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PHYTOMORPHOLOGY

Morphological diversity of South Indian banana cultivars

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Abstract

Morphological diversity analysis of 38 *Musa* cultivars from Kerala was carried out using a total of fifty-one traits including vegetative, inflorescence, floral and fruit characteristics based on descriptors for banana. The UPGMA-derived dendrogram based on vegetative characters revealed two main clusters: cluster I, which consisted of twenty-one cultivars of the AB, AAB, and ABB genome groups divided into two groups, and cluster II, which consisted of fifteen cultivars, including all AAA triploids, five AA diploids, and three AAB triploids. According to Euclidean distance metrics, Nendran and Quintal Nendran (AAB) had the most morphological resemblance, whereas Pisanglilin (AA) and Perumpadali (AAB) had the greatest morphological dissimilarity. Cluster analysis based on fifty-one morphological features distinguished cultivars with the *acuminata* genome alone from cultivars with a hybrid genome composition. The results of PCO analysis using morphological data were similar to those of cluster analysis.

Keywords: Banana, cluster analysis, Kerala, morphological analysis, *Musa*

Introduction

Bananas and plantains have long been important to human well-being. They are a staple food for millions of people around the world, providing a well-balanced diet while also contributing to income through crop production, processing, and marketing. They are one of the oldest cultivated fruit crops, with deep roots in Indian heritage and culture. As a highly evolved and domesticated crop, many banana cultivars have a lot of synonyms, resulting in a somewhat confused taxonomical position.

Simmonds (1962) concluded that the present day cultivars have evolved by the hybridization of two main species, *M. acuminata* and *M. balbisiana*, which were considered the main contributors of A and B genomes, respectively. All cultivars were classified into various genomic groups such as AA, AAA, AB, AAB and ABB, respectively based on a morphological scoring method (Stover & Simmonds, 1987). The primary centre of diversity of wild *M. acuminata* is the Malayan area extending to Assam, Burma, Siam, Indochina and Philippines. The wild *M. balbisiana* are found in peninsular India

and Western Ghats along with M. *acuminata* (Simmonds, 1962). Recently, cultivars derived from hybridization with *M. schizocarpa* have been identified among the *Musa* germplasm of Papua New Guinea (Rekha et al., 2001). A Philippine clone was considered to be the result of an ancient hybridization between *M. balbisiana* and *M. textilis*. D'Hont et al. (2000) observed the occurrence of *M. schizocarpa* and *M. textilis* genomes among the chromosome complement of *Musa* cultivars. These observations reveal the complexity of the genomic structure of present day banana cultivars and their evolution.

Kerala along with two other South Indian states – Tamil Nadu and Karnataka – are known for the varied genetic resources, especially the AB, AAB and ABB genomic groups under the *Eumusa* series of edible bananas (Stover & Simmonds, 1987). A few reports are available on the abundance of AB, AAB and ABB groups in the cultivated bananas of South India especially, Kerala (Amalraj, 1992). The practice of providing local names to cultivars based on fruit and plant traits has resulted in a large number of synonyms and homonyms that must be eliminated for successful and cost-effective germplasm conservation, management, and utilisation (Shanmugavelu et al., 1992). Morphological characterisation has been the primary approach for categorising banana cultivars into several genetic groups. Valsalakumari et al. (1984) and Valsalakumari & Nair (1993) investigated the diversity and genetic divergence of Indian banana varieties. Rekha et al. (2001) investigated the morphological, quantitative, and genetic correlations among South Indian banana cultivars using D2 analysis. The current study tried to analyse the genomic categorisation of thirty-eight banana cultivars from Kerala using fifty-one morphological features derived from banana descriptors (Anonymous, 1996).

Materials and Methods

Plant materials

Thirty-eight *Musa* cultivars comprising diploids and triploids of six different genomic groups have been used as experimental materials for the present study (Table 1).

Morphological characterization

Morphological characterization of the cultivars were done based on eighteen vegetative characters (Table 2), eleven male inflorescence characters (Table 3), thirteen male flower characters (Table 4) and ten fruit characters (Table 5). The traits were based on the banana descriptors of INIBAP/ IPGRI (Anonymous, 1996). Five competitive plants per cultivar were randomly chosen to record observations. The data were recorded from direct field observations by repeated field visits.

Data analysis

The data obtained were subjected to statistical analysis to summarize the information on each of the characters studied. For all the qualitative traits, the numerical values of the codes for different descriptor states were used for analysis. The coded data were subjected to Euclidean distance analysis to obtain a matrix based on morphological descriptors. The distance matrix thus obtained was used for cluster analysis using UPGMA method followed by PCO analysis with the software MVSP 3.0.

Table 1. List of banana cultivars used for the present study

Sl. No.	Name of the cultivar	Genome constitution	Place of collection
1	Pisanglilin	AA	Banana Nursery, Peringammala, TVM
2	Matti	AA	Banana Nursery, Peringammala, TVM
3	Kadali	AA	Banana Nursery, Peringammala, TVM
4	Sannachenkadali	AA	Banana Nursery, Peringammala, TVM
5	Chingan	AA	Botanical garden, Dept. of Botany
6	Calcutta 4*	AA	BRS, Kannara, Thrissur
7	Sikuzani	AA	BRS, Kannara, Thrissur
8	Adukkan	AB	Banana Nursery, Peringammala, TVM
9	Poomkalli	AB	Banana Nursery, Peringammala, TVM
10	Njalipoovan	AB	Banana Nursery, Peringammala, TVM
11	Valiyakunnan	AB	BRS, Kannara, Thrissur
12	Adakkakunnan	AB	BRS, Kannara, Thrissur
13	Padalimoongil	AB	BRS, Kannara, Thrissur
14	Velipputtubale	AB	BRS, Kannara, Thrissur
15	Red Banana	AAA	Banana Nursery, Peringammala, TVM
16	Robusta	AAA	Banana Nursery, Peringammala, TVM
17	Dwarf Cavendish	AAA	Banana Nursery, Peringammala, TVM
18	Grandnaine	AAA	Banana Nursery, Peringammala, TVM
19	Green red	AAA	Banana Nursery, Peringammala, TVM
20	Monsmarie	AAA	Banana Nursery, Peringammala, TVM
21	Gros Michel	AAA	Banana Nursery, Peringammala, TVM
22	Poovan	AAB	Banana Nursery, Peringammala, TVM
23	Perumpadali	AAB	Banana Nursery, Peringammala, TVM
24	Dudhsagar	AAB	Banana Nursery, Peringammala, TVM
25	Mysore ethan	AAB	Banana Nursery, Peringammala, TVM
26	Palayankodan	AAB	Banana Nursery, Peringammala, TVM
27	Krishnavazhai	AAB	Banana Nursery, Peringammala, TVM
28	Charapadathi	AAB	Banana Nursery, Peringammala, TVM
29	Nendran	AAB	Banana Nursery, Peringammala, TVM
30	Quintal nendran	AAB	Banana Nursery, Peringammala, TVM
31	Padathi	AAB	Banana Nursery, Peringammala, TVM
32	Velipadathi	AAB	Banana Nursery, Peringammala, TVM
33	Kosthabontha	ABB	Banana Nursery, Peringammala, TVM
34	Karpooravalli	ABB	Banana Nursery, Peringammala, TVM
35	Boothibale	ABB	Banana Nursery, Peringammala, TVM
36	Kanchikela	ABB	Banana Nursery, Peringammala, TVM
37	Peyan	ABB	Banana Nursery, Peringammala, TVM
38	Elavazhai*	BB	BRS, Kannara, Thrissur

