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Genetic variability of banana with ornamental potential

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Abstract The *Musa* germplasm collection at Embrapa Cassava and Fruits detains accessions from different sections of the *Musa* genus. The objective of the present study was to identify and morphologically characterize banana accessions from the banana germplasm with ornamental potential, as well as to quantify their genetic variability; and identify possible progenitors to be used in breeding aiming to achieve ornamental crossbreeds. The accessions were evaluated with the use of 32 morphological descriptors. Then, they were the following grouped into categories: landscape plants, cut flower, potted plants, and male inflorescence minifruits. The pre-selected accessions presented great genetic variability and ornamental potential for different uses. The accessions of the *Rhodochlamys* and *Callimusa* sections were selected to be used as landscape plants, cut flowers, potted plants, male inflorescence and minifruits. Most of the diploids from the *Eumusa* section evaluated in this study are indicated for the production of ornamental minifruits, except for 'Lidi' and Cici, which can also be indicated as landscape plants. The BB diploids have great potential for the use of the male inflorescence in floral arrangements, and did not offer any other indication.

Keywords *Musa* spp. · Genetic diversity · Morphological descriptors · Ornamental plants · Pre-breeding

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Introduction

The banana germplasm bank of the Embrapa Cassava and Fruits is the largest in Brazil. It was created in 1983 with the collection and interchange of germplasm inside and outside Brazil. Nowadays, it comprises 273 accessions, and is considered a good representative of species of the genus *Musa*, gathering cultivars and wild species, mainly *M. acuminata* and *M. balbisiana*, with different degrees of ploidy and combinations of the genomes A and B, besides representatives of the sections *Rhodochlamys* and *Callimusa* (Silva et al. 2001; Santos-Serejo et al. 2007).

The large genetic variability of this collection has allowed the generation of crossbreeds for feeding, which are resistant to the main pests to the culture,

such as yellow and black Sigatokas and Panama disease. In recent years, the crossbreeds Pacovan Ken (AAAB), Preciosa (AAAB), Japira (AAAB) and Tropical (AAAB) were generated, besides several varieties, such as Caipira (AAA), Thap Maeo (AAB), Prata Baby (AAA) and Prata-Graúda (AAAB) (Silva et al. 2001), which have been extremely important for the availability of the culture in the regions where the pests occur.

However, the best use of the existing variability can be achieved through the identification of new applications for the preserved germplasm, aggregating value to it. Works aimed at identifying and selecting genotypes with ornamental value have been carried out since 2003 (Santos-Serejo et al. 2007).

Some accessions of the bank, such as *M. coccinea*, *M. ornata* and *M. velutina*, have already been marketed, but they can be better explored to generate new varieties.

Besides genotypes with appropriate characteristics for landscape plants, potted plants and floral arrangements, there are several diploid accessions which produce very small fruits in the banana germplasm bank, which can be used as ornamental plants. The banana minifruits for floral arrangements are a novelty, mainly due to their originality, representing an innovation for the flower and ornamental plant market, but they have not been commercially explored.

Characterization is an essential activity in the management of germplasm collections, since it involves the collection of data to describe, identify and differentiate accessions inside species, classes or categories. This activity must consider, particularly, easily visible or measurable botanic characters of high heritability, which consistently express themselves in all environments.

One of the great problems for the efficient application of morphological descriptors is the environmental influence, mainly when metric characters are considered, which are mostly controlled by a large number of genes and, consequently, highly influenced by the environment. Therefore, it is important to use descriptors with high heritability and stability, such as the qualitative descriptors.

A series of descriptors has been elaborated aiming at characterizing and identifying banana genetic resources, such as the descriptors elaborated by IPGRI (1996); Ortiz (1997); Ortiz et al. (1998) and Nsabimana and Staden (2005).

The studies on characterization and evaluation of banana germplasm produce knowledge about the genetic variability between the accessions, forming an important data base for the support of genetic breeding with several objectives, such as improving the production and quality of the fruits, identifying functional attributes or even for the use as ornamental plants.

Works developed by Santos-Serejo et al. (2007) showed the characteristics that should be considered to identify and select ornamental banana trees, such as the size of the plants, the color of the leaves, morphology, color of the fruits and male inflorescence. Based on this work, 31 accessions with some potential for ornamental use were selected.

Therefore, this work aimed at identifying and characterizing morphologically the accessions of the banana germplasm bank with ornamental potential, and quantifying their genetic variability, identifying possible parents for genetic breeding aimed at the achievement of ornamental crossbreeds.

Materials and methods

The study was conducted at the Banana Germplasm Bank (BGB) of the Embrapa Cassava and Fruits, located at 12° 40′ of latitude south and 39° 06′ of longitude west, located in the municipality of Cruz das Almas, Recôncavo da Bahia, Brazil.

The weather in the municipality of Cruz das Almas, according to the Köppen classification, is a transition from Am to Aw zones, with annual average rainfall of 1,143 mm, average temperature of 24.28°C and relative humidity of 60.47%. The soil of the experimental area is a typical dystrophic yellow Latosol, moderate A, with loamy sandy–clayey texture, kaolinitic, hypoferric, subperennial–semideciduous rainforest transition phase, with slope of 0–3%.

A total of 31 accessions of banana with probable ornamental potential listed in the Table 1 were preselected as genotypes for this study. A completely randomized design with four replications was used for the qualitative and qualitative characters. Thirty-two qualitative and quantitative descriptors were applied. The list of the descriptors is found in IPGRI (1996).

