

# Genetic variation of *Citrus* and related genera with ornamental potential

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**Abstract** The interest in *Citrus* and related genera as ornamental plants has increased in recent years, motivating studies aimed at identifying genotypes, varieties and hybrids suitable for this purpose. The *Citrus* Active Germplasm Bank of the Embrapa Cassava & Fruits, a research unit of the Brazilian Agricultural Research Corporation—Embrapa, contains more than 750 accessions with wide genetic variability, and their utilization for ornamental purposes is the objective of this study. For this purpose, we characterized 37 accessions with ornamental potential, classified in four categories for use in floriculture: potted plants, minifruit, hedges and landscaping. Through the use of 39 quantitative and qualitative morphological descriptors, the following accessions stood out for use landscaping and as potted plants: ‘Variegated’ calamondin, ‘Nasnaran’ mandarin, ‘Chinotto’ orange, ‘Trifoliate limeberry’, ‘Papeda Kalpi’, ‘Talamisan’ orange, ‘Wart Java’ lime, and

‘Chinese box-orange’, besides accessions of the genera *Fortunella*, *Poncirus* and *Microcitrus*. Among the accessions identified as having potential for use as minifruit plants, the common ‘Sunki’ mandarin was the most suitable, and in the hedge category, ‘Chinese box-orange’ and ‘Trifoliate limeberry’ stood out. The results obtained provide information to support citrus breeding programs for ornamental purposes.

**Keywords** Fruits · Floriculture · Genetic diversity · Morphological descriptors · Ornamental plants · Pre-breeding

## Abbreviations

CAGB *Citrus* active germplasm bank  
UPGMA Unweighted pair group method using an arithmetic average

## Introduction

*Citrus* L. and related genera belong to the family Rutaceae and contain species with huge economic value, the highlights being trees producing sweet oranges [*C. sinensis* (L.) Osbeck], besides lemons [*C. limon* (L.) Burm. f.], limes (various species), tangerines and mandarins (various species) and grapefruits (*C. paradisi* Macfad.). In 2012, global production of citrus fruits reached 131.3 million metric tons (FAO 2015). The potential uses of citrus

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fruits, however, go beyond consumption of fresh fruit and juice, including raw materials such as essential oils for the production of medicines, pesticides, fragrances and flavorings (Silva 1995; Bizzo 2009).

Regarding the use of citrus plants for ornamental purposes, the first reports date to circa 1000 B.C. in China (Donadio et al. 2005). Despite this long heritage, the ornamental exploitation of citrus plants is still incipient and restricted to recommendations by a few landscape experts. In Europe in particular, a movement is starting to gain force in favor of ornamental citriculture, not only for use of varieties described and cultivated in the past, but also to establish genetic improvement programs to develop hybrids for this purpose, such as the efforts of research institutions in Italy (Del Bosco 2003).

The *Citrus* Active Germplasm Bank (CAGB) of Embrapa Cassava & Fruits, located in Cruz das Almas, Bahia state, Brazil, contains more than 750 accessions, making it highly representative in number of species and genera. It has potential for identification and generation of ornamental varieties, considering the significant genetic variability of its accessions. The study of this variability can support genetic improvement programs to generate ornamental hybrids. In this respect, the characterization of the accessions preserved is an essential step to identify the potential of this germplasm bank, because the data obtained from such studies will define the diversity of the accessions and determine their potential for employment in different categories of ornamental use, such as for potted plants, minifruit, landscaping or hedges.

Similar studies have been conducted for characterization of fruit-bearing species and their classification in ornamental use categories with pineapple (*Ananas*) (Souza et al. 2012a) and banana (*Musa*) (Souza et al. 2012b), resulting in a rich database for diverse applications as well as for genetic breeding, refinement of knowledge on taxonomy and evolution and conservation studies.

Investigation of the genetic resources available in the CAGB is important to generate new products to meet the needs of the market (Koehler-Santos et al. 2003). The most important traits involve the plant crown, leaves and fruits, where the major part of the available descriptors are concentrated.

Similar studies have been conducted by Mazzini and Pio (2010), who characterized the morphology of

six citrus varieties and identified the ornamental potential of the Buddha's hand citron [*C. medica* var. *sarcodactylis* (Hoola van Nooten) Swingle], so named because its fruits are similar to a hand and have strong yellow color, as well as the 'Cipó' and 'Imperial' sweet oranges, because of their drooping branches and variegated fruits and leaves.

Likewise, the purpose of this study was to characterize the accessions of the *Citrus* Active Germplasm Bank of Embrapa Cassava & Fruits by means of quantitative and qualitative morphological descriptors, to identify genotypes with ornamental potential and to classify them in different use categories. Another objective was to generate information for use in genetic improvement programs for development of ornamental citrus varieties.

## Materials and methods

This study was conducted at the CAGB experimental area, located at 12°40'19" south latitude and 39°06'22" west longitude, in the municipality of Cruz das Almas, Bahia, Brazil.

According to the Köppen classification, the climate in Cruz das Almas is a transition between the Am and Aw zones, with average annual rainfall of 1143 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, A moderate, sandy clay loam texture, kaolinite, hypoferric, transition zone between subperennial and semideciduous rainforest, with slope of 0–3 %.

The CAGB is composed of at least two plants of each accession, which receive routine crop treatments. The rootstocks used are the 'Rangpur' lime (*C. limonia* Osbeck), 'Volkamer' lemon (*C. volkameriana* Ten. & Pasq) and 'Cleopatra' mandarin (*C. reshni* hort. ex Tanaka). The plants are grown with spacing of 5 m × 4 m or 6 m × 4 m, in function of the vigor of the different accessions.

We selected 37 accessions of citrus with ornamental potential: 'Nasranan' mandarin [*C. amblycarpa* [(Hassk.) Ochse]], 'Galego Inerme Key' lime [*C. aurantiifolia* (Christm.) Swingle], 'Narrow Leaf' sour orange (*C. aurantium* L.), 'Bergamot' orange (*C. bergamia* Risso & Poit.), 'Taiwan' mandarin (*C. depressa* Hayata), 'Mauritius papeda' (*C. hystrix* DC.), *C. hystrix* hybrid, 'Variegated' true lemon (*C.*

*limon*), ‘Talamisan’ orange (*C. longispina* Wester), ‘Etrog’ citron (*C. medica* L.), ‘Variegated’ calamondin (*C. madurensis* auct.), ‘Chinotto’ orange (*C. myrtifolia* Raf.), ‘Star Ruby’ grapefruit (*C. paradisi* Macfad.), ‘Cleopatra’ mandarin (*C. reshni* hort. ex Tanaka), ‘Fairchild’ tangerine-tangelo [*C. clementina* hort. ex Tanaka × (*C. paradisi* × *C. tangerina* hort. ex Tanaka)], ‘Szincom’ mandarin (*C. reticulata* Blanco), ‘Valencia Trepadeira’ sweet orange (*C. sinensis*), ‘Variegated’ sweet orange (*C. sinensis*), ‘Jaboti’ tangor (*C. sinensis* × *C. unshiu* Marcow.), common ‘Sunki’ mandarin [*C. sunki* (Hayata) hort. ex Tanaka], ‘Tachibana’ orange [*C. tachibana* (Makino) Tanaka], ‘Mency’ tangor (*C. tangerina* × *C. sinensis*), ‘Papada Kalpi’ (*C. webberi* Wester var. *montana* Wester), ‘Jindou’ kumquat [*Fortunella hindsii* (Champ. ex Benth.) Swingle], *Fortunella* sp., ‘Changshou’ kumquat (*F. <sup>x</sup>obovata* hort. ex Tanaka); ‘Jindan’ kumquat (*F. <sup>x</sup>crassifolia* Swingle); ‘Wart Java’ lime (*Citrus* sp.), *Microcitrus papuana* Winters, ‘Benecke’ trifoliolate orange [*Poncirus trifoliata* (L.) Raf.], ‘Coleman’ citrange (*C. sinensis* × *P. trifoliata*), ‘Flying Dragon’ trifoliolate orange (*P. trifoliata*), ‘Chinese box-orange’ (*Severinia buxifolia* [(Poir.) Ten.], ‘Limeberry’ {*Triphasia trifolia* [(Burm. f.) P. Wilson]}, ‘Cravo’ mandarin (*C. reticulata*), ‘Citros Processo’ (*Citrus* sp.), and ‘Jerônimo’ lime (*Citrus* sp.).

We applied 39 descriptors, 10 of them quantitative and 29 qualitative (IPGRI 1999). Among the quantitative descriptors, three were related to traits of the plants, four to leaf traits and three to fruit traits. Of the qualitative descriptors, five were related to attributes of the plants, nine to the leaves, five to the flowers and ten to the fruits. The definition of each ornamental category for classification of the accessions was based on the following characteristics:

- *Potted plants* Plant height below 170 cm, crown diameter smaller than 150 cm, moderate or dense branching, preferably with few or no spines. Accessions with larger height and crown diameter could be considered, if associated with dwarf rootstock or plants manageable by topiary to keep them small.
- *Minifruits plants* Fruit diameter (or length for elongated fruits) varying from 2.5 cm to 4.5 cm.
- *Hedges plants* Dense branching.
- *Landscaping plants* Broad category, possibly including potted plants, minifruit and hedges.

One desirable common feature of plants in this category is absence or low density of spines.