*wild

Table 2. List of vegetative characters selected for the morphological characterization of the cultivars

Vegetative traits	*Distribution of traits*
Pseudostem colour	Green/Green yellow-1 Medium green-2 Green-3 Dark green-4 Medium green with pink-5 Green-Red-6 Red purple-7 Others-8
Pseudostem appearance	Waxy-1 Not waxy-2
Leaf habit	Erect-1 Intermediate-2 Drooping-3
Wax on leaf sheath	Very little or no sign of wax-1 Very few wax-2 Moderately waxy-3 Very waxy-4
Blotches at the petiole base	Sparse blotching-1 Small blotches-2 Large blotches-3 Extensive pigmentation-4
Blotches colour	Brown-1 Dark brown-2 Brown black-3 Black-4
Petiolar canal	Open with margins spreading-1 Wide with erect margins-2 Straight with erect margins-3 Margins curved inwards-4 Margins overlapping-5 Margins curved outwards-6
Petiole margins	Winged and not clasping the pseudostem-1 Winged and clasping the pseudostem-2 Not winged and clasping the pseudostem-3 Not winged and not clasping the pseudostem-4
Petiole margin colour	Green-1 Pink-purple -2 Others-3
Edge of petiolar margin	Colourless-1 With a colour line along-2
Colour of leaf upper surface	Green-1 Medium green-2 Dark green-3
Colour of leaf lower surface	Green-1 Medium green-2 Dark green-3
Wax on leaves (lower surface)	No or very little sign of wax-1 Sparsely waxy-2 Moderately waxy-3 Very waxy-4
Colour of midrib dorsal surface	Light green-1 Green-2 Pink-purple-3 Red purple-4 Others-5
Colour of midrib ventral surface	Light green-1 Green-2 Pink-purple-3 Red purple-4 Others-5
Colour of cigar leaf dorsal surface	Green-1 Red purple-2
Blotches on leaves of water sucker	Without blotches-1 Little or narrow blotches-2 Large purple blotches-3
Shape of leaf blade base	Both sides rounded-1 One side rounded, one pointed-2 Both sides pointed-3 Auriculated rounded-4

Table 3. List of male inflorescence characters selected for the morphological characterization of the cultivars

Male inflorescence	*Distribution of traits*
Bract curling	Reflex and rolls back-1
	Lifts upwards-2
	male bud absent-3
Bract shape	Lanceolate-1
	Narrowly ovate-2
	Broadly ovate-3
	male bud absent-4
Bract apex	Acute-1
	Intermediate-2
	Obtuse-3
	male bud absent-4
Outer bract colour	Yellow-1
	Red purple-2
	Purple brown-3
	Pink purple-4
	Maroon-5
	male bud absent-6
Inner bract colour	Yellow-1
	Orange red-2
	Red-3
	Pink/Pink purple-4
	male bud absent-5
Bract scars on rachis	Prominent-1
	Medium-2
	Not prominent-3
Bract colour fading	Colour fades towards base-1
	Colour homogenous-2
	male bud absent-3
Wax on the bract	Very little or no visible sign of wax-1
	Very few wax-2
	Moderately waxy-3
	Very waxy-4
	male bud absent-5
Peduncle colour	Light green-1
	Green-2
	Dark green-3
	Red or Pink purple-4
Peduncle hairiness	Hairless-1
	Slightly hairy-2
	Very hairy, Short hairs-3,
	Very hairy, Long hairs-4

Table 4. List of male flower characters selected for the morphological characterization of the cultivars

Male flower traits	*Distribution of traits*
Free tepal of male flower	Simple folding under apex-1
	More or less smooth-2
	Several folding under apex-3
	male bud and flowers absent-4
Compound tepal basic colour	Cream-1
	White-2
	Pink purple-3
	male bud and flowers absent-4
Compound tepal pigmentation	No visible sign of pigmentation-1
	Presence of pink-2
	male bud and flowers absent-3
Lobe colour of compound tepal	Cream-1
	Yellow-2
	Orange-3
	male bud and flowers absent-4
Free tepal colour	Translucent white-1
	Opaque white-2
	Tinted with pink-3
	Full of pink-4
	male bud and flowers absent-4
Filament colour	White-1
	Cream-2
	Pink shaded-3
	male bud and flowers absent-4
Anther colour	White-1
	Cream-2
	Pink purple-3
	male bud and flowers absent-4
Style basic colour	White-1
	Cream-2
	White with pink-3
	male bud and flowers absent-4
Style pigmentation	Without pigmentation-1
	Pink/Pink purple-2
	male bud and flowers absent-3
Stigma colour	Cream-1
	Yellow-2
	Orange-3
	male bud and flowers absent-4
Dominant colour of male flower	Cream-1
	White-2
	Pink purple-3
	male bud and flowers absent-4
Ovary shape	Straight-1
	Arched-2
	B& bud and flowers absent-3
Ovary basic colour	White/Cream-1
	Pink purple-2
	Green-3
	male bud and flowers absent-3

Table 5. List of fruit characters selected for the morphological characterization of the cultivars

Fruit traits	*Distribution of traits*
Bunch position	Hanging vertically-1
	Slightly angled-2
	Hanging at angle 45° -3
	Horizontal-4
	Erect-5
Bunch shape	Cylindrical-1
	Truncated cone shape-2
	Asymmetric-3
Fruit position	Curved towards stalk-1
	Parallel to stalk-2
	Curved upwards-3
	Perpendicular to stalk-4
Pedicels	Long-1
	Short-2
Pedicel surface	Hairless-1
	Hairy-2
Immature fruit	Light green-1
peel colour	Green-2
	Dark green-3
	Others-4
Mature fruit	Yellow-1
peel colour	Bright yellow-2
	Light green-3
	Red purple-4
Fruit shape	Straight or slightly curved-1
	Straight in the distal part-2
	Curved-3
Fruit apex	Lengthily pointed-1
	Pointed-2
	Bottle-necked-3
	Blunt-tipped –4
Remains of	Without any floral relicts-1

Results

Morphological observations based on vegetative characters

Morphological observations of vegetative characters showed wide variation among cultivars of AA genomic group. Pseudostem was green or green yellow, with or without waxy appearance. Sannachenkadali was distinct from all other cultivars, with red coloured pseudostem. Leaf habit was erect in most of the cultivars. Wax on leaf sheath was absent in Matti and Calcutta 4, while leaf sheath was very waxy in Kadali. Other cultivars of this group showed a little wax on leaf sheath. Dorsal surface of cigar leaf was red purple in Sannachenkadali, while it was green in all other cultivars. Midrib on dorsal and ventral surface of leaf was also red purple in Sannachenkadali. Leaf surface of water suckers was either without blotches or with little/narrow blotches in the cultivars of AA genomic group.

