Selection of the Most Discriminating Morphological Qualitative Variables for Characterization of Fig Germplasm

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ABSTRACT. Most descriptor lists for the characterization of genetic resources in plants include a large number of traits whose evaluation is a lengthy and expensive process making the characterization of large germplasm collections difficult. Consequently, to facilitate the study and the conservation of germplasm, it is important to select carefully the most informative variables for each species. In this work, we applied sequential statistical procedures to select the most discriminant variables in fig (Ficus carica L.) from the initial 134 qualitative variables studied. A total of 34 variables was finally selected and broken down in 97 characters that were grouped by principal component analysis in 11 principal components that explain 93.34% of the total variability. The unweighted pair group method with arithmetic mean dendrogram derived from a similarity matrix generated using the Pearson’s correlation coefficient among the 11 principal components selected classifies the cultivars in four main groups mainly based in the production type. These results show that redundant information can be obtained in morphological studies with a large number of variables resulting from correlation between variables. Consequently, a carefully selected and reduced number of highly discriminating variables can allow efficient fig germplasm characterization and discrimination resulting in significant savings of time and resources.

The common fig is a gynodioecious woody perennial species with two tree types: the inedible capriforn, which is functionally a male fig that produces syconia with both male and short-styled female flowers, and the female trees that produce syconia with only female flowers that will develop into the edible seeded figs (syconia with multiple one-seed fruit) (Stover et al., 2007; Valdeyron and Lloyd, 1979). Three different types of female figs can be distinguished depending on the cropping/pollination characteristics, common type, Smyrna, and San Pedro (Stover et al., 2007). Most of the fig genotypes are the common type that produces parthenocarpic fruit without pollination; common-type figs are able to produce one (unifera types) or two crops (bifera types). The Smyrna type requires pollination with pollen from caprifigs (caprification) for fruit development to occur. Finally, the San Pedro type can produce two crops; the first crop (brevas) is parthenocarpic and the second crop (figs) is produced only after pollination.

Figs seem to have been part of food production in the Mediterranean basin since the end of the early Bronze Age, providing fresh fruit in summer and storable, sugar-rich, dry figs during the whole year (Zohary and Spiegel-Roy, 1975). In fact, the fig is considered the first domesticated plant of the Neolithic Revolution some 11,000 years ago (Kislev et al., 2006), probably as a result of the simplicity of its vegetative propagation through cuttings.

In Spain, cultivated, wild and feral fig trees are found in most areas of the country. However, fig remains mostly as a traditional crop and, like in other Mediterranean countries, important genetic erosion is taking place as a result of biotic and abiotic processes (urbanization, extension of intensive crops, absence of caprification, water deficit in marginal areas, etc.) (Mars et al., 1998; Salhi-Hannachi et al., 2004). The increasing concerns on reduced levels of genetic diversity in crop species (Esquinas-Alcazar, 2005; Tanksley and McCouch, 1997) have led to the need to preserve as much genetic diversity as possible both in situ and ex situ not only for the long-term survival of the species, but also to have enough variability available for breeding programs. Although several efforts have been carried out to conserve fig genetic resources in germplasm banks (Flaishman et al., 2008; Giraldo et al., 2008a; Stover and Aradhya, 2008), appropriate management of the germplasm collections requires defining patterns of phenotypic variability within the collections and to select the most significant variables to establish strategies for better conservation and use of...
genetic resources. For this purpose, the analysis of genetic diversity in germplasm collections facilitates reliable classification of the accessions conserved and the identification of subsets or core accessions with possible use for specific breeding purposes (Escribano et al., 2008; Mohammadi and Prasanna, 2003).

Despite the advances in molecular characterization in fig (Achtak et al., 2009; Giraldo et al., 2005, 2008a; Ikegami et al., 2009; Khadari et al., 2005), phenotypic characterization is always needed and it should be included in any program of conservation and use of genetic resources (Giraldo et al., 2008b). Ideally, this characterization should be made under the same edaphoclimatic conditions. However, morphological characterization is a complex process and, to optimize it, descriptor lists for a high number of species have been developed. In fig, a group of international experts developed and published a list of descriptors (International Plant Genetic Resources Institute and Centre International de Hautes Etudes Agronomiques Méditerranéennes, 2003) with the aim of facilitating the characterization process in this species. However, the analyses of morphological traits in fig are even more complex than in most fruit tree species as a result of some particular characteristics of this species such as the frequent production of two different crops (breba and main crop), the presence of four different types of leaves, or its complex floral biology.

Consequently, the current descriptors list available has a total of 192 traits from which 126 are qualitative and 66 are quantitative. This high number of traits and the need to replicate observations during at least 2 years makes phenotypic characterization in this species a slow and time- and resource-consuming process, especially in developing countries with scarce economic resources.

Thus, to optimize the qualitative morphological characterization of fig cultivars, in this work, we analyzed a set of qualitative traits with the objective of selecting the most discriminating traits that should be prioritized for future studies in the different germplasm collections of this species. The approach followed in this work can be also useful to optimize phenotypic characterization in other woody plant species.

Materials and Methods

Plant material. Observations were made in 35 fig accessions conserved in the fig germplasm collection in the Finca La Orden–Valdesequera in Badajoz, Spain (Table 1). Those accessions were selected among those available in our collection base at two selection criteria: they should be at least 10 years old at the time of analysis and at least three trees with uniform growth should be represented for each accession. Three trees were evaluated from each accession and data were taken during three consecutive biological cycles (2001 to 2004) to minimize environmental effects.

