant for the tallest tiller. Tiller width was recorded for 3 tillers for all plants of the each accession.

Data analysis: The data recorded for quantitative traits were subjected to different methods of multivariate statistics. Cluster and principal components analyses were performed to see the clustering and grouping pattern of ginger genotypes. A distance matrix based on the Euclidean dissimilarity coefficients between all pairs of entries was constructed, which was then used to perform cluster analysis. A correlation matrix based on quantitative characters was used to perform principal component analysis. The two analyses were carried out using numerical taxonomy based software NTSYS-pc (Numerical Taxonomy System, version 2.0; Rohlf, 2000). Descriptive statistics was employed to study variance for the quantitative characters. The association among different traits was determined through correlation coefficients. To study the significance of the variability over the years, analysis of variance was conducted using statistical software MSTATC (Bricker, 1991).

Results

Variability in general: A high to moderate variance for plant height, rhizome weight, rhizome thickness, sheath length, tillers plant^{-1} and leaf length was observed in the germplasm assayed during 2005 and 2006 (Table 3). The mean values for most of the traits assayed for the 19 ginger accessions were high in the first year compared with the second year (Fig. 3).

Distribution pattern of gingers: To know the variability and distribution pattern of gingers, principal component analysis was conducted. The cumulative contribution of the first four principal components (PCs) for variability amongst 19 genotypes evaluated for 12 quantitative traits was 81.97% and 97.08% in 2005 and 2006, respectively (Table 4). Out of 12 characters analyzed plant height, number of leaves tiller^{-1}, leaf length, sheath length and rhizome thickness and weight plant^{-1} contributed positively to PC1 during the both year. In contrast sheath width and tillers plant^{-1} contributed negatively to PC1 for the two years. Leaf width, leaf length/width ratio, ligule length and tiller width had positive contribution to PC1 during 2005 and in contrast these traits contributed negatively during 2006. PC1 accounted for 34.57% during first year, whereas its contribution was 67.71% in second year. Most of the characters contributing positively to first component were growth and yield related traits. Rhizome is the main plant part utilized multipurposely and all yield contributing traits exhibited high contribution to PC1. PC2 accounted for 19.30% and 18.48% of the total variance explained by PCA in first and second year, respectively. For PC2 seven characters contributed negatively in 2005 and four in 2006.

Table 2. Morphological traits and their description recorded in ginger (*Z. officinale*).

Parameter/Character	Description of the trait
Descriptive traits:	
Leaf shape	Deltoid, elliptic, lanceolate, linear, oblong
Leaf apex	Acuminate, Acute, Obtuse, Broadly Rounded, Truncate, Emarginate
Leaf base	Acute, obtuse, cuneate, oblique, cordate
Leaf color	Green, dark green, yellowish-green, light green
Leaf margins	Ciliate, crenate, dentate, serate, double serrate, entire
Leaf arrangement	Alternate, opposite, basal, equitant, imbricate
Leaf attachment pattern	Sessile, semi-sessile, petiolated
Leaf pubescence	No, low, intermediate, high
Leaf blade blistering	Low, intermediate, high
Ligule	Absent, membranous, fringe of hairs
Ligule color	Light green, green, yellowish green, whitish green, dark green
Ligule shape	Acute, obtuse, truncate, emarginate, bi-lobed
Ligule margins	Entire, notched, lacerate, ciliate
Collar region	Broad, narrow, divided, oblique, pubescent, ciliate
Collar pubescence	No, low, medium, high
Sheath type	Split, split but overlapping, closed
Sheath pubescence	No, low, intermediate, high
Sheath attachment	Semi-compact, compact, loose
Sheath color	Light green, green, dark green, yellowish green
Rating of plant foliage	Small, intermediate, large
Quantitative traits:	
Leaf length	Measurement from leaf-tip to the leaf-base
Leaf width	Measured at point of maximum width
Leaf length/width ratio	Ratio of the leaf length to leaf width
No. of leaves tiller^{-1}	Total number of leaves on the tillers
Ligule length	Measured from ligule base to its top point
Sheath length	Measured from ground surface to the ligule of top fully opened leaf
Sheath diameter	Measured for the top most fully opened leaf
Plant height	Height of plant from soil surface to its highest point
No. of tillers plant^{-1}	Counting all those tillers that emerged out of soil
Tillers width	At the base of tillers
Rhizome thickness	Measured at the thickest point of rhizome
Weight (g plant^{-1})	Weigh the rhizome on individual plant basis

To view the distribution of gingers accessions on the scatter plot, first two PCs were plotted (Fig. 1), which yielded an informative spread of the genotypes. In general there was a clear distinction among the groups separated from each other based on plant height, rhizome thickness and rhizome weight during the year 2005. Genotypes with high mean values for these characters were grouped together followed by medium and low mean values. However, two accessions (ZO84 and ZO58) appeared as unique spots on the plot showing divergence from rest of the genotypes. These traits can potentially be useful for the improvement of gingers. However, for the second year distribution pattern and placement of the accessions on the plot differed from the pattern that was observed during the first year (Fig. 1). Three accessions (ZO28-1, ZO50 and ZO81) appeared as divergent taxa from rest of the genotypes during the second year.

Relationships among gingers: Dissimilarity coefficients based on Euclidean distance ranged from 0.09 to 2.46 with the mean distance of 0.86 in the first year, whereas it ranged from 0.03 to 5.61 leading to the mean value of 1.28 in the second year (Table 6). The lowest distance in 2005 was observed between ZO72-1 and ZO73-1, and the highest between ZO19-1 and ZO84. For the year 2006 the lowest and the highest dissimilarity coefficients were observed between ZO84 and ZO31-1, and ZO28-1 and ZO31-1, respectively. Cluster analysis, in general, assigned ginger accessions into 3 clusters during both the years and the placement of accessions into different clusters during the two years was not the same (Fig. 2). In the first year accessions with high mean values for these traits were grouped together in cluster I and accessions on the similar basis were grouped together into cluster II during the second year (Fig. 2). No correspondence between collection source and clustering pattern was observed, instead clustering pattern reflected grouping based on quantitative characters. The grouping pattern was also complimented by the PCA.