The cultivars of AB genomic group had waxy pseudostem with small or sparse blotches at the petiole base. Leaf sheath was moderately waxy. Leaf habit was intermediate except in Valiyakunnan and Padalimoongil. Blotches at the petiole base were brown or brown black in colour. Petiole margins were not winged and clasped the pseudostem except in Padalimoongil.

Blotches were absent on the leaf surface of water suckers. Pseudostem was green or green red in the cultivars of AAA genomic group except in Red banana which showed characteristic red coloured pseudostem. Leaf habit was intermediate in all the cultivars and was characterized by the presence of large blotches at the petiole base. Petiolar canal was open with spreading margins. The margins were winged and not clasped the pseudostem. Surface of water sucker leaves was either without or with large purple/little narrow blotches. Base of the leaf blade was pointed at both sides.

Pseudostem was medium green with light pink shade in most of the cultivars

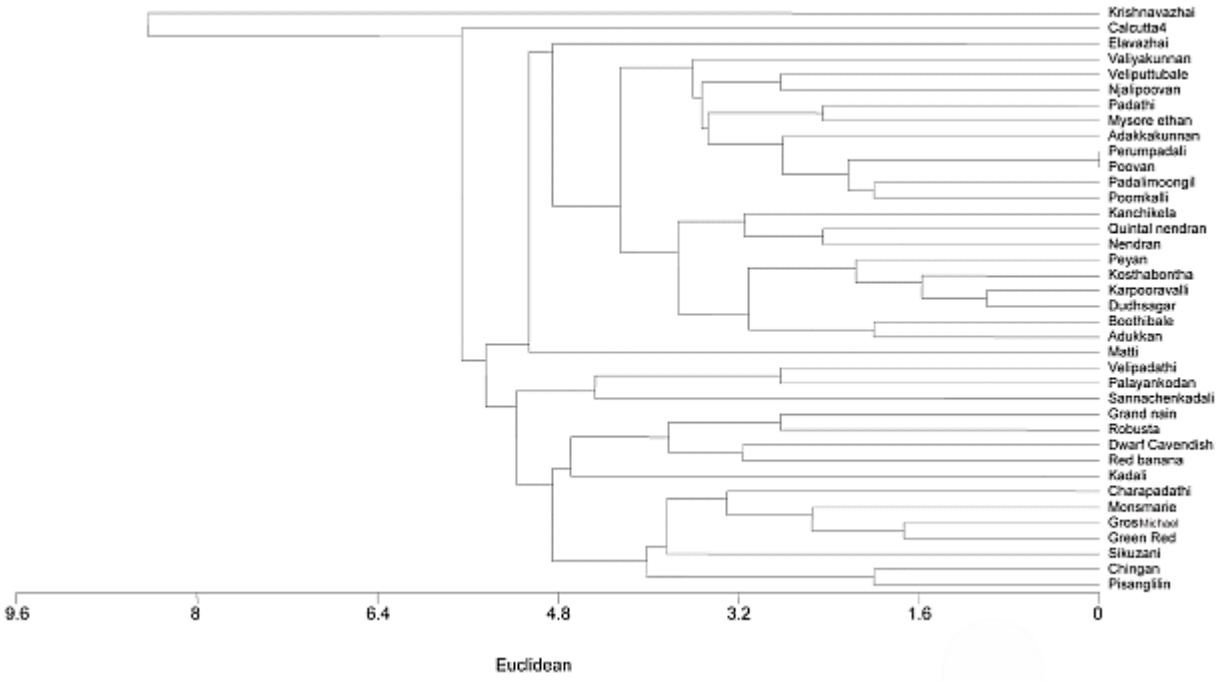

Fig. 1. UPGMA derived dendrogram based on vegetative characters

of AAB genomic group. Petiole margin was pink purple and with a colour line along the margin except in Dudhsagar. Only in Krishnavazhai, pseudostem was bluish black in colour. Petiole margins were not winged and clasped the pseudostem. Blotches were either present or absent on the leaf surface of the water sucker.

Pseudostem was green or medium green with waxy appearance in the cultivars of ABB genomic group. Only in Kanchikela, pseudostem was not waxy. Sparse or small blotches were observed at the petiole base. Blotches were brown or dark brown in colour. Petiolar canal was closed with its margins overlapping or curved inwards. Petiolar margins were not winged and clasped the pseudostem. Edge of petiolar margin was colourless except in Boothibale. Blotches were absent on the surface of the leaves of water sucker. Base of leaf blade was auriculated rounded in all cultivars.

Cluster analysis based on vegetative characters

UPGMA derived dendrogram for thirty-eight banana cultivars based on vegetative characters showed two main clusters (Fig 1). Cluster I comprised twenty-one cultivars arranged in two groups. Ten cultivars were clustered together in the first group which included six AB diploids and four AAB triploids. Of which, Poovan (AAB) and Perumpadali (AAB) showed 100% similarity in vegetative characters. In the other group all ABB cultivars were clustered together. Adukkan (AB), Nendran (AAB) and Quintal Nendran (AAB) were found to be associated with the ABB group. Elavazhai (BB) and Matti (AA) showed association with the cluster I however remained as separate outliers. Cluster II comprised fifteen cultivars including all the AAA triploids and five AA diploids along with three AAB triploids. Wild diploid Calcutta 4 (AA) and

Krishnavazhai (AAB) were separated from rest of the cultivars. Cluster analysis of vegetative characters showed close association between AB and AAB as well as AA and AAA genomic groups.

Morphological observations based on male inflorescence characters

Male inflorescence characters showed curling of bracts in all AA cultivars. Bract shape was lanceolate with acute apex in most of the cultivars. Bract apex was slightly obtuse in Matti. Outer bract colour was red/red purple or purple brown in most of them. However, it was maroon/ deep maroon in Kadali and Sannachenkadali, respectively. Outer and inner bract colour was yellow in Sikuzani. Bract scars were medium or very prominent.

Bract shape was narrowly or broadly ovate with obtuse apex in AB group. Outer bract colour was red/pink purple or purple brown. Inner bract colour was red in most of them and continuous from apex to base in all cultivars. Peduncle was green or dark green and hairless in most of the cultivars.

Lanceolate or narrowly ovate bracts with acute apex were observed in the cultivars of AAA genomic group. Bracts rolled back in all of them except in Dwarf Cavendish. Bract scars were very prominent. Bract colour faded to yellow towards the base in all cultivars.

Peduncle was very hairy with long hairs. In the cultivars of AAB genomic group, the bracts were either reflex and rolled back or lifted upwards without rolling. Bract apex was obtuse or slightly obtuse. Outer bract colour was purple brown or red purple. Inner bract colour was continuous from base to apex. Bracts were very waxy or moderately waxy.

In the cultivars of ABB and BB genomic groups, bracts were broadly ovate with obtuse apex. Outer bract colour was purple brown or red purple. Inner bract colour was red or orange red and continuous from apex to base. Bract scars were medium or not prominent. Peduncle was hairless.