Traits evaluated. A total of 134 qualitative variables were studied; 91 of them were described by the International Plant Genetic Resources Institute and Centre International de Hautes Etudes Agronomiques Méditerranéennes (2003) and 43 are new variables not included previously but, according to our observations, could be of interest for fig characterization (Table 2). The variables studied include two biological variables, 21 vegetative variables, 36 breba crop variables, 36 fig crop variables, 14 three-lobed leaf variables, 14 five-lobed leaf variables, and 11 entire leaf variables (Table 2).

To determine the variable “rooting ability of the cuttings,” a trial with 10 cuttings/cultivar was made in the nursery. To study the leaf variables, 20 fully developed leaves localized in the middle third of the shoot were collected from each tree (10 + 10 for the two predominant shapes). Leaves of 10 random shoots/tree were counted to evaluate the variables “number of leaves per shoot” and “leaf shape.” To evaluate the fruit variables, 20 fruit/tree (20 of the breba crop and 20 of the main crop, 10 to determine morphological variables, and 10 for organoleptic variables) and 60 fruit/cultivar (60 of the breba crop and 60 of the main crop) were measured. To evaluate the variables “amount of fruitlets” and “fruitlet size,” fruitlets of the longitudinal section of the fruit were counted and measured with a digital caliper. In all cases, color variables were determined using the Royal Horticultural Society Color Chart (Royal Horticultural Society, 2001).

Statistical analyses. The data collected for each variable were codified as present/absent in databases and analyzed statistically using SPSS (Version 12.0; SPSS, Chicago, IL). A new quantitative variable was created for each of the classes of qualitative traits, in which the frequency indicates the presence

Table 1. Fig accessions analyzed in this work to select the most discriminant variables with their reported origin.

| No. | Accession          | Reported origin         |
|-----|--------------------|-------------------------|
| 1   | Alacantina         | Balearic Islands, Spain |
| 2   | Albarata           | Valencian Community, Spain |
| 3   | Arail              | Andalusia, Spain       |
| 4   | Blanca Albondón    | Andalusia, Spain       |
| 5   | Blanca Valenciana  | Andalusia, Spain       |
| 6   | Blava              | Balearic Islands, Spain |
| 7   | Bota Morada        | Castile and Leon, Spain |
| 8   | Boyuna             | Extremadura, Spain     |
| 9   | Calabacita R       | Catalonia, Spain       |
| 10  | Colar Elche        | Valencian Community, Spain |
| 11  | Cuello Dama Negro  | Valencian Community, Spain |
| 12  | Franciscana        | Castile-La Mancha, Spain |
| 13  | Goen               | Extremadura, Spain     |
| 14  | Gota La Miel       | Valencian Community, Spain |
| 15  | Honigal            | Extremadura, Spain     |
| 16  | Kadota             | USA                     |
| 17  | Lampa Preta        | Portugal                |
| 18  | Lampaga            | Andalusia, Spain       |
| 19  | Mare de Deu        | Balearic Islands, Spain |
| 20  | Martinenca Mina    | Balearic Islands, Spain |
| 21  | Moscatel           | Castile-La Mancha, Spain |
| 22  | Nazaret            | Israel                  |
| 23  | Negra Cabezuela    | Extremadura, Spain     |
| 24  | Negra Calabacilla  | Andalusia, Spain       |
| 25  | Negra Común        | Andalusia, Spain       |
| 26  | Negra Pozuelo      | Andalusia, Spain       |
| 27  | Pacueca            | Andalusia, Spain       |
| 28  | Pefomuda           | Andalusia, Spain       |
| 29  | Picholetera        | Extremadura, Spain     |
| 30  | Roja Almohadin     | Castile-La Mancha, Spain |
| 31  | San Joao Branco    | Portugal                |
| 32  | Tocal              | Andalusia, Spain       |
| 33  | Verde Pozuelo      | Andalusia, Spain       |
| 34  | Verdejuela         | Extremadura, Spain     |
| 35  | Verdejo            | Extremadura, Spain     |
Table 2. List of variables (biological, vegetative, leaf, and fruit) and categories for each variable studied in this work in the 35 fig accessions listed in Table 1.

