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Morphological diversity in litchi based on phenological traits

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ABSTRACT

Twenty-nine quantitative phenological traits were used to assess the morphological diversity among 30 Indian litchi genotypes. Coefficients of variation for length and width of panicle, number of primary and secondary dichasia, the maximum length of primary and secondary dichasia, the maximum and minimum distance between two primary dichasia and origin of several primary dichasia (primary branches on panicle) from the same point, filament length, length and diameter of the anther, number of fruits/cluster and yield/ plant were more than 20%. The number of secondary dichasia was highly correlated with the length of stigma. Similarly, the number of fruits per cluster and yield, fruit weight, and pedicle thickness were also correlated. Genotypes were divided into two main groups corresponding to the panicle size and yield. Cluster-I contained genotypes of comparatively small panicles with a lower yield, while cluster-II comprised larger panicles with a higher yield. From variability analysis, the length and width of the panicle, number of secondary dichasia, the maximum length of primary dichasia, length of male flower, stamen length, the thickness of pedicle, number of fruits/cluster and fruit weight were identified as essential traits for identifying high-yielding genotypes.

Keywords: *Litchi chinensis*, Variability, Principal Component Analysis, Cluster analysis.

INTRODUCTION

Litchi (*Litchi chinensis* Sonn.) has a narrow genetic diversity that can be expanded by hybridization and seedling selection. The same litchi cultivar is known by different names in different places, and different cultivars have the same name. Such practices affect germplasm conservation, breeding and fruit production in litchi. Litchi genotypes were distinguished and classified based on morphological characters (Wu *et al.,* 15). Different molecular markers are used for the identification of litchi cultivars (Liu *et al.,* 7; Liu *et al*., 8). These markers provide accurate synonymy and homonymy results, but it is costly and requires professional skills. Further, it is very difficult to find out the key information of polymorphic loci to distinguish litchi cultivars through molecular marker (Wu *et al.,* 15). Moreover, different types of molecular markers provide different identification results (Ding *et al*., 2). Identification of litchi genotypes based on morphological characters is highly acceptable and easily distinguishable. Morphological characteristics such as leaf, fruit and flower are used to distinguish litchi genotypes (Khurshid *et al*., 6; Madhou *et al*., 9). It was envisaged to develop an easy and sensitive method for distinguishing litchi cultivars based on phenological characters, which can provide theoretical knowledge for the early identification of hybrids and management of litchi genotypes. So this study was initiated to assess the diversity of phenological characters (panicles and flowers) in 30 Indian litchi genotypes and to explore the phylogenetic relationships among genotypes.

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MATERIAL AND METHODS

This investigation was conducted at the National Active Germplasm Site, ICAR-NRC on Litchi, Muzaffarpur, Bihar, India. Thirty genotypes were selected in a randomized block design with three replications. Based on litchi descriptors by IPGRI (Rome Italy) a total of 29 phenological traits were observed in 2018 and 2019. After testing for homogeneity, the mean values of 29 traits for both years were pooled and subjected to analysis of variance (ANOVA) to test the presence of significant differences among genotypes (Panse and Sukhatme, 10). Phenotypic and genotypic coefficients of variation were calculated using the formula proposed by Burton (1). Broad sense heritability was estimated using the method adopted by Singh and Chaudhary (13). Genetic advances percentage was estimated according to the methods illustrated by Johnson *et al.* (5). To examine the relationships between morphological traits among litchi genotypes, principal component analysis (PCA) was used (Everitt and Dunn, 3), following the prcomp function from the built-in R stats v3.4.2 package. A scatter diagram visualizing the association between principal components and traits was also plotted.

RESULTS AND DISCUSSION

In this study, the genotypes showed (Table 1) the significant differences ranging from 16.20 to

Table 1. Phenological characters of litchi genotypes.