Cluster analysis based on male inflorescence characters

UPGMA dendrogram for thirty-eight banana cultivars based on male inflorescence characters revealed two major clusters. Cluster I comprised only three cultivars namely Elavazhai (BB genome), Peyan (ABB genome) and Kanchikela (ABB genome) with 100% similarity. Cluster II was subdivided into two sub clusters II A and II B. Cluster II A included twenty-four cultivars. All the AAB cultivars were grouped together in this cluster along with three cultivars belonging to AA, AAA and ABB genome groups each respectively and four cultivars belonging to AB genomic group. Rest of the eleven cultivars including four cultivars of AA and AAA genome groups, respectively, and three cultivars with AB genome were grouped together in cluster II B. Cluster analysis revealed close association of BB and ABB genome groups. Similarly, AB genome group was associated with AAB and ABB groups.

Morphological observations based on male flower characters

Observations on male floral characters showed cream or white flowers in the cultivars with AA genome. Compound tepal was cream or white without pigmentation. Free tepal was translucent white. Anther and filament was cream or white in colour. Style was white or cream and with or without pigmentation. Stigma was orange coloured except in Chingan.

In the cultivars belonging to AB genomic group, dominant colour of male flower was pink or pink purple. Compound tepal was pigmented with pink in all cultivars, though the basic colour was cream or white. Lobes of compound tepal were yellow in colour. Free tepal was either translucent/opaque white or pink. Anther and filament was cream or white in colour. Style was white with or without pigmentation.

Free tepal of male flower in AAA group showed several foldings below the tip. Compound tepal was cream in colour except in Red banana. Free tepal was translucent white in all the cultivars. Anther and filament colour was cream or white. Style was white or cream with pink pigmentation. Style pigmentation was absent in Red banana and Green Red. In the cultivars belonging to ABB genomic group, compound tepal was pink/pink purple except in Karpooravalli. Pigmentation was noticed in the compound tepal of all cultivars. Free tepal was either fully pink or tinted with pink. In Karpooravalli, free tepal was opaque white. Lobe colour was yellow in all the cultivars. Filament was cream/white or pink shaded. In BB group, free tepal of male flower was smooth and translucent white. Dominant colour of male flower was pink purple.

In AAB group, basic colour of compound tepal was cream except in Charapadathi, which was pink in colour. Free tepal was either translucent white or tinted with pink colour. In Mysore Ethan and Dudhsagar, tip of the free tepal was smooth. Compound tepal was either pink pigmented or without pigmentation. Filament was cream or white, while in Charapadathi it was pink shaded. Style was cream/white with pink or pink purple

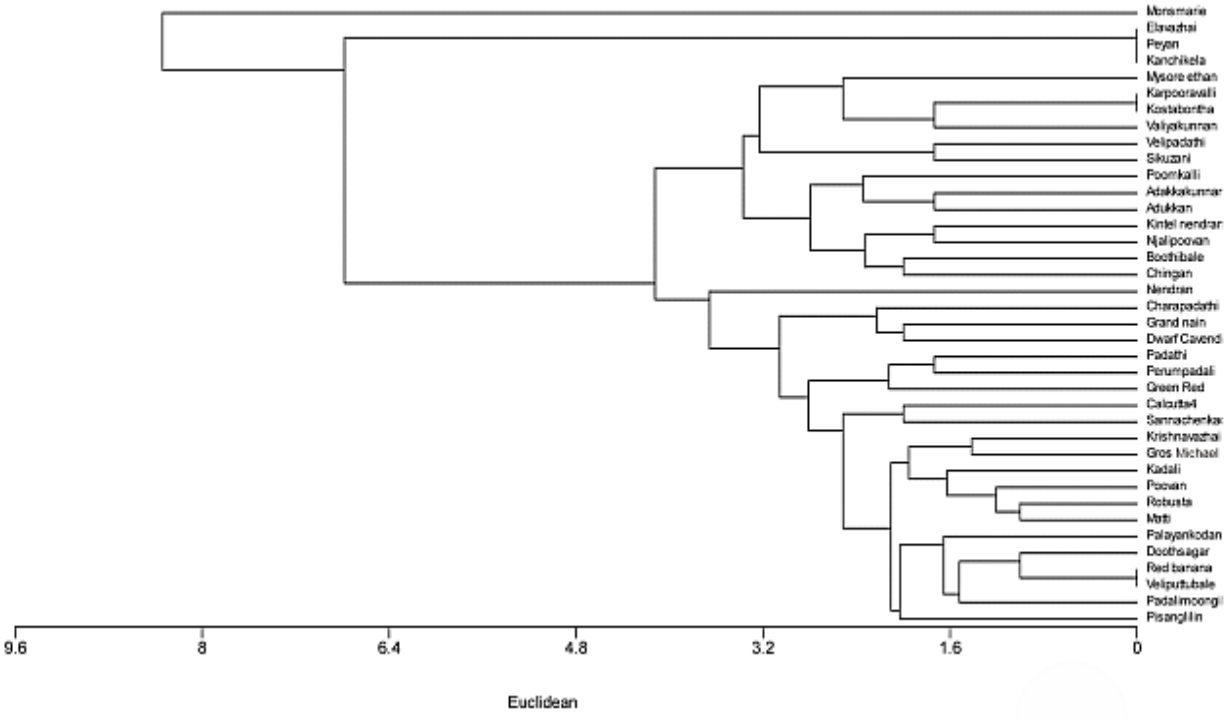

Fig. 2. UPGMA derived dendrogram based on male flower characters

pigmentation. Style pigmentation was absent in Mysore ethan and Palayankodan. Male flowers were completely absent in Perumpadali.

Cluster analysis based on male flower characters

UPGMA dendrogram for thirty-eight banana cultivars based on male flower characters revealed two major clusters (Fig. 2). Cluster I included only three cultivars namely Elavazhai (BB), Peyan (ABB) and Kanchikela (ABB) with 100% similarity. Cluster II was divided into two sub clusters II A and II B. Cluster II A grouped thirteen cultivars together under two micro clusters A1 and A2. Mysore ethan (AAB), Velipadathi (AAB), Sikuzani (AA), Valiyakunnan (AB), Kosthabontha (ABB) and Karpooravalli (ABB) were grouped together in the cluster A1. Kosthabontha (ABB) and Karpooravalli (ABB) showed 100% similarity and Valiyakunnan (AB) was found to be closely associated with these cultivars. Cluster A2 grouped four AB diploids together with one AAB, ABB and AA cultivars each. Cluster II B comprised twenty-one cultivars with mainly AAA, AA and AAB genomes along with two AB diploids. Monsmarie (AAA) remained as a separate out group. Close association was observed between AA, AAA and AAB genome groups. However, AB and BB genome showed close association with ABB group in male flower characteristics.

