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Additional Information

Characterization of a collection of local varieties of tomato (*Solanum lycopersicum* L.) using conventional descriptors and the high-throughput phenomics tool Tomato Analyzer

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Abstract

Conventional tomato (*Solanum lycopersicum* L.) descriptors are of great utility for gross morphological characterization but may not be practical for the precise fruit description required for distinguishing closely related cultivar groups. Tomato Analyzer is a new phenomics tool that provides multiple fruit morphology data from scanned images of fruit sections. We characterized 69 accessions of local tomato varieties from the region of València (Spain) corresponding to eight cultivar groups (Borseta, Cherry, Cor, Penjar, Plana, Pruna, Redona, and Valenciana) with 64 conventional and 38 Tomato Analyzer descriptors. Significant differences were found among accessions for all traits except for five monomorphic conventional descriptors, revealing a large diversity in the collection. Significant differences were also found among cultivar groups for 36 conventional and 37 Tomato Analyzer descriptors. The groups Borseta, Cherry, Penjar, Plana, and Pruna were clearly distinct and each of them presented many significant differences with the rest of groups. Conventional descriptors did not differentiate well the Cor, Redona, and Valenciana cultivar groups, but Tomato Analyzer descriptors clearly distinguish Valenciana from Cor and Redona groups. A multivariate principal components analysis showed that with the exception of six (8.7%) accessions, the different cultivar groups (including the very similar Cor and Redona) plotted in separate areas of the PCA graph. The results have shown that combined conventional and Tomato Analyzer descriptors in conjunction with PCA analysis are a powerful tool for characterization and classification of local tomato varieties, as well as for distinguishing between related cultivar groups. This has important implications for the enhancement and protection of local tomato varieties.

Keywords Cultivar groups · Descriptors · Local varieties · Morphology · Phenomics · *Solanum lycopersicum* · Tomato Analyzer

Introduction

Local varieties of tomato (*Solanum lycopersicum* L.) have been grown and selected by farmers under specific conditions of a limited geographical area and have provided the genetic background for breeding new improved varieties. Introgression of genes from wild relatives into selected materials derived from local varieties created the élite lines for the development of modern hybrid tomato varieties with multiple resistances (Díez and Nuez 2008). The loss of genetic diversity due to the replacement of local tomato varieties by improved cultivars has been in many cases mitigated by the collection and safe storage of germplasm in genebanks (Hammer et al. 2003). At present, there are more than 83.000 tomato accessions stored worldwide in *ex situ* germplasm collections (FAO 2010). Many of these accessions correspond to local varieties of cultivated tomato (Díez and Nuez 2008).

Apart from the interest of local tomato varieties as genetic resources for breeding, during the last years there has been an increasing demand by consumers for local tomato varieties with a "flavour of the past" (Brugarolas et al. 2009, Causse et al. 2010). When these local varieties are recognized with a certification or guaranteed status that protects against imitation and fakes they get an added value and represent an economically attractive alternative for local farmers and retailers (Rao et al. 2006, Cebolla-Cornejo et al. 2007, Trichopoulou et al. 2007, Brugarolas et al. 2009).

Local varieties often lack proper typification and characterization, which makes difficult identifying specific and objective distinctive characteristics for defining cultivar groups, which are established on the basis of defined similarity (Hammer 2003, Spooner et al. 2003, Hammer and Diederichsen 2009, Spataro and Negri 2013). Although molecular markers are of great utility for studying the relationships among local tomato varieties (Terzopoulos and Bebeli 2008, Mazzucato et al. 2010, Cebolla-Cornejo et al. 2013, García-Martínez et al. 2013), morphological characterization is essential to define the characteristics of local varieties for their protection and registration as recognized conservation varieties (Spataro and Negri 2013; Hurtado et al. 2014). In this respect, tomato characterization has usually been performed with conventional highly heritable morphological descriptors based on seedling, plant, inflorescence, flower, fruit, and agronomic traits (IPGRI 1996, Scott 2010, UPOV 2013). These descriptors are very useful for description of varieties but have some limitations, especially when characteristics used for establishing cultivar groups in local varieties correspond to subtle differences in fruit morphology (Scott 2010). In these cases, conventional descriptors may need to be complemented with more precise characterization tools.

Recently, a free high-throughput phenomics software tool (Tomato Analyzer) for the analysis of fruit shape and flesh colour of tomato has been developed (Brewer et al. 2006, Gonzalo and van der Knaap 2008, Rodríguez et al. 2010a, 2010b, Strecker et al. 2010). Tomato Analyzer allows scoring a large number of fruit shape and flesh colour traits from scanned images of fruit sections. Several studies have been performed with Tomato Analyzer to characterize local tomato varieties (Mazzucato et al. 2010, Scott 2010, Rodríguez et al. 2011, Panthee et al. 2013) as well as to study the genetics of fruit shape in this crop (Brewer et al. 2007, Gonzalo and van der Knaap 2008, Gonzalo et al. 2009, Rodríguez et al. 2011, 2013). These studies reveal that Tomato Analyzer is a powerful tool for precisely describing tomato fruit morphology. In consequence Tomato Analyzer may be a complementary tool to conventional descriptors for the characterization of tomato local varieties and to distinguish closely related materials.