The representative accessions acquired from the genebank remained dispersed in the three clusters during both the years displaying variability and scattered distribution. One of the two accessions from farmers' collection (ZO31-1) stayed in cluster II during both the years, whereas the other accession (ZO28-1) grouped in cluster I and Cluster III during 2005 and 2006, respectively. The ginger accessions collected from local markets were found interspersed among all clusters during both the years.

Table 3. Variability in ginger landraces based on different morphological traits for the year 2005 and 2006.

Trait	Mean ± SE	SD	Variance	Range
	2005			
Leaf length (cm)	21.13 ± 0.67	2.92	8.52	15.90(ZO84) - 25.00 (ZO81)
Leaf width (cm)	2.53 ± 0.07	0.32	0.10	2.10(ZO28-1) - 3.12 (ZO75-1)
Length /width ratio	8.52 ± 0.31	1.36	1.84	6.10(ZO85) - 11.57 (ZO28-1)
No. of leaves tiller^{-1}	19.05 ± 0.65	2.83	8.02	14.00(ZO81) - 23.17 (ZO87)
Ligule length (mm)	4.99 ± 0.22	0.96	0.92	3.76(ZO75-1) - 7.50 (ZO79)
Sheath length (cm)	46.36 ± 2.59	11.31	127.81	26.60(ZO28-1) - 68.30 (ZO85)
Sheath diameter (mm)	3.50 ± 0.17	0.75	0.57	2.47(ZO12-1) - 5.35 (ZO81)
Plant height (cm)	66.77 ± 2.74	11.94	142.48	41.20(ZO4-1) - 86.80 (ZO72-1)
Tillers plant^{-1} (No.)	7.68 ± 0.81	3.55	12.61	2.00(ZO85) - 16.20 (ZO88)
Tillers width (mm)	9.39 ± 0.43	1.86	3.47	4.50(ZO4-1) - 13.00 (ZO75-1)
Rhizome thickness (mm)	24.94 ± 1.30	5.67	32.10	15.80(ZO56) - 34.80 (ZO84)
Rhizome weight (g plant^{-1})	141.2 ± 19.55	85.20	7258.53	50.00(ZO58) - 385.00 (ZO84)
	2006			
Leaf length (cm)	18.97 ± 069	2.99	8.92	10.95 (ZO52) - 22.77 (ZO79)
Leaf width (cm)	2.56 ± 0.19	0.84	0.71	1.45 (ZO52) - 5.71 (ZO79)
Length /width ratio	7.72 ± 0.30	1.32	1.73	3.99 (ZO79) - 9.67 (ZO12-1)
No. of leaves tiller^{-1}	16.09 ± 0.49	2.12	4.51	12.78 (ZO4-1) - 20.89 (ZO73-1)
Ligule length (mm)	4.88 ± 0.16	0.71	0.51	4.0 (ZO4-1) - 6.23 (ZO56)
Sheath length (cm)	35.25 ± 2.34	10.20	104.07	17.33 (ZO52) - 51.58 (ZO12-1)
Sheath width (mm)	3.84 ± 0.12	0.51	0.26	3.0 (ZO52) - 5.28 (ZO85)
Plant height (cm)	58.49 ± 3.43	14.96	223.82	20.40 (ZO52) - 77.0 (ZO75-1)
Tillers plant^{-1} (No.)	5.76 ± 0.72	3.15	9.93	1.0 (ZO52) - 14.67 (ZO12-1)
Tillers width (mm)	8.34 ± 0.31	1.34	1.78	5.30 (ZO52) - 11.06 (ZO72-1)
Rhizome thickness (mm)	24.31 ± 1.14	4.96	24.60	15.42 (ZO52) - 33.25 (ZO84)
Rhizome weight (g plant^{-1})	115.57 ± 14.18	61.82	3822.27	40.0 (ZO52) - 231.67 (ZO73.1)

Table 4. Principal components of the 12 quantitative traits in ginger genotypes assayed during the year 2005 and 2006.

	2005				2006			
	PC1	**PC2**	**PC3**	**PC4**	**PC1**	**PC2**	**PC3**	**PC4**
Eigen value	4.148	2.315	2.161	1.212	8.125	1.939	0.937	0.354
Percent	34.568	19.296	18.007	10.102	67.71	16.16	7.81	2.95
Cumulative	34.568	53.864	71.871	81.973	67.71	83.86	91.68	97.08
	Eigen vector				**Eigen vector**			
Leaf length (cm)	0.551	0.636	0.089	0.475	0.9219	0.0834	0.0867	0.2477
Leaf width (cm)	0.284	-0.344	-0.741	0.453	-0.9533	-0.1820	0.0915	-0.1171
Length /width ratio	0.242	0.732	0.571	0.133	-0.4215	0.7121	-0.4932	-0.0783
No. of leaves tiller^{-1}	0.756	-0.284	0.438	0.011	0.5742	0.6920	-0.2948	0.1146
Ligule length (mm)	0.427	0.720	-0.040	-0.069	-0.9404	0.0466	-0.1534	-0.1749
Sheath length (cm)	0.626	-0.082	-0.358	0.167	0.8373	-0.2891	-0.2605	-0.3315
Sheath width (mm)	-0.091	0.540	-0.527	-0.579	-0.9849	0.0071	0.0999	-0.0183
Plant height (cm)	0.914	0.055	0.018	-0.018	0.8793	-0.4120	0.0215	0.0083
Tillers plant^{-1} (No.)	-0.029	-0.444	0.780	0.063	-0.8046	-0.4070	-0.2607	0.3219
Tillers width (mm)	0.709	-0.274	-0.190	0.052	-0.8876	0.1110	0.3559	-0.0368
Rhizome thickness (mm)	0.838	-0.124	-0.101	-0.182	0.5159	0.6363	0.5404	-0.0659
Rhizome weight (g/plant)	0.713	-0.263	0.155	-0.596	-0.9104	0.2742	0.0555	0.0996