Morphological observations based on fruit characters

Fruit apex was lengthily pointed in most of the cultivars with AA genome. Colour of mature and immature fruit peel was red purple in Sannachenkadali, while it was light green/green and yellow in all others. Persistent styles were present at the apex of mature fruits in Kadali. In AB group, fruit bunches were cylindrical or truncated cone shapes, hanging at 45° angle or slightly angled. Fruits were straight or straight in the distal part. In the cultivars of AAA genomic group, bunches were cylindrical and hanging vertically. Fruits were curved with pointed apex. Pedicels were short and hairy. In the cultivars of AAB genomic group, bunches were cylindrical and hanging at 45° angle or slightly angled. Fruits were straight or slightly curved with their apex being blunt or bottle necked. In the cultivars of ABB genomic group, bunches were cylindrical. Fruit pedicels were long and hairless.

Cluster analysis based on fruit characters

UPGMA derived dendrogram for thirty-eight banana cultivars based on fruit characters revealed two major clusters (Fig 3). Cluster I included the two wild diploids namely Elavazhai (BB genome) and Calcutta 4 (AA genome). Cluster II comprised two sub clusters II A and II B. Cluster II A was again divided into two micro clusters A1 and A2. Cluster A1 consisted of two distinct groups, of which first group comprised ten cultivars including eight AAB as well as one ABB and AB cultivars each, respectively. The second group comprised eleven cultivars including four ABB and AB cultivars each along with three cultivars with AAB genome. Six AAA triploids and two AA diploids were grouped together in the A2 cluster. Robusta (AAA genome) remained as an outlier. Cluster II B comprised four AA cultivars together with two AB cultivars. Non edible wild as well as edible cultivars were distinctly separated into two groups in the dendrogram. Majority of the AAB cultivars were grouped together. AAA cultivars except Robusta were also grouped together in the dendrogram.

Diversity estimates and clustering pattern of banana cultivars based on morphological characters

Genetic diversity estimates were calculated for 38 banana cultivars based on the coded data obtained for fifty-one morphological descriptors. Euclidean distance obtained for the cultivars ranged from 3.2 to 12.4. Highest morphological similarity was observed between Nendran (AAB) and Quintal nendran (AAB), while lowest similarity was observed between Perumpadali (AAB) and Pisanglilin (AA). Cluster analysis was performed on the basis of the distance matrix obtained. Two main clusters were revealed in the UPGMA derived dendrogram based on gross morphological characters (Fig 4). Cluster II included two sub clusters II A and II B. Cluster II A included ABB cultivars along with Dudhsagar (AAB).

Elavazhai (BB) showed close association with this group. Cluster II B included AB and AAB cultivars along with one ABB cultivar (Boothibale) arranged in two groups. First group comprised six AAB cultivars along with one AB cultivar while the second group comprised rest of the six AB cultivars along with Boothibale (ABB) and Charapadathi (AAB). Perumpadali (AAB), Velipadathi (AAB) and Krishnavazhai (AAB) were remained as separate outliers. Cluster I comprised all the cultivars belonging to AA and AAA genomic groups.

Principal co-ordinate analysis

PCO analysis produced results similar to that of cluster analysis (Fig 5). Cultivars with acuminata genome and hybrid genome formed distinct clusters in the PCO scatter plot. The first five most informative principal components explained more than 60% of the total variation. Krishnavazhai (AAB) with bluish black pseudostem and Velipadathi