The characteristics considered for each category of use are described as follows:

Potted plants plant height inferior to 145 cm, number of leaves per plant, color of the leaves, stalk

Table 1 Accessions identified and characterized in the banana germplasm bank of the Embrapa Cassava and Fruits with ornamental potential and their respective section, genome group and collection site

Name of the accession	Section	Group	Collection site	Ornamental potential				
				L	C	P	H	M
BB Belgium	*Eumusa*	BB	Belgium				X	
BB France	*Eumusa*	BB	France				X	
BB IAC	*Eumusa*	BB	Brazil				X	
BB Panama	*Eumusa*	BB	Panama				X	
Benedetta	*Eumusa*	ABB	France	X			X	
'Berlin'	*Eumusa*	AA	Indonesia					X
Bronze	*Rhodochlamys*	–	Brazil	X	X	X	X	
Burmannica	*Eumusa*	AA	Honduras				X	X
Butuhan	*Eumusa*	BB	Philippines				X	
Cacambou Naine	*Eumusa*	ABB	Ecuador	X		X		
Calcutta 4	*Eumusa*	AA	Jamaica				X	X
Caru Roxo	*Eumusa*	AAA	Brazil	X				
Cici	*Eumusa*	AA	Java	X			X	
Fique Rose Naine	*Eumusa*	AAB	France	X				
Jambi	*Eumusa*	AA	Indonesia				X	X
Jari Buaya	*Eumusa*	AA	Honduras				X	
Khai Nai On	*Eumusa*	AA	Thailand				X	
Krasan Saichon	*Eumusa*	AA	Thailand				X	
'Lidi'	*Eumusa*	AA	Honduras				X	X
Monyet	*Eumusa*	AA	Indonesia	X				
Pa Songkla	*Eumusa*	AA	France					X
Royal[a]	*Rhodochlamys*	–	France	X	X	X	X	
Tambi	*Eumusa*	AA	Honduras				X	X
M. balbisiana	*Eumusa*	BB	Brazil				X	
M. basjoo	*Eumusa*	–	France	X			X	
M. coccinea	*Callimusa*	–	Brazil	X	X	X		
M. laterita	*Rhodochlamys*	–	France	X	X	X	X	
M. ornata	*Rhodochlamys*	–	Brazil	X	X	X	X	
M. velutina	*Rhodochlamys*	–	France	X	X	X	X	
Dwarf mutant	*Eumusa*	AAA	Brazil	X		X		
Variegated mutant	*Eumusa*	–	Brazil	X		X		

L landscape plants, *C* cut flower, *P* potted plant, *H* heart, *M* minifruit

[a] Crossbreed (*M. ornata* × *M. velutina*)

length inferior to 25 cm, number of hands/bunch, number of fruits/hand, position of the bunch, size and form of the heart, color of the fruits and heart.

Cut flower stalk length superior to 20 cm; stalk diameter inferior to 4 cm, number of hands/bunch, number of fruits/hand, position of the bunch, size and shape of the heart, color of the fruits and heart.

Minifruits shape and size of the fruits, number of fruits/hand, distance between the hands and color of the fruits.

Male inflorescence (heart) size and diameter of the heart, shape of the heart, presence of imbrication, persistence and opening of floral bracts.

Landscape plants wide category that can include potted plants, cut, minifruits and male inflorescence,

provided that they are small. An important characteristic for this category is the tillering capacity.

Analyses of variance were carried out and the following descriptive statistics were calculated: average, maximum value, minimum value, standard deviation, variation coefficient, *F* test and average square, considering all the accessions evaluated. The averages were compared by the Scott-Knott test at 1% of probability. For such, the SAS statistical software system (SAS Institute Inc 2004) was used.

The Singh (1981) criterion was used to calculate the relative contribution of each quantitative. This analysis was performed by the Genes (Cruz 1997) software system.

A joint analysis of the qualitative and quantitative data was carried out to determine the genetic distance, based on the Gower algorithm (Gower 1971).

The hierarchical groupings of the accessions were achieved by the unweighted pair-group method using an arithmetic average (UPGMA) methods based on the average Euclidean distance among all the accessions. The validation of the groupings was determined by the cophenetic correlation coefficient (r) (Sokal and Rohlf 1962).

The R development core team 2006 statistical software system was used in the analyses of genetic distance, hierarchical groupings and cophenetic correlation. The significance of the cophenetic correlation was calculated by the *t* and Mantel tests (10,000 permutations). The dendrogram was generated based on the distance matrix by the MEGA 4 software system (Tamura et al. 2007).

Results and discussion

The application of morphological descriptors for the characterization of the pre-selected banana accessions revealed great variability in the banana germplasm bank and allowed the identification of accessions with great ornamental potential that can be aimed at many uses, generating new products and aggregating value to the preserved germplasm.

The descriptive statistics of the evaluations carried out in the BGB, considering all the 31 accessions of the study, allowed to detect a wide variety for most characteristics, as observed in Table 2.

By the Singh method (Singh 1981), used to assess the relative importance of the 15 quantitative descriptors, it was determined that five of them contributed with 99.21% for genetic divergence, while ten of them contributed with only 0.77%. Plant height provided

Table 2 Descriptive statistics for 15 descriptors of ornamental banana tree

Descriptors	Average	Minimum	Maximum	*S*	CV (%)	Fc	QM
Plant height (cm)	209.16	41.75	373.75	12.11	5.79	215.33**	31117.67
Pseudostem diameter (cm)	21.10	9.17	68.75	11.67	55.29	4.66**	642.68
Leaf length (cm)	128.80	35.75	262.00	11.98	9.30	76.48**	11026.27
Leaf width (cm)	40.82	14.00	96.50	2.30	5.63	404.43**	2100.46
Number of leaves in flowering	7.91	4.00	13.25	0.81	10.26	84.53**	45.44
Number of leaves in the harvest	6.85	2.75	11.50	0.61	8.86	125.92**	37.91
Stalk length (cm)	34.62	5.25	69.50	5.73	16.54	50.14**	1340.80
Stalk diameter (cm)	3.89	2.50	5.62	0.19	4.93	267.47**	8.05
Number of hands	5.50	2.75	10.25	0.66	11.99	53.44**	18.96
Number of hands/bunch	10.49	1.10	16.77	0.64	6.12	332.22**	111.77
Distance between hands (cm)	4.76	2.27	8.12	0.46	9.62	96.24**	16.50
Fruit length (cm)	7.96	3.62	16.42	0.45	5.60	410.00**	66.58
Fruit diameter (cm)	2.46	1.05	4.45	0.14	5.85	476.72**	8.11
Heart length (cm)	14.90	4.02	24.87	0.76	5.09	341.82**	155.63
Heart diameter (cm)	6.01	2.47	10.60	0.28	4.67	478.65**	30.66

S standard deviation, *CV* variation coefficient, *Fc* value of the calculated F test, *QM* mean square

** $P < 0.01$)

the highest contribution, with 64.19%, followed by leaf length (25.29%), leaf width (5.49%), stalk length (2.50%) and pseudostem diameter (1.74%). These results indicate the existence of significant genetic variability for these characters in the genotypes evaluated. In general, the length and diameter of the heart, fruit length and diameter, number of leaves in the flowering and harvest, distance between hands, number of hands, number of hands/bunch and stalk diameter offered little contribution to explain the variability observed among the genotypes (Table 3).