The Mediterranean region is a secondary center of diversity for tomato and many local varieties have accumulated in the region (Hammer et al. 1999, Terzopoulos and Bebeli 2008, Mazzucato et al. 2008, 2010, García-Martínez et al. 2013). The region of València, in eastern Spain has a long time horticultural tradition and many local varieties of tomato exist in the region (Ruiz et al. 2005, Cebolla-Cornejo et al. 2007, 2013, García-Martínez et al. 2013). Although a continuous variation exists for morphology, local varieties are grouped in cultivar groups. Among others, these include the commonly known rounded (Redona), flattened (Plana), rounded heart-shaped (Cor), canning (Pruna), or cherry (Cherry) tomatoes (Díez and Nuez 2008). Other local types are less known outside the region, as the pear-shaped (Borseta), or long-storage (Penjar) tomato (Casals et al. 2012, García-Martínez et al. 2013). The latter present the alcobaça (*alc*) mutation, which delays ripening and allows conservation for months at room temperature (Casals et al. 2012). However, the most locally known and appreciated local tomatoes correspond to the prominently pointed heart-shaped cultivar group known as Valenciana, its name reflecting that it is a local variety native to the region of València (Cebolla-Cornejo et al. 2007).

We characterized a collection of local varieties of tomato of the region of València from different cultivar groups using conventional and Tomato Analyzer descriptors. The objective was to provide phenotypic information of relevance on the diversity and relationships of the different cultivar groups. We hypothesize that the high-thoughput phenomics tool Tomato Analyzer will provide useful and complementary information to the one provided by conventional descriptors for describing the diversity of local tomato varieties and for detecting differences among cultivar groups. The information generated will be useful for the typification and eventual registration or recognition with a protected status of the most representative local varieties of tomato from the Spanish region of València.

Material and Methods

Plant material

Sixty-nine accessions of local varieties of tomato collected by the authors in the region of València (Spain) were used for the present study (Fig. 1). Accessions belong to eight cultivar groups commonly recognized in the region: Cherry (2), Borseta (5), Cor (7), Penjar (11), Plana (7), Pruna (5), Redona (19), and Valenciana (13) (Fig. 2). Accessions of some of the cultivar groups were mostly distributed in certain areas. For example, Penjar accessions were mostly found in the northern part of the region (Dellà lo riu Uixò demarcation and northern part of Horta i Riberes demarcation), Cor and Valenciana and Pruna in the central part (Horta i Riberes and Dellà lo riu Xúquer demarcations), and Borseta in the southern area (Dellà lo riu Xixona demarcation) (Fig. 1).

For each accession five plants were grown in an open-air field plot (GPS coordinates: 39º57’18”N; 0º06’57”W) in Vila-Real (Dellà lo riu Uixò, Region of València, Spain) during the spring-summer season (transplant at the end of February and harvesting peak in July-August). Average monthly temperatures ranged between 11.0ºC in February to 26.6ºC in July. Plants were distributed following a completely randomized design. Plants were spaced 1.2 m between the rows and 0.3 m within the row and watered with a drip irrigation system. Plants were trained with canes and cultivated using the standard horticultural practices in the area for local tomato varieties.

Conventional descriptors characterization

Individual plants were characterized using 64 conventional tomato descriptors commonly used for tomato characterization by breeders and germplasm banks (IPGRI 1996). These descriptors included seedling (5), plant (12), inflorescence and flower (11), fruit (33), and agronomic (3) descriptors (Table 1). Eighteen descriptors were quantitative, five were meristic (described by full numbers), 30 were measured in a quantitative scale, and eleven were dichotomous. Full details on the conventional characterization descriptors and their measurement can be found in the IPGRI (1996) tomato descriptors list. For most traits, several measurements were made for each plant according to the IPGRI (1996) instructions.

Tomato Analyzer descriptors characterization

Ten commercially ripe fruits per accession were longitudinally cut and scanned with an Epson Stylus SX218 photo scanner (Epson, Düsseldorf, Germany) at a resolution of 300 dpi and subjected to morphometric and colourimetric analysis with Tomato Analyzer version 3 software (Rodríguez et al. 2010a, Strecker et al. 2010). Data were recorded for a total of 38 Tomato Analyzer descriptors, which included basic (7), fruit shape (3), blockiness (3), homogeneity (3), proximal fruit end shape (4), distal fruit end shape (4), asymmetry (6), internal eccentricity (5), and colour (3) descriptors. All Tomato Analyzer descriptors were quantitative. Default settings were used for blockiness and proximal fruit end shape and distal fruit end shape descriptors (Rodríguez et al. 2010a). A complete description of these traits can be found elsewhere (Rodríguez et al. 2010a, Strecker et al. 2010).