The only accession from Japan and Malaysia constituted a sub-cluster in Cluster-I during 2005, whereas the same accessions were placed in cluster-II when analyzed for the second year. The three accessions from Pakistan were assigned each to cluster I, II and III during the second year, whereas in first year two of the accessions (ZO81 and ZO85) grouped together in Cluster II and ZO84 was placed in cluster I. The only accession from Bangladesh was placed in the cluster II and Cluster III during the year 2005 and 2006, respectively.

Cluster-I, during the year 2005, comprised the genotypes with high mean values for leaves tiller^{-1}, plant height, tillers plant^{-1}, tillers width, rhizome thickness and rhizome weight. During the year 2006, cluster II may correspond to the cluster I in 2005 by grouping accessions with high mean values for different traits (Table 5). The order of clusters based on yield contributing traits in 2005 were cluster I, II and III which may correspond to cluster II, III and I in the second year.

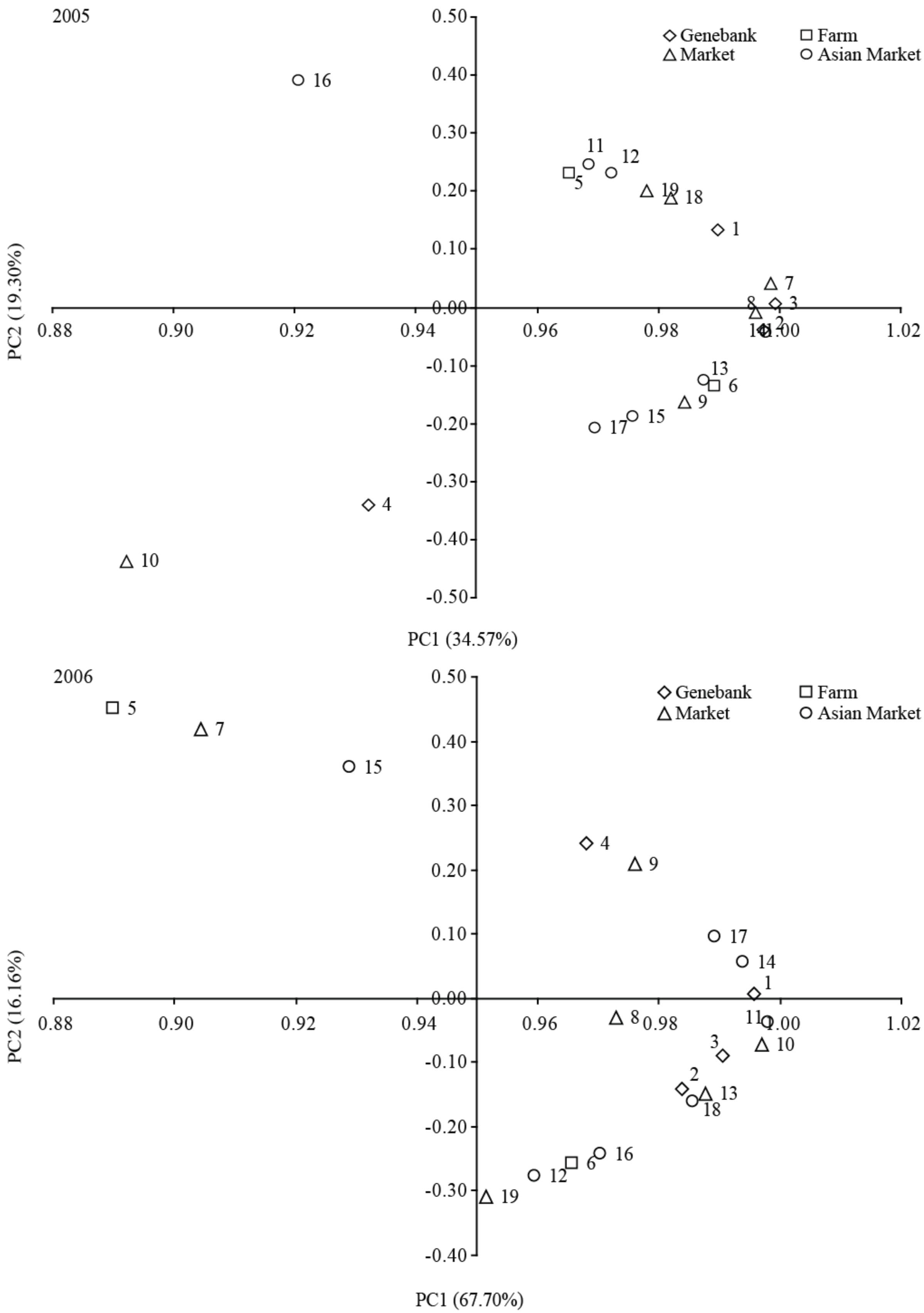

Fig. 1. PCA scatter plot showing distribution pattern of the ginger genotypes for the year 2005 and 2006.