The multi-category analysis carried out with the 31 accessions allowed the formation of eight groups (Fig. 1) by the UPGMA clustering method, based on the average Euclidean distance, using the average genetic dissimilarity as the cutoff point ($D\,dg = 0.58$). Considering the relevant characteristics for each category of use, it was possible to identify the accessions with specific potential for one or more categories. Some groupings presented good plasticity for use, while others are indicated for one or few uses, such as Monyet, whose interesting characteristic is the exuberant and variegated foliage with anthocyanin, and purple fruits and heart.

The cophenetic correlation coefficient of the dendrogram ($r = 0.91, P < 0.0001$, 10,000 permutations) revealed good adjustment between the graphic representation of the distances and their original matrix (Rohlf and Fisher 1968).

The group G1 is formed by five accessions: *M. laterita* Cheesman, *M. velutina* H. Wendl. & Drude, *M. ornata* Roxb., Bronze and Royal. All of them belong to the section *Rhodochlamys*, whose great ornamental potential has already been recognized in other countries (Häkkinen and Sharrock 2002; Häkkinen 2001, 2004, 2007; Häkkinen and Väre 2008; Wallace and Häkkinen 2009). The inflorescence of these genotypes is erect, the fruits and bracts present attractive colors that range from light green, light pink, violet-pink and salmon. All these accessions are small, with height inferior to 145 cm (Table 4), which gives

Table 3 Relative contribution (%) of the descriptors for the study on variability based on the Singh criterion (Singh 1981)

Descriptors	*S.j*	*S.j* (%)
Plant height	4,887,881.00	64.19
Leaf length	1,925,491.50	25.29
Leaf width	418,300.69	5.49
Stalk length	190,612.29	2.50
Pseudostem diameter	132,935.74	1.74
Heart length	16,364.92	0.21
Number of hands per bunch	15,122.10	0.19
Fruit length	9,164.24	0.12
Number of leaves in the flowering	4,795.75	0.06
Number of leaves in the harvest	4,394.00	0.06
Heart diameter	3,703.63	0.05
Distance between hands	1,741.74	0.02
Number of hands	1,687.00	0.02
Fruit diameter	1,241.08	0.02
Stalk diameter	538.15	0.01

S.j contribution of the variable *x* for the value of the Euclidean distance between the genotypes *i* and *i*

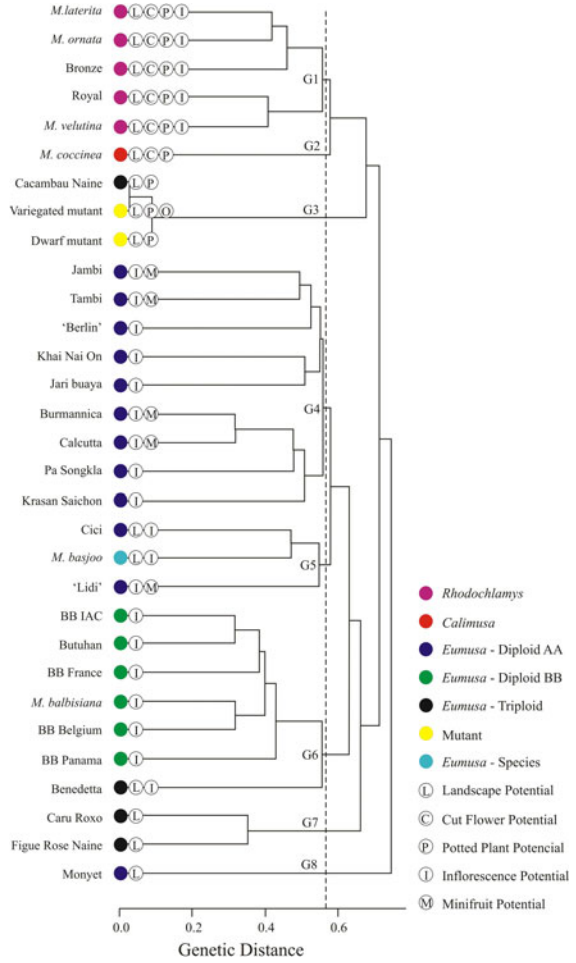


Fig. 1 Dendrogram of genetic dissimilarities among 31 banana accessions, achieved by the UPGMA method, based on the Gower algorithm, from thirty-two qualitative and quantitative characters

Table 4 Quantitative and qualitative characteristics of the plant in 31 accessions of the banana germplasm bank of the Embrapa Cassava and Fruits with ornamental potential