Genotypes	Length of Panicle (cm)	Width of Panicle (cm)	Number of primary Dichasia	Number of Secondary Dichasia	Maximum length of Primary Dichasia (cm)	Maximum length of Secondary Dichasia (cm)	Maximum Distance between two Primary Dichasia (cm)	Minimum Distance between two Primary Dichasia (cm)	Origin of primary Dichasia from same point	Degree of primary Dichasia	Length of flower bud (mm)	Diameter of flower bud (mm)	Length of male flower (mm)	Diameter of male flower (mm)
IC-0615585	25.95	16.50	13.33	9.00	15.00	4.50	5.70	0.10	2.00	58.33	2.98	2.21	10.65	8.97
IC-0615586	31.00	20.50	13.00	5.00	18.00	4.50	4.70	1.00	1.20	63.33	1.72	1.67	7.04	6.21
IC-0615587	24.50	15.00	11.50	6.00	12.00	2.90	2.50	0.80	1.00	46.25	2.12	2.18	8.47	7.97
IC-0615588	25.85	10.75	10.00	6.33	6.00	1.80	3.00	0.40	1.00	67.50	2.02	1.56	6.83	7.30
IC-0615589	36.75	22.00	12.75	8.00	18.00	4.20	5.60	0.20	1.20	65.83	2.43	2.27	8.15	6.56
IC-0615590	38.20	19.00	11.75	10.33	18.00	3.43	4.00	0.30	1.60	55.00	2.53	2.06	11.13	9.74
IC-0615591	35.40	16.50	13.00	9.33	15.00	3.37	5.20	0.10	2.00	50.00	2.17	2.15	10.63	9.15
IC-0615592	36.50	24.50	20.00	11.50	16.00	3.00	4.20	0.40	1.00	51.67	2.43	1.97	8.24	8.64
IC-0615593	21.00	11.90	18.25	8.00	13.00	3.00	2.00	0.50	1.20	60.50	2.43	2.00	8.98	8.60
IC-0615594	41.45	30.30	15.50	7.33	23.00	6.00	5.50	0.90	1.40	61.80	2.24	2.45	10.27	9.88
IC-0615595	24.25	13.50	9.00	6.00	11.00	3.00	3.50	0.20	1.00	70.83	2.09	1.78	7.30	7.70
IC-0615596	24.30	12.50	15.67	6.50	10.00	5.00	2.80	0.60	1.60	60.00	2.21	2.12	9.43	8.38
IC-0615597	43.88	28.50	13.25	8.67	17.00	5.00	6.50	0.80	1.20	54.00	2.12	2.14	10.14	8.05
Coll. 39	32.73	19.00	8.33	8.67	14.00	2.67	3.60	0.20	1.00	67.50	2.23	2.10	10.14	7.85
IC-0615599	28.25	16.00	11.00	6.00	10.00	5.00	5.00	0.20	1.00	63.33	2.27	1.74	9.45	7.78
IC-0615600	41.38	30.25	13.50	8.00	22.00	4.40	6.20	0.20	1.40	69.80	2.37	2.06	9.91	7.93
IC-0615601	39.00	26.50	11.67	6.67	15.00	8.00	5.50	0.50	1.80	70.00	2.18	1.98	7.85	6.45
IC-0615602	44.65	33.50	16.00	8.67	30.00	3.00	6.20	0.90	1.20	59.17	2.31	2.26	9.38	8.42
IC-0615603	34.50	20.50	14.67	8.00	13.00	3.00	3.50	0.50	1.40	52.50	1.54	2.00	11.89	11.42
IC-0615604	32.50	18.73	17.00	6.00	18.00	3.00	4.00	0.60	1.40	54.60	2.12	2.06	5.80	5.81
IC-0615605	25.00	13.50	9.33	5.00	8.00	3.00	2.20	0.50	1.00	73.33	2.52	1.96	8.77	6.42
IC-0615606	41.15	20.50	12.67	4.50	15.00	5.50	4.50	1.00	1.20	66.40	2.65	2.29	9.08	7.81
IC-0615608	35.20	18.50	11.00	5.50	10.00	1.80	4.20	0.20	1.25	55.00	2.35	2.07	8.77	7.66
IC-0615610	47.50	26.50	11.00	7.33	23.00	4.60	6.60	0.70	1.80	60.00	2.14	2.20	10.30	10.45
IC-0615611	41.43	18.50	11.33	8.00	22.00	3.00	5.00	0.10	1.40	53.00	1.93	1.96	8.20	5.80
IC-0615613	16.20	9.15	10.67	3.33	6.00	1.90	3.50	1.00	1.20	60.00	2.08	1.94	7.75	7.26
Coll. 35	32.75	20.50	10.67	7.33	22.00	8.00	4.00	0.90	2.00	74.40	3.67	2.75	7.90	7.98
Coll. 36	33.00	21.50	9.67	11.25	22.00	3.33	4.50	0.20	1.40	46.25	1.88	1.78	10.64	11.57
Coll. 37	37.50	23.50	14.50	11.00	20.00	3.90	4.40	0.10	2.00	48.25	2.27	2.10	10.85	9.79
Coll. 38	30.30	18.50	10.50	9.00	17.00	3.50	4.00	0.10	1.25	55.00	1.99	1.68	10.02	8.30
SE(d)	0.67	0.44	0.25	0.14	0.37	0.10	0.10	0.009	0.02	1.26	0.05	0.03	0.19	0.18
CD(P≤0.05)	1.34	0.88	0.51	0.29	0.74	0.21	0.20	0.01	0.05	2.54	0.10	0.07	0.38	0.37