| Variable* | Categories |
|-----------|------------|
| **Biological** | |
| Crop setting fruit | Bifera, unifera, San Pedro, Smyrna, caprifig |
| Pollination requirement for fruit set | No, yes |
| **Vegetative** | |
| Tree growth habit | Erect, semierect, open, spreading, weeping |
| Apical dominance of seasonal growth | Absent, present, alternate |
| Apical dominance in the structure of the tree | Absent, present, alternate |
| Relative degree of branching | Sparse, intermediate, dense |
| Lateral shoot formation on seasonal growth | Absent, present |
| Size of the tree | Large, medium, small |
| Terminal bud shape | Conical, spherical, other |
| Terminal bud color in dormancy | Yellow, light green, green, reddish, orange, brown |
| Terminal bud color in activity | Yellow, light green, green, reddish, orange, brown |
| Seasonal shoot color in vegetative resting | Green, grey, orange, brown, light brown |
| Seasonal shoot color in activity | Green, grey, orange, brown, light brown |
| Tendency to form suckers | None, low, medium, high |
| Rooting ability of the cuttings | Low, medium, high |
| Nodal swelling prominence | Absent, soft, intermediate, prominent |
| Nodal swelling location | Trunk, older branches, young branches, trunk and older branches, trunk, older branches, and young branches |
| Bark tuber quantity | Absent, rare, frequent, abundant |
| Bark tuber shape | Globe, elongate, globe and elongate |
| Bark tuber location | Trunk, trunk and older branches, trunk, young branches and older branches, older branches |
| Burr knots | Absent, rare, frequent, abundant |
| Leaf shape (%) | Entire, three lobes, five lobes, rare, intermediate, frequent, abundant |
| Number of leaves per shoot | |
| **Leaf** | |
| Shape of central lobe (lobed leaves) | Spatulate, linear, lyrate, latate |
| Shape of lobe (entire leaves) | Triangular, asymmetric triangular, cordate, lanceolate, oblong, unilobulated |
| Little lobes in central lobe | Absent, rare, intermediate, abundant |
| Little lobes in lateral lobes (lobed leaves) | Absent, rare, intermediate, abundant |
| Little lobes in sinus (lobed leaves) | Absent, rare, intermediate, abundant |
| Large basal lateral lobes on petiole sinus (lobed leaves) | Absent, in one sinus, in both sinuses |
| Shape petiole sinus | Decurrent, truncate, cordate, calcarate, open calcarate |
| Leaf margin | Crenate, serrate, parted, entire, undulate, dentate |
| Density of hairs on leaf upper surface | None, sparse, intermediate, dense |
| Density of hairs on leaf lower surface | Unapparent, slightly apparent, apparent |
| Venation on leaf lower surface | Unapparent, slightly apparent, apparent |
| Leaf lower surface color | Light green, green, dark green, yellow-green |
| Leaf upper surface color | Light green, green, yellow–green |
| Petiole cross-section | Circular, ovoid, triangular, flattened, ovoid flattened |
| Petiole color | Light green, green, yellow–green, yellow, brown, light yellow |
| **Fruit** | |
| Fruit shape | Spherical, cucurbiform, turbinate, ovoidal, pyriform, spherical–ovoidal, turbinate–pyriform, spherical–turbinate, turbinate–ovoidal, spherical–pyriform, ovoidal–pyriform, cucurbiform–pyriform |
| Fruit symmetry | Symmetrical, asymmetric |
| Ostiole opening | Yes, no |
| Ostiole prominency | Absent, present |
| Drop at the ostiole | Absent, present |
| Ostiole cracks | Absent, present |

*continued next page*
of the observed quality in the individual phenotype. Estimated descriptive tests and contingency tables were obtained for each categorical variable. To calculate phenotypic correlations, the chi square test \( \chi^2 = \sum \sum (n_{ij} - m_{ij})^2/m_{ij} \) in which \( n_{ij} \) = observed frequency and \( m_{ij} \) = expected frequency (Pearson, 1911), was estimated. Chi square determines if there is some dependence relation between the variables studied and the cultivar. The contingency coefficient \( C_s = \chi^2/\chi^2 + n \), was estimated to assess the degree of relation between the variables studied and the cultivar. \( C \) is based on the chi square-corrected statistic, minimizing the effect of the sample size on the quantification of the associated degree. The variables were selected by the standardized contingency coefficient, \( C_s = C_s/(K-1)/k \) with values of \( C_s = 1 \), \( C_s > 0.75 \) or \( C_s > 0.80 \) for vegetative, leaf, or fruit variables, respectively. The reason to use different \( C_s \) values was the different sizes of the samples.

The number of selected variable categories was also reduced with values of \( C_s > 0.75 \) or \( C_s > 0.80 \) for the Pearson’s coefficients among the 11 PCs selected in this work from the qualitative morphological categories.

### Results and Discussion

Contingency tables and estimated descriptive tests. Contingence tables and descriptive tests made for each of the variables and cultivars provided a visualization of the frequency distribution of the different categories studied. The cultivars studied showed mainly a semiaupright growth habit, a medium size with a dense degree of branching, absence of nodal swellings, abundant bark tubers located in the trunk and in the older branches, absence of burr knots, and high cutting rooting ability. The leaves had mainly five lobes with a latate central lobe and a cordate and calcarate petiole sinus; the number of leaves per shoot ranged from four to nine. Fruit are asymmetric and firm with purple skin, abundant white lenticels, and amber pulp color. Differences were found between the two crops, main and brebas. Thus, the shape of the breba crop was mainly cucurbiform and the shape of the main crop was turbinate meaning that the breba crop shows a longer neck than the main crop. Moreover, the abundance of fruit ribs was intermediate in the breba crop and abundant in the main crop, and the amount and size of fruitless were abundant and larger in size in the breba crop compared with intermediate and small