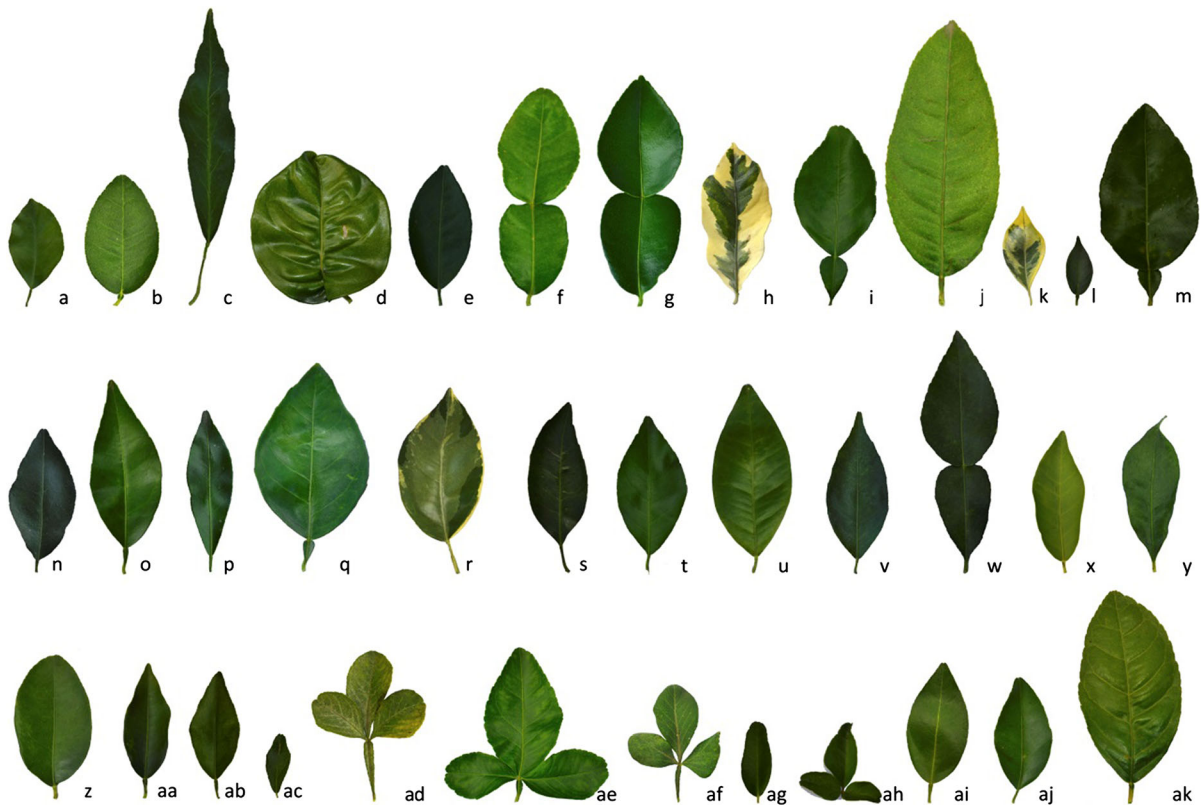
The data were submitted to analysis of variance and the means were compared by the Scott–Knott test at 5 % probability, using the SAS statistical program (SAS Institute 2010). The colors were compared with the color chart of the Royal Horticulture Society (RHS). The relative contribution of each quantitative variable was calculated using the criterion of Singh (1981) by the Genes program (Cruz 2006). Finally, the Gower algorithm (1971) was applied for joint analysis qualitative and quantitative data by determining the genetic distance.

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

The statistical software system (R Development Core Team 2006) was used for the analyses of genetic distance, hierarchical clusterings and cophenetic correlation. 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

From applying the morphological descriptors utilized it was possible to characterize the accessions with ornamental potential, besides classify them in the use categories. The variability found was probably due to the great diversity among individuals in the CAGB regarding size, color and shape of the leaves (Fig. 1), fruits (Fig. 2) and flowers (Fig. 3). The evaluation of the relative importance of the 10 quantitative descriptors in judging the variability among the accessions was carried out by the method of Singh (1981). The crown diameter descriptor contributed 68.93 % of the morphological divergence between individuals, followed by plant height, which accounted for 30.92 %. These results show that these two variables are responsible for a significant part of the phenotypical variability identified (Table 1).



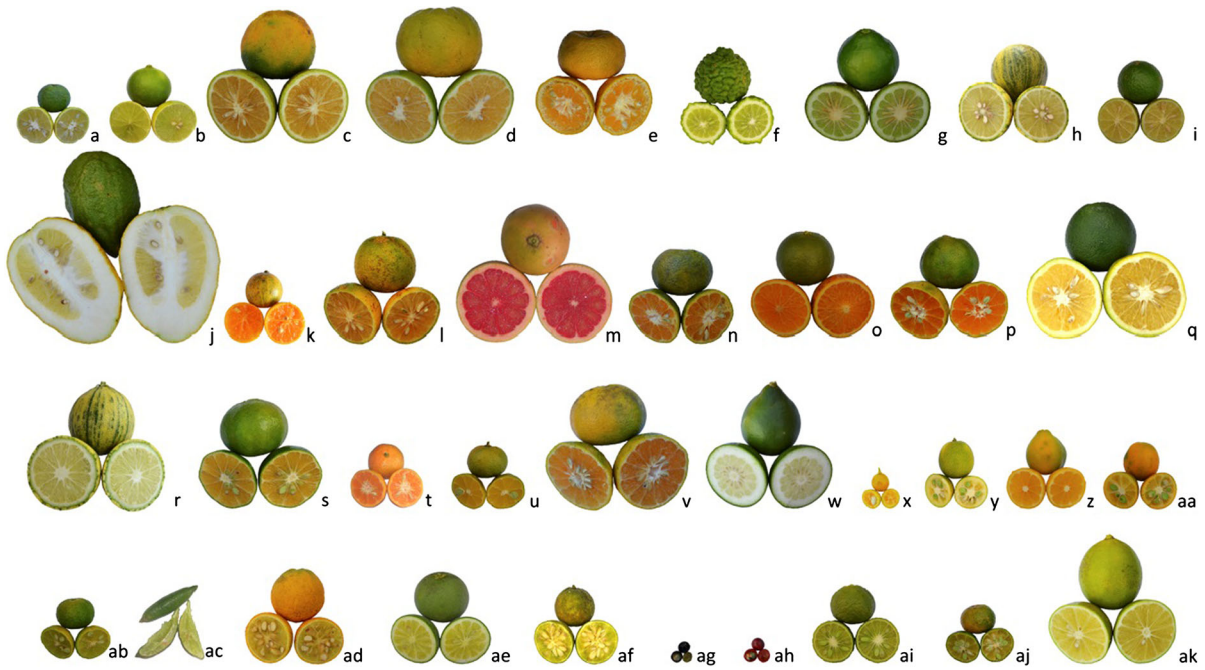
**Fig. 1** Morphological variability of leaves of 37 accessions of *Citrus* L. and related genera. **a** ‘Nasranan’ mandarin (*C. amblycarpa*), **b** ‘Galego Inerme Key’ lime (*C. aurantiifolia*), **c** ‘Narrow Leaf’ sour orange (*C. aurantium*), **d** ‘Bergamot’ orange (*C. bergamia*), **e** ‘Taiwan’ mandarin (*C. depressa*), **f** ‘Mauritius papeda’ (*C. hystrix*), **g** *C. hystrix* hybrid, **h** ‘Variegated’ true lemon (*C. limon*), **i** ‘Talamisan’ orange (*C. longispina*), **j** ‘Etrog’ citron (*C. medica*), **k** ‘Variegated’ calamondin (*C. madurensis*), **l** ‘Chinotto’ orange (*C. myrtifolia*), **m** ‘Star Ruby’ grapefruit (*C. paradisi*), **n** ‘Cleopatra’ mandarin (*C. reshni*), **o** ‘Fairchild’ tangerine-tangelo [*C. clementina* × (*C. paradisi* × *C. tangerina*)], **p** ‘Szincom’ mandarin (*C. reticulata*), **q** ‘Valencia Trepadeira’ sweet orange (*C. sinensis*), **r** ‘Variegated’ sweet orange (*C. sinensis*), **s** ‘Jaboti’

tangor (*C. sinensis* × *C. unshiu*), **t** common ‘Sunki’ mandarin (*C. sunki*), **u** ‘Tachibana’ orange (*C. tachibana*), **v** ‘Mency’ tangor (*C. tangerina* × *C. sinensis*), **w** ‘Papeda Kalpi’ (*C. webberi* var. *montana*), **x** ‘Jindou’ kumquat (*Fortunella hindsii*), **y** *Fortunella* sp., **z** ‘Changshou’ kumquat (*F. <sup>x</sup>obovata*), **aa** ‘Jindan’ kumquat (*F. <sup>x</sup>crassifolia*), **ab** ‘Wart Java’ lime (*Citrus* sp.), **ac** *Microcitrus papuana*, **ad** ‘Benecke’ trifoliolate orange (*Poncirus trifoliata*), **ae** ‘Coleman’ citrange (*C. sinensis* × *P. trifoliata*), **af** ‘Flying Dragon’ trifoliolate orange (*P. trifoliata*), **ag** ‘Chinese box-orange’ (*Severinia buxifolia*), **ah** ‘Limeberry’ (*Triphasia trifolia*), **ai** ‘Cravo’ mandarin (*C. reticulata*), **aj** ‘Citros Processo’ (*Citrus* sp.), **ak** ‘Jerônimo’ lime (*Citrus* sp.). Bars 5 cm

The joint analysis of the qualitative and quantitative data of the 37 accessions evaluated led to the formation of eight groups (Fig. 4) by UPGMA based in the pairwise Euclidean distance between all the accessions, using the genetic dissimilarity ( $D_{dg} = 0.4$ ) as the cutoff point.

The dendrogram generated presented cophenetic correlation coefficient of  $r = 0.70$  ( $P < 0.0001$ , 10,000 permutations). This coefficient permits assessing the consistency of the grouping pattern between the elements of the dissimilarity matrix as

well as the elements of the simplified matrix obtained by the grouping method. Values near one indicate better graphical representation (Rohlf and Fisher 1968). According to the results, there was a good fit between the graphical representation of the Euclidean distances and the original matrix. In a similar study with pineapple, Souza et al. (2012a) found a relatively high cophenetic correlation coefficient ( $r = 0.81$ ), a value considered good when dealing with quantitative and qualitative morphological data.