Contd...

Table 1 contd...

Table 1. Phenological characters of litchi genotypes (*Contd*...)

Diameter of male flower (mm)	Length of female flower (mm)	Diameter of female flower (mm)	Length of M2 flower (mm)	Diameter of M2 flower (mm)	Stamen length (mm)	Filament Length (mm)	Anther length (mm)	Diameter of anther (mm)	Length of stigma (mm)	Stamen length of Female (F) flower (mm)	Thickness of pedicle (mm)	Number of fruits/cluster	Fruit weight (g)	Maturity (Days)	Yield (Kg/plant)
IC-0615585	8.45	4.24	13.07	8.57	6.40	5.30	1.10	0.93	4.98	2.33	0.74	5.50	25.76	70.50	15.00
IC-0615586	8.75	3.94	7.16	5.67	4.10	2.95	1.15	0.61	4.54	2.26	0.71	7.06	18.38	59.50	13.50
IC-0615587	8.90	3.85	7.11	5.34	5.46	4.34	1.12	0.66	4.72	2.36	0.55	4.12	16.19	67.00	11.50
IC-0615588	7.84	4.22	9.20	8.60	4.50	3.29	1.21	0.80	4.69	2.35	0.63	3.02	17.03	67.50	10.30
IC-0615589	9.60	3.79	7.12	7.42	5.04	3.47	1.57	0.67	4.77	2.38	0.71	8.86	18.90	65.50	14.64
IC-0615590	8.75	4.47	8.98	7.07	6.23	5.35	0.88	0.51	5.25	2.92	0.77	13.51	22.45	67.50	23.18
IC-0615591	7.65	4.85	10.20	8.43	6.53	5.11	1.42	0.51	5.62	2.81	0.78	12.69	22.24	63.50	19.81
IC-0615592	8.45	3.42	9.73	7.29	5.21	3.72	1.49	0.78	5.32	2.03	0.70	12.72	23.03	65.50	22.31
IC-0615593	6.65	3.79	9.47	10.39	4.00	2.45	1.55	1.11	4.71	2.35	0.83	4.36	21.05	65.00	17.00
IC-0615594	8.26	4.95	7.99	7.33	6.42	4.58	1.84	0.84	4.92	2.66	0.87	10.88	21.23	62.00	20.61
IC-0615595	9.19	5.11	9.58	8.10	4.56	3.58	0.98	0.62	5.62	3.13	0.46	1.00	15.55	63.50	8.70
IC-0615596	8.10	4.70	8.95	7.94	4.82	3.56	1.26	1.01	4.67	2.40	0.73	4.69	19.97	63.50	19.50
IC-0615597	9.13	3.83	9.38	6.68	5.42	4.27	1.15	0.80	5.19	2.27	0.74	10.78	20.91	61.00	20.66
Coll. 39	8.26	3.74	7.69	7.58	5.14	4.06	1.08	0.56	5.09	2.67	0.72	4.94	19.10	62.50	16.50
IC-0615599	9.38	4.66	8.95	6.06	5.81	4.76	1.05	0.83	5.74	2.08	0.64	3.70	20.50	60.50	14.12
IC-0615600	7.85	4.11	8.11	6.53	5.23	4.14	1.09	0.66	5.15	2.38	0.69	9.88	22.39	63.00	18.73
IC-0615601	8.52	3.61	9.15	7.90	4.45	3.46	0.99	0.71	5.14	2.26	0.62	9.88	23.08	63.50	18.50
IC-0615602	9.22	3.99	7.33	6.62	3.68	2.68	1.00	0.72	5.14	1.84	0.74	7.25	21.99	65.00	16.97