Data analyses

Data analyses of all conventional and Tomato Analyzer descriptors were performed using standard parametric statistics (Little and Hills 1978). Mean and range values were calculated for each local variety and cultivar group, respectively. Analyses of variance (ANOVA) tests were performed on individual plant (conventional descriptors) or individual fruits (Tomato Analyzer descriptors) values to detect differences among accessions. Mean values for each accession were used to perform additional ANOVA analyses to detect differences among cultivar group means. For the conventional descriptors Fruit Weight and Number of Locules, and for the Tomato Analyzer descriptor Area, log transformed data were used for the ANOVA tests in order to avoid scaling effects (Little and Hills 1978). Significant differences among cultivar group means were detected using the Student-Newman-Keuls (SNK) multiple range test. The number of significant differences for conventional and Tomato Analyzer descriptors between pairs of cultivar group means were calculated. Principal components analysis (PCA) were performed using pairwise Euclidean distances among accession means.

Results

Differences among accessions

Out of the 64 conventional descriptors used, highly significant differences ($P<0.001$) among accessions were found for 58 descriptors, and significant differences ($P<0.01$) for one of them (Stamen Length) (Table 2). The five remaining descriptors (Hypocotyl Pubescence, Corolla Colour, Corolla Blossom Type, Dehiscence, Presence of Jointless Pedicel) were monomorphic. For most of the 59 polymorphic descriptors a wide range of variation was observed in most cases, both for quantitative and meristic traits and for those measured in a scale (Table 2). This ample diversity was well exemplified in the wide range of variation for some quantitative traits, like Vine Length (55-230 cm), Flowers per Inflorescence (4.80-20.20), Fruit Weight (2.7-511.6 g), Fruit Length (1.88-9.57 cm), Fruit Width (2.15-11.40 cm), Width of Pedicel Scar (2.2-22.6 mm), Number of Locules (2.00-18.33), or Yield per Plant (292-2851 g). However, for some polymorphic descriptors the variation was limited, like for the Exterior Colour of Mature Fruit in which only two states of the descriptors (pink or red) out of six states included in the IPGRI (1996) descriptors were found in the collection (Table 2). Also, for some descriptors, although variation was found, most accessions presented only one of the possible states of the descriptor. This was the case of Anthocyanin Colouration of Leaf Veins (mostly Normal), Style Hairiness (mostly Present), Exterior Colour of Mature Fruit (mostly Red), or Skin Colour of Ripe Fruit (mostly Yellow).

Regarding the 38 Tomato Analyzer descriptors evaluated, highly significant differences ($P<0.001$) among accessions were found for 35 descriptors and significant differences ($P<0.01$) for one of them (Proximal eccentricity) (Table 2). The two only descriptors for which no significant differences were found were two asymmetry descriptors (V.Asymmetry and H.Asymmetry.Ob). Wide ranges of variation were found for most of the descriptors studied in each of the descriptor categories. In this respect, the descriptors with largest variation for each of the descriptors categories were the Area (273-6086 mm^2), Fruit Shape Index External II (0.47-0.87), Fruit Shape Triangle (0.95-1.91), Circular (0.03-0.22), Proximal Indentation Area (0.02-0.26), Distal end Protrusion (0.00-0.15), H.Asymmetry.Ov (0.00-0.46), Fruit Shape Index Internal (0.48-1.88), and Average Hue (38.1-64.1). For four descriptors of the categories distal fruit end shape (Distal Indentation Area and Distal End Protrusion) and asymmetry (Obovoid and H.Asymmetry.Ob) there were accessions presenting values of 0.00.

Differences among cultivar groups

For 36 of the conventional descriptors evaluated significant ($P<0.05$) differences were found among the means of the eight cultivar groups studied; for 28 of these descriptors the differences were highly significant ($P<0.001$) (Table 3). Most of the significant differences found corresponded to fruit descriptors (27). In contrast, few differences were found among cultivar groups for seedling (1), plant (2), or agronomic (1) descriptors. Some of the significant differences detected among cultivar groups resulted from specific characteristics of a single cultivar group. In this respect, the Pruna group was significantly different (with lower values) to the rest of groups for the Plant Growth Type and Vine Length; the Cherry group had shorter Pedicel Length and lower Easiness of Fruit Wall (Skin) to Be Peeled than the other groups; and, the Plana group had higher values for the Fruit Cross-Sectional Shape than the rest of groups (Table 3). Many significant differences were found for fruit size traits (Table 3).

Significant ($P<0.05$) differences were found among the means of the eight cultivar groups studied for 37 out of the 38 the Tomato Analyzer descriptors evaluated (Table 4). The only descriptor for which no significant differences among group means were found was Proximal Eccentricity. For 33 of the Tomato Analyzer descriptors differences were highly significantly ($P<0.001$) (Table 4). For the basic descriptors related to fruit size traits, groups with small sized and large sized fruits presented significant differences. For descriptors related to ratios between fruit length and width, the flattened group Plana generally differed from the more elongated groups (Pruna, Borseta, and Valenciana) (Table 4). Heart-shaped Valenciana and Cor also presented higher values for Fruit Shape Triangle than obovoid shaped Borseta, which in turn presented higher values for Obovoid. Groups with pointed fruits, like Pruna and Valenciana, presented lower values of the Distal Angle Micro and Distal Angle Macro than the flattened Plana. The Cherry group had much lower Average L* (i.e., darker) fruit flesh than the rest of groups, and Penjar and Borseta presented higher values of Average Hue (i.e., more yellow and less red) and lower Average Chroma (i.e., less intense colour) than the rest of groups (Table 4).