**Fig. 2** Morphological variability of fruits of 37 accessions of *Citrus* L. and related genera. **a** ‘Nasranan’ mandarin (*C. amblycarpa*), **b** ‘Galego Inerne Key’ lime (*C. aurantiifolia*), **c** ‘Narrow Leaf’ sour orange (*C. aurantium*), **d** ‘Bergamot’ orange (*C. bergamia*), **e** ‘Taiwan’ mandarin (*C. depressa*), **f** ‘Mauritius papeda’ (*C. hystrix*), **g** *C. hystrix* hybrid, **h** ‘Variegated’ true lemon (*C. limon*), **i** ‘Talamisan’ orange (*C. longispina*), **j** ‘Etrog’ citron (*C. medica*), **k** ‘Variegated’ calamondin (*C. madurensis*), **l** ‘Chinotto’ orange (*C. myrtifolia*), **m** ‘Star Ruby’ grapefruit (*C. paradisi*), **n** ‘Cleopatra’ mandarin (*C. reshni*), **o** ‘Fairchild’ tangerine-tangelo [*C. clementina* × (*C. paradisi* × *C. tangerina*)], **p** ‘Szincom’ mandarin (*C. reticulata*), **q** ‘Valencia Trepadeira’ sweet orange (*C. sinensis*), **r** ‘Variegated’ sweet orange (*C. sinensis*), **s** ‘Jaboti’

tangor (*C. sinensis* × *C. unshiu*), **t** common ‘Sunki’ mandarin (*C. sunki*), **u** ‘Tachibana’ orange (*C. tachibana*), **v** ‘Mency’ tangor (*C. tangerina* × *C. sinensis*), **w** ‘Papeda Kalpi’ (*C. webberi* var. *montana*), **x** ‘Jindou’ kumquat (*Fortunella hindsii*), **y** *Fortunella* sp., **z** ‘Changshou’ kumquat (*F. <sup>x</sup>obovata*), **aa** ‘Jindan’ kumquat (*F. <sup>x</sup>crassifolia*), **ab** ‘Wart Java’ lime (*Citrus* sp.), **ac** *Microcitrus papuana*, **ad** ‘Benecke’ trifoliolate orange (*Poncirus trifoliata*), **ae** ‘Coleman’ citrange (*C. sinensis* × *P. trifoliata*), **af** ‘Flying Dragon’ trifoliolate orange (*P. trifoliata*), **ag** ‘Chinese box-orange’ (*Severinia buxifolia*), **ah** ‘Limeberry’ (*Triphasia trifolia*), **ai** ‘Cravo’ mandarin (*C. reticulata*), **aj** ‘Citros Processo’ (*Citrus* sp.), **ak** ‘Jerônimo’ lime (*Citrus* sp.). Bars 5 cm

Group G1 is composed of only one accession, *M. papuana*, which originates from tropical Asia (USDA 2014) and has several attractive characteristics from the ornamental standpoint. Its small size and dense ellipsoidal crown (Table 2) make this species highly recommended for the potted plant and landscaping categories. Its high branch density and presence of spines allows its use to form hedges and its small elongated fruits (Tables 3, 4; Fig. 5a) are attractive and decorative. Probably the distinctive morphological traits of the fruits and leaves were decisive for this accession to be alone in this group. *M. papuana* has been successfully employed by the *Citrus* Genetic Improvement Program of Embrapa Cassava & Fruits as a parental in crosses aiming to obtain plants with

ornamental qualities as well as to generate rootstocks, given the high drought tolerance of the genus *Microcitrus* (Swingle) (Swingle 1967).

Group G2 is formed of two well-defined subgroups, the first composed of the ‘Benecke’ and ‘Flying Dragon’ trifoliolate oranges and the ‘Coleman’ citrange.

Varieties of *P. trifoliata* are widely distributed in northern and central China (USDA 2014). The trees are small to medium in size, with long spines (Table 2). Their leaves are trifoliate (Fig. 1ad, af) and their fruits (Fig. 2ad, af) have a papillate texture and are bright yellow when ripe, besides being highly aromatic, an important characteristic of ornamental plants. The flowering of *Poncirus* Raf. is abundant and its flowers and spines are large (Table 5; Figs. 3q, s,



**Fig. 3** Morphological variability of flowers of 21 accessions of *Citrus* L. and related genera. **a** ‘Nasranan’ mandarin (*C. amblycarpa*), **b** ‘Galego Inerne Key’ lime (*C. aurantiifolia*), **c** ‘Taiwan’ mandarin (*C. depressa*), **d** ‘Mauritius papeda’ (*C. hystrix*), **e** *C. hystrix* hybrid, **f** ‘Variegated’ true lemon (*C. limon*), **g** ‘Talamisan’ orange (*C. longispina*), **h** ‘Etrog’ citron (*C. medica*), **i** ‘Variegated’ calamondin (*C. madurensis*), **j** ‘Star Ruby’ grapefruit (*C. paradisi*), **k** ‘Valencia Trepadeira’ sweet

orange (*C. sinensis*), **l** ‘Papeda Kalpi’ (*C. webberi* var. *montana*), **m** ‘Jindou’ kumquat (*Fortunella hindsii*), **n** *Fortunella* sp., **o** ‘Changshou’ kumquat (*F. obovata*), **p** ‘Jindan’ kumquat (*F. crassifolia*), **q** ‘Benecke’ trifoliolate orange (*Poncirus trifoliata*), **r** ‘Coleman’ citrange (*C. sinensis* × *P. trifoliata*), **s** ‘Flying Dragon’ trifoliolate orange (*P. trifoliata*), **t** ‘Chinese box-orange’ (*Severinia buxifolia*), **u** ‘Limeberry’ (*Triphasia trifolia*). Bars 5 cm

**Table 1** Relative contribution (%) of quantitative descriptors to the morphological variability of 37 accessions of *Citrus* L., related genera, based on the criterion of Singh (1981) and Mahalanobis distance

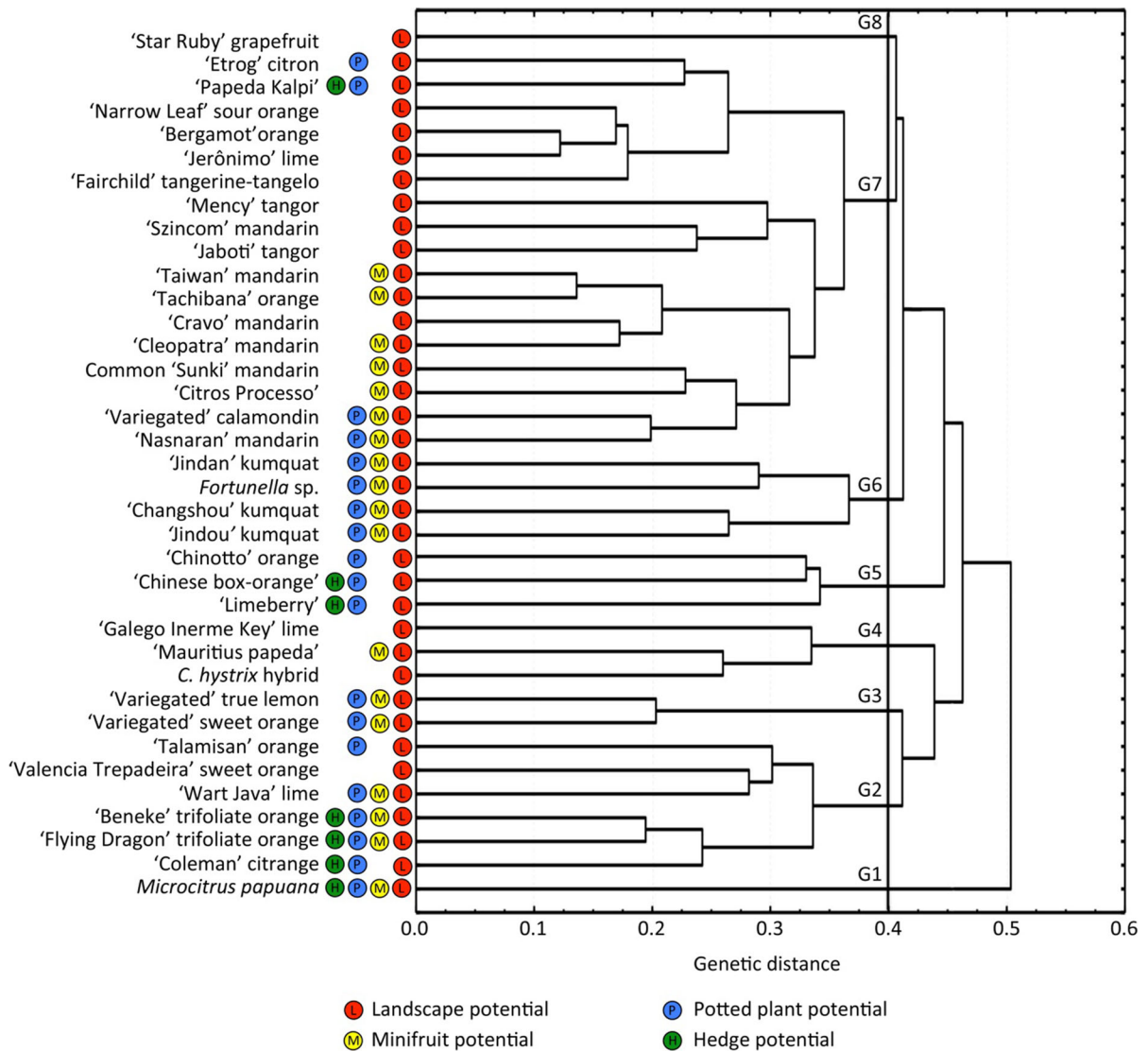
Descriptors	$S_j$	$S_{j1}$ (%)
Crown diameter	19,068,161.3	68.93
Plant height	8,553,852.5	30.92
Leaf length	9283.8	0.03
Trunk diameter	8506.3	0.03
Fruit length	6271.4	0.02
Fruit diameter	5957.8	0.02
Leaf width	3527.7	0.01
Phyllode length	2963.7	0.01
Number of fruits per bunch	2781.9	0.01
Phyllode width	1257.7	0.01

$S_j$  = contribution of the variable  $x$  for the value of the Euclidean distance between genotypes  $i$  and  $j$

5b), favoring use in landscaping and as hedges of for production of minifruit plants.