### Table 2. Continued.

| Variable                          | Categories                                           |
|-----------------------------------|------------------------------------------------------|
| **Scale color ostiolum**          | Detached, adhered, semiadhered                       |
| **Scale adhesion ostiolum**       | Short and thick, variously enlarged, long and slender |
| **Shape of the fruit stalk**       | Short and thick, variously enlarged, long and slender |
| Presence of hair in the fruit stalk| Absent, present                                     |
| Fruit stalk color                  | Orange–gray, purple, green, light green, yellow–green, beige, yellow |
| Fruit stalk cross-section          | Circular, flattened, rhomboid, triangular            |
| Scale of the neck quantity        | Scarce, numerous                                     |
| Scale of the neck disposition      | Free, superimposed                                   |
| Scale of the neck color            | Brown, purple, green, light green, yellow–green, beige, yellow |
| **Fruit ribs**                    | None, rare, intermediate, abundant                   |
| **Fruit skin cracks**             | Absent, minute, scanty and longitudinal, abundant and longitudinal |
| Hairs in the fruit skin            | None, rare, intermediate, abundant                   |
| **Firmness of the fruit skin**     | Soft, medium, firm, rubbery                          |
| Length of style                    | Short, medium, long                                  |
| Location of the female flower      | Center of the pulp, wings of the pulp, ostiole       |
| Numbers of sepals                  | Rare, intermediate; abundant                         |
| Length of sepals                   | Larger than gynceum, similar to gynceum, smaller than gynceum |
| Numbers of stigmas                 | Simple, forked                                       |
| Length of the peduncle of the flower| Longer than the flower, similar to the flower, smaller than the flower |
| Presence of male flowers           | Absent, present                                      |
| **Fruit skin ground color**        | Absent, black, purple, green, light green, yellow–green, yellow |
| **Overcolor: regular band**       | Absent, black, purple, green, light green, yellow–green, yellow |
| **Overcolor: irregular patches**   | Absent, black, purple, green, light green, yellow–green, yellow |
| **Fruit lenticel quantity**       | Absent, scarce, intermediate, numerous               |
| **Fruit lenticel color**           | White, green, beige, pink, yellow, yellow–green, purple, brown |
| **Fruit lenticel size**            | Small, medium, large                                 |
| **Pulp internal color**            | White, amber, pink, red, dark red                    |
| **Pulp cavity**                    | Absent, very small, small, medium, large, very large |
| **Amount of fruitlet**             | None, low, medium, high                              |
| **Fruitlet size**                  | Small, medium, large                                 |

\(^a\)Variables included in the fig descriptor list published by International Plant Genetic Resources Institute and Centre International de Hautes Etudes Agronomiques Méditerranéennes (2003) are in bold.
the main crop. Finally, there were also important differences in female flowers between breba and main crops.

**Selection of variables using contingency ($C_s$) and Pearson ($c^2$) coefficients.** A total of 34 quantitative variables were selected by the $C_s$ reducing by 74% the 134 initially studied variables (Table 3). The 175 initial categories corresponding to the 34 selected variables were reduced to 97 categories (Table 3). These results show that most of the variables were broken down in more categories than necessary. Only two or three of the total number of categories for each studied variable depended strongly on the cultivar. Sixteen variables with high $C_s$, related with the terminal bud (shape and color), seasonal growth color, and ostiole (aperture, cracks, and scales), showed significant differences among trees and years, probably as a result of variation in environmental conditions during the 3 years of evaluation and/or subjective evaluation. Consequently, those 16 variables were finally discarded.

The variables “regular bands” and “pulp cavity” were selected in the main crop but not in the breba crop. The “pulp cavity” variable in the breba crop presented a $C_s$ of 0.72 that, according to the selection criteria, corresponds to the absence of significant differences among cultivars. However, in the main crop, the $C_s$ value was 0.82 that corresponds to significant differences among the cultivars studied. The difference in the $C_s$ value between both crops (fig and breba crop) could be the result of differences in the length of time from fruit formation until maturation in each crop, heat stress, or water deficit during the maturation process. Regarding the variable “regular bands,” among the cultivars studied, this character was only present in the unifera-type cultivar Calabacita R.

**Principal component analysis.** The PCA study was used to identify patterns of variability among the 97 selected categories (Iezzoni and Pritts, 1991). PCA for variable number reduction has been widely used in different species (Badenes et al., 1998, 2000; Chatti et al., 2003; Ferriol et al., 2004; Goulão et al., 2001; Hagidimitriou et al., 2005; Martínez-Calvo et al., 2008; Pereira-Lorenzo et al., 1996, 2003; Pérez-Gonzáles, 1992; Rotondi et al., 2003; Semagn, 2002; Zamora et al., 2003). This study showed that the first 11 PCs contributed 93.3% of the total variability and the first four PCs explained 79% of the variability (Table 4).

Table 3. List of the 34 qualitative variables and 97 categories selected in this work after analysis of the 35 fig accessions listed in Table 1 in base to the standardized contingency coefficient.