IC-0615603	7.69	4.51	9.66	7.58	6.20	4.86	1.34	0.57	5.29	3.42	0.70	13.39	19.21	63.50	18.62
IC-0615604	6.98	4.61	8.90	8.21	3.12	1.18	1.94	1.25	4.84	2.48	0.81	4.56	21.17	63.50	18.61
IC-0615605	9.05	4.38	9.24	6.28	3.89	2.70	1.19	0.70	5.08	3.16	0.65	7.29	18.90	62.00	13.38
IC-0615606	8.10	3.91	6.40	5.07	5.10	3.52	1.58	0.60	5.12	1.98	0.76	8.75	21.03	62.50	20.49
IC-0615608	7.82	3.00	8.75	6.85	5.20	4.10	1.10	0.58	4.76	2.52	0.70	8.42	21.93	55.50	15.00
IC-0615610	8.95	4.48	7.68	5.40	5.98	4.50	1.48	0.82	5.17	2.53	0.48	12.94	22.51	63.50	24.80
IC-0615611	8.87	3.91	9.78	5.62	5.01	3.54	1.47	0.79	5.16	2.90	0.75	13.48	22.25	67.00	25.64
IC-0615613	9.10	3.89	8.48	6.10	5.22	4.26	0.96	0.82	4.17	2.37	0.70	2.97	24.77	66.00	14.50
Coll. 35	8.09	3.39	6.82	5.96	4.17	2.98	1.19	0.92	5.95	3.11	0.77	9.91	19.92	62.00	18.34
Coll. 36	8.70	4.30	9.25	9.17	7.75	6.23	1.52	0.74	5.54	3.22	0.71	8.64	18.87	60.00	21.50
Coll. 37	8.60	4.02	9.08	7.17	6.75	5.38	1.37	0.58	5.67	2.11	0.92	12.74	19.88	68.50	24.35
Coll. 38	8.54	5.62	10.04	8.47	6.32	5.29	1.03	0.70	5.62	2.75	0.66	9.60	19.20	65.00	23.50
SE(d)	0.16	0.08	0.20	0.16	0.11	0.09	0.03	0.01	0.11	0.06	0.01	0.17	0.41	1.47	0.39
CD (P≤0.05)	0.32	0.16	0.41	0.33	0.22	0.18	0.06	0.03	0.22	0.12	0.03	0.35	0.82	2.96	0.80

47.50 cm for panicle length, 9.15 to 33.50 cm for panicle width, 8.33 to 20.00 for the number of primary dichasia, 3.33 to 11.50 for the number of secondary dichasia, 0.1 to 1.0 cm for the minimum distance between two primary dichasia and 1.0 to 13.51 for the number of fruits/cluster. Significantly, maximum panicle length was recorded in IC-0615610 (47.50 cm). The maximum number of primary dichasia was recorded in IC-0615592 (20.00). The length of primary dichasia was found maximum in IC-0615602 (30.00 cm). The maximum length of secondary dichasia was found in Coll. 35 (8.00 cm). The maximum number of fruits/bunch was recorded in IC-0615590 (13.51), which was statistically at par with IC-0615603 (13.39). Maximum fruit weight was recorded in IC-0615585 (25.76 g), while maximum yield was recorded in IC-0615611 (25.64kg/plant).