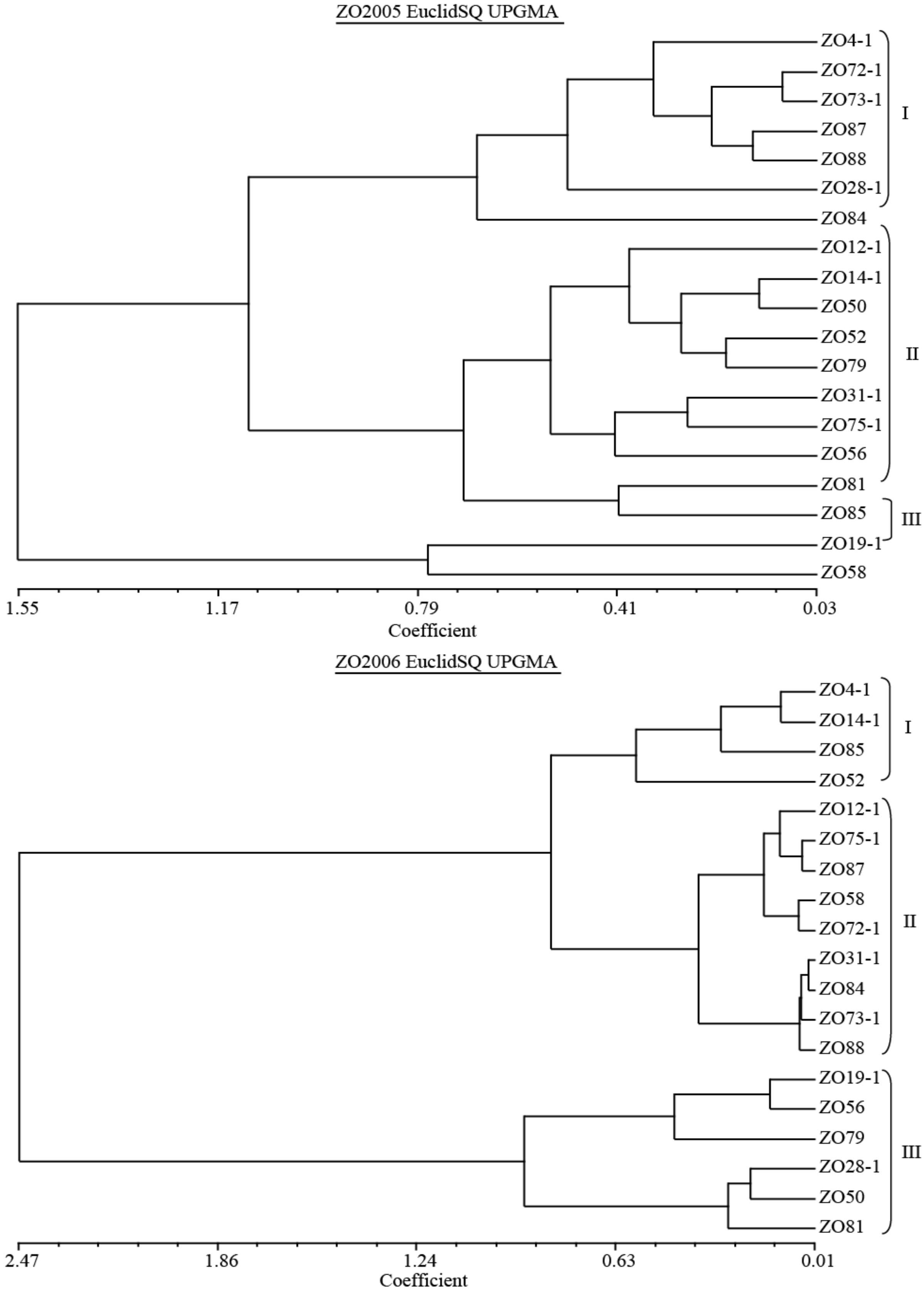

Fig. 2. Phenogram showing the clustering pattern in ginger (*Z. officinale*) accessions based on different morphological traits during the year 2005 and 2006.

Table 5. Inter-cluster variation in *Z. officinale* based on different morphological traits observed during 2005 and 2006 (Mean ± SE).

Trait	Cluster-I	Cluster-II	Cluster-III
2005			
Leaf length (cm)	20.92 ± 1.33	21.15 ± 0.86	21.83 ± 2.47
Leaf width (cm)	2.45 ± 0.13	2.64 ± 0.09	2.27 ± 0.14
Length /width ratio	8.63 ± 0.54	8.22 ± 0.44	9.60 ± 0.54
No. of leaves tiller^{-1}	21.04 ± 1.08	18.04 ± 0.73	17.17 ± 1.17
Ligule length (mm)	4.87 ± 0.23	5.24 ± 0.37	4.20 ± 0.10
Sheath length (cm)	46.77 ± 5.12	47.27 ± 3.52	40.42 ± 1.91
Sheath diameter (mm)	3.51 ± 0.25	3.50 ± 0.28	3.43 ± 0.57
Plant height (cm)	71.96 ± 5.46	64.47 ± 3.28	60.14 ± 2.53
No. of tillers plant^{-1}	9.17 ± 1.23	6.51 ± 0.92	8.34 ± 5.34
Tillers width (mm)	9.77 ± 0.98	9.34 ± 0.45	8.32 ± 0.08
Rhizome thickness (mm)	27.08 ± 2.51	24.40 ± 1.55	20.14 ± 2.77
Rhizome weight (g plant^{-1})	222.93 ± 33.73	101.10 ± 7.73	55.84 ± 5.83
2006			
Leaf length (cm)	15.09 ± 1.60	20.26 ± 0.62	19.63 ± 0.90
Leaf width (cm)	2.19 ± 0.29	2.55 ± 0.10	2.81 ± 0.58
Length /width ratio	6.99 ± 0.33	8.02 ± 0.35	7.75 ± 0.78
No. of leaves tiller^{-1}	13.68 ± 0.58	17.04 ± 0.74	16.26 ± 0.44
Ligule length (mm)	4.13 ± 0.11	4.94 ± 0.17	5.3 ± 0.34
Sheath length (cm)	21.16 ± 1.68	40.99 ± 2.75	36.04 ± 2.58
Sheath width (mm)	3.90 ± 0.50	3.91 ± 0.10	3.71 ± 0.17
Plant height (cm)	36.35 ± 6.33	66.20 ± 3.25	61.69 ± 2.78
No. of tillers plant^{-1}	3.08 ± 0.76	7.26 ± 1.20	5.31 ± 0.79
Tillers width (mm)	7.36 ± 0.99	9.11 ± 0.32	7.84 ± 0.28
Rhizome thickness (mm)	21.55 ± 2.49	27.63 ± 1.37	21.17 ± 1.22
Rhizome weight (g plant^{-1})	62.34 ± 9.04	171.76 ± 12.67	66.76 ± 8.60