The number of significant differences between pairs of groups for the 64 conventional descriptors was very variable. These data revealed that some of the groups were clearly differentiated from the rest of groups, like Cherry (between 14 and 22 significant differences) or Pruna (between 8 and 26 differences) (Table 5). Also, considerable differences were found between Plana and Borseta (17), Plana and Penjar (17), Penjar and Valenciana (16), Penjar and Cor (14), or Borseta and Valenciana (13). On the contrary, some of the groups presented very low significant differences for the conventional descriptors (Table 5). For example, the Cor group presented only one significant difference with both

Redona (Style shape, with high values in Cor) and Valenciana (Inflorescence type, with higher values in Valenciana) groups, and Redona and Valenciana groups presented only two significant differences (Inflorescence type and Style shape, both of them with higher values in Valenciana). Other pairs of groups with reduced number of differences were Plana and Valenciana (5), Borseta and Penjar (6), or Plana and Cor (6) (Table 5).

When considering the 38 Tomato Analyzer descriptors, all groups, except Cor, Redona and Valenciana were clearly differentiated from the rest of groups. In this respect, the number of significant differences with other groups was between 11 and 24 for Borseta, 14 and 27 for Cherry, 8 and 17 for Penjar, 11 and 25 for Plana, and 16 and 25 for Pruna (Table 5). Groups Cor, Redona and Valenciana presented a reduced number of differences. However, in this case, many more differences were found between Valenciana on one side and Cor (5) and Redona (8) on the other. However, no significant differences were found between Cor and Redona groups for any of the Tomato Analyzer descriptors (Table 5).

Principal components analysis

The first and second components of the PCA performed with 102 variable descriptors (64 conventional and 38 Tomato Analyzer descriptors) accounted, respectively, for 22.6% and 11.8% of the total variation among accession means. The first component was positively correlated with traits associated to large (e.g., Fruit Weight, Fruit Width, Size of Core, Number of Locules, Perimeter, Area, Width Mid-height, Maximum Width) and flattened (e.g., Fruit Width, Fruit Shoulder Shape, Width of Pedicel Scar, Fruit Fasciation, Ellipsoid, Proximal Angle Macro, V.Asymmetry) fruits, and negatively with Eccentricity (Table 6). The second component was positively correlated with elongated fruit traits (e.g., Fruit Length; Height Mid-Width, Maximum Height, Curved Height, Fruit Shape Index External I, Fruit Shape Index External II, Curved Fruit Shape Index, and Fruit Shape Index Internal), and negatively with blocky fruits (e.g., Distal Fruit Blockiness, Rectangular) with no point (Distal Angle Micro and Distal Angle Macro) (Table 6).

The projection of the accessions on a two-dimensional PCA plot confirmed that each of the groups was diverse for morphological traits, as accessions of a single group presented a certain degree of dispersion in the PCA plot (Fig. 3). Accessions of the different groups, in general, plotted in different areas of the graph. Accessions of the four groups with smallest fruits (Borseta, Cherry, Penjar, and Pruna) presented negative values for the first component. The Pruna accessions had positive values for the second component, and Cherry and Penjar accessions had negative values for this second component, although the Cherry accessions had lower values than Penjar accessions for the first component (Fig. 3). Borseta accessions had higher values than Penjar either for the first or second components, or for both. Regarding the large fruited accessions (Cor, Plana, Redona, and Valenciana) they had, in general, positive or low negative values for the first component. In general, Plana accessions were characterized by high positive values for the first component and negative ones for the second one. Cor, Redona and Valenciana accessions were basically separated by the second component with larger values for Valenciana, lower for Redona, and intermediate for Cor (Fig. 3). Also, on average Valenciana accessions had higher values for the first component than Redona, with Cor being intermediate again. All accessions but six (8.7%) plotted in the PCA graph in areas corresponding to their cultivar groups (Fig. 3). Accessions that plotted with other groups corresponded to one Cor and one Plana clustering with Redona, one Redona clustering with Borseta, and three Valenciana clustering with each of the Cor, Redona, and Plana groups.

Discussion

The collection studied was very variable for both conventional and tomato Analyzer descriptors, confirming that the Mediterranean region is a secondary center of diversity for tomato (Mazzucato et al. 2008, Terzopoulos and Bebeli 2010, Blanca et al. 2012, García-Martínez et al. 2013). The only descriptors which were monomorphic in the collection corresponded to conventional descriptors that usually distinguish between wild and cultivated materials (e.g., the Corolla Colour of corolla, Corolla Blossom Type, and Dehiscence), or that correspond to introgressions from wild relatives in modern cultivars (e.g., Presence of Jointless Pedicel) (Díez and Nuez 2008).

Conventional descriptors allowed detecting large differences among accessions for vegetative and agronomic traits of interest for tomato production. The large differences found for Plant Size, Number of Days to Flowering, Number of Days to Maturity, and Yield per Plant in the collection indicates that selection of the accessions having a better combination of productive traits can be of advantage for enhancing the local production. Several studies (Gómez et al. 2001, Bletsos et al. 2002, Casals et al. 2011) showed that selection among tomato local varieties within a cultivar group can result in an improvement of yield, quality, or both. As occurred in other crops, participatory selection programmes would likely improve the efficiency of selection for productive traits (Lammerts van Bueren et al. 2011).