A huge morphological diversity was observed in the litchi genotypes studied. The coefficients of variation (CV) for panicle length and width, number of primary and secondary dichasia, maximum length of primary and secondary dichasia, maximum and minimum distance between two primary dichasia and origin of number of primary dichasia from the same point, number of fruits/cluster and yield/plant were more than 20%, while CV values of the remaining characters were less than 20% (Table 2). The phenotypic and genotypic coefficients of variation were high for the minimum distance between two primary dichasia (67.28 and 67.24), the number of fruits/cluster (44.83 and 44.76), the maximum length of the secondary dichasia (39.43 and 39.29), maximum length of primary dichasia (35.18 and 35.06), panicle width (30.69 and 30.57), maximum distance between two primary dichasia (28.45 and 28.32), filament length (27.01 and 26.86), number of secondary dichasia (26.88 and 26.77), number of primary dichasia originated from same point (24.52 and 24.41), yield/plant (24.29 and 24.14), diameter of anther (23.31 and 23.16), length of panicle (23.08 and 22.95), number of primary dichasia (22.12 and 21.98) and diameter of anther (23.31 and 23.16) and length of anther (21.12 and 20.91), and were medium to low for rest of the properties (Table 2).

The PCV estimates were higher in magnitude than the GCV, and the range was nominal, indicating

Table 2. Analysis on twenty five quantitative traits estimated in litchi genotypes.

Traits	SD	Mean	CV	Range	h^2	GCV	PCV	GA%
Length of Panicle (cm)	7.68	33.40	23.01	16.20-47.50	98.86	22.95	23.08	47.01
Width of Panicle (cm)	6.16	20.00	30.81	9.15-33.50	99.22	30.57	30.69	62.73
Number of primary Dichasia	2.84	12.66	22.44	8.33-20.00	98.73	21.98	22.12	44.99
Number of Secondary Dichasia	2.04	7.49	27.21	3.33-11.50	99.21	26.77	26.88	54.9
Maximum length of Primary Dichasia (cm)	5.70	16.00	35.63	6.00-30.00	99.34	35.06	35.18	71.99
Maximum length of Secondary Dichasia (cm)	1.56	3.89	40.13	1.80-8.00	99.28	39.29	39.43	80.65
Maximum Distance between two Primary Dichasia (cm)	1.25	4.36	28.61	2.00-6.60	99.05	28.32	28.45	58.06
Minimum Distance between two Primary Dichasia (cm)	0.32	0.49	64.98	0.10-1.00	99.87	67.24	67.28	138.43
Origin of primary Dichasia from same point	0.32	1.35	23.65	1.00-2.00	99.07	24.41	24.52	50.06
Degree of primary Dichasia	8.11	59.84	13.56	46.25-74.40	96.29	13.25	13.50	26.79
Diameter of flower bud (mm)	0.36	2.24	16.28	1.56-2.75	97.34	16.81	17.04	34.18
Length of male flower (mm)	0.24	2.04	11.97	5.80-11.89	96.18	11.74	11.98	23.73
Diameter of male flower (mm)	1.44	9.08	15.84	5.80-11.57	97.39	15.71	15.92	31.94
Length of flower bud (mm)	1.50	8.17	18.37	1.54-3.67	97.69	18.01	18.22	36.67
Length of female flower (mm)	0.70	8.45	8.27	6.65-9.60	92.05	8.01	8.35	15.83
Diameter of female flower (mm)	0.57	4.17	13.59	3.00-5.62	96.95	13.28	13.48	26.94
Length of M2 flower (mm)	1.06	8.63	12.27	6.40-10.20	96.49	14.93	15.20	30.22

Contd...

Table 2 contd...

Traits	SD	Mean	CV	Range	h^2	GCV	PCV	GA%
Diameter of M2 flower (mm)	1.26	7.13	17.66	5.07-10.39	97.49	17.54	17.76	35.68
Stamen length (mm)	1.04	5.22	19.94	3.12-7.75	98.26	19.83	20.00	40.50
Filament Length (mm)	1.06	3.94	26.95	1.18-6.23	98.88	26.86	27.01	55.02
Anther length (mm)	0.27	1.28	21.08	0.88-1.94	97.99	20.91	21.12	42.64
Diameter of anther (mm)	0.17	0.74	23.34	0.51-1.25	98.75	23.16	23.31	47.43
Length of stigma (mm)	0.41	5.13	8.01	4.17-5.95	89.51	7.75	8.19	15.10
Stamen length of F flower (mm)	0.41	2.54	15.97	1.84-3.42	96.71	15.71	15.97	31.83
Thickness of pedicle (mm)	0.10	0.71	14.14	0.46-0.92	95.49	13.81	14.13	27.80
Number of fruits/cluster	3.72	8.35	44.62	1.00-13.51	99.66	44.76	44.83	92.05
Fruit weight (g)	2.14	20.47	10.46	15.55-25.76	95.41	11.12	11.39	22.38
Maturity (Days)	2.79	63.60	4.39	55.50-70.50	71.06	4.44	5.26	7.71
Yield (kg/plant)	4.40	18.11	24.27	8.70-25.64	98.75	24.14	24.29	49.42