The ‘Coleman’ citrange has very similar traits to those of the *Poncirus* accessions, which compose its group (‘Benecke’ and ‘Flying Dragon’) and can also be recommended in the potted plant category.

Also in this group, the accessions ‘Wart Java’ lime, ‘Valencia Trepadeira’ sweet orange and ‘Talamisan’ orange form a second grouping. According to the system of Tanaka (1961), *C. sinensis* and *C. longispina* originated in Asia and are part of the subgenus *Archicitrus*. Due to the presence of highly dense crowns and uniform branching, the ‘Talamisan’ orange and ‘Wart Java’ lime are recommended as potted plants and for landscaping (Fig. 5c). The ‘Wart Java’ lime is also suitable for producing small fruits, because they have a rough peel and light yellow color when ripe (Fig. 2ab; Table 4).



**Fig. 4** Genetic dissimilarity dendrogram for 37 accessions of *Citrus* L. and related genera, obtained by the UPGMA (unweighted pair group method using arithmetic average) based on the Gower algorithm, for 39 qualitative and quantitative traits

The ‘Valencia Trepadeira’ sweet orange is an accession of Asian origin (USDA 2014) and although it produces relatively large leaves (Fig. 1q) and fruits (Fig. 2q) among sweet orange varieties (Table 4), it has an ovoid crown, with drooping branches, which can be supported on lattices to form pergolas, making it recommended for landscaping (Fig. 5d). Besides this, its flowering is intense, with large flowers and pinkish floral buds (Fig. 3k). It is also recommended as a parental to form hybrids because of its small size. In a similar study, Mazzini and Pio (2010) evaluated

the ‘Cipó’ sweet orange, a synonym of ‘Valencia Trepadeira’, also finding it to have the same recommended uses as found here.

Group G3 is composed of only two accessions, the ‘Variegated’ sweet orange (Fig. 5e, f) and ‘Variegated’ true lemon (Fig. 5g, h). These accessions, whose species belong to the subgenus *Archictrus* (Lanjouw 1961; Tanaka 1961), are very similar and can be easily confused. They are medium-sized erect plants with ellipsoid crown (Table 2). They have great ornamental potential and can be managed through pruning or

**Table 2** Quantitative and qualitative plant traits in 37 accessions from the *Citrus* Active Germplasm Bank of Embrapa Cassava & Fruits with ornamental potential

Name of the accession	PLH	TRD	CRD	CRS	DBR	SPD	SPL	SPS
'Nasranan' mandarin	175.00 d	5.90 d	160.00 e	OVO	DEN	SPA	≤5 mm	STR
'Galego Inerme Key' lime	330.00 a	11.20 b	540.00 a	OVO	DEN	MED	≤5 mm	STR
'Narrow Leaf' sour orange	354.00 a	10.20 c	335.00 c	ELI	MED	ABS	ABS	ABS
'Bergamot' orange	335.00 a	9.90 c	245.00 d	ELI	MED	ABS	ABS	ABS
'Taiwan' mandarin	315.00 b	10.75 c	475.00 b	ELI	DEN	ABS	ABS	ABS
'Mauritius papeda'	283.00 b	9.60 c	290.00 c	OVO	DEN	MED	≤5 mm	STR
<i>C. hystrix</i> hibrid	215.00 c	7.50 d	225.00 d	SPH	DEN	MED	6–15 mm	STR
'Variegated' true lemon	250.00 c	7.50 d	200.00 d	ELI	SPA	SPA	6–15 mm	STR
'Talamisan' orange	110.00 d	6.70 d	155.00 e	ELI	DEN	SPA	6–15 mm	STR
'Etrog' citron	210.00 c	10.00 c	330.00 c	OVO	SPA	HIG	16–40 mm	STR
'Variegated' calamondin	115.00 d	3.65 f	120.00 e	SPH	MED	ABS	ABS	ABS
'Chinotto' orange	190.00 c	6.20 d	160.00 e	OVO	SPA	ABS	ABS	ABS
'Star Ruby' grapefruit	220.00 c	9.00 c	246.00 d	SPH	DEN	SPA	6–15 mm	STR
'Cleopatra' mandarin	365.00 a	11.70 b	465.00 b	ELI	MED	ABS	ABS	ABS
'Fairchild' tangerine-tangelo	297.50 b	9.30 c	360.00 c	OVO	MED	ABS	ABS	ABS
'Szincom' mandarin	290.00 b	9.60 c	347.50 c	SPH	DEN	ABS	ABS	ABS
'Valencia Trepadeira' sweet orange	140.00 d	8.85 c	260.00 d	OVO	MED	SPA	6–15 mm	STR
'Variegated' sweet orange	215.00 c	6.50 d	155.00 e	ELI	MED	ABS	ABS	ABS
'Jaboti' tangor	336.00 a	10.40 c	415.00 b	SPH	DEN	ABS	ABS	ABS
Common 'Sunki' mandarin	375.00 a	11.15 b	445.00 b	SPH	DEN	ABS	ABS	ABS
'Tachibana' orange	365.00 a	9.75 c	375.00 c	OVO	DEN	ABS	ABS	ABS
'Mency' tangor	328.00 a	9.30 c	380.00 c	SPH	MED	SPA	16–40 mm	STR
'Papeda Kalpi'	190.00 c	7.00 d	250.00 d	OVO	DEN	ABS	ABS	ABS
'Jindou' kumquat	160.00 d	3.20 f	108.00 e	ELI	MED	MED	6–15 mm	STR
<i>Fortunella</i> sp.	235.00 c	6.65 d	140.00 e	ELI	MED	SPA	6–15 mm	STR
'Changshou' kumquat	220.00 c	7.70 d	143.33 e	ELI	MED	ABS	ABS	ABS
'Jindan' kumquat	245.00 c	8.10 d	163.00 e	ELI	SPA	ABS	ABS	ABS
'Wart Java' lime	170.00 d	5.10 e	150.00 e	SPH	MED	SPA	≤5 mm	STR
<i>Microcitrus papuana</i>	140.00 d	3.05 f	85.00 e	ELI	DEN	HIG	6–15 mm	STR
'Benecke' trifoliolate orange	245.00 c	5.40 e	185.00 e	ELI	MED	HIG	>40 mm	STR
'Coleman' citrange	266.00 b	6.90 d	213.00 d	ELI	MED	HIG	16–40 mm	STR
'Flying Dragon' trifoliolate orange	223.00 c	5.90 d	115.00 e	ELI	MED	HIG	16–40 mm	CUR
'Chinese box-orange'	210.00 c	8.15 d	180.00 e	SPH	DEN	HIG	16–40 mm	STR
'Limeberry'	170.00 d	5.15 e	205.00 d	SPH	DEN	MED	6–15 mm	STR
'Cravo' mandarin	362.50 a	13.05 a	390.00 c	SPH	DEN	ABS	ABS	ABS
'Citros Processo'	380.00 a	12.40 a	350.00 c	ELI	MED	SPA	6–15 mm	STR
'Jerônimo' lime	160.00 d	6.60 d	245.00 d	OVO	SPA	SPA	6–15 mm	STR

Averages followed by the same letter do not differ by the Scott–Knott test at 5 % probability

PLH plant height (cm), TRD trunk diameter (cm), CRD crown diameter (cm), CRS crown shape, DBR density of branches, SPD spine density, SPL spine length, SPS spine shape, OVO ovoid, ELI ellipsoid, SPH spheroid, DEN dense, MED medium, SCA sparse, ABS absent, HIG high, STR straight, CUR curved



**Table 3** Quantitative and qualitative leaf traits in 37 accessions from the *Citrus* Active Germplasm Bank of Embrapa Cassava & Fruits with ornamental potential