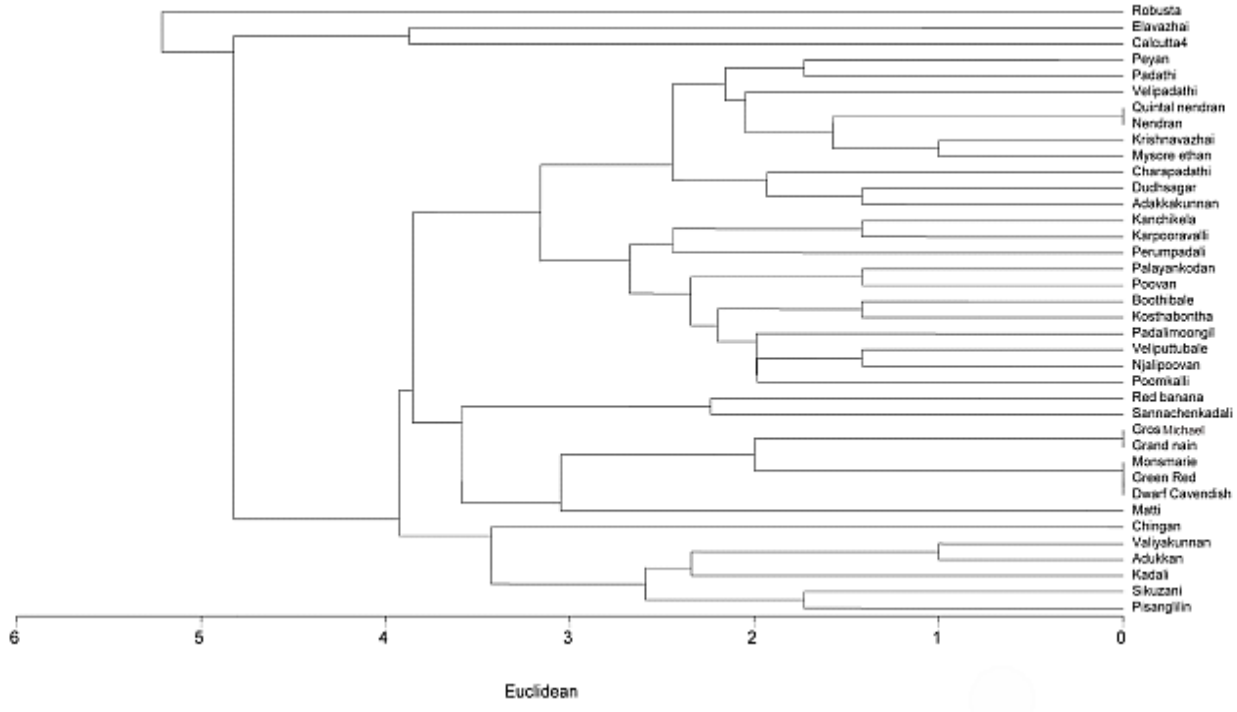

Fig. 3. UPGMA derived dendrogram based on fruit characters

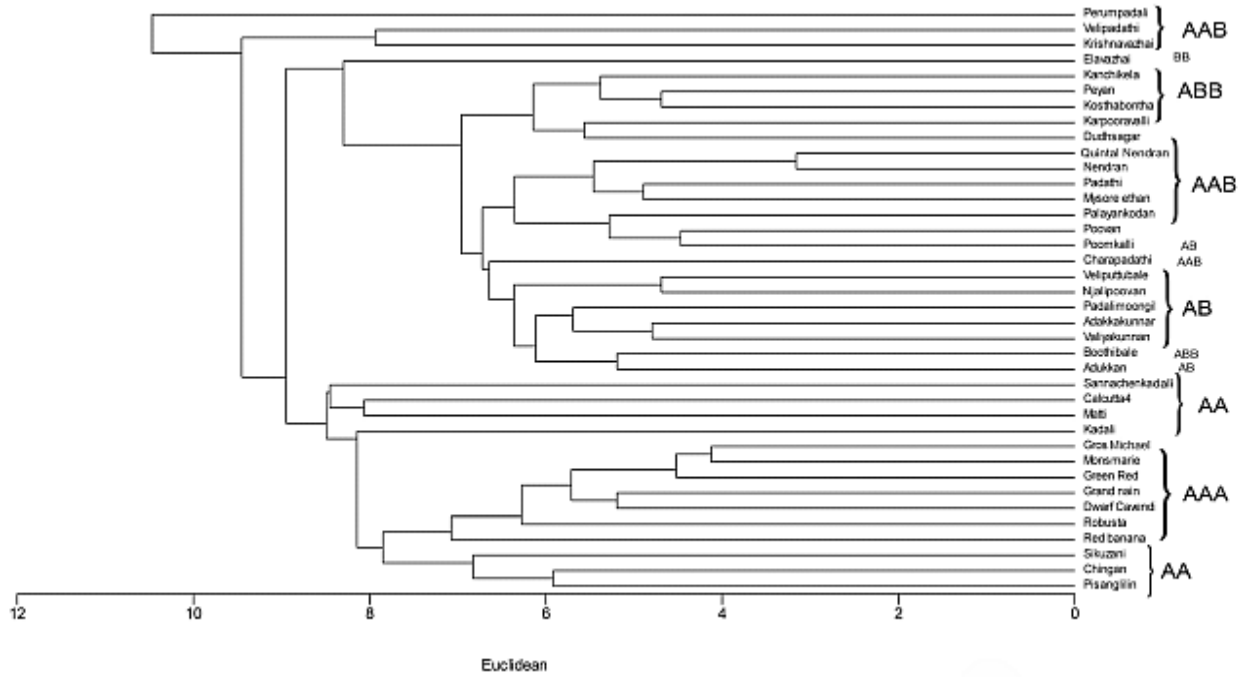

Fig. 4. UPGMA derived dendrogram based on gross morphology

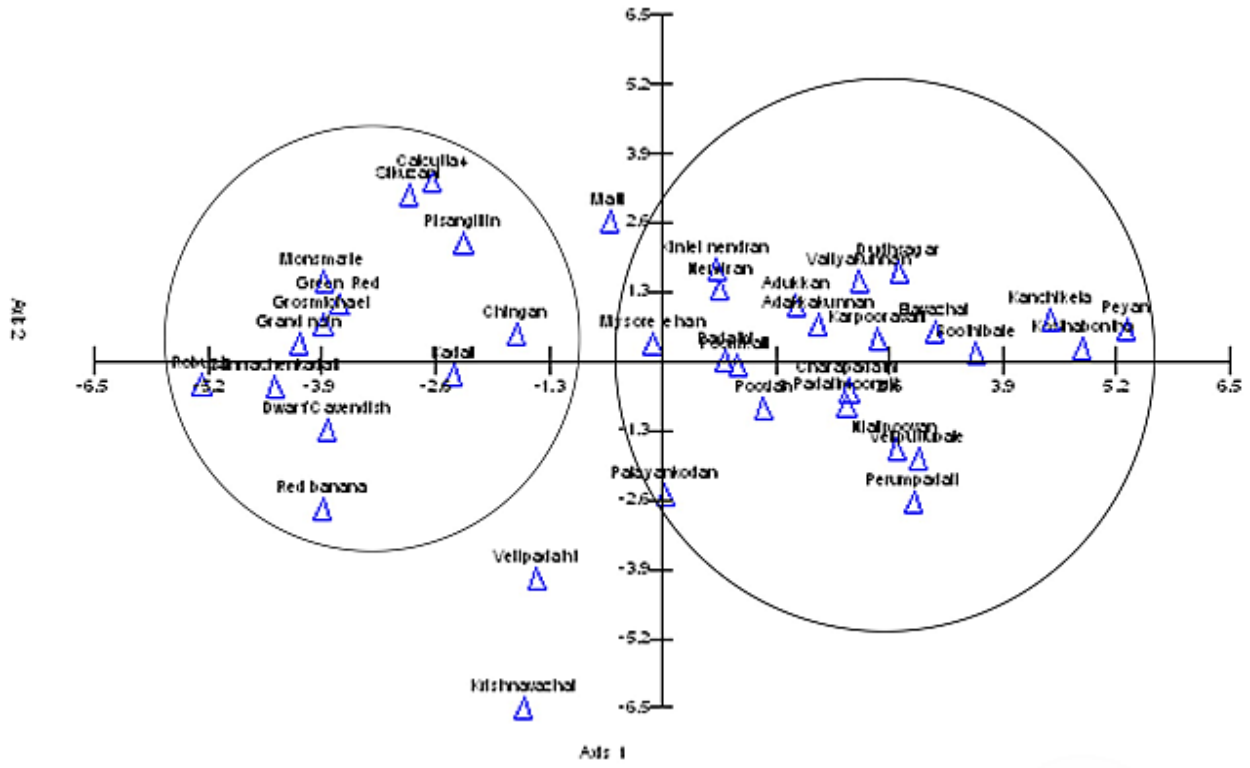

Fig. 5. PCO scatter plot based on morphological characters

(AAB) remained as distinct genotypes in the scatter plot.

Discussion

IPGRI/INIBAP (Anonymous, 1996) defined a set of 119 agro-morphotaxonomic descriptors as a norm of description for bananas. Variations in vegetative characters occur mainly in the colour of the pseudostem, the presence and colour of blotches at the base of petioles, the shape of the petiolar canal section and the size and shape of the plant (Jenny et al., 2003). Several key qualitative morphological descriptors such as extent of pseudostem blotching, shape of leaf lamina base, leaf petiole canal and margin, sucker orientation, peduncle hairiness, prominence of bract scars in male axis, traits of male bracts, corrugation and texture of free tepal, colour of male flower, fruit base insertion, fruit orientation and fruit apex are most important for their diagnostic value to distinguish between diploid *Musa* species (Ortiz, 1997). In the present study, AA group of cultivars was characterized by the presence of erect leaf habit, lanceolate bracts with acute apex and fruits with lengthily pointed apex. *Acuminata* diploids possessed similar distinct characteristics as reported by Singh et al. (2001). Pascua (1988) prepared a tentative key to AA, AAA, AAB, ABB, ABBB, BB/BBB genomic groups of Philippine bananas based on IBPGR banana descriptor list. He described diploid *acuminata* cultivars (AA) as short statured plants with erect and narrow leaves. AB group of cultivars was characterized by the presence of broadly or narrowly ovate bracts with obtuse apex and fruit bunches hanging at 45º angle. As suggested by Ortiz (1997) these characterization descriptors exhibited polymorphism, either between or within taxa and they were highly heritable, easy to visually score and consistently expressed in all environments. AAA cultivars were characterized by the presence of green/green red colour of pseudostem, large blotches at the petiole base, open petiolar canal with spreading margins, winged petiolar margins not clasping the pseudostem, base of leaf blade pointed at both sides, cylindrical and vertically hanging bunches, slightly curved fruits with pointed apex and short hairy pedicels. Most East African highland bananas (AAA) are easily recognized by the intense black blotches (Karamura & Pickersgill, 1999). Most of the AAB cultivars were distinguished by the medium green coloured pseudostem with light pink shade and presence of cylindrical bunches hanging at an angle of 45º. Morphological features that identify ABB cultivars include medium green waxy pseudostem, closed petiolar canals with overlapping margins or margins curved inwards, petiolar margins with colourless edges, base of leaf blade auriculated, rounded pink colour of male flower (both compound tepal and free tepal pink in colour), white coloured style without pigmentation, arched shape of ovary and long hairless pedicels. Singh et al. (2001) focussed priority and emphasis on conspicuous plant parameters like stature, pigmentation, bunch orientation, male bud characters etc. and prepared a tentative key for the identification and classification of Indian bananas which supports the present observations. Cluster analysis based on vegetative characters grouped Pisanglilin, Chingan and Sikuzani along with AAA Cultivars. Calcutta 4 was separated from rest of the cultivars. Sannachenkadali showed close association with AAB cultivars Palayankodan and