that there was less environmental influence on the studied traits. Traits with high genotypic variation could, therefore, be considered, and used for selection. Gupta and Kour (4) reported high GCV and PCV for fruit yield per plant in guava. The knowledge of PCV and GCV is very useful for predicting the amount of variation present in a given genetic strain. However, the genotypic coefficient of variation does not offer the full range for estimating the variation that is heritable in nature, and thus an estimate of heritability becomes necessary. Broad sense heritability was more than 90% for all characters except stigma length and days to maturity. Rajan *et al.* (12) also observed high heritability for various traits in several fruit crops. The extent of crop improvement through selection is limited with low to moderate heritability. Thus, calculation of heritability alone will not be sufficient to effectively improve fruit traits unless there is a higher genetic gain involving additive gene action that can be achieved through selection. The estimated heritability associated with genetic advance is more reliable than heritability alone for predicting the impact of selection. Higher heritability together with high genetic advance provides the most effective criteria for selection in crop improvement (Johnson *et al*., 5). In this study, higher heritability estimates accompanied by greater genetic advance was observed for all parameters except stigma length and days to maturity, suggesting that these characters showed additive gene action and phenotypic selection may be more fruitful for all these traits. Similar findings were also reported by Srivastava *et al.* (14) in other fruit crops.

Twenty-nine phenological traits were considered for principal component analysis. The first five principal components (PC1: 24.69, PC2: 16.54, PC3: 11.99, PC4: 7.69 and PC: 6.37) of the data accounted for 67.29% of the total variance among genotypes and their Eigenvalues are presented in the Table 3. The first principal component (PC1) explained 24.69% of the total variance, contributed by the degree of primary dichasia, minimum distance between two primary dichasia and anther diameter. PC2 accounted for 16.54% of the variance for panicle length and width, maximum primary and secondary dichasia length, minimum distance between two primary dichasia and flower bud diameter. These traits were the most effective parameters for distinguishing genotypes. Cluster analysis was performed based on 29 phenological characters (Fig. 1). The dendrogram showed the phylogenetic relationship among the 30 litchi genotypes. Thirty genotypes were classified into two main clusters (Cluster-I and Cluster-II), which were further categorized into different clusters. Cluster-I genotypes were characterized by a relatively small panicle, which produced a lower yield. The main cluster-II included 19 genotypes with larger panicle size which gave higher yield. The clustering method grouped the litchi genotypes based on the characters they had. The results of cluster analysis on 30 litchi genotypes indicated that there was enough variation for different traits among the studied genotypes (Fig. 1). Accessions with greater similarity for morphological characters were placed in the same cluster. Cluster analysis is of great practical importance to plant breeders, because it divides genotypes into different clusters. The result of identification based on morphological characters could be slightly different from the result based on molecular markers (Pathak *et al*., 11).

In the present study, 30 litchi genotypes showed great differences in panicle and flower characteristics.

Table 3. Eigen values, accumulated variance and correlations between original variables and the first four PCs representing variability of litchi genotypes.