Name of the accession	LFL	LFW	LFD	LVA	LCO	LLI	LLS	LLM	LAP	PHY	PHL	PHW	PHS
'Nasranan' mandarin	7.41 d	3.45 d	SIM	ABS	DAR (Fan3-147a)	SES	OVA	SIM	ATT	PRE	1.43 f	0.33 e	OBO
'Galago Inerme Key' lime	9.12 c	4.49 d	SIM	ABS	LIG (Fan3-143b)	SES	OVA	SIM	ATT	PRE	1.09 h	0.36 e	OBD
'Narrow Leaf' sour orange	13.17 a	2.59 e	SIM	ABS	DAR (Fan3-N137a)	LON	LAN	SMO	ACU	PRE	3.12 c	0.35 e	OBD
'Bergamot' orange	9.13 c	6.18 b	SIM	ABS	MED (Fan3-146b)	SES	ORB	SMO	ROU	ABS	ABS	ABS	ABS
'Taiwan' mandarin	7.51 d	3.61 d	SIM	ABS	DAR (Fan3-N137c)	SES	OVA	SIM	ATT	ABS	ABS	ABS	ABS
'Mauritius papeda'	9.38 c	4.05 d	SIM	ABS	LIG (Fan3-137a)	LON	OVA	SIM	ATT	PRE	4.52 b	3.51 b	OBD
<i>C. hystrix</i> hibrid	10.81 b	4.35 d	SIM	ABS	DAR (Fan3-N137b)	LON	ELP	SIM	ATT	PRE	5.01 a	3.87 a	OBO
'Variegated' true lemon	9.75 c	5.81 b	SIM	PRE	VAR	SES	ELP	CRE	ATT	ABS	ABS	ABS	ABS
'Talamisan' orange	8.80 c	4.06 d	SIM	ABS	DAR (Fan3-137b)	BRE	ELP	SMO	ATT	PRE	2.41 d	1.19 d	OBO
'Etrog' citron	13.21 a	4.15 d	SIM	ABS	LIG (Fan3-N137a)	SES	ELP	SIM	ATT	ABS	ABS	ABS	ABS
'Variegated' calamondin	5.71 d	2.74 e	SIM	PRE	VAR	SES	OVA	SMO	ATT	ABS	ABS	ABS	ABS
'Chinotto' orange	3.24 e	1.36 f	SIM	ABS	DAR (Fan3-147a)	SES	OVA	SMO	ATT	ABS	ABS	ABS	ABS
'Star Ruby' grapefruit	9.20 c	6.20 b	SIM	ABS	DAR (Fan3-135a)	BRE	OBO	CRE	ATT	PRE	1.20 g	1.00 d	OBD
'Cleopatra' mandarin	7.97 c	3.72 d	SIM	ABS	DAR (Fan3-N137c)	SES	ELP	SIM	ATT	ABS	ABS	ABS	ABS
'Fairchild' tangerine-tangelo	9.08 a	3.33 d	SIM	ABS	MED (Fan3-146a)	BRE	ELP	SIM	ATT	PRE	1.85 e	0.33 e	OBO
'Szincom' mandarin	8.26 c	2.51 e	SIM	ABS	DAR (Fan3-N137d)	SES	LAN	CRE	ACU	ABS	ABS	ABS	ABS
'Valencia Trepadeira' sweet orange	11.03 a	5.74 b	SIM	ABS	MED (Fan3-N147b)	BRE	OVA	SIM	ATT	PRE	2.27 d	0.98 d	OBC
'Variegated' sweet orange	9.56 b	5.03 c	SIM	PRE	VAR	BRE	ELP	CRE	ATT	PRE	1.35 g	0.45 e	OBC
'Jaboti' tangor	8.64 b	3.49 d	SIM	ABS	DAR (Fan3-N137c)	BRE	ELP	SIM	ATT	ABS	ABS	ABS	ABS
Common 'Sunki' mandarin	6.34 b	3.39 c	SIM	ABS	DAR (Fan3-N137c)	SES	ELP	SIM	ATT	ABS	ABS	ABS	ABS
'Tachibana' orange	6.26 c	3.16 c	SIM	ABS	MED (Fan3-137c)	SES	ELP	SIM	ROU	ABS	ABS	ABS	ABS
'Mency' tangor	7.06 c	3.31 e	SIM	ABS	DAR (Fan3-N137b)	SES	OVA	SIM	ACU	ABS	ABS	ABS	ABS
'Papeda Kalpi'	11.77 a	4.29 d	SIM	ABS	DAR (Fan3-139a)	LON	OVA	CRE	ATT	PRE	5.17 a	3.19 c	OBD
'Jindou' kumquat	5.00 d	2.30 e	SIM	ABS	LIG (Fan3-N144a)	SES	ELP	SMO	ACU	ABS	ABS	ABS	ABS
<i>Fortunella</i> sp.	8.28 c	2.88 e	SIM	ABS	MED (Fan3-138a)	SES	ELP	CRE	ACM	ABS	ABS	ABS	ABS
'Changshou' kumquat	6.78 d	4.13 d	SIM	ABS	MED (Fan3-137d)	SES	OVA	CRE	ROU	ABS	ABS	ABS	ABS
'Jindan' kumquat	8.42 c	3.10 e	SIM	ABS	MED (Fan3-137d)	SES	ELP	CRE	ATT	ABS	ABS	ABS	ABS
'Wart Java' lime	6.30 d	2.79 e	SIM	ABS	MED (Fan3-138a)	SES	ELP	CRE	ATT	PRE	1.57 f	0.42 e	OBO
<i>Microcitrus papuana</i>	2.28 e	0.96 f	SIM	ABS	MED (Fan3-138a)	SES	OVA	CRE	ATT	ABS	ABS	ABS	ABS
'Benecke' trifoliolate orange	7.31 d	6.78 b	TRI	ABS	LIG (Fan3-144a)	LON	OBO	CRE	ROU	PRE	2.32 d	0.45 e	OBO
'Coleman' citrange	9.57 c	8.73 a	TRI	ABS	LIG (Fan3-N143b)	BRE	OBO	CRE	ATT	PRE	1.50 f	0.42 e	OBO
'Flying Dragon' trifoliolate orange	6.66 d	6.27 b	TRI	ABS	LIG (Fan3-143a)	LON	OBO	CRE	ROU	PRE	2.09 e	0.39 e	OBD

**Table 3** continued

Name of the accession	LFL	LFW	LFD	LVA	LCO	LLI	LLS	LLM	LAP	PHY	PHL	PHW	PHS
'Chinese box-orange'	4.40 d	1.81 f	SIM	ABS	MED (Fan3-146b)	SES	ELP	DEN	ATT	ABS	ABS	ABS	ABS
'Limeberry'	3.62 e	3.96 d	TRI	ABS	MED (Fan3-137d)	SES	ELP	SIM	ATT	ABS	ABS	ABS	ABS
'Cravo' mandarin	8.28 c	3.85 d	SIM	ABS	LIG (Fan3-144a)	SES	ELP	SIM	ATT	ABS	ABS	ABS	ABS
'Citros Processo'	6.67 c	4.17 d	SIM	ABS	LIG (Fan3-143a)	SES	ELP	SIM	ATT	ABS	ABS	ABS	ABS
'Jerônimo' lime	10.24 b	5.16 c	SIM	ABS	LIG (Fan3-143a)	SES	ELP	DEN	ATT	ABS	ABS	ABS	ABS

Averages followed by the same letter do not differ by the Scott–Knott test at 5 % probability. Colors compared with the Color Chart of the Royal Horticulture Society (RHS) LFL leaf length (cm), LFW leaf width (cm), LFD leaf division, LVA leaf variegation, LCO leaf color, LLI leaf lamina insertion, LLS leaf lamina shape, LLM leaf lamina margin, LAP leaf apex, PHY phyllode, PHL phyllode length (cm), PHW phyllode width (cm), PHS phyllode shape, SIM simple, TRI trifoliolate, ABS absent, PRE present, LIG light, MED medium, DAR dark, VAR variegated, SES sessile, BRE brevipedicelate, LON longipedicelate, ELP elliptic, OBO obovate, LAN lanceolate, OVA ovate, ORB orbicular, SIN sinuate, CRE crenate, SMO smooth, DEN dentate, ATT attenuate, ACU acute, ROU rounded, EMA emarginate, ACM acuminate, OBD obdeltate, OBC obovate

topiary, for use in pots or for landscaping. Their leaves have varied colors, with green and white or light cream shades and elliptical shape (Fig. 1h, r; Table 3). The fruits also have varied color, from yellow to dark green (Fig. 2h, r). They have the medium size of the common sweet orange, but the plant can be classified in the minifruit ornamental category because of the fruits appealing appearance when unripe. Probably the morphological traits of coloration and leaf shape were decisive in these two accessions isolation in this group.

The decorative value of the 'Variegated' sweet orange and 'Variegated' true lemon can be significantly enhanced by using dwarf rootstocks, a strategy that can also be applied to the other accessions evaluated.

Group G4 contains *C. hystrix*, along with a hybrid of this species and the 'Galego Inerme Key' lime. According to Tanaka (1961), these species belong to the subgenus *Archicitrus*. The 'Galego Inerme Key' lime is recommended for use in landscaping and in crosses aimed at producing ornamental hybrids, since this accession of totally free of spines (Fig. 5i).

The species *C. hystrix* is native to temperate and tropical Asia (USDA 2014). It has a dense crown with branches starting near the base (Fig. 5j). Its leaves are dark green and longipetiolate, with large phyllodes, composing up to 50 % of their size (Fig. 1f). The fruits are aromatic, green and highly attractive from the ornamental viewpoint due to their rough peels (Fig. 2f; Table 4). This accession is recommended for minifruit and landscaping plants.

According to Swingle (1967), *C. hystrix* is naturally hybridized with other species of the *Citrus* genus, and some of these hybrid varieties being included among the different forms described by Wester in the period between 1913 and 1915. This can explain the origin of the *C. hystrix* hybrid evaluated in this study, whose characteristics of size and foliage (Fig. 1g) are very similar to those of other *C. hystrix* varieties and is suitable for landscaping.

Three accessions formed Group G5: 'Limeberry', 'Chinese box-orange' and 'Chinotto' orange. The first is small, with dense branching (Table 2) and elliptical trifoliate leaves (Fig. 1ah; Table 3). The flowers are small and white and have three petals (Table 5; Fig. 3u). Its fruits are small and abundant, with dark green color (Fig. 2ah; Table 4), a trait that contrasts with the leaf color, giving it good ornamental potential (Fig. 5k). The 'Limeberry' probably originated in Asia (USDA 2014), and it is widely cultivated in

tropical and subtropical regions as an ornamental and hedge plant. The observations in this study corroborate the indications by Swingle (1967) for this accession, which can be used as a potted plant, in landscaping and to form hedges.