Velipadathi. Gopimony (1980) classified Sannachenkadali under AAB group. Valsalakumari & Pushkaran (1996) also reported that Sannachenkadali had some characteristics of *Musa balbisiana*. UPGMA derived dendrogram based on vegetative characters showed that Grandnaine, Robusta, Dwarf Cavendish and Red banana are closely associated. Monsmarie, Gros Michel and Green red were also grouped together and showed association with the above cultivars. AB and AAB cultivars showed close relation in the dendrogram derived on the basis of vegetative characters. Six AB cultivars (except Adukkan) and four AAB cultivars (Padathi, Mysore Ethan, Poovan and Perumpadali) were grouped together in the dendrogram. Poovan and Perumpadali showed 100% similarity in vegetative characters. Perumpadali is a natural uncommon mutant of Poovan with long bunch and without male phase (Pushkaran, 1998). Adukkan was closely related to ABB group in vegetative characteristics. AAB cultivars Nendran, Quintal Nendran and Dudhsagar showed an association with ABB group. Krishnavazhai (AAB) was separated from rest of the cultivars. Simmonds (1966) assigned AAB genome status to Krishnavazhai, Padalimoongil and Adakkakunnan. However, earlier studies assigned AB genome status to Krishnavazhai, Padalimoongil and Kosthabontha based on chromosome numbers and morphological description of the cultivars (Valsalakumari et al., 1993).

In the present study, cluster analysis based on vegetative characters grouped ABB cultivars Peyan, Kosthabontha, Karpooravalli and Boothibale together along with Dudhsagar (AAB) and Adukkan (AB). Kanchikela (ABB) showed association with AAB cultivars Nendran and Quintal Nendran. Nayar (1962) examined the taxonomic status of 46 South Indian banana varieties and classified them into four groups (*Musa acuminata* group, *Musa sapientum* group, *Musa paradisiaca* group and *Musa balbisiana* group) based on eighteen diagnostic characters of *M. accuminata* and *M. balbisiana*. However, the cultivars were classified irrespective of their genome and ploidy status. Kadali, Sannachenkadali, Lal Kel, Poovan, Matti, and Chingan were classified under *Musa acuminata* group. Krishnavazhai and Adakkakunnan were placed in the *Musa sapientum* group. Peyan, Boothibale and Nendran were included in the *Musa paradisiaca* group. The selected male inflorescence characters did not group the cultivars with AA, AB or AAB genome into distinct clusters. AA cultivars were associated with AB diploids. Raman et al. (1968) also made a comparative assessment of morphological variation pattern in 24 diploid bananas based on fruit volume, peduncle hairiness, number of hands per bunch, length of pedicel, shape of fruit, width of petiolar canal and length/breadth ratio of bract. Clones with AA genome showed a wide dispersion over the diagram in the metroglyph analysis and exhibited expression of characteristics of *M. balbisiana* and those intermediate between *M. balbisiana* and *M. acuminata*.

Cluster analysis based on male flower characters grouped only Adukkan, Adakkakunnan and Poomkalli of AB genomic group together whereas all other AB cultivars were scattered in the dendrogram. Raman et al. (1971) examined morphology of hybrid progenies derived by hybridization of cultivated triploid clones with wild *Musa* species based on eleven morphological characters viz., pseudostem height, degree of

suckering, girth of petiole, nature of petiole margin, length and width of lamina, hairiness of peduncle, length of pedicel, seed content and reported the existence of high morphological variability in South Indian bananas which is attributable to varying degrees of introgression of gene complex of *Musa balbisiana*. This variability was distributed in both triploid and diploid forms (Raman et al., 1968). Peyan, Kanchikela and Elavazhai as well as Karpooravalli and Kosthabontha showed 100% similarity in male flower characters.

Cluster analysis based on fruit characteristics grouped Chingan, Kadali, Sikuzani and Pisanglilin together along with two AB diploids. The results of metroglyph analysis of several South Indian banana cultivars revealed that most are closer to *M. balbisiana* than *M. acuminata* (Raman et al., 1968). However Matti and Sannachenkadali were associated with AAA cultivars. Wild diploid Calcutta 4 was separated from rest of the cultivars in fruit characters. Present results suggest that AAA cultivars can readily be identified on the basis of bunch characteristics. Gros Michel and Grandnaine showed 100% similarity in bunch characters. Similarly, Monsmarie, Green red and Dwarf Cavendish showed 100% similarity and all the five cultivars were grouped together in the dendrogram. Though, Red banana showed close association with this group, Robusta was placed as an outlier. AAB cultivars were grouped together along with AB and ABB cultivars in the dendrogram derived on the basis of bunch characteristics. Rekha et al. (2001) grouped 28 banana accessions belonging to AA, BB, AB, AAB and ABB genomic constitution based on plant morphology and quantitative yield and fruit parameters viz., number of days from flowering to harvest, plant height, pseudostem girth, number of suckers, number of leaves, leaf length, leaf width, bunch length, number of hands, number of fingers, bunch weight, finger length, finger girth, finger weight. Using D2 analysis, they observed five morphological clusters for 28 banana cultivars including three synthetic hybrids. Similar to our results the dendrogram possessed cultivars from different genomic groups in the same cluster.