While many differences were found in the collection for conventional descriptors, these were quite limited to differentiate subtle characteristics of tomato fruit morphology important for classification in closely related cultivar groups (Rao et al. 2006, Mazzucato et al. 2010, Cebolla-Cornejo et al. 2013). The phenomics study performed with the high-throughput Tomato Analyzer software tool allowed the automatic acquisition of data for many fruit morphology traits not dealt with by the conventional descriptors (Brewer et al. 2006, Gonzalo and van der Knaap 2008, Rodríguez et al. 2010a, 2010b, Strecker et al. 2010). This made possible the precise description of fruit morphology and detecting many differences for fruit morphology among accessions.

The conventional and Tomato Analyzer characterization performed detected many differences between cultivar groups for many traits. However, most of the differences among cultivar groups were for fruit traits. This was expected as cultivar groups in tomato are established according to the fruit morphology (Díez and Nuez 2008). Some of the cultivar groups were clearly distinguished on the basis of conventional and Tomato Analyzer descriptors, as they had clearly defined morphological differences in fruit traits. This was the case of the Borseta (pear-shaped), Cherry (very small size), Penjar (small size, flattened, *alc* mutation), Plana (large size flattened), and Pruna (cylindrical) accessions. However, for the Cor, Redona, and Valenciana the situation was different. These three groups included accessions which presented a continuous range of variation, from completely round accessions (Redona) to heart-shaped (Cor) to prominently pointed heart-shaped (Valenciana), and adscription to one or other group may be ambiguous, as the limits between these groups are diffuse. For these three groups only one or two significant differences were found among them for conventional descriptors and none of them was for fruit traits. When considering Tomato Analyzer traits, we found that the Valenciana group was significantly different from the Cor and Redona groups by five and eight descriptors, respectively. This shows that Tomato Analyzer is able to distinguish among cultivar groups which can not be clearly differentiated by morphological traits (Mazzucato et al. 2010, Panthee et al. 2013). However, no significant differences were observed between the Cor and Redona cultivar groups means for any of the Tomato Analyzer traits, indicating that both cultivar groups are very similar in morphology and very likely overlapping. This situation has also been reported in local cultivar groups of tomato, like the 'San Marzano' (Rao et al. 2006) and 'A pera Abruzzese' (Mazzucato et al. 2010).

The multivariate principal component analysis using combined conventional and Tomato Analyzer descriptors data allowed a fairly good separation of the eight cultivar groups. This is in contrast with other studies made with collections of local tomato varieties performed using only conventional markers (Cebolla-Cornejo et al. 2013) in which the different cultivar groups are intermingled in the morphological PCA graph. In our case, despite the high similitude between Cor and Redona groups, most accessions of these groups were found to plot in different areas of the graph, so that Cor was situated in the intermediate area between Redona and Valenciana. This shows that PCA of morphological data is a powerful tool for classification and grouping of local tomato accessions (Mohammadi and Prasanna 2003). The PCA analysis also revealed that a few accessions of the groups with largest sized fruits, like Cor, Plana, Redona, and Valenciana plotted in the PCA with other cultivar groups. This may indicate that these accessions, which were originally ascribed to one of the groups are intermediate and that ascription to a specific group may on occasion be ambiguous, as has been found in other crops, like melon (Pitrat et al. 2000) or brassicas (Izzah et al. 2013).

The collection included very different fruit sizes, from the small Cherry group to the large sized Plana and Valenciana groups. This range of variation for fruit size is common in collections of local varieties (Rodríguez-Burruezo et al. 2005, Panthee et al. 2013). Some of the varieties we evaluated had very large fruit sizes, with average fruit weight above 500 g. These large sized fruits are in increasing demand in the local markets, as they are associated to traditional local tomato varieties and therefore may have an interest for local producers. On the other side, although local varieties of Cherry tomatoes are not very frequent in the region of València, they are highly appreciated in some regions of Italy and Greece (Andreakis et al. 2004, Terzopoulos and Bebeli 2010). The increased demand of this type of small sized tasty tomatoes also represents an opportunity for the enhancement in Spain of these specialty local varieties (Causse et al. 2010). Also, as already found in other collections of local tomato varieties (Rodríguez-Burruezo et al. 2005, Mazzucato et al. 2008, Terzopoulos and Bebeli 2010, Cebolla-Cornejo et al. 2013, Panthee et al. 2013), large differences have been found in the collection for fruit morphology. However, despite the large variation, for some traits the variation has been limited. For example, although yellow and orange-coloured accessions are present in collections of local tomato varieties (Rodríguez-

Burruezo et al. 2005), all accessions evaluated here have been red or pink. This was probably caused by local preferences for red-coloured fruits.