Traits	PC1	PC2	PC3	PC4	PC5
Length of Panicle (cm)	-0.265	0.209	-0.146	0.175	-0.053
Width of Panicle (cm)	-0.244	0.237	-0.126	0.169	-0.018
Number of primary Dichasia	-0.088	0.153	0.374	0.214	0.044
Number of Secondary Dichasia	-0.284	-0.127	0.109	0.023	0.028
Maximum length of Primary Dichasia (cm)	-0.256	0.205	-0.034	0.089	-0.097
Maximum length of Secondary Dichasia (cm)	-0.112	0.242	-0.083	-0.334	-0.084
Maximum Distance between two Primary Dichasia (cm)	-0.227	0.174	-0.158	0.073	0.217
Minimum Distance b/n two Primary Dichasia (cm)	0.090	0.291	-0.037	0.097	-0.097
Origin of primary Dichasia from same point	-0.228	0.044	0.113	-0.338	0.059
Degree of primary Dichasia	0.170	0.172	-0.149	-0.332	-0.073
Length of flower bud (mm)	-0.029	0.191	0.054	-0.510	0.089
Diameter of flower bud (mm)	-0.139	0.278	0.037	-0.265	-0.081
Length of male flower (mm)	-0.278	-0.169	-0.055	-0.046	-0.003
Diameter of male flower (mm)	-0.246	-0.179	0.019	-0.003	-0.161
Length of female flower (mm)	-0.010	-0.011	-0.385	0.043	0.260
Diameter of female flower (mm)	-0.037	-0.219	0.006	-0.017	-0.210
Length of M2 flower (mm)	-0.063	-0.278	0.225	-0.134	0.250
Diameter of M2 flower (mm)	-0.010	-0.221	0.332	-0.076	-0.097
Stamen length (mm)	-0.252	-0.258	-0.085	0.003	0.035
Filament Length (mm)	-0.226	-0.280	-0.153	-0.043	0.118
Anther length (mm)	-0.079	0.119	0.281	0.183	-0.341
Diameter of anther (mm)	0.086	0.129	0.363	-0.088	-0.025
Length of stigma (mm)	-0.197	-0.084	-0.132	-0.256	-0.215
Stamen length of F flower (mm)	-0.028	-0.207	-0.069	-0.207	-0.433
Thickness of pedicle (mm)	-0.144	0.104	0.308	-0.001	-0.036
Number of fruits/cluster	-0.309	0.058	-0.048	0.071	-0.065
Fruit weight (g)	-0.152	0.123	0.162	-0.078	0.434
Maturity (Days)	-0.041	-0.090	0.173	-0.085	0.355
Yield/plant (kg)	-0.300	0.050	0.089	0.086	-0.050
Eigen value	2.676	2.190	1.864	1.494	1.360
Proportion of variance (%)	24.69	16.54	11.99	7.69	6.37
Cumulative variance (%)	24.69	41.23	53.22	60.91	67.29

The cluster-I comprised of the genotypes of small panicle with lower yield, while cluster-II composed of larger panicle with higher yield. The length and width of panicle, number of secondary dichasia, maximum length of primary dichasia, length of male flower, stamen length, thickness of pedicle, number of fruits/cluster and fruit weight were identified as important traits for identifying high-yielding genotypes. Overall, identification based on morphological features could provide key information for cultivar identification in litchi, which could play an important complementary role for diversity analysis and cultivar classification.

AUTHORS' CONTRIBUTION

Conceptualization of research (NL, VN, SDP); Designing of the experiments (NL, SKS, VN); Execution of field/lab experiments and data collection

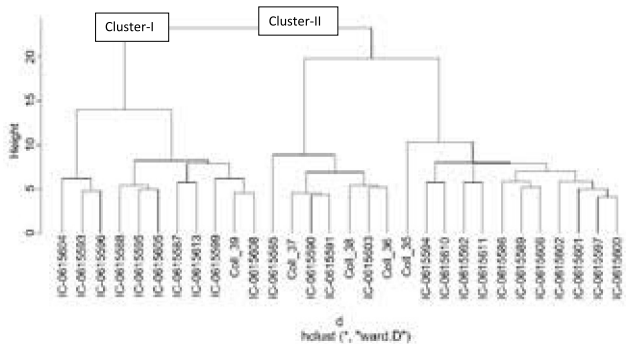

Fig. 1. Cluster analysis of 30 different litchi genotypes based on phenological traits.

(NL, AK); Analysis of data and interpretation (NL, AS); Preparation of the manuscript (NL, AK, AS).

DECLARATION

The authors declare no conflict of interest.

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