Estimation of genetic distance based on Euclidean measures for 38 banana cultivars recorded highest morphological dissimilarity between Pisanglilin (AA) and Perumpadali (AAB). Euclidean or straight-line measure of distance is the most commonly used statistic for estimating genetic distance between individuals (genotypes or populations) by morphological data (Mohammadi and Prasanna, 2003; Nassiry et al., 2009). Diploid AA cultivars were closely related to AAA group of cultivars in the dendrogram derived on the basis of gross morphological characters and Sikuzani, Chingan and Pisanglilin showed close relationship. AAA cultivars were grouped together and close association was observed between Gros Michel and Monsmarie as well as Grandnaine and Dwarf Cavendish. Cluster analysis based on gross morphological characters grouped AAB cultivars Nendran, Quintal Nendran, Padathi, Mysore Ethan, Palayankodan and Poovan together along with Poomkalli (AB). Dudhsagar (AAB) was associated with ABB group of cultivars whereas Charapadathi (AAB) was grouped along with AB cultivars. Though, Velipadathi and Krishnavazhai showed an association, both of them along with Perumpadali remained

separately in the dendrogram. Veliputtubale, Njalipoovan, Padalimoongil, Adakkakunnan, Valiyakunnan and Adukkan of AB genomic group clustered together in the dendrogram though, they were closely associated with AAB group of cultivars. ABB cultivars Kanchikela, Peyan, Kosthabontha and Karpooravalli were grouped together along with Dudhsagar (AAB). However, Boothibale was morphologically closely related to AB group of cultivars. AAB and ABB groups of cultivars exhibit the characteristic traits of *Musa acuminata* and *M. balbisiana* in various degrees (Valsalakumari & Nair, 1993). Genetic divergence studies conducted with 62 cultivars of banana by Valasalakumai et al. (1984) showed that the clustering pattern was not influenced by the genomic constitution and the same cluster included cultivars belonging to different genomic groups. Results of PCO analysis were also comparable to that of cluster analysis. However, the present study grouped *acuminata* and bispecific cultivars distinctly based on morphological descriptors.

Conclusions

Cultivars of AA group were characterized mainly by the presence of erect leaf habit, lanceolate bracts with acute apex and fruits with lengthily pointed apex. AB group was characterized by the presence of broadly or narrowly ovate bracts with obtuse apex and fruit bunches hanging at 45° angle. AAA cultivars were characterized by the presence of green/ green red colour of pseudostem, large blotches at the petiole base, open petiolar canal with spreading margins, winged petiolar margins not clasping the pseudostem, base of leaf blade pointed at both sides, cylindrical and vertically hanging bunches, slightly curved with pointed apex and short hairy pedicels. Most of the AAB cultivars were distinguished by the medium green coloured pseudostem with light pink shade and presence of cylindrical bunches hanging at an angle of 45°. Morphological features that characterized ABB cultivars included medium green waxy pseudostem, closed petiolar canals with overlapping margins or margins curved inwards, petiolar margins with colourless edges, base of leaf blade auriculated rounded, pink colour of male flower (both compound tepal and free tepal pink in colour), white coloured style without pigmentation, arched shape of ovary and long hairless pedicels. Cluster analysis based on fifty=one morphological traits separated cultivars with *acuminata* genome alone and cultivars with hybrid genome composition. Results of PCO analysis based on morphology data were comparable to that of cluster analysis. Morphological observations were inadequate for the classification of different *Musa* genomic groups at different ploidy levels.

References

Amalraj VA 1992. Collecting banana germplasm in South India. Plant Genetic Resources Newsletter, 88-89: 64-66.

Anonymous 1996. Descriptor for banana (*Musa* spp.). INIBAP, Montpellier, France.

D'Hont A, Goy AP, Escoute J & Carreel F 2000. The interspecific genome structure of cultivated banana, *Musa* spp. revealed by genomic DNA *in situ* hybridization. Theoretical and Applied Genetics, 100: 177-183. https://doi.org/10.1007/s001220050024

Gopimony R 1980. Genomic classification of 25 banana cultivars of Kerala. Agricultural Research Journal Kerala (now Journal of Tropical Agriculture), 17(2): 293-295.

Jenny C, Carreel F, Tomekpe K, Perrier X, Dubois C, Horry JP & Montcel HT 2003. Banana. In:

Hamon P, Seguin M, Perrier X & Gaszman JC (Eds.). Genetic Diversity of Cultivated Tropical Plants. Science Publishers, UK.

Karamura D & Pickersgill B 1999. A classification of the clones of East African highland bananas (*Musa*) found in Uganda. Plant Genetic Resources Newsletter, 119: 1-6.

Mohammadi SA & Prasanna BM 2003. Analysis of genetic diversity in crop plants–salient statistical tools and considerations. Crop Science, 43: 1235-1248. https://doi.org/10.2135/cropsci2003.1235

Nassiry MR, Javanmard A & Tohidi R 2009. Application of statistical procedures for analysis of genetic diversity in domestic animal populations. American Journal of Animal & Veterinary Science, 4(4): 136-141. https://thescipub.com/abstract/ajavsp.2009.136.141

Nayar TG 1962. Banana in India. The FACT Technical Society, Udyogamandal, Kerala.

Ortiz R 1997. Morphological variation in *Musa* germplasm. Genetic Resources and Crop Evolution, 44: 393-404. https://doi.org/10.1023/A:1008606411971

Pascua OC 1988. A tentative key to Philippine bananas. pp. 67-75. In: Jarret RE (Ed.), Identification of Genetic Diversity in the Genus *Musa*. 1990. INIBAP, Montpellier, France.

Pushkaran K 1998. Genetic diversity of bananas in South India with special reference to Kerala. Pp. 199-207. In: Picq C, Foure E & Frison EA (Eds.). Bananas and Food Security. International Symposium, Douala (CMR), 10–14 November 1998, INIBAP, Montpellier, France.

Raman VS, Alikhan WM, Manimekalai G and Bhakthavalsalu 1971. A study of the cytomorphology of some banana hybrids. The Madras Agricultural Journal, 58(2): 55-62. https://doi.org/10.29321/MAJ.10.A03462

Raman VS, Sreerangaswamy SR & Alikhan WM 1968. Metroglyph analysis of South Indian varieties in banana complex. Indian Journal of Botanical Society, 47: 210-218.

Rekha A, Ravishankar KV, Anand L & Hiremath 2001. Genetic and genomic diversity in banana (*Musa* species and cultivars) based on D2 analysis and RAPD markers. Infomusa, 10(2): 29-34.

Shanmugavelu KG, Aravindakshan K & Sathiamoorthy S 1992. Banana Taxonomy, Breeding and Production Technology. Metropolitan Book Co., New Delhi, India.

Simmonds NW 1962. The Evolution of Bananas. Longman, London, UK.

Simmonds NW 1966. Bananas. (2nd ed.). Longman, London, UK.

Singh HP, Uma S & Sathiamoorthy S 2001. A Tentative Key for Identification and Classification of Indian Bananas. NRC for Banana, Tiruchirapalli, India.

Stover RH & Simmonds NW 1987. Bananas. (3rd ed.). Longman, London, UK.

Valsalakumari PK & Nair PCS 1993. Genomic classification of Indian banana cultivars. Tropical Agriculture (Trinidad and Tobago), 70(2): 162-164. https://journals.sta.uwi.edu/ojs/index.php/ta/article/view/7086

Valsalakumari PK & Pushkaran K 1996. Crop improvement. Pp. 9-41. In: Aravindakshan M & Pushkaran K (Eds.). Banana Compendium. Kerala Agriculture University, Thrissur, India.

Valsalakumari PK, Nair PCS & Prabhakaran PV 1984. Genetic divergence in banana. Agricultural Research Journal of Kerala (now Journal of Tropical Agriculture), 23(2): 146-149.