The results we obtained show that the combined utilization of conventional and Tomato Analyzer descriptors are a powerful tool for studying the relationships and distinctive characteristics of cultivar groups of local varieties of tomato. Even when some of the cultivar groups are very similar in gross morphology (e.g., Cor, Redona, and Valenciana) it has been possible to separate them in a PCA multivariate analysis. The detailed characterization of fruit shape provided by the phenomics tool Tomato Analyzer may be of great relevance for the morphology-based delimitation of closely related tomato cultivar groups. Given that DUS tests are based only on morphological characterization (UPOV 2002), this information is useful for the typification, classification, protection, registration, and enhancement of local varieties of tomato.

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Table 1 Conventional descriptors used and mean and range observed in the collection of 69 local tomato varieties studied. Full details of the descriptors can be consulted elsewhere (IPGRI, 1996)

Descriptors	Units/scale	Mean	Range[b]
	Seedling descriptors		
Hypocotyl Colour	1=Green; 4=Purple	3.08	1.00-4.00***
Hypocotyl Colour Intensity	3=Low; 7=High	4.06	2.20-7.00***
Hypocotyl Pubescence	0=Absent; 1=Present	1.00	1.00-1.00[ns]
Primary Leaf Length	cm	3.61	2.34-5.78***
Primary Leaf Width	cm	0.76	0.46-1.25***
	Plant descriptors		
Plant Growth Type	1=Dwarf; 4=Indeterminate	3.66	2.00-4.00***
Plant Size	3=Small; 7=Large	5.53	4.00-7.00***
Vine Length	cm	159	55-230***
Stem Pubescence Density	3=Sparse; 7=Dense	4.94	4.00-6.00***
Stem Pubescence Length	cm	0.51	0.40-0.70***
Stem Internode Length	cm	6.17	3.28-9.50***
Foliage Density	3=Sparse; 7=Dense	3.14	3.00-7.00***
Number of Leaves Under 1st Inflorescence	---	9.01	3.80-12.20***
Leaf Attitude	3=Semi-erect; 7=Dropping	5.64	4.00-7.00***
Leaf Type[a]	2=Potato leaf; 3=Standard	2.99	2.00-3.00***
Degree of Leaf Dissection	3=Low; 7=High	4.41	3.00-7.00***
Anthocyanin Colouration of Leaf Veins	1=Obscure vein; 2=Normal (clear)	1.98	1.00-2.00***
	Inflorescence and flower descriptors		
Inflorescence Type	1=Generally uniparous; 3=Generally multiparous	1.72	1.00-3.00***
Flowers per Inflorescence	---	7.09	4.80-20.20***
Corolla Colour	1=White; 3=Orange	2.00	2.00-2.00[ns]
Corolla Blossom Type	1=Closed; 2=Open	1.00	1.00-1.00[ns]
Petal Length	cm	1.38	1.01-1.83***
Sepal Length	cm	1.30	0.65-3.70***
Style Position	1=Inserted; 4=Highly exserted	1.61	1.00-4.00***
Style Shape[a]	1=Simple; 2=Fasciated	1.46	1.00-2.00***
Style Hairiness	0=Absent; 1=Present	0.97	0.00-1.00***
Stamen Length	cm	1.01	0.88-1.55**
Dehiscence	1=Poricidal; 2=Longitudinal	2.00	2.00-2.00[ns]
	Fruit descriptors		
Exterior Colour of Immature Fruit	1=Greenish-white; 9=Very dark green	3.59	1.00-7.00***
Presence of Green (Shoulder) Trips on the	0=Absent; 1=Present	0.89	0.00-1.00***

Fruit			
Intensity of Greenback (Shoulder)	3=Slight; 7=Strong	2.99	0.00-6.00***
Fruit Pubescence	3=Sparse; 7=Dense	2.94	2.00-3.00***
Fruit Size	1=Very small; 5=Very large	3.08	1.00-5.00***
Fruit Size Homogeneity	3=Low; 7=High	5.20	0.00-9.00***
Fruit Weight	g	139.3	2.7-511.6***
Fruit Length	cm	7.09	1.88-9.57***
Fruit Width	cm	7.87	2.15-11.40***
Exterior Colour of Mature Fruit[a]	4=Pink; 5=Red	4.89	4.00-5.00***
Intensity of Exterior Colour	3=Light; 7=Dark	6.04	4.00-7.00***
Easiness of Fruit to Detach from the Pedicel	3=Easy; 7=Difficult	4.42	1.00-7.00***
Fruit Shoulder Shape	1=Flat; 7=Strongly depressed	4.02	1.00-8.00***
Pedicel Length	cm	3.56	2.09-5.50***
Pedicel Length from Abscission Layer	cm	1.21	0.55-1.85***
Presence of Jointless Pedicel	0=Absent; 1=Present	0.00	0.00-0.00^{ns}
Width of Pedicel Scar	mm	12.6	2.2-22.6***
Size of Corky Area Around Pedicel Scar	mm	3.12	0.03-8.30***
Easiness of Fruit Wall (Skin) to Be Peeled	3=Easy; 7=Difficult	4.91	3.00-7.00***
Skin Colour of Ripe Fruit	1=Colourless; 2=Yellow	1.90	1.00-2.00***
Thickness of Pericarp	mm	6.40	1.67-9.11***
Flesh Colour of Pericarp (Interior)[a]	4=Pink; 5=Red	4.97	4.00-5.00***
Flesh Colour Intensity	3=Light; 7=Dark	6.38	3.00-7.00***
Colour (Intensity) of Core	1=Green; 7=Dark	5.54	2.00-7.00***
Fruit Cross-Sectional Shape	1=Round; 3=Irregular	1.35	1.00-3.00***
Size of Core	cm	3.22	0.83-5.13***
Number of Locules	---	7.68	2.00-18.33***
Fruit Blossom End Shape	1=Indented; 3=Pointed	1.91	1.00-3.00***
Fruit Firmness (After Storage)	3=Soft; 7=Firm	4.57	3.00-7.00***
Radial Cracking	1=Corky lines; 7=Severe	2.40	0.00-6.00***
Concentric Cracking	1=Corky lines; 7=Severe	1.24	0.00-7.00***
Fruit Fasciation	3=Slight; 7=Severe	2.18	0.00-7.00***
Puffiness Appearance	3=Slight; 7=Severe	0.56	0.00-6.00***
	Agronomic descriptors		
Number of Days to Flowering	---	89	64-126***
Number of Days to Maturity	---	139	103-170***
Yield per Plant	g	1074	292-2851***