Table 6. Euclidean distance matrix for the year 2005 (below diagonal) and 2006 (above diagonal).

	ZO 4-1	ZO 12-1	ZO 14-1	ZO 19-1	ZO 28-1	ZO 31-1	ZO 50	ZO 52	ZO 56	ZO 58	ZO 72-1	ZO 73-1	ZO 75-1	ZO 79	ZO 81	ZO 84	ZO 85	ZO 87	ZO 88
ZO4-1		0.66	0.11	0.81	2.42	0.90	2.19	0.42	0.65	0.20	0.19	1.12	0.51	0.37	1.64	0.81	0.16	0.40	1.19
ZO12-1	0.62		0.52	1.72	4.18	0.29	3.67	1.18	1.45	0.15	0.26	0.25	0.09	0.49	2.86	0.25	1.10	0.15	0.48
ZO14-1	0.48	0.32		1.44	3.46	0.46	3.18	0.41	1.22	0.17	0.22	0.67	0.30	0.62	2.54	0.40	0.44	0.20	0.64
ZO19-1	1.64	1.06	1.27		0.62	2.75	0.58	1.69	0.15	1.11	0.96	2.99	1.86	0.53	0.23	2.62	0.43	1.71	3.38
ZO28-1	0.57	1.05	0.88	1.97		5.61	0.21	3.41	0.86	3.17	2.83	5.99	4.29	2.04	0.28	5.39	1.57	4.10	6.42
ZO31-1	0.93	0.48	0.51	0.85	1.25		5.20	1.26	2.48	0.40	0.61	0.04	0.16	1.20	4.25	0.03	1.51	0.14	0.05
ZO50	0.37	0.38	0.14	1.38	0.81	0.63		2.77	0.57	2.84	2.44	5.45	3.84	1.64	0.27	4.91	1.55	3.80	5.93
ZO52	0.58	0.49	0.28	1.28	0.88	0.47	0.32		1.20	0.73	0.67	1.46	0.96	1.00	2.55	1.11	0.85	0.95	1.43
ZO56	1.01	0.43	0.65	0.66	1.40	0.36	0.74	0.69		0.92	0.72	2.65	1.54	0.35	0.41	2.28	0.43	1.52	3.01
ZO58	1.96	1.48	1.55	0.77	2.26	1.10	1.67	1.49	1.10		0.06	0.50	0.11	0.28	2.14	0.34	0.48	0.08	0.65
ZO72-1	0.44	0.98	0.82	2.01	0.48	1.29	0.70	0.92	1.39	2.32		0.71	0.19	0.18	1.96	0.48	0.37	0.20	0.86
ZO73-1	0.37	0.92	0.77	1.95	0.49	1.25	0.65	0.88	1.33	2.28	0.09		0.19	1.28	4.50	0.06	1.82	0.23	0.06
ZO75-1	0.97	0.54	0.53	0.95	1.27	0.28	0.63	0.48	0.47	1.16	1.28	1.24		0.58	3.13	0.09	0.94	0.05	0.29
ZO79	0.63	0.35	0.22	1.13	0.97	0.33	0.33	0.20	0.53	1.38	0.99	0.95	0.40		1.21	1.07	0.39	0.59	1.59
ZO81	1.14	0.63	0.75	0.79	1.53	0.53	0.86	0.86	0.43	1.04	1.47	1.42	0.65	0.67		4.11	1.11	2.96	5.00
ZO84	0.90	1.46	1.31	2.46	0.68	1.77	1.19	1.38	1.86	2.77	0.51	0.56	1.75	1.47	1.95		1.39	0.12	0.06
ZO85	1.23	0.71	0.82	0.80	1.66	0.59	0.91	0.91	0.52	1.06	1.55	1.50	0.64	0.77	0.41	2.03		0.78	1.92
ZO87	0.25	0.77	0.63	1.80	0.48	1.10	0.52	0.75	1.18	2.14	0.23	0.17	1.10	0.80	1.29	0.71	1.37		0.31
ZO88	0.30	0.80	0.71	1.82	0.51	1.16	0.60	0.83	1.21	2.20	0.28	0.22	1.17	0.87	1.34	0.70	1.43	0.15	

The within-cluster mean value based on dissimilarity matrix was 0.173, 0.881, 2.504 for cluster-I, II, and III, respectively for the year 2005 and the corresponding values for the year 2006 were 0.239, 0.447, 2.045 in cluster I, II and III, respectively. The mean distance was high (1.806) between cluster-I and III, followed by (1.569) between Cluster II and III, and (0.238) between cluster-I and II during the year 2005. The similar pattern was observed in 2006 with a high mean distance (2.330) between cluster-I and III, followed by (1.623) between Cluster II and III, and (0.708) between cluster-I and II.