| Variable                           | IC (no.) | SC (no.) | Selected categories                                                                 |
|-----------------------------------|----------|----------|-------------------------------------------------------------------------------------|
| Crop setting fruit                | 5        | 5        | Bifera, unifera, San Pedro, Smyrna, caprifig                                         |
| Tree growth habit                 | 5        | 3        | Semierect, open, spreading                                                          |
| Relative degree of branching      | 3        | 3        | Sparse, intermediate, dense                                                         |
| Size of the tree                  | 3        | 2        | Large, small                                                                       |
| Bark tubers shape                 | 3        | 3        | Globe, elongate, globe and elongate                                                |
| Leaf shape (%)                    | 3        | 3        | Entire, three lobes, five lobes                                                     |
| Shape of central lobe (three-lobed leaves) | 4     | 3        | Spatulate, lyrate, lanceolate                                                       |
| Shape of central lobe (five-lobed leaves) | 4     | 4        | Spatulate, linear, lyrate, lanceolate                                               |
| Shape of lobe (entire leaves)     | 6        | 3        | Triangular, cordate, unilobulated                                                   |
| Shape petiole sinus (three-lobed leaves) | 5     | 5        | Decurrent, truncate, cordate, calcarate, open calcarate                            |
| Shape petiole sinus (five-lobed leaves) | 5     | 4        | Truncate, cordate, calcarate, open calcarate                                       |
| Shape petiole sinus (entire leaves) | 5     | 5        | Decurrent, truncate, cordate, calcarate, open calcarate                            |
| Petiole color (three-lobed leaves) | 6        | 3        | Light green, yellow, brown                                                          |
| Petiole color (five-lobed leaves) | 5        | 3        | Light green, yellow, brown                                                          |
| Fruit shape figs                   | 11       | 5        | Spherical, cucurbiform, turbinate, ovoidal, pyriform                               |
| Fruit shape brebas                 | 12       | 5        | Spherical, cucurbiform, turbinate, ovoidal, pyriform                               |
| Fruit stalk color figs             | 6        | 2        | Purple, beige                                                                      |
| Fruit stalk color brebas           | 7        | 2        | Purple, beige                                                                      |
| Firmness of the fruit skin figs    | 4        | 2        | Soft, firm                                                                         |
| Firmness of the fruit skin brebas  | 4        | 2        | Soft, firm                                                                         |
| Presence of male flower figs       | 2        | 1        | Present                                                                            |
| Presence of male flower brebas     | 2        | 1        | Present                                                                            |
| Fruit skin ground color figs       | 6        | 2        | Black, green                                                                       |
| Fruit skin ground color brebas     | 7        | 2        | Black, green                                                                       |
| Overcolor: regular band figs       | 2        | 1        | Green                                                                              |
| Overcolor: irregular patches figs  | 5        | 3        | Purple, brown, green                                                               |
| Overcolor: irregular patches brebas| 7        | 3        | Purple, brown, green                                                               |
| Fruit lenticel quantity figs       | 4        | 2        | Scarce, intermediate                                                               |
| Fruit lenticel quantity brebas     | 4        | 2        | Scarce, intermediate                                                               |
| Fruit lenticel color figs          | 7        | 3        | White, green, pink                                                                 |
| Fruit lenticel color brebas        | 8        | 3        | White, green, pink                                                                 |
| Pulp internal color figs           | 5        | 2        | Amber, dark red                                                                    |
| Pulp internal color brebas         | 5        | 2        | Amber, dark red                                                                    |
| Pulp cavity figs                   | 5        | 3        | Absent, small, large                                                               |

*Initial categories.  
Selected categories.
Table 5 represents the values obtained for each genotype for each of the four main PCs, whereas Table 6 represents the correlations among the 97 categories of the 34 selected variables explains a higher variability for each of the first four PCs.

Table 4. Eigenvalues and proportion of total variability among the 35 fig cultivars studied explained by the first 11 principal components (PCs) as obtained with principal component analysis.

| PC   | Eigenvalue | Variance (%) | Accumulative variance (%) |
|------|------------|--------------|---------------------------|
| 1    | 28.35      | 29.23        | 29.23                     |
| 2    | 24.16      | 24.91        | 54.13                     |
| 3    | 14.94      | 15.40        | 69.54                     |
| 4    | 9.54       | 9.84         | 79.37                     |
| 5    | 2.92       | 3.02         | 82.39                     |
| 6    | 2.68       | 2.76         | 85.15                     |
| 7    | 2.17       | 2.24         | 87.39                     |
| 8    | 1.83       | 1.89         | 90.76                     |
| 9    | 1.44       | 1.48         | 90.76                     |
| 10   | 1.33       | 1.37         | 92.13                     |
| 11   | 1.18       | 1.21         | 93.34                     |

Table 5. Factor loadings of each of the 35 fig cultivars studied for each of the first four principal components (PCs).