[a] Qualitative descriptor potentially polytomous, but which has been found to be dichotomous in the collection

[b] ***, **, *, and ^{ns} indicate significant at P<0.001, P<0.01, P<0.05, or non-significant, respectively

Table 2 Tomato Analyzer descriptors used and mean and range observed in the collection of 69 local tomato varieties studied. Full details of the descriptors can be consulted elsewhere (Brewer et al., 2006, 2008; Darrigues et al., 2008; Rodríguez et al., 2010a, 2010 b; Strecker et al., 2010)

Descriptors	Units	Mean	Range[c]
	Basic descriptors		
Perimeter	mm	227	63-335***
Area	mm^2	3264	273-6086***
Width Mid-Height	mm	66.8	19.3-102.6***
Maximum Width	mm	67.6	19.4-103.2***
Height Mid-Width	mm	53.0	16.3-86.7***
Maximum Height	mm	58.8	16.8-88.0***
Curved Height	mm	61.5	18.8-88.7***
	Fruit shape index descriptors		
Fruit Shape Index External I	---	0.90	0.62-1.87***
Fruit Shape Index External II	---	0.83	0.47-1.87***
Curved Fruit Shape Index	---	0.95	0.70-1.91***
	Blockiness descriptors		
Proximal Fruit Blockiness	---	0.75	0.66-0.84***
Distal Fruit Blockiness	---	0.61	0.39-0.72***
Fruit Shape Triangle	---	1.26	0.95-1.91***
	Homogeneity descriptors		
Ellipsoid	---	0.05	0.02-0.10***
Circular	---	0.09	0.03-0.22***
Rectangular	---	0.54	0.45-0.62***
	Proximal fruit end shape descriptors		
Shoulder Height	---	0.05	0.01-0.12***
Proximal Angle Micro	Degrees	234.2	180.2-284.2***
Proximal Angle Macro	Degrees	213.4	121.1-261.4***
Proximal Indentation Area	---	0.10	0.02-0.26***
	Distal fruit end shape descriptors		
Distal Angle Micro	Degrees	168.9	121.0-208.4***
Distal Angle Macro	Degrees	152.7	104.1-186.0***
Distal Indentation Area	---	0.01	0.00-0.04***
Distal End Protrusion	---	0.01	0.00-0.15***
	Asymmetry descriptors		
Obovoid	---	0.02	0.00-0.14***
Ovoid	---	0.15	0.02-0.27***
V.Asymmetry	---	0.12	0.02-0.36[ns]
H.Asymmetry.Ob	---	0.02	0.00-0.11[ns]

H.Asymmetry.Ov	---	0.21	0.02-0.46***
Width Widest Pos	---	0.46	0.38-0.57***
	Internal eccentricity descriptors		
Eccentricity	---	0.72	0.60-0.79***
Proximal Eccentricity	---	0.90	0.88-0.93**
Distal Eccentricity	---	0.89	0.86-0.90***
Fruit Shape Index Internal	---	0.84	0.48-1.88***
Eccentricity Area Index	---	0.44	0.38-0.52***
	Flesh colour descriptors		
Average L*	---	40.2	33.4-49.3***
Average Hue	Degrees	46.7	38.1-64.1***
Average Chroma	---	30.2	24.4-39.0***

[a] ***, **, *, and ns indicate significant at P<0.001, P<0.01, P<0.05, or non-significant, respectively

Table 3 Mean values for each cultivar group for the conventional descriptors for which significant (P<0.05) differences were found among cultivar group means