Trait association: The ginger genotypes analyzed in this study displayed positive and significant correlations among different quantitative traits during the two years (Table 7). Plant height had a positive and significant correlation with rhizome weight, rhizome thickness sheath length and leaves tiller^{-1}. Leaves tiller^{-1} and tiller width showed positive and significant correlation with both rhizome thickness and weight. A significant correlation among rhizome thickness, rhizome weight and tiller width was also observed. The plant characters showing correlation during both the years were leaves tiller^{-1} and sheath length with plant height, rhizome thickness and leaves tiller^{-1} with rhizome weight, and tiller width with rhizome thickness. In the present study, plant height, leaves tiller^{-1}, tiller thickness appeared to be of prime importance as these directly influence rhizome weight as well as thickness. Leaf length and leaves tiller^{-1} had significant correlation with plant height also useful for indirectly affecting yield. These traits provide a good indication for future's emphasis in crop improvement in gingers.

Variability pattern over the years: Among the different traits studied, plant height, Rhizome thickness, Rhizome weight and tiller width were found significantly different from each other. Rest of the plant characters displayed non-significant differences (Table 8). However, variability pattern for different characters displayed the high mean values for most of the characters observed during the year 2005 as compared to 2006 (Fig. 3). The conducive agro-climatic conditions during the first year might have favored high mean values compared with the second year where comparatively a high rainfall was observed (Fig. 5).

Table 7. Association of different traits in *Z. officinale* based on correlation coefficients studied in 2005 and 2006.

Character	LL	L/Sht	ShL	PH	TillW	RT
2005						
No. of leaves per tiller^{-1}	0.289					
Sheath length (cm)	0.287	0.277				
Plant height (cm)	0.495	0.651*	0.762*			
Tillers width (mm)	0.234	0.428	0.302	0.522		
Rhizome thickness (mm)	0.319	0.668*	0.320	0.633*	0.661*	
Rhizome weight (g plant^{-1})	-0.017	0.646*	0.330	0.644*	0.511	0.701*
2006						
No. of leaves tiller^{-1}	0.642*					
Sheath length (cm)	0.837*	0.685*				
Plant height (cm)	0.930**	0.654*	0.911*			
Tillers width (mm)	0.711*	0.471	0.630*	0.711*		
Rhizome thickness (mm)	0.540	0.229	0.462	0.526	0.725*	
Rhizome weight (g plant^{-1})	0.541	0.619*	0.637*	0.571	0.588*	0.690*

* Significantly correlated at $\alpha = 0.05$, **Highly significantly correlated at $\alpha = 0.01$

Table 8. Analysis of variance for different for different plant traits displaying significance over the years.

Plant character	SS[a]	MS	F-value	Prob.	CV (%)
Leaf length (cm)	169.241	9.402	1.1688	0.3721	14.14
Leaf width (cm)	8.053	0.447	1.2141	0.3425	23.87
Length /width ratio	40.861	2.27	1.7455	0.1234	14.05
No. of leaves tiller^{-1}	138.936	7.719	1.6028	0.1629	12.49
Ligule length (mm)	16.613	0.923	1.8317	0.1044	14.38
Sheath length (cm)	2284.284	126.905	1.209	0.3458	25.11
Sheath width (mm)	8.465	0.47	1.314	0.2842	16.3
Plant height (cm)	4346.949	241.497	1.9349	0.0085*	17.84
No. of tillers plant^{-1}	240.173	13.343	1.4499	0.2192	45.12
Tillers width (mm)	74.181	4.121	3.6542	0.0043*	11.98
Rhizome thickness (mm)	783.866	43.548	3.311	0.0074*	14.73
Rhizome weight (g plant^{-1})	141609.4	7867.1	2.4481	0.0326*	44.15

[a]: SS = Sum of squares; MS = Mean squares

* = Significantly different at p=0.05

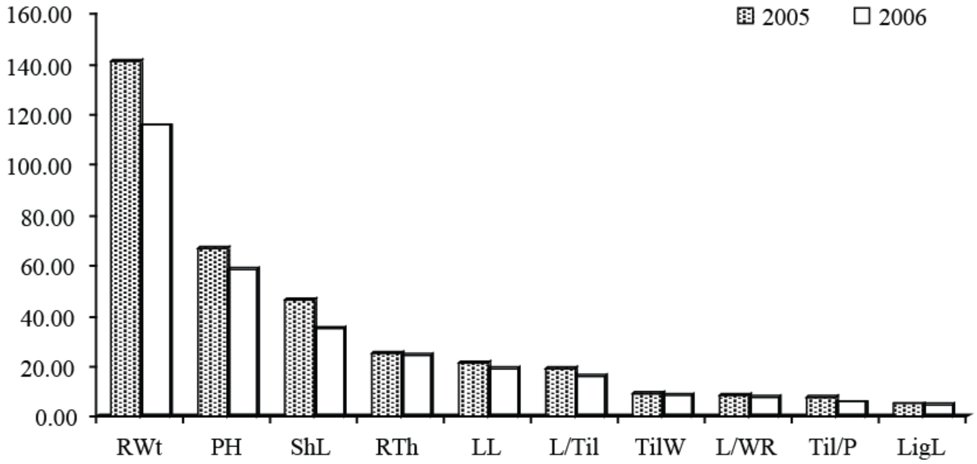

Fig. 3. Variability pattern in plant characters observed in ginger accessions in 2005 and 2006.