Genotype	Plant traits								
	HEI	DPS	NLF	NLH	LLL	WLL	CLE	ANL	PLE
BB Belgium	297.50 d	16.50 c	13.25 a	11.25 a	136.25 f	47.50 e	DGR	ABS	MPE
BB France	288.75 d	16.25 c	11.00 b	10.25 b	148.75 e	52.00 d	DGR	ABS	MPE
BB IAC	307.50 c	23.50 c	12.75 a	11.50 a	148.50 e	51.75 d	DGR	ABS	MPE
BB Panama	319.00 c	28.00 c	9.75 c	8.25 c	154.25 e	55.25 d	DGR	ABS	MPE
Benedetta	293.75 d	20.50 c	6.25 e	5.50 e	131.00 f	24.25 h	LGR	ABS	MPE
'Berlin'	161.25 i	40.50 b	7.25 e	6.75 d	150.50 e	40.00 f	LGR	ABS	MPE
Bronze	123.75 j	14.75 c	7.50 d	7.25 d	96.50 g	23.50 h	LGR	ABS	MPE
Burmannica	164.00 i	17.62 c	8.50 d	7.25 d	121.00 f	26.50 h	LGR	ABS	AER
Butuhan	286.25 d	23.50 c	12.00 b	11.00 a	150.50 e	53.50 d	DGR	ABS	MPE
Cacambou Naine	103.75 k	17.50 c	*	*	94.50 g	51.75 d	LGR	ABS	MPE
Calcutta 4	172.50 h	17.75 c	7.75 d	7.00 d	105.75 g	20.75 i	LGR	ABS	AER
Caru Roxo	308.75 c	23.50 c	8.25 d	6.00 e	243.75 b	93.50 a	LGR	ABS	MPE
Cici	153.00 i	15.00 c	5.25 f	4.75 f	89.50 h	22.50 i	LGR	ABS	AER
Fique Rose Naine	285.00 d	28.40 c	8.50 d	8.25 c	262.00 a	96.50 a	LGR	ABS	MPE
Jambi	208.00 g	9.17 c	8.00 d	7.00 d	155.50 e	37.00 g	LGR	ABS	AER
Jari Buaya	373.75 a	56.75 a	7.75 d	7.25 d	225.75 c	61.75 c	LGR	ABS	AER
Khai Nai On	272.50 e	18.12 c	6.25 e	5.75 e	198.75 d	80.50 b	LGR	ABS	AER
Krasan Saichon	272.50 e	15.75 c	9.25 c	8.00 c	183.00 d	61.75 c	LGR	ABS	AER
'Lidi'	228.25 f	68.75 a	6.75 e	4.75 f	128.00 f	42.50 f	LGR	ABS	AER
Monyet	221.50 f	17.25 c	7.00 e	6.25 e	95.00 g	22.25 i	ANT	MUC	AER
Pa Songkla	184.00 h	20.00 c	6.00 e	5.00 f	129.50 f	24.50 h	LGR	ABS	MPE
Royal	130.75 j	14.20 c	5.25 f	4.75 f	88.25 h	20.25 i	LGR	ABS	MPE
Tambi	149.75 i	13.50 c	6.75 e	5.50 f	106.50 g	63.50 c	LGR	ABS	AER
M. balbisiana	344.25 b	16.50 c	13.00 a	11.25 a	140.25 f	50.00 e	DGR	ABS	MPE
M. basjoo	180.00 h	17.00 c	4.75 f	3.00 g	86.25 h	20.50 i	LGR	ABS	SBE
M. coccinea	121.00 j	12.50 c	6.50 e	5.00 f	73.00 h	14.00 l	LGR	ABS	MPE
M. laterita	100.25 k	13.00 c	4.00 g	2.75 g	57.50 i	14.00 k	LGR	ABS	AER
M. ornata	145.00 i	14.75 c	6.25 e	5.50 e	99.50 g	18.25 j	LGR	ABS	AER
M. velutina	112.50 j	13.62 c	6.00 e	5.25 f	93.00 g	20.00 i	LGR	ABS	MPE
Dwarf mutant	41.75 l	14.00 c	*	*	35.75 j	22.75 i	DGR	ABS	MPE
Variegated mutant	85.00 k	20.25 c	*	*	76.00 h	21.75 i	VCL	ABS	MPE

Averages followed by the same letter do not differ by the Scott-Knott test at 1% probability

HEI plant height in (cm), *DPS* pseudostem diameter in (cm), *NLF* number of leaves in the flowering season, *NLH* number of leaves in the harvest, *LLL* length of the longest leaf in (cm), *WLL* width of the longest leaf in (cm), *CLE* color of the leaf, *ANL* presence of anthocyanin in the leaves, *PLE* position of the leaves, *LGR* light green, *DGR* dark green, *ANT* presence of anthocyanin, *ABS* absent; *MUC* much, *AER* almost erect, *MPE* medium pendant, *SBE* strongly bent

* Non-evaluated

them a great potential to be used as potted plants, in landscape plants or even "cut flower" for floral arrangements.

Musa laterita was described by Cheesman (1949) as a plant that spreads freely, releasing its tillers far from the mother plant, forming some clumps (Fig. 2a). Its name comes from its clayey-red bracts known as laterita (Häkkinen 2001). The plant was small, with average height of 100.25 cm (Table 4), and small heart (10.50 cm in length and 3.20 cm in diameter),

salmon bracts in the inner and outer parts, slender shape and erect inflorescence (Table 7). Its hands contain few (3.50) small (4.20 cm) and green fruits (Table 6). This species, however, is known and marketed in the United States under the name of *M. ornata* Bronze or *M. ornata* Red Salmon, which evidences some difficulties for banana tree classification (Häkkinen 2004). On the other hand, an accession called Bronze was identified in the BGB, with intermediate characteristics, between *M. laterita* and *M. ornata*, which may be a crossbreed between them, although there are no studies to corroborate this hypothesis (Fig. 2b).

Musa velutina was described by a German, Hermann Wendland, and an Englishman, George Drude, as a plant with pink and velvety fruits, giving origin to the name of the species (Häkkinen 2001, 2004, 2007) (Fig. 2c). The plant was small (112 cm), with many tillers, green leaves with pink petiole and pink-purple short peduncle and erect inflorescence (Table 4). When the fruits are ripe, the hull opens, revealing a central mass of the white pulp full of seeds, which promotes a very ornamental effect. The heart is small, with 10.62 cm in length and 3.10 cm in diameter, slender, pink-violet, with moderate serosity, which opens two to three bracts at a time (Table 7).

Musa ornata was described by Roxburgh in 1824, but its taxonomy is strongly contested with *M. pinkcea* Jacq. and *M. rosea* Baker (Fig. 2d). *M. ornata* is the tallest (145 cm) (Table 4) of all the accessions of the section *Rhodochlamys* evaluated. Häkkinen (2007) mentions that this species may reach 180 cm, which will certainly depend on the edaphoclimatic conditions. The leaves are green, with high concentration of wax, large number of tillers, erect inflorescence, with an average of five hands/bunch and four fruits/hand. The fruits are smalls (with average of 5.50 cm in length and 1.50 cm in diameter) and grayish-green color (Table 6). The heart is light pink, with an elongate form and round apex without imbrication (Table 7).