| Cultivar            | Type         | PC 1 | PC 2 | PC 3 | PC 4 |
|---------------------|--------------|------|------|------|------|
| Gota la Miel        | Bifera       | 0.42 | 0.81 | 0.42 | 0.24 |
| Bota Morada         | Bifera       | 0.32 | 0.92 | 0.46 | 0.20 |
| Nazaret             | San Pedro    | –1.96 | 0.92 | 0.83 | 0.41 |
| San Joao Branco     | Caprifig     | –0.55 | –1.18 | 0.18 | –2.94 |
| Lampa Preta         | San Pedro    | –1.59 | 0.84 | –1.86 | 0.13 |
| Moscatel            | Bifera       | 0.43 | 0.94 | 0.49 | 0.16 |
| Negra Cabezuela     | Bifera       | 0.46 | 0.93 | 0.44 | 0.32 |
| Picholetera         | Unifera      | 0.92 | –1.26 | –2.49 | 0.17 |
| Blanca Alondón      | Smyrna       | –1.94 | –1.10 | 0.75 | 0.49 |
| Negra Calabacilla   | Unifera      | –1.95 | 0.13 | 0.64 | 0.49 |
| Blanca Valenciana   | Unifera      | 0.61 | –1.17 | 0.28 | 0.51 |
| Verde Pozuelo       | Unifera      | 0.53 | 0.10 | 0.40 | 0.41 |
| Negra Pozuelo       | Unifera      | 0.56 | –1.10 | 0.36 | 0.60 |
| Calabacita R        | Unifera      | 0.53 | –1.08 | 0.39 | 0.47 |
| Negra Común         | Bifera       | 0.46 | 0.87 | 0.41 | 0.28 |
| Lampaga             | San Pedro    | –1.61 | 0.87 | –1.84 | 0.17 |
| Pezonuda            | Unifera      | 0.46 | –1.10 | 0.37 | 0.49 |
| Arai                | Smyrna       | –1.85 | –0.74 | 0.49 | –2.54 |
| Pauceca             | San Pedro    | –1.61 | 0.88 | –1.83 | 0.17 |
| Verdejo             | Bifera       | 0.90 | 0.78 | –2.23 | 0.001 |
| Boyuna              | Bifera       | 0.45 | 0.91 | 0.47 | 0.09 |
| Goen                | Bifera       | 0.44 | 0.86 | 0.46 | 0.47 |
| Tocal               | Caprifig     | –1.82 | –1.04 | 0.89 | 0.65 |
| Colar Elche         | Bifera       | 0.53 | 0.90 | 0.44 | 0.26 |
| Albera              | Bifera       | 0.38 | 0.88 | 0.48 | 0.22 |
| Kadota              | Bifera       | 0.44 | 0.85 | 0.36 | 0.39 |
| Blava               | Bifera       | 0.53 | 0.95 | 0.44 | 0.40 |
| Verdejuela          | Bifera       | 0.46 | 0.88 | 0.45 | 0.33 |
| Hoñigal             | Unifera      | 0.53 | –1.04 | 0.31 | 0.62 |
| Martinecna Mina     | Unifera      | 0.83 | –1.37 | –2.49 | 0.32 |
| Franciscana         | Unifera      | 0.55 | –0.87 | 0.16 | –2.69 |
| Mare de Deu         | Unifera      | 0.54 | –1.06 | 0.38 | 0.64 |
| Alacantina          | Unifera      | 0.54 | –1.16 | 0.38 | 0.54 |
| Cuello Dama Negro   | Bifera       | 0.48 | 0.89 | 0.45 | 0.18 |
| Roja Almohadín      | Unifera      | 0.48 | –0.90 | 0.16 | –2.64 |

PC1 explains 29% of the total variability (Table 4) and it is represented by 26 categories that correspond to 11 variables related to figs from parthenocarpic accessions (unifera and bifera type) (Table 6). This component presents a negative correlation with the cultivars of San Pedro, caprifig, and Smyrna types because they do not produce parthenocarpic figs and with 'Negra Calabacilla' considered as unifera but that has very low production of figs (Table 5). PC2 explains 25% of the total variability (Table 4) and it is constituted by 22 categories that correspond to nine variables (Table 6) related to the breba crop, typical characters from cultivars of bifera and San Pedro types (Table 5). This component presents a negative correlation with the unifera (–0.80), caprifig (–0.18), and Smyrna (–0.15) cultivars. The variables "pulp cavity" and "overcolor: regular band" have not been included in breba characterization because no differences for those two variables were found among the accessions studied (Table 6). It is important to note the importance of the qualitative variables related to fruit because the first two PCs explain more than 54% of the total variability. PC3 explains 15% of the total variability (Table 4) and it is represented by 11 categories corresponding to three qualitative variables related to five-lobed leaves (Table 6). This component presents negative correlations with variables related to entire leaves. PC4 explains 10% of the total variance (Table 4) and it is constituted by 11 categories corresponding to three qualitative variables related to three-lobed leaf variables with a negative correlation with five-lobed and entire leaf variables.

**Morphological variability.** The UPGMA dendrogram, obtained with 11 PCs and with the 35 fig accessions, is shown in Figure 1. It reflects the similarity among the accessions studied based on measured qualitative variables and shows the discriminative power of the approach followed in this work to classify fig accessions. The accessions are clustered into four main groups mainly based on the production type. Group 2 includes parthenocarpic fig-producing common-type accessions (unifera or bifera accessions with very low production) ‘Verde Pozuelo’, ‘Negra Pozuelo’, ‘Alacantina’, ‘Mare de Deu’, ‘Calabacita R’, ‘Pezonuda’, and ‘Hoñigal’ with high percentages of three-lobed and five-lobed leaves. This group is divided into two profiles according to the morphology of the leaves and of the main crop. Group 3 includes the San Pedro type accessions ‘Nazaret’, ‘Lampa Preta’, ‘Lampaga’, and ‘Pauceca’. Group 4 is constituted by cultivars characterized by the presence of five-lobed leaves with latate central lobe, light green petioles, and with a low percentage of entire leaves and can be divided into two subgroups according to the type of production. Subgroup 4A includes the accessions ‘Negra Cabezuela’, ‘Negra Común’, ‘Albera’, ‘Blava’, ‘Boyuna’, ‘Goen’, ‘Colar Elche’, and ‘Cuello Dama Negro’, which are bifera type and classified according to tree growth habit in the Subgroups 4AA (open growth habit) and 4AB (spreading growth habit). Subgroup 4B includes two Smyrna accessions (‘Blanca Alondón’ and ‘Arai’) and ‘Negra Calabacilla’, a unifera accession with low fig production. Finally, Group 1, unlike the previous groups, includes accessions of different production types (bifera, unifera, and caprifigs). The presence of two caprifig cultivars (Tocal and San Joao Branco) together with parthenocarpic accessions in Group 1B has also been obtained with molecular markers and could indicate a common origin derived from crosses between caprifigs and parthenocarpic accessions (Giraldo et al., 2008a). On the other hand, accessions from the different prospected geographic areas are
Table 6. Values of the 97 categories of the 34 selected variables for the first four principal components (PCs) in the 35 fig cultivars analyzed listed in Table 1.