*S. buxifolia*, commonly called the ‘Chinese box-orange’ or boxthorn, is native to tropical and temperate Asia (USDA 2014). It has medium size and a dense crown (Table 2; Fig. 5l, m) with high density of leaves and spines (Fig. 1ag) and small fruits (Fig. 2ag) and flowers (Fig. 3t). The fruits, which resemble berries, are black when ripe and abundant. This accession can be used as a potted plant or for landscaping.

*C. myrtifolia*, also known as the ‘Chinotto’ orange (Hodgson 1967), is small and without spines (Table 2), with branches completely covered by small, shiny, dark green leaves (Table 3). The coloration of its abundant fruits ranges from dark yellow to orange, making this species recommended for ornamental use in pots and landscaping (Fig. 5n). It is cultivated in Italy as a decorative plant (Saunt 1990; USDA 2014). It can also be recommended in the minifruit category.

In this study, we evaluated four species of *Fortunella* (Swingle), or kumquat, all of them in Group G6: *F. hindsii*, known as the ‘Jindou’ kumquat (Fig. 5o), *F. xobovata*, also called the ‘Changchou’ kumquat (Fig. 5p), *Fortunella* sp. and *F. xcrassifolia*, popularly known as the ‘Jindan’ kumquat (Fig. 5q).

The data found for the ‘Jindou’ kumquat coincide with the descriptions of Swingle (1967) and Saunt (1990), who stated that the plants of this species are small with thin branches, differing from other species of the genus, which are much larger. This accession produces small, bright orange colored fruits and has strong ornamental potential (Fig. 2x; Table 4). The use of this species for ornamental landscaping was mentioned by Saunt (1990), and we can recommend it as a potted and/or minifruit plant as well.

The other three *Fortunella* accessions analyzed are very similar to each other and are recommended for use in the same categories mentioned above. The Changchou stands out for its pyriform fruits, which are quite different from the other kumquat species. These small fruits can also be used in decorative arrangements (Fig. 2z; Table 4).

Species of the *Fortunella* genus all produce small and abundant orange-colored fruits that are highly aromatic. The peel is fleshy and edible when the fruit is

ripe. They are widely cultivated in Japan and China along with other subtropical regions (Swingle 1967).

Group G7 is formed of 17 accessions, of them 12 species and hybrids in the tangerine or micro-tangerine category. Tangerines and mandarins trees fall in an extensive and diversified group, containing different species and varieties that often have sharp distinctions, making it hard to list traits common to all of them. In general, they produce small flowers and medium-sized fruits with orange color that are easy to peel (Hodgson 1967; Saunt 1990).

These results are in accordance with the findings of Nicolosi et al. (2000), who studied the phylogenetic aspects of accessions of *Citrus* and related genera based on RAPD and SCAR markers, finding considerable genetic similarity among tangerine accessions. A similar result was obtained by Bastianel et al. (2001), who grouped tangerine and sour orange species in the same group, like in this study.

The ‘Cravo’ mandarin tree is probably native to Asia (USDA 2014). It is tall, without spines, with dense spheroid crown (Table 2) and produces medium-sized fruits with slightly rough surface and deep orange color when ripe (Fig. 2ai; Table 4). Because of its size, it is only recommended for landscaping (Fig. 5r), but is an interesting candidate for genetic alteration with parentals to reduce its stature, as has been achieved with *Fortunella*, *Poncirus* and *Microcitrus*. The size of the hybrids obtained could be reduced even more by using dwarf rootstock varieties. Another *C. reticulata* accession is the ‘Szincom’ mandarin, which has similar characteristics to the ‘Cravo’ variety and the same potential use.

The ‘Sunki’ mandarin tree is widely grown in temperate Asia (USDA 2014) and produces fruits classified as micro-tangerines (Fig. 5s, t). According to Araújo and Salibe (2002), this term refers to species or varieties of *Citrus* that have small leaves, flowers and (generally sour) fruits. As an adult, it reaches up to 4 meters (Table 2), with a dense spheroid crown and no spines. Its leaves are small and dark green (Fig. 1t; Table 3) and it yields plentiful fruit for most of the year. These micro-tangerines are oblate, with few seeds and have deep orange peels when ripe (Fig. 2t). Despite its tall size, the ‘Sunki’ mandarin tree is widely used for ornamental purposes due to the sharp contrast between its fruits and foliage. It can be used for landscaping of large open areas, although its best use is for production of small fruits. At the *Citrus*

**Table 4** Quantitative and qualitative fruit traits in 37 accessions from the *Citrus* Active Germplasm Bank of Embrapa Cassava & Fruits with ornamental potential

Name of the accession	FRL	FRD	FRS	FSB	FSA	FRV	IFC	RFC	FST	ALC	PUC	NFB	AFB
'Nasranan' mandarin	2.58 h	3.19 e	OBL	TRU	TRU	ABS	GRE	YEL	RGH	WHI	YEL	1.45 d	2-4
'Galego Inerne Key' lime	3.46 g	3.94 d	SPH	ROU	CON	ABS	GRE	LYE	SMO	WHI	GRE	1.80 d	2-4
'Narrow Leaf' sour orange	7.14 c	7.41 b	SPH	ROU	CON	ABS	GRE	YEL	RGH	WHI	YEL	1.40 d	2-4
'Bergamot' orange	6.38 d	7.69 b	OBL	TRU	TRU	ABS	GRE	DYE	RGH	WHI	YEL	1.30 d	2-4
'Taiwan' mandarin	2.75 h	3.90 d	OBL	TRU	TRU	ABS	GRE	ORA	SMO	WHI	ORA	3.45 b	4-6
'Mauritius papada'	3.91 g	4.25 d	PYR	CON	NEC	ABS	GRE	GRE	RGH	WHI	GRE	2.25 c	2-4
<i>C. hystrix</i> hybrid	8.80 a	5.53 b	PYR	CON	NEC	ABS	GRE	GRE	SMO	WHI	GRE	1.00 d	2-4
'Variegated' true lemon	6.36 d	5.82 c	SPH	MAM	CON	PRE	VAR	YEL	RGH	WHI	YEL	1.20 d	2-4
'Talamisan' orange	5.50 e	5.35 c	SPH	ROU	CON	ABS	GRE	YEL	RGH	WHI	YEL	1.25 d	+6
'Etrog' citron	12.48 c	8.95 b	OVO	ACU	CON	ABS	GRY	YEL	RGH	WHI	YEL	1.00 d	2-4
'Variegated' calamondin	2.91 h	2.89 e	SPH	ROU	CON	PRE	VAR	YEL	SMO	ORA	ORA	1.25 d	2-4
'Chinotto' orange	4.93 f	5.63 c	SPH	TRU	TRU	ABS	GRE	DYE	SMO	WHI	YEL	2.30 c	2-4
'Star Ruby' grapefruit	9.10 b	9.80 a	SPH	ROU	TRU	ABS	GRY	YEL	SMO	PIN	RED	1.40 d	2-4
'Cleopatra' mandarin	3.73 g	4.00 d	OBL	TRU	TRU	ABS	GRE	ORA	SMO	WHI	ORA	3.65 b	4-6
'Fairchild' tangerine-tangelo	5.30 e	6.10 c	SPH	TRU	TRU	ABS	GRE	ORA	SMO	YEL	ORA	1.20 d	2-4
'Szincom' mandarin	3.67 g	3.88 d	SPH	TRU	CON	ABS	GRE	LOR	SMO	WHI	YEL	1.35 d	2-4
'Valencia Trepadeira' sweet orange	6.64 d	7.26 b	SPH	ROU	TRU	ABS	GRE	YEL	SMO	WHI	YEL	1.85 d	2-4
'Variegated' sweet orange	6.41 d	6.40 c	SPH	ROU	CON	PRE	VAR	YEL	RGH	WHI	YEL	1.20 d	2-4
'Jaboti' tangor	4.63 f	6.27 c	OBL	TRU	TRU	ABS	GRY	ORA	SMO	WHI	YEL	1.30 d	2-4
Common 'Sunki' mandarin	3.35 g	4.20 d	OBL	OUT	TRU	ABS	GRE	ORA	SMO	ORA	ORA	9.55 a	+6
'Tachibana' orange	3.33 g	3.23 e	OBL	TRU	TRU	ABS	GRE	LYE	SMO	WHI	YEL	1.35 d	2-4
'Mency' tangor	4.28 f	4.33 d	OBL	TRU	TRU	ABS	GRE	ORA	SMO	WHI	YEL	1.30 d	2-4
'Papada Kalpi'	6.76 d	7.90 b	PYR	ROU	NEC	ABS	GRE	GRE	SMO	WHI	GRE	1.20 d	2-4
'Jindou' kumquat	1.61 i	1.42 f	SPH	ROU	CON	ABS	GRY	ORA	SMO	WHI	YEL	1.40 d	2-4
<i>Fortunella</i> sp.	2.65 h	2.50 e	ELL	ROU	CON	ABS	GRE	ORA	SMO	WHI	YEL	1.25 d	2-4
'Changshou' kumquat	4.10 f	4.16 d	PYR	TRU	NEC	ABS	GRE	YEL	SMO	WHI	LOR	1.33 d	2-4
'Jindan' kumquat	2.75 h	2.50 e	ELL	ROU	CON	ABS	GRE	ORA	SMO	WHI	YEL	1.40 d	2-4
'Wart Java' lime	2.68 h	3.34 e	OBL	TRU	TRU	ABS	GRE	LYE	RGH	YEL	YEL	2.30 c	2-4
<i>Microcitrus papuana</i>	5.45 e	1.90 f	OUT	OUT	OUT	ABS	GRE	YEL	RGH	GRS	GRE	1.25 d	2-4
'Benecke' trifoliolate orange	4.23 f	4.31 d	SPH	ROU	TRU	ABS	GRE	YEL	PAP	WHI	YEL	1.60 d	2-4
'Coleman' citrange	5.80 e	6.00 c	SPH	ROU	CON	ABS	GRE	LYE	PAP	WHI	YEL	1.35 d	2-4
'Flying Dragon' trifoliolate orange	3.90 g	4.05 d	SPH	ROU	TRU	ABS	GRE	YEL	PAP	YEL	YEL	1.20 d	2-4
'Chinese box-orange'	0.98 j	0.91 f	SPH	ROU	CON	ABS	GRE	OUT	SMO	OUT	OUT	1.20 d	+6