The variety Royal results from the crossing between *M. ornata* and *M. velutina*, thus presenting characteristics of both species (Fig. 2e). The fruits are pinkish, similarly to those of *M. velutina*, but without hair and with smaller diameter and length, with values of 2.50, 5.50 cm (Table 6), respectively. The plant has intermediate size (130.74 cm in height) in relation to the parents (Table 4), the bunch is erect, in the vertical position (Table 5) and the heart is violet-pink, with 12.37 cm in length and 3.25 cm in diameter, with slender shape (Table 7).

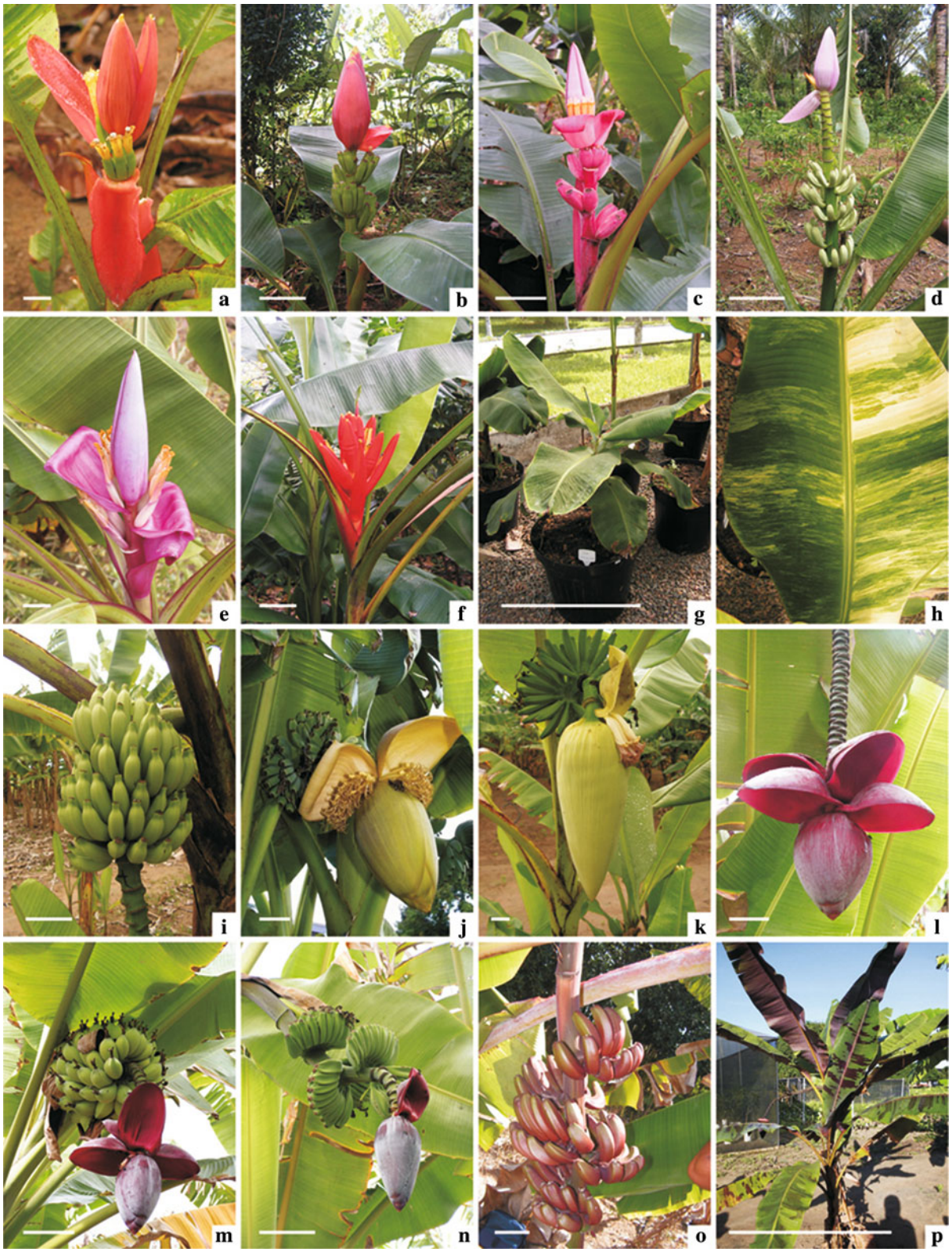
All the accessions of this group can be indicated for landscape plants, potted plants and cut plants, since the inflorescence set (heart) and fruits are very attractive. Using only the heart is also indicated in this group, mainly because they are very colorful and small. The use of the banana heart as ornamental component is one of the novelties of this work, which identified this potential, from the characterization of these BGB accessions.

The group G2 involves only *M. coccinea* Andrews, and the only representative of the section *Callimusa* of the BGB (Fig. 2f). It is the most marketed accession among the Musaceae, mainly for cut flower, because its inflorescence is erect and red, and its bracts persist for many days. They can be also used as potted plant and in landscape plants. This species presented the smallest heart size (4.02 cm in length and 2.47 cm in diameter) of all the accessions evaluated, with whitish color (Table 6), lanceolate shape (Table 7), few fruits (1.10)/hand, average length of 3.62 cm and diameter of 1.62 cm. Its seeds are cylindrical or barrel-shaped, as described in literature (Daniells et al. 2001; Häkkinen 2007).

Mutant genotypes, dwarf mutant (Fig. 2g), variegated mutant and Cacambou Naine, which present reduced size, are among the plants selected for cultivation in vase. Their leaves are short, wide and green, except for variegated mutant, which has yellowish sectors (Fig. 2h). These three accessions form the group G3.