| Variable | PC 1 | PC 2 | PC 3 | PC 4 | Variable | PC 1 | PC 2 | PC 3 | PC 4 |
|----------|------|------|------|------|----------|------|------|------|------|
| Crop setting fruit: Fruit shape figs | | | | | Bifera | 0.40 | 0.73 | 0.21 | 0.21 | Spherical | 0.86 | 0.00 | 0.14 | 0.05 |
| | | | | | Unifera | –0.80 | –0.11 | –0.03 | 0.94 | Cucuriform | –0.07 | –0.08 | 0.05 |
| | | | | | San Pedro | 0.32 | –0.43 | 0.08 | 0.86 | Turbinata | 0.22 | 0.19 | 0.01 |
| | | | | | Smyrna | –0.47 | –0.15 | 0.19 | –0.41 | Ovoidal | 0.90 | 0.12 | 0.18 | 0.00 |
| | | | | | Caprifig | –0.32 | –0.18 | 0.16 | 0.11 | Pyriform | –0.10 | 0.19 | –0.06 | |
| Tree growth habit: Fruit shape brebas | | | | | Bifera | 0.43 | –0.80 | –0.11 | –0.03 | Spherical | 0.07 | 0.95 | –0.01 | –0.03 |
| | | | | | Unifera | 0.47 | –0.26 | 0.19 | 0.05 | Cucuriform | 0.94 | 0.13 | 0.12 |
| | | | | | San Pedro | 0.04 | –0.04 | 0.08 | –0.15 | Turbinata | 0.00 | 0.95 | –0.05 | 0.06 |
| | | | | | Sparse | 0.03 | –0.22 | 0.40 | 0.03 | Fruit stalk color figs | 0.95 | –0.02 | 0.11 | –0.06 |
| | | | | | Dense | 0.05 | 0.18 | –0.48 | –0.09 | Purple | 0.89 | 0.09 | 0.15 | 0.10 |
| Relative degree of branching: Fruit stalk color brebas | | | | | Type: Beige | 0.07 | 0.95 | –0.01 | 0.03 | Firmness fruit skin figs | 0.95 | –0.02 | 0.11 | –0.06 |
| | | | | | Type: Purple | 0.25 | 0.04 | –0.23 | 0.60 | Soft | 0.05 | 0.96 | –0.02 | 0.07 |
| | | | | | Five lobes | 0.00 | –0.12 | 0.59 | –0.50 | Firm | 0.10 | 0.93 | 0.05 | 0.12 |
| | | | | | Shape of central lobe: three lobes | | | | | Presence male flower figs | 0.93 | 0.10 | 0.13 | –0.18 |
| | | | | | | | | | | | Firmness fruit skin brebas | 0.85 | –0.11 | 0.06 | –0.05 |
| | | | | | | | | | | | Soft | 0.81 | 0.16 | 0.17 | 0.05 |
| | | | | | | | | | | | Firm | 0.90 | 0.06 | 0.12 | 0.11 |
| | | | | | | | | | | | Presence male flower brebas | 0.93 | 0.10 | 0.13 | –0.18 |
| | | | | | | | | | | | Presence female flower brebas | 0.93 | 0.10 | 0.13 | –0.18 |
| | | | | | | | | | | | Firmness fruit skin brebas | 0.90 | 0.06 | 0.12 | 0.11 |
| | | | | | | | | | | | Soft | 0.84 | 0.14 | 0.15 | 0.02 |
| | | | | | | | | | | | Firm | 0.94 | 0.06 | 0.16 | 0.03 |
| | | | | | | | | | | | Presence male flower brebas | 0.05 | 0.96 | –0.04 | 0.08 |
| | | | | | | | | | | | Presence female flower brebas | 0.05 | 0.96 | –0.04 | 0.08 |
| | | | | | | | | | | | Firmness fruit skin brebas | 0.95 | –0.02 | 0.11 | –0.06 |
| | | | | | | | | | | | Soft | 0.89 | 0.09 | 0.15 | 0.10 |
| | | | | | | | | | | | Firm | 0.90 | 0.06 | 0.12 | 0.11 |
| | | | | | | | | | | | Presence male flower brebas | 0.05 | 0.96 | –0.04 | 0.08 |
| | | | | | | | | | | | Presence female flower brebas | 0.05 | 0.96 | –0.04 | 0.08 |
| | | | | | | | | | | | Firmness fruit skin brebas | 0.90 | 0.06 | 0.12 | 0.11 |
| | | | | | | | | | | | Soft | 0.84 | 0.14 | 0.15 | 0.02 |
| | | | | | | | | | | | Firm | 0.94 | 0.06 | 0.16 | 0.03 |
| | | | | | | | | | | | Presence male flower brebas | 0.93 | 0.10 | 0.13 | –0.18 |
| | | | | | | | | | | | Presence female flower brebas | 0.93 | 0.10 | 0.13 | –0.18 |
| | | | | | | | | | | | Firmness fruit skin brebas | 0.90 | 0.06 | 0.12 | 0.11 |
| | | | | | | | | | | | Soft | 0.84 | 0.14 | 0.15 | 0.02 |
| | | | | | | | | | | | Firm | 0.94 | 0.06 | 0.16 | 0.03 |
| | | | | | | | | | | | Presence male flower brebas | 0.05 | 0.96 | –0.04 | 0.08 |
| | | | | | | | | | | | Presence female flower brebas | 0.05 | 0.96 | –0.04 | 0.08 |
| | | | | | | | | | | | Firmness fruit skin brebas | 0.90 | 0.06 | 0.12 | 0.11 |
| | | | | | | | | | | | Soft | 0.84 | 0.14 | 0.15 | 0.02 |
| | | | | | | | | | | | Firm | 0.94 | 0.06 | 0.16 | 0.03 |
| | | | | | | | | | | | Presence male flower brebas | 0.93 | 0.10 | 0.13 | –0.18 |
| | | | | | | | | | | | Presence female flower brebas | 0.93 | 0.10 | 0.13 | –0.18 |
| | | | | | | | | | | | Firmness fruit skin brebas | 0.90 | 0.06 | 0.12 | 0.11 |
| | | | | | | | | | | | Soft | 0.84 | 0.14 | 0.15 | 0.02 |
| | | | | | | | | | | | Firm | 0.94 | 0.06 | 0.16 | 0.03 |
| | | | | | | | | | | | Presence male flower brebas | 0.05 | 0.96 | –0.04 | 0.08 |
| | | | | | | | | | | | Presence female flower brebas | 0.05 | 0.96 | –0.04 | 0.08 |
| | | | | | | | | | | | Firmness fruit skin brebas | 0.90 | 0.06 | 0.12 | 0.11 |
| | | | | | | | | | | | Soft | 0.84 | 0.14 | 0.15 | 0.02 |
| | | | | | | | | | | | Firm | 0.94 | 0.06 | 0.16 | 0.03 |