**Table 4** continued

Name of the accession	FRL	FRD	FRS	FSB	FSA	FRV	IFC	RFC	FST	ALC	PUC	NFB	AFB
'Limeberry'	1.77 i	1.08 f	SPH	ROU	CON	ABS	GRE	RED	SMO	RDS	RED	1.80 d	2–4
'Cravo' mandarin	3.38 h	4.70 e	OBL	TRU	TRU	ABS	GRE	LAE	RGH	ORA	ORA	1.25 d	2–4
'Citros Processo'	3.24 g	4.02 d	OBL	TRU	TRU	ABS	GRE	ORA	SMO	ORA	ORA	1.00 d	2–4
'Jerônimo' lime	7.51 c	6.29 c	ELL	TRU	CON	ABS	GRE	LYE	SMO	WHI	YEL	1.15 d	2–4

Averages followed by the same letter do not differ by the Scott–Knott test at 5 % probability

FRL fruit length (cm), FRD fruit diameter (cm), FRS fruit shape, FSB shape of fruit base, FSA shape of fruit apex, FRV fruit variegation, IFC immature fruit color, RFC ripe fruit color, FST fruit surface texture, ALC albedo color, PUC pulp color, NFB number of fruits per bunch, AFB average amount of fruits per bunch, ELL ellipsoid, SPH spheroid, OBL obloid, PYR pyriform, OVO ovoid, OUT outer, TRU truncate, ROU rounded, MAM mammiform, ACU acute, CON convex, NEC necked, PRE present, ABS absent, GRE green, GRY green–yellow, VAR variegated, YEL yellow, LYE light yellow, DYE dark yellow, ORA orange, LOR light orange, RED red, RGH rough, SMO smooth, PAP papillate, WHI white, PIN pink, GRS greenish, RDS reddish

Genetic Improvement Program of Embrapa Cassava & Fruits the common 'Sunki' stands out as an important female parental in controlled crosses (Soares Filho et al. 2013, 2014). Observations in populations of hybrids in the field indicate that the 'Sunki' mandarin has great potential to minifruit production.

The 'Cleopatra' mandarin, *Citrus* sp. (in this article identified as 'Citros Processo'), 'Tachibana' orange and *C. depressa* ('Taiwan' mandarin) are similar to the common 'Sunki' mandarin and can be recommended for the same ornamental uses. The 'Cleopatra', which is widely cultivated in tropical Asia and South America (USDA 2014), is a prolific fruit producer, making it attractive as an ornamental plant, mainly in the minifruit category (Hodgson 1967).

*Citrus* sp. refers to an accession that was impossible to identify to the species level, but it has characteristics very near those of the common 'Sunki' mandarin, as well as some similarity with the 'Cleopatra' variety, although the latter's fruits are larger. The fruits are small (Table 4) and differ from the 'Sunki' variety only by the lighter orange color (Fig. 2aj). It is recommended for landscaping and decorative arrangements of minifruit plants.

*C. amblycarpa*, also known as 'Nasranan' mandarin (USDA 2014), is a micro-tangerine species with dense ovoid crown and sparse spines (Table 2). The fruits are oblate and have rough peels which turn yellow when ripe (Fig. 2a; Table 4). It is a species recommended as a potted plant, for landscaping and as a minifruit plant (Fig. 5u).

The 'Tachibana' orange, native to Japan (USDA 2014), has similar appearance to micro-mandarin species, with tall stature, dense crown and no spines (Table 2). The fruits are small and oblate and turn yellow when ripe (Fig. 2u; Table 4). This accession can be recommended for landscaping and minifruit plants.

The 'Jaboti' tanger is a hybrid of the 'Natal' sweet orange and the 'Satsuma' mandarin. The accession is tall, with dense spheroid crown and has no spines (Table 2). Its leaves are dark green (Fig. 1s; Table 3). The fruits are oblate and medium sized, with deep orange color when ripe (Fig. 2s; Table 4). Due to the size of its crown, it is recommended for landscaping, but can also be used as a parental in crosses to obtain hybrids with other potential ornamental uses.

The 'Mency' tanger is a hybrid of the 'Dancy' tangerine and the 'Mediterranean' sweet orange (Hodgson 1967), with similar characteristics to the

‘Jaboti’ tangor, so the ornamental recommendations are the same.

The ‘Fairchild’ tangerine-tangelo is a hybrid of the ‘Clementine’ tangerine (*C. clementina*) and the ‘Orlando’ tangelo (*C. paradisi* x *C. tangerina*), commercially launched in 1964 (Soost and Roose 1996). It has medium size, ovoid crown and no spines (Table 2). It produces many fruits, which are orange and spheroid, with slightly truncated apex and base (Fig. 2o; Table 4). The description of Hodgson (1967) for this hybrid coincides with our observations. It is recommended for landscaping and as a parental to produce genotypes with ornamental potential.

The ‘Variegated’ calamondin is short, with spherical crown, no spines and medium to dense branching (Fig. 5v; Table 2). Its leaves are variegated, oval and small (Fig. 1k; Table 3), giving it good ornamental potential. The fruits are abundant, small, spherical and variegated when immature (Fig. 2k; Table 4). It is recommended for use as a potted plant, for landscaping and as a minifruit plant. It is sold by nurseries in Florida and California (USA) as a potted plant (Hodgson 1967).

Besides the 12 accessions with fruits classified as tangerines or mandarins already mentioned, five others are contained in Group G7: ‘Jerônimo’ lime, ‘Narrow Leaf’ sour orange, ‘Bergamot’ orange, ‘Papada Kalpi’ and ‘Etrog’ citron.

The ‘Jerônimo’ lime was classified as *Citrus* sp., although it is possibly a natural hybrid of the rough lemon (*C. jambhiri* Lush.). This accession has small size, ovoid and drooping crown, with sparse to average branching (Table 2). It was included in this study mainly because of its small size and drooping branches, allowing it to be used as coverage for pergolas.

The ‘Narrow Leaf’ sour orange is cultivated in tropical and subtropical regions, and possibly originates from China (USDA 2014). It is a tall tree that grows vertically straight, with elliptical crown and no spines (Fig. 2o; Table 2). It has dark green lanceolate leaves that are long and narrow (Fig. 1c; Table 3), hence its name. According to Saunt (1990), sour orange varieties are grown for ornamental purposes in public and private gardens in many countries due to their perceived beauty. This is especially the case along the Mediterranean coast and in places in Arizona and California. Therefore, the ‘Narrow Leaf’ tree can be used for landscaping and in genetic improvement programs to generate hybrids with other potential ornamental uses.

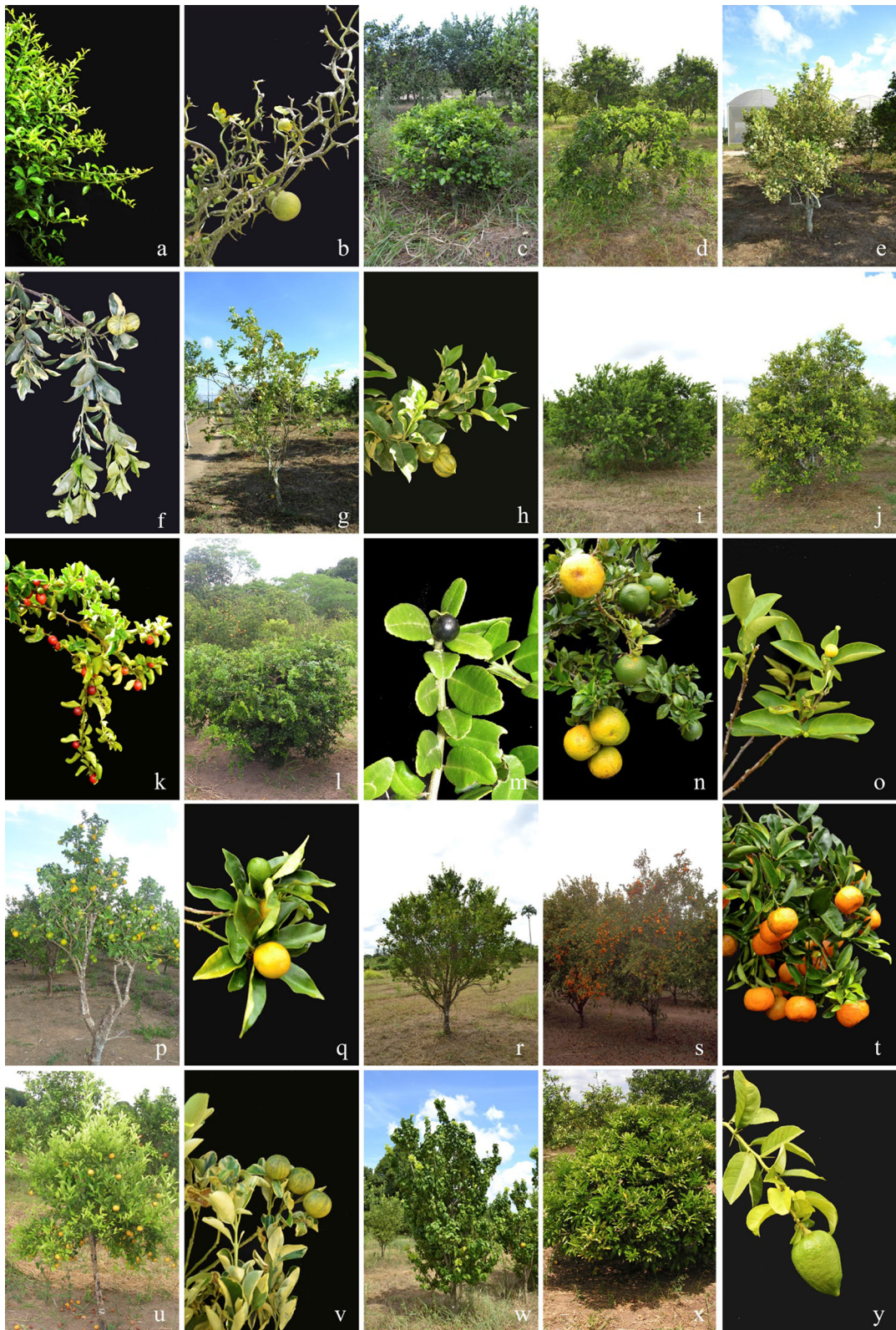
**Fig. 5** Plant and detail of the branches of accessions of *Citrus* L. and related genera. **a** *M. papuana*, **b** ‘Flying Dragon’ trifoliolate orange (*P. trifoliata*), **c** ‘Talamisan’ orange (*C. longispina*), **d** ‘Valencia Trepadeira’ sweet orange (*C. sinensis*), **e, f** ‘Variegated’ sweet orange (*C. sinensis*), **g, h** ‘Variegated’ true lemon (*C. limon*), **i** ‘Galego Inerme Key’ lime (*C. aurantiifolia*), **j** ‘Mauritius papeda’ (*C. hystrix*), **k** ‘Limeberry’ (*Triphasia trifolia*), **l, m** ‘Chinese box-orange’ (*Severinia buxifolia*), **n** ‘Chinotto’ orange (*C. myrtifolia*), **o** ‘Jindou’ kumquat (*Fortunella hindsii*), **p** ‘Changshou’ kumquat (*F. xobovata*), **q** ‘Jindan’ kumquat (*F. xcrassifolia*), **r** ‘Cravo’ mandarin (*C. reticulata*), **s, t** common ‘Sunki’ mandarin (*C. sunki*), **u** ‘Nas-naran’ mandarin (*C. amblycarpa*), **v** ‘Variegated’ calamondin (*C. madurensis*), **w** ‘Bergamot’ orange (*C. bergamia*), **x** ‘Papada Kalpi’ (*C. webberi*), **y** ‘Etrog’ citron (*C. medica*)