The groups G4 and G5 are formed by the diploids of the section *Eumusa*, of the genome group AA (genome of the *M. acuminata* Colla), except for *M. basjoo* Inuma. These two groups presented great potential for the use as minifruits and male inflorescence. Minifruits have attracted the attention of consumers in preliminary evaluations of their acceptance in the market and their potential for commercial exploitation. Similarly, the use of banana heart is another ornamental and innovative component for the flower and ornamental plant market. Miniatures form peculiar and innovative arrangements that may occupy a unique niche market.

However, they must have well formed fruits, without undulations and size ranging from 5 to 7 cm to be marketed. The accessions Burmannica, 'Berlin',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◀**Fig. 2** Accessions of the banana germplasm bank of the Embrapa Cassava and Fruits with ornamental potential; **a**–**e** accessions of the section *Rhodochlamys*: **a** *M. laterita*; **b** Bronze; **c** *M. velutina*; **d** *M. ornata*; **e** Royal; **f** accession of the section *Callimusa*, *M. coccinea*; **g**–**p** accessions of the section *Eumusa*: **g** dwarf mutant as potted plant; **h** detail of the leaf of the variegated mutant accession; **i** Calcutta 4, minifruits; **j**) *M. basjoo*; **k** detail of male bud of the accession Cici; **l**, **m** *M. balbisiana*; **n** Benedetta—detail of welded fruits; **o** purple fruits of the accession Caru Roxo; **p** Monyet—detail of leaf with purple areas. *Bar* 1.00 cm

Calcutta 4, Jambi, 'Lidi' and Tambi were selected with this purpose, since they meet these demands. The number of hands ranged from 5 for Tambi to 6.25 for Burmannica and the number of fruits/hand ranged from 11.77 for accession Jambi to 14.20 for Calcutta 4 (Table 6).

Another characteristic considered important in the selection of minifruits is the distance between hands. It must be sufficient to allow a good finger detachment without causing injuries to the fruits, which would impair the post-harvest procedures. The accessions Burmannica and Calcutta 4 (Fig. 2i) presented the lowest values, 2.77 cm, thus affecting its finger detachment (Table 6).

Another interesting accession in this group was *M. basjoo,* with greenish pseudostem, leaves and fruits, while its male inflorescence stood out due to the olive-green color. The bunch is horizontal with small fruits (6.90 cm) in small number/hand (Table 5). In spite of the average height found (1.80 m), this species has potential to be used in landscape plants (Table 4). The accession Cici also presented olive-green color in the male inflorescence, in a truncated form (Fig. 2k) (Table 7), with an average height of 153 cm, a very reduced size, which is interesting for potted plants and landscape plants (Table 4).

The group G6 is formed by the diploid banana trees of the genome group BB, except for the accession Benedetta, which is a triploid ABB. They are extremely strong, fast growing plants, widely used in the Philippines for fibers and windbreaks (Ploetz et al. 2007). All these accessions are taller than 286 cm, reaching up to 344 cm in the *M. balbisiana*. Therefore, they are discarded for landscape plants or potted plants (Table 4). Their use as cut flower is hampered by the size of the fruits and of the set as a whole.

The accessions of the genome group BB were mainly included in the work because of their attractive inflorescences and hearts, which present the opening of three or more bracts at a time, besides the very beautiful shades of dark red colors and great concentrations of wax (Fig. 2l). Imbrication (overlapping of the floral bracts) is an important characteristic in the hearts, since it facilitates their manipulation, so that inflorescence will look like real flowers. All these accessions of the group G6 presented this characteristic, with different intensities.

As previously mentioned the use of male inflorescence is a novelty for the flower market and can be used as a differentiated and original component in floral arrangements. However, a serious hindrance for the use of these materials is the fast oxidation of their structures, which demands a daily maintenance for the removal of the oxidated bract. Thus, post harvest works are necessary to improve the management of these structures and ensure a more comfortable handling for consumers.

The accession BB Panama presented elongate heart and the others, a truncated shape. As for the length and diameter of the heart, it was verified that the accessions BB Panama and BB France presented the highest values with 21.92 cm × 6.17 and 20.25 cm × 9.10 cm, respectively (Fig. 2m). These accessions were targeted for the use of male inflorescence in floral arrangements (Table 7).

The accession Benedetta presented potential for the use of male inflorescence and its fruits, which are peculiarly welded, forming a closed hand (Fig. 2n). However, the fruits are large (14.15 cm in length), in spite of the differentiated and exotic morphology (Table 6). Thus, this accession can be targeted to genetic breeding, in search for this peculiar characteristic.

The accessions Figue Rose Naine and Caru Roxo form the group G7 and have large fruits, with nearly 13.97 cm in length and 3.75 cm in diameter, which makes them unfit for the category of minifruits (Table 6). However, since the fruits are purple, the accession can be used in the breeding programs for the transference of this single characteristic (Fig. 2o). Besides, they were tall, close to three meters of height, which is not a desirable trait in ornamental bananas.

The accession Monyet, also called *M. acuminata* ssp. *zebrina*, formed the group G8 isolately. Its leaves present intense spots due to the presence of anthocyanin, a very ornamental characteristic (Fig. 2p; Table 4). The presence of variegation in the purple, yellowish or whitish leaves is much appreciated in

Table 5 Quantitative and qualitative characteristics of the bunch in 31 accessions of the banana germplasm bank of the Embrapa Cassava and Fruits with ornamental potential