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present scattered in the different groups confirming previous results with molecular markers (Giraldo et al., 2008a) that indicated that geographic origin is not the main criterion for the grouping of fig cultivars. A similar grouping is observed when the accessions are plotted on the first three PCs (Fig. 2). In this case, four groups are observed differentiating unifera, bifera, San Pedro, and caprifigs and Smyrna types.

Similarity values between the different fig accessions ranged from –0.76 (‘Calabacita R’ and ‘Goen’) to 0.90 and 1 (‘Lampa Preta’, ‘Lampaga’, and ‘Pacueca’; ‘Colar Elche’ and ‘Cuello de Dama Negro’, ‘Verde Pozuelo’, and ‘Negra Pozuelo’; ‘Calabacita R’ and ‘Pezonuda’; ‘Franciscana’ and ‘Roja Almohadin’; ‘Gota la Miel’ and ‘Kadota’ among the indistinguishable morphologically accessions). Previous results with molecular markers on the same set of 35 accessions (Giraldo et al., 2008a) revealed that they corresponded to 27 different genetic profiles. Those results generally coincide with the results obtained in this work in which the cultivars are classified, with a level of similarity of 0.90, in five groups of two and three undistinguishable accessions. However, in two cases (‘Negra Pozuelo’ and the group of ‘Verde Pozuelo’ and ‘Alacantina’ and ‘Calabacita R’ and ‘Pezonuda’), there were differences in the molecular profiles not reflected in the morphological analyses. In the case of ‘Goen’, there are morphologic differences with the group formed by ‘Colar Elche’ and ‘Cuello de Dama Negro’, although they are indistinguishable using molecular markers; this can be explained by a flood in 1998 that affected the area where the ‘Goen’ trees are planted.

The approach used in this work (the correlation between variables and cultivars based on trait frequencies and multivariate analysis followed by PCA) has allowed to select a subset of highly discriminant qualitative traits in fig that, in order of importance, are the following: 1) production type: common type (bifera and unifera type), Smyrna, San Pedro, and caprifigs and Smyrna types; 2) morphology of the main crop and the breba crop [fruit shape, lenticels color and abundance, skin ground color, overcolor (regular bands and irregular patches), pulp and pulp cavity color, stalk color, skin firmness, and presence of male flowers]; 3) morphology of five-lobed and three-lobed leaves: central lobe shape, petiole sinus shape, petiole color; 4) morphology of entire leaves: leave shape, petiole sinus shape; and 5) tree morphology: tree growth habit, size of the tree, degree of branching, and bark tubers. Most of the variables are related to fruit characteristics (both brebas and figs) highlighting the importance of correct fruit characterization to correctly identify fig accessions.

The selection of highly discriminant variables is important to optimize resources for a feasible morphologic characterization. This is especially important in a crop such as fig with hundreds of genotypes described worldwide in which a high
number of homonyms and synonyms can be observed. Further work to select the most discriminating quantitative variables to classify fig cultivars is needed. Complete qualitative and quantitative morphological characterization together with molecular characterization will allow optimizing fig germplasm management to distinguish synonyms and homonyms and to study conserved diversity. The approach used in this work can also be useful to select highly discriminant traits in other woody perennial tree species.

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