*C. bergamia*, known as ‘Bergamot’, is a natural hybrid from crossing *C. medica* and [*C. maxima* (Burm.) Merr. x *C. reticulata*] (USDA 2014). The crown is pronouncedly erect (Fig. 5w), it does not have spines and its leaves stand out for their orbicular shape, bright green color and curled format (Fig. 1d). It is recommended for landscaping and in genetic improvement programs due to its unique foliage.

*C. webberi* var. *montana*, also known as ‘Papada Kalpi’, is medium-sized, with a dense ovoid crown and no spines (Fig. 5x; Table 2). Its leaves are oval and longipetiolate, with winged petioles having the same size as the leaf limbus (Fig. 1w; Table 3). It is attractive for landscaping due to the shape and density of the crown, and can also be recommended as a potted plant and for forming hedges.

The ‘Etrog’ citron probably is native to China and India (USDA 2014), and is one of the basic *Citrus* species. Along with *C. maxima* and *C. reticulata* sensu Swingle, it is at the root of the ancestral species of *Citrus* (Barrett and Rhodes 1976; Velasco and Licciardello 2014). It has medium size, a crown with scarce to medium branching and has spines (Fig. 5y; Table 2). The fruits are large and ovoid, with a characteristic fragrance and yellow color when ripe (Fig. 2j; Table 4). Some varieties of the citron group, such as the ‘Buddha’s Hand’, are already widely used for ornamental purposes (Swingle 1967). The ‘Etrog’ citron can be used as a potted plant or for landscaping.

Group G8 only contains one accession, the ‘Star Ruby’ grapefruit. The tree is medium-sized with a spheroid crown that has plentiful branches and low density of spines (Table 2). The ripe fruits are yellow and reddish pulp. This is the trait that sets it apart from the other accessions (Fig. 2m). It is recommended for



**Table 5** Quantitative and qualitative flower traits in 37 accessions from the *Citrus* Active Germplasm Bank of Embrapa Cassava & Fruits with ornamental potential

Name of the accession	COF	FLL	FLP	ARO	ARP
'Nasranan' mandarin	WHI	BOT	BOT	FRU	NPE
'Galego Inerme Key' lime	WHI	BOT	BOT	BOT	NPE
'Narrow Leaf' sour orange	WHI	BOT	BOT	FLO	NPE
'Bergamot' orange	WHI	BOT	BOT	FRU	NPE
'Taiwan' mandarin	WHI	BOT	BOT	FRU	PER
'Mauritius papeda'	WHI	BOT	BOT	FRU	PER
<i>C. hystrix</i> hibrid	WHI	BOT	BOT	FRU	PER
'Variegated' true lemon	WHI	BOT	BOT	FRU	NPE
'Talamisan' orange	WHI	BOT	BOT	FRU	NPE
'Etrog' citron	WHI	BOT	BOT	FRU	NPE
'Variegated' calamondin	WHI	BOT	BOT	FRU	NPE
'Chinotto' orange	WHI	BOT	BOT	FRU	NPE
'Star Ruby' grapefruit	WHI	INF	BOT	FRU	NPE
'Cleopatra' mandarin	WHI	BOT	BOT	FRU	NPE
'Fairchild' tangerine-tangelo	WHI	BOT	BOT	BOT	NPE
'Szincom' mandarin	WHI	BOT	BOT	FRU	NPE
'Valencia Trepadeira' sweet orange	WHI	BOT	BOT	FRU	NPE
'Variegated' sweet orange	WHI	BOT	BOT	FRU	NPE
'Jaboti' tangor	WHI	BOT	BOT	FRU	NPE
Common 'Sunki' mandarin	WHI	BOT	BOT	FRU	NPE
'Tachibana' orange	WHI	BOT	BOT	FRU	NPE
'Mency' tangor	WHI	BOT	BOT	FRU	PER
'Papeda Kalpi'	WHI	BOT	BOT	FRU	NPE
'Jindou' kumquat	WHI	BOT	BOT	BOT	NPE
<i>Fortunella</i> sp.	WHI	BOT	BOT	BOT	NPE
'Changshou' kumquat	WHI	BOT	BOT	BOT	NPE
'Jindan' kumquat	WHI	BOT	BOT	BOT	NPE
'Wart Java' lime	WHI	BOT	BOT	FRU	NPE
<i>Microcitrus papuana</i>	WHI	BOT	BOT	FRU	NPE
'Benecke' trifoliolate orange	WHI	BOT	BOT	FRU	PER
'Coleman' citrange	WHI	BOT	BOT	FRU	NPE
'Flying Dragon' trifoliolate orange	WHI	BOT	BOT	FRU	NPE
'Chinese box-orange'	WHI	BOT	BOT	FRU	NPE
'Limeberry'	WHI	BOT	BOT	FRU	NPE
'Cravo' mandarin	WHI	BOT	BOT	FRU	NPE
'Citros Processo'	WHI	BOT	BOT	FRU	NPE
'Jerônimo' lime	PIN	BOT	BOT	FRU	NPE

COF colour of open flower, FLL flower layout, FLP flower/inflorescence position, ARO aroma, ARP aroma persistence, WHI white, PIN pink, BOT both, INF inflorescence, FLO flours, FRU fruits, NPE not persistent, PER persistent

landscaping and its fruits can be used in decorative arrangements.

Although the fruit persistence on trees was not directly evaluated in this work, it was observed that the accessions *P. trifoliata* selections, 'Chinotto' orange, 'Star Ruby' grapefruit, 'Wart Java' lime, *M. papuana*, 'Jerônimo' lime, 'Variegated' calamondin,

'Variegated' true lemon, 'Variegated' sweet orange, 'Jaboti' tangor, 'Etrog' citron, 'Galego Inerme Key' lime, 'Papeda Kalpi', 'Narrow Leaf' sour orange, 'Bergamot' orange, 'Mauritius papeda' and *C. hystrix* clearly presented more persistent fruits. On the other hand, mandarins, tangerines, micro-tangerines, and *Fortunella* spp., visually presented lower fruit



persistence, indicated by the precocious fruit drop, in spite of their profuse fruiting. Fruit persistence is one of the traits to considerate for ornamental use in citrus, besides flowering and fruit set. Fruit persistence is particularly of interest because it determines the general value and attractiveness of a citrus ornamental tree, and might be a limitant factor in windy locations. All these traits are typical of the genotype and are genetically controlled, even though several environmental and physiological conditions might influence on them being also mediated by abiotic and biotic stresses and horticultural practices.

## Conclusion

1. The great morphological variability of the citrus accessions studied allows their classification in different ornamental use categories.
2. The ‘Nasranan’ mandarin, ‘Talamisan’ orange, ‘Variegated’ calamondin, ‘Chinotto’ orange, ‘Wart Java’ lime, ‘Limeberry’, ‘Variegated’ true lemon, ‘Variegated’ sweet orange, as well as the accessions belonging to the genera *Fortunella* and *Poncirus*, can be used in the potted plant and landscaping categories, although attention should be paid to the presence of spines in the case of *Poncirus*.
3. ‘Chinese box-orange’, ‘Limeberry’ and *M. papuana* can be employed as ornamental hedges.
4. The common ‘Sunki’ mandarin can be used as a minifruit plant.
5. The accessions studied can be used as parentals in crosses to generate ornamental citrus hybrids.

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