Genotype	Bunch traits								
	SLE	SDI	SPU	CST	PBU	NHB	DBH	PRA	CRA
BB Belgium	41.50 c	4.07 e	ABS	GRE	TDO	6.00 c	5.25 d	TDO	GRE
BB France	54.50 b	5.25 b	ABS	GRE	TDO	10.25 a	4.40 e	TDO	GRE
BB IAC	47.75 c	5.00 c	ABS	GRE	TDO	6.75 b	4.40 e	TDO	GRE
BB Panama	69.50 a	4.20 e	ABS	GRE	TDO	4.25 e	5.40 d	TDO	GRE
Benedetta	41.50 c	4.85 c	ABS	GRE	TDO	5.00 d	8.12 a	TDO	GRE
'Berlin'	28.50 e	3.60 f	AVE	GRE	HOR	7.00 b	4.55 e	TDO	GRE
Bronze	27.50 e	3.45 g	ABS	GRE	GRE	4.50 e	4.75 e	VET	GRE
Burmannica	33.25 d	3.17 h	AVE	GRE	TDO	6.25 c	2.27 g	TDO	GRE
Butuhan	47.75 c	5.00 c	ABS	GRE	TDO	5.50 c	4.40 e	TDO	GRE
Cacambou Naine*	–	–	–	–	–	–	–	–	–
Calcutta 4	32.50 d	3.35 g	AVE	GRE	TDO	5.50 c	2.27 g	TDO	GRE
Caru Roxo	45.05 c	4.82 c	AVE	PUR	TDO	5.75 c	7.50 b	TDO	PUR
Cici	28.25 e	3.02 h	ABS	GRE	TUP	3.25 f	4.20 e	TDO	GRE
Fique Rose Naine	57.75 b	4.35 e	AVE	PUR	TDO	7.00 b	7.22 b	TDO	PUR
Jambi	16.62 f	2.50 i	MUC	GRE	TUP	6.25 c	4.30 e	TDO	GRE
Jari Buaya	59.75 b	4.67 d	AVE	GRE	TDO	7.75 b	5.75 d	TDO	GRE
Khai Nai On	36.00 d	3.72 f	AVE	GRE	HOR	5.25 d	6.15 c	TDO	GRE
Krasan Saichon	15.40 f	4.52 d	AVE	GRE	TDO	5.25 d	5.32 d	HOR	GRE
'Lidi'	38.50d	3.32 g	ABS	GRE	TDO	6.00 c	7.77 a	TDO	GRE
Monyet	39.25d	4.20 e	MUC	BPU	HOR	5.25 d	4.50 e	TDO	BPU
Pa Songkla	51.00 b	5.62 a	AVE	GRE	TDO	6.25 c	5.02 d	HOR	GRE
Royal	15.75 f	3.25 h	ABS	PPU	GRE	4.00 e	3.95 e	VET	PPU
Tambi	16.90 f	2.72 i	AVE	GRE	TUP	5.00 d	4.00 e	TDO	GRE
M. balbisiana	36.00 d	4.30 e	ABS	GRE	TDO	4.75 d	4.90 d	TDO	GRE
M. basjoo	21.00 f	3.12 h	ABS	GRE	HOR	5.25 d	3.40 f	TDO	GRE
M. coccinea	23.50 e	3.05 h	ABS	ORR	GRE	5.00 d	3.07 f	VET	RED
M. laterita	14.50 f	3.00 h	ABS	GRE	GRE	2.75 f	3.40 f	VET	GRE
M. ornata	24.75 e	3.80 f	ABS	GRE	GRE	5.00 d	4.00 e	VET	GRE
M. velutina	5.25 g	3.17 h	MUC	PPU	GRE	3.25 f	3.17 f	VET	PPU
Dwarf mutant*	–	–	–	–	–	–	–	–	–
Variegated mutant*	–	–	–	–	–	–	–	–	–

Averages followed by the same letter did not differ by the Scott-Knott test at 1% probability

SLE stalk length in (cm), *SDI* stalk diameter in (cm), *SPU* stalk pubescence, *CST* color of the stalk, *PBU* position of the bunch, *NHB* number of hands in the bunch, *DBH* distance between hands in (cm), *PRA* position of the rachis, *CRA* color of the rachis, *ABS* absent, *AVE* averagely, *MUC* much, *GRE* green, *PUR* purple, *BPU* brown-purple, *PPU* pink-purple, *RED* red, *ORR* orange-red, *VET* vertical, *TUP* tilted upwards, *HOR* horizontal, *TDO* tilted downward

* Non-evaluated

potted plants and landscape plants. The fruits of this accession are hairy and brown-purple, with bunch in the horizontal position. These characteristics make this accession interesting as a parent in the breeding program.

Conclusions

The preselected accessions from the banana germplasm bank presented great genetic variability and may be used in different categories of ornamental use;

Table 6 Quantitative and qualitative characteristics of the fruits in 31 accessions of the banana germplasm bank of the Embrapa Cassava and Fruits with ornamental potential

Genotype	Traits of fruits							
	NFR	FLE	FDI	FLE	FPU	COF	WFR	SFA
BB Belgium	11.57 f	11.45 d	4.00 b	MCU	ABS	GRE	ABS	SHO
BB France	13.87 d	9.17 f	4.42 a	MCU	ABS	GRA	ABS	SHO
BB IAC	9.92 g	8.37 g	3.60 c	ERE	ABS	GRE	ABS	LOG
BB Panama	5.45 i	12.17 c	4.32 a	MCU	ABS	GRA	ABS	LOG
Benedetta	14.70 c	14.25 b	3.62 c	ERE	ABS	GRE	PRE	INS
'Berlin'	12.35 e	6.87 h	2.15 e	MCU	ABS	GRE	ABS	SHO
Bronze	4.12 j	5.95 i	1.60 f	ERE	ABS	GRE	ABS	SHO
Burmannica	14.20 d	5.40 i	1.05 h	VCU	ABS	GRE	ABS	LOG
Butuhan	13.37 d	10.67 e	4.40 a	MCU	ABS	GRA	ABS	LOG
Cacambou Naine*	–	–	–	–	–	–	–	–
Calcutta 4	12.85 e	5.20 j	1.27 g	VCU	ABS	GRE	ABS	LOG
Caru Roxo	14.75 c	11.15 e	2.47 d	VCU	ABS	PUR	ABS	INS
Cici	11.45 f	6.60 h	1.50 f	VCU	ABS	GRE	ABS	LOG
Fique Rose Naine	9.70 g	13.97 b	3.75 c	VCU	ABS	PUR	ABS	INS
Jambi	11.77 f	4.07 l	1.05 h	MCU	ABS	GRE	ABS	LOG
Jari Buaya	16.77 a	16.42 a	4.05 b	MCU	ABS	GRE	ABS	LOG
Khai Nai On	15.05 c	10.72 e	4.10 b	MCU	ABS	GRE	ABS	LOG
Krasan Saichon	15.55 b	6.42 h	2.02 e	VCU	ABS	GRE	ABS	LOG
'Lidi'	13.82 d	8.67 g	1.47 f	VCU	ABS	GRE	ABS	INS
Monyet	11.47 f	4.75 k	1.40 f	MCU	ABS	BPU	ABS	LOG
Pa Songkla	11.95 f	5.40 j	1.17 g	VCU	ABS	GRE	ABS	LOG
Royal	4.47 j	4.45 k	1.20 g	ERE	ABS	PPU	ABS	INS
Tambi	13.87 d	6.00 i	1.55 f	VCU	ABS	GRE	ABS	SHO
M. balbisiana	11.60 f	9.57 f	4.45 a	MCU	ABS	GRE	ABS	SHO
M. basjoo	7.07 h	6.90 h	1.60 f	ERE	ABS	GRE	ABS	INS
M. coccinea	1.10 l	3.62 l	1.62 f	ERE	ABS	WYE	ABS	SHO
M. laterita	2.95 k	4.07 l	1.27 g	ERE	ABS	GRE	ABS	INS
M. ornata	4.45 j	5.25 j	1.45 f	ERE	ABS	GRE	ABS	INS
M. velutina	3.50 k	5.52 j	2.52 d	ERE	MUC	PPU	ABS	INS
Dwarf mutant*	–	–	–	–	–	–	–	–
Variegated mutant*	–	–	–	–	–	–	–	–