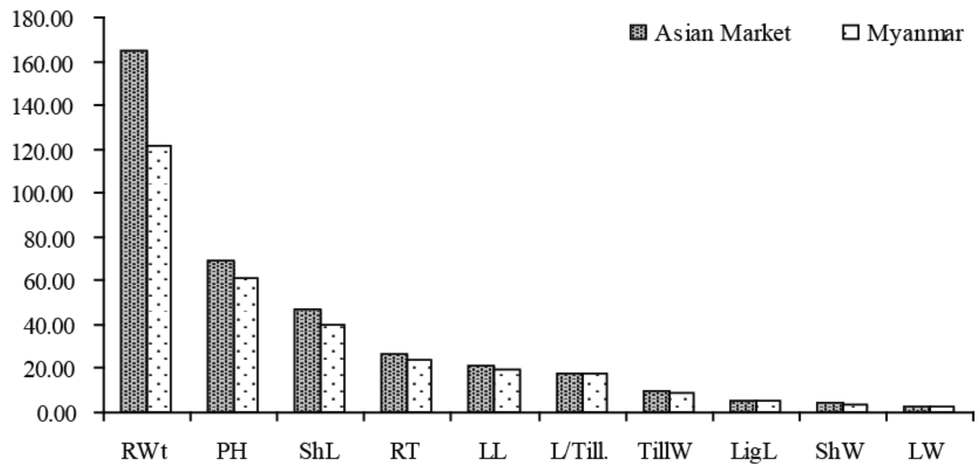

Fig. 4. Variability pattern in plant characters observed in ginger from Myanmar and Asian market.

Variability pattern in ginger from Myanmar compared with Asian market: The mean distance based on Euclidean coefficients for the ginger from Myanmar during the first and second year was 0.93 and 1.33, respectively, leading to an average distance of 1.27. The corresponding values for the ginger from Asian countries were 1.25 and 1.24 with an average distance of 1.24. The mean distance for two years (1.27 vs 1.24) was not much different, and it was also supported with a low to medium variance observed for different characters in gingers from Myanmar versus Asian countries (Table 9). However, ginger accessions acquired from different Asian countries representing market collections displayed comparatively high mean values for the two years for most of the traits observed (Fig. 4).

Descriptive characters: *Leaf based:* Predominant leaf shape in gingers was linear-lanceolate to lanceolate with aristate leaf apex. In some accessions extra long leaf apex, gradually tapering to pointed end was observed. Leaf base was cunneate and obtuse, however, few accessions with intermediate leaf base were also observed. Leaf foliage was green to dark green in color. Leaves had entire margins and a narrow to prominent membranous line along the margins. Leaves were attached to the leaf tillers in a semi-sessile to sessile mode with alternate arrangement of leaves. Leaf pubescence was observed mainly on lower surface of the leaves, including mid rib, collar regions. Extent of leaf pubescence was extremely low to intermediate. A low to medium leaf blade blistering was observed in gingers.

Ligule and collar based: A membranous ligule was present in all ginger accession studied with light green to whitish green color. Shape of ligule could be divided into emarginate, bi-lobed and highly bi-lobed with entire margins with the exception of one accession (ZO84) having ciliate margin. A narrow, intermediate and broad collar was observed in gingers. Some of the accessions with pubescence on collar were noticed.

Sheath based: A split leaf-sheath with non-overlapping margins, and a narrow to medium sized membranous band or strip along the margin was observed. In general split was straight, however, in some cases spiral or angular split was also observed. Sheath color was light green to dark green and sheath attachment pattern was semi-compact to compact.

Table 9. Variability pattern in ginger from Myanmar vs Asian markets based morphological traits during the year 2005 and 2006.

2005	Myanmar			Asian countries		
Trait	**Mean ± SE**	**SD**	**Variance**	**Mean**	**SD**	**Variance**
Leaf length (cm)	20.96 ± 0.77	2.79	7.76	21.52 ± 1.40	3.43	11.78
Leaf width (cm)	2.48 ± 0.08	0.28	0.08	2.64 ± 0.16	0.39	0.15
Length /width ratio	8.63 ± 0.37	1.35	1.82	8.28 ± 0.60	1.47	2.16
No. of leaves tiller^{-1}	19.00 ± 0.81	2.93	8.60	19.17 ± 1.17	2.87	8.22
Ligule length (mm)	4.83 ± 0.23	0.84	0.71	5.35 ± 0.48	1.18	1.39
Sheath length (cm)	42.28 ± 2.67	9.64	93.00	55.20 ± 4.08	9.99	99.86
Sheath diameter (mm)	3.29 ± 0.18	0.63	0.40	3.95 ± 0.35	0.85	0.72
Plant height (cm)	62.81 ± 3.20	11.54	133.10	75.37 ± 3.26	8.00	63.92
Tillers plant^{-1} (No.)	8.61 ± 1.01	3.63	13.21	5.67 ± 1.05	2.56	6.57
Tillers width (mm)	9.05 ± 0.51	1.86	3.45	10.13 ± 0.74	1.81	3.26
Rhizome thick. (mm)	23.67 ± 1.46	5.26	27.63	27.68 ± 2.45	6.00	36.04
Rhizome wt. (g/plant)	115.01 ± 14.57	52.54	2760.44	198.00 ± 48.05	117.69	3851.20
2006	**Myanmar**			**Asian countries**		
Trait	**Mean ± SE**	**SD**	**Variance**	**Mean**	**SD**	**Variance**
Leaf length (cm)	18.40 ± 0.93	3.34	11.18	20.22 ± 0.66	1.61	2.59
Leaf width (cm)	2.29 ± 0.09	0.33	0.11	3.15 ± 0.53	1.30	1.70
Length /width ratio	8.04 ± 0.25	0.91	0.82	7.01 ± 0.75	1.84	3.39
No. leaves tiller^{-1}	15.74 ± 0.56	2.01	4.03	16.84 ± 0.96	2.36	5.58
Ligule length (mm)	5.00 ± 0.22	0.78	0.61	4.64 ± 0.20	0.50	0.25
Sheath length (cm)	33.61 ± 2.89	10.42	108.63	38.81 ± 3.91	9.58	91.78
Sheath diameter (mm)	3.70 ± 0.11	0.40	0.16	4.15 ± 0.26	0.63	0.39
Plant height (cm)	56.38 ± 4.68	16.87	284.68	63.08 ± 3.78	9.25	85.57
Tillers plant^{-1} (No.)	5.50 ± 0.90	3.23	10.42	6.33 ± 1.30	3.19	10.18
Tillers width (mm)	7.85 ± 0.32	1.16	1.35	9.38 ± 0.46	1.12	1.25
Rhizome thick. (mm)	23.69 ± 1.26	4.53	20.51	25.64 ± 2.46	6.02	36.24
Rhizome wt. (g/plant)	108.21 ± 16.14	58.19	3386.46	131.51 ± 29.40	72.02	5186.66

Plant based: All gingers observed were with erect to semi-erect plant stature. Foliage volume in gingers was low, medium and high. Few accessions (ZO14-1, ZO31-1, ZO73-1 and ZO75-1) have born flowering stalk in 2005 only, but none of them bloomed. Thick and fleshy roots with medium to large size were observed.