Averages followed by the same letter do not differ by the Scott-Knott test at 1% probability

NFR number of fruits, *FLE* fruit length in (cm), *FDI* fruit diameter in (cm), *FLE* flexion of the fruits, *FPU* fruit pubescence, *COF* color of the fruits, *WFR* welding of the fruits, *SFA* size of the fruit apex, *VCU* very curved, *MCU* moderately curved, *ERE* erect, *ABS* absent, *PRE* present, *AVE* average, *MUC* much, *INS* insignificant, *GRE* green, *GRA* grayish-green, *PUR* purple, *BPU* brown-purple, *WYE* whitish yellow, *PPU* pink-purple, *SHO* short, *LOG* long

* Non-evaluated

the accessions of the group 1 are selected and recommended for landscape plants, cut flower, potted plants and male inflorescence; The diploids of the groups 3 and 4 are indicated for the production of ornamental minifruits. 'Lidi' and Cici can also be used for landscape plants; The diploids BB have great potential solely for the use of male inflorescence in floral arrangements.

Table 7 Quantitative and qualitative characteristics of the male inflorescence in 31 accessions of the banana germplasm bank of the Embrapa Cassava and Fruits with ornamental potential

Genotype	Traits of male inflorescence (heart)					
	LHT	DHT	HSH	SHA	COC	IMB
BB Belgium	15.00 f	8.22 d	TRU	OBT	DGR	PIM
BB France	20.25 c	9.10 c	TRU	OBT	DGR	PIM
BB IAC	16.00 f	8.17 d	TRU	OBT	DGR	PIM
BB Panama	21.92 b	6.17 g	ELO	ACU	DGR	PIM
Benedetta	15.62 f	6.05 g	TRU	OBT	BPU	MIB
'Berlin'	14.97 f	6.50 f	LAN	OBT	RED	NIM
Bronze	15.67 f	6.25 g	ELO	ROU	SAL	SIM
Burmannica	24.87 a	3.27 k	ELO	ACU	DAP	MIB
Butuhan	16.37 e	6.60 f	TRU	OBT	DGR	PIM
Cacambou Naine*	–	–	–	–	–	–
Calcutta 4	24.50 a	3.52 k	ELO	ACU	DAP	MIB
Caru Roxo	17.25 d	8.32 d	TRU	OBT	RSH	PIM
Cici	11.12 i	4.25 i	TRU	OBT	GRO	NIB
Fique Rose Naine	15.72 f	7.32 e	TRU	OBT	RSH	PIM
Jambi	8.10 j	4.27 i	LAN	ACU	RED	NIM
Jari Buaya	18.02 d	6.17 g	ELO	OBT	ORR	NIM
Khai Nai On	10.65 i	3.85 j	LAN	OBT	PUR	NIM
Krasan Saichon	17.25 d	9.75 b	ELO	OBT	DAP	PIM
'Lidi'	10.87 i	6.45 f	LAN	OBT	RSH	NIM
Monyet	11.42 i	4.40 i	OVL	ACU	BPU	SIM
Pa Songkla	12.70 h	7.25 e	LAN	ACU	BPU	NIM
Royal	12.37 h	3.25 k	ELO	ROU	VIP	NIB
Tambi	10.60 i	6.22 g	LAN	ACU	DGR	NIM
M. balbisiana	15.50 f	8.17 d	TRU	OBT	DGR	PIM
M. basjoo	13.90 g	10.60 a	OVW	ROU	GRO	MIB
M. coccinea	4.02 k	2.47 l	LAN	ROU	RED	MIB
M. laterita	10.95 i	3.30 k	ELO	ROU	SAL	PIM
M. ornata	14.35 g	5.07 h	ELO	ROU	PIL	NIB
M. velutina	10.62 i	3.10 k	ELO	ROU	VIP	NIB
Dwarf Mutant*	–	–	–	–	–	–
Variegated mutant*	–	–	–	–	–	–

Averages followed by the same letter do not differ by the Scott-Knott test at 1% probability

LHT length of the heart in (cm), *DHT* heart diameter in (cm), *HSH* heart shape, *SHA* shape of the heart apex, *IMB* heart imbrication, *ELO* elongate, *LAN* lanceolate, *OVA* ovate, *OVW* oval-wide, *TRU* truncated, *ACU* acute, *OBT* obtuse, *ROU* round, *NIB* non-imbricated, *SIM* slightly imbricated, *MIB* much imbricated, *DGR* dark green, *RED* red, *DAP* dark purple, *SAL* salmon, *ORR* orange-red, *RSH* reddish porple, *PIL* pink-light, *GRO* olive-green, *VIP* violet-pink, *PUR* purple

* Non-evaluated

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