Discussion

Species and varietal diversity are important components of biodiversity, especially in clonally propagated crops like ginger (Sasikumar, 1999), which allows selection forces to act on it. The long history of domestication of gingers into diverse geographical niches might have played a major role in the evolution of this crop. However, variability tends to limit in cultivars grown in the same region compared to the ones growing in geographically distant locations (Ravindran *et al.,* 2005). In the current study considerable diversity for various traits existed in the ginger germplasm that mainly came from central Myanmar, and this depicted the diverse base of the ginger assayed in this study. Among one of the major forces that found to influence divergence of cultivars is yield plant^{-1} (Singh *et al.,* 1999), and same trait also displayed high variance in the current study. Variability is the basis of selection and the plant characters that show direct and/or indirect influence on yield and yield contributing traits could be the potential source that needs to be focused for plant improvement. However, the decline in the mean values from high in the first year to low in the second year could be attributed to environmental change/stress, as the second year witnessed more rainfall compared with the first year (Fig. 5).

The germplasm assayed during both the years represented genebank, farm, Myanmar-market and collection from other Asian countries. The dispersed distribution of genebank, farm and market collections have reflected non-similarity of accessions among each other. Absence of any relationship between distribution pattern and acquisition source observed in this study may likely to exist as quantitative traits vary when subjected to environmental changes. Though assignment of different accessions into different clusters and groups reflected by both the methods of multivariate analyses in both the years was different, however, one common feature was observed in both the years that multivariate statistical methods made distinction among the genotypes based on plant stature and rhizome weight plant^{-1}. The clustering pattern observed in this study may correspond to the ginger types classified in Japan according to plant stature and yield into small-sized plants with a small rhizome, medium-sized plants with a medium-sized rhizome, and large-sized plants with fewer tillers and larger rhizomes (Ravindran *et al.,* 2005). Inter-cluster variation based on Euclidean coefficients, though differed in magnitude, gave similar trend in both the years, and supported the clustering pattern based on quantitative characters.

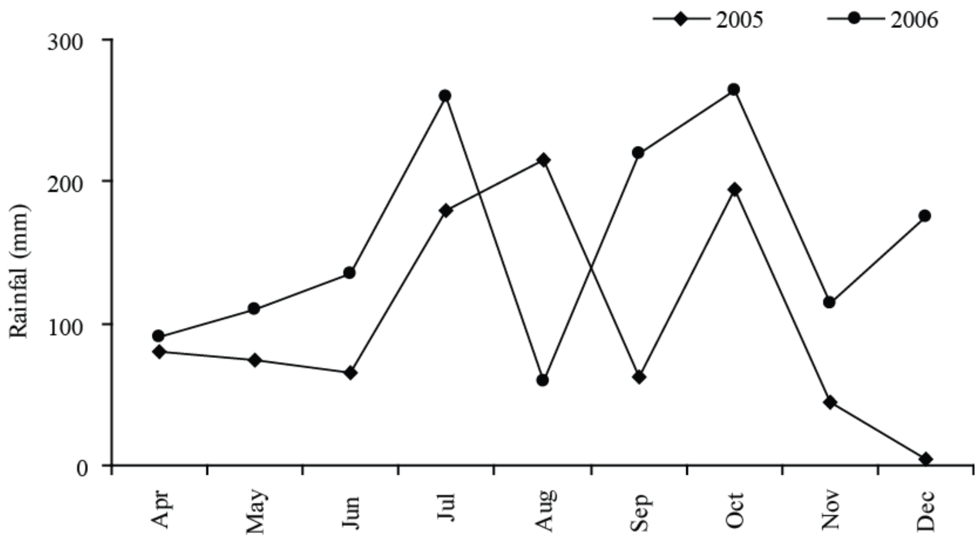

Fig. 5. Monthly mean rain fall for the year 2005 and 2006.

The association among different traits is an important and useful feature which helped to identify various traits that can potentially be focused for further consideration and crop improvement. In addition, the characters that displayed consistency in trait association over the years could be the potential traits that need to be addressed for the improvement of gingers. Plant height appeared to display significant and positive correlation with yield contributing traits. The same trait was also concluded to be of prime importance in the selection program on the basis of its positive and significant correlation with rhizome yield (Sasikumar *et al.,* 1992).

As indicated by different variability assessment approaches, no considerable differences in the variability pattern were observed in gingers from Myanmar and Asian markets. However in a relative context to Asian countries, ginger from Myanmar, being collection from only one country displayed variability than the collection from different countries. Myanmar is one of the centers of diversity for different species including ginger and rich genetic resources. However, the prevailing trend of cultivating high yielding cultivars in the production areas of ginger is feared to replace local landraces and cultivar that will ultimately lead to genetic erosion of unique germplasm. Similar emphasis has already been made for other crops like tomato (San-San-Yi *et al.,* 2008) from Myanmar. We suggest conserving and utilizing the ginger genetic resources for crop improvement and sustainable utilization.

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