Trait	Borseta[a]	Cherry	Cor	Penjar	Plana	Pruna	Redona	Valenciana	Prob. F
N	5	2	7	11	7	5	19	13	
Primary Leaf Length (cm)	4.27 a	2.41 b	3.54 ab	3.62 ab	3.32 ab	3.30 ab	3.56 ab	3.92 a	0.049
Plant Growth Type	3.90 a	4.00 a	3.39 a	3.82 a	3.73 a	2.73 b	3.79 a	3.66 a	<0.001
Vine Length (cm)	167 a	193 a	152 a	193 a	154 a	107 b	152 a	157 a	<0.001
Inflorescence Type	1.64 b	1.00 b	1.76 b	1.40 b	2.63 a	1.15 b	1.14 b	2.70 a	<0.001
Flowers per Inflorescence	8.12 b	14.60 a	6.99 b	7.11 b	7.32 b	5.93 b	6.24 b	7.12 b	<0.001
Petal Length (cm)	1.24 b	1.23 b	1.35 ab	1.42 ab	1.26 b	1.46 a	1.47 a	1.32 ab	0.006
Style Position	2.24 a	2.00 ab	1.12 ab	1.61 ab	2.19 a	1.00 b	1.34 ab	1.89 ab	0.002
Style Shape	1.20 b	1.00 b	1.86 a	1.00 b	2.00 a	1.00 b	1.29 b	1.92 a	<0.001
Exterior Colour of Immature Fruit	3.20 ab	5.00 a	4.57 ab	3.82 ab	2.29 b	2.20 b	3.47 ab	4.23 ab	0.009
Presence of Green (Shoulder) Trips on the Fruit	1.00 a	1.00 a	1.00 a	1.00 a	0.71 a	0.00 b	0.97 a	1.00 a	<0.001
Intensity of Greenback (Shoulder)	4.00 a	3.50 ab	3.14 ab	3.00 ab	1.71 b	0.00 c	3.11 ab	4.08 a	<0.001
Fruit Size	2.80 ab	1.00 c	3.29 a	2.36 b	3.68 a	2.80 ab	3.34 a	3.38 a	<0.001
Fruit Size Homogeneity	5.20 bcd	9.00 a	4.71 bcd	6.45 bc	3.57 d	6.60 b	5.11 bcd	4.31 cd	<0.001
Fruit Weight (g)	114.5 b	5.2 d	157.5 ab	60.0 c	196.5 a	64.1 c	146.8 ab	213.9 a	<0.001
Fruit Width (cm)	7.55 c	2.41 e	8.50 bc	5.69 d	10.13 a	5.62 d	8.56 bc	9.01 b	<0.001
Exterior Colour of Mature Fruit	5.00 a	5.00 a	5.00 a	4.59 b	4.57 b	5.00 a	5.00 a	5.00 a	<0.001
Intensity of Exterior Colour	5.80 ab	7.00 a	6.29 a	4.82 b	5.86 a	5.80 ab	6.58 a	6.31 a	<0.001
Easiness of Fruit to Detach the Pedicel	5.00 ab	6.00 a	4.00 ab	4.27 ab	3.14 b	5.80 a	4.58 ab	4.23 ab	0.005

Fruit Shoulder Shape	2.00 d	3.00 cd	3.86 bcd	2.73 cd	6.29 a	1.66 d	4.47 abc	5.15 ab	<0.001
Pedicel Length (cm)	3.38 a	2.35 b	3.68 a	3.83 a	4.02 a	3.38 a	3.37 a	3.61 a	0.012
Width of Pedicel Scar (mm)	10.4 b	2.7 c	15.5 a	8.2 b	16.0 a	7.5 b	14.2 a	14.9 a	<0.001
Size of Corky Area Around Pedicel Scar (mm)	1.08 bc	0.22 c	4.12 a	1.14 bc	4.68 a	0.86 c	4.76 a	3.14 ab	<0.001
Easiness of Fruit Wall (Skin) to Be Peeled	4.80 a	3.00 b	5.14 a	4.36 a	4.57 a	4.20 a	5.37 a	5.38 a	<0.001
Thickness of Pericarp (mm)	8.09 a	2.39 c	6.03 b	6.91 b	5.47 b	8.30 a	6.52 b	5.71 b	<0.001
Flesh Colour Intensity	5.40 cb	7.00 a	6.14 ab	5.09 c	7.00 a	6.80 a	6.84 a	6.69 a	<0.001
Colour (Intensity) of Core	3.40 b	2.75 b	6.83 a	3.00 b	7.00 a	3.20 b	6.47 a	7.00 a	<0.001
Fruit Cross-Sectional Shape	1.50 b	1.00 b	1.21 b	1.09 b	2.43 a	1.00 b	1.11 b	1.54 b	<0.001
Size of Core (cm)	2.64 b	1.02 c	3.66 a	2.18 b	3.97 a	2.34 b	3.59 a	3.80 a	<0.001
Number of Locules	4.36 c	2.04 d	10.56 ab	2.70 d	14.03 a	2.52 d	7.72 b	10.96 ab	<0.001
Fruit Blossom End Shape	1.70 ab	2.00 ab	1.86 ab	1.82 ab	1.43 b	2.90 a	1.58 b	2.42 ab	0.003
Fruit Firmness (After Storage)	4.20 ab	4.50 ab	4.14 ab	5.64 a	3.71 b	5.60 a	4.58 ab	4.08 ab	<0.001
Radial Cracking	0.88 bc	0.00 c	2.57 abc	0.36 c	3.57 ab	0.00 c	3.21 ab	4.08 a	<0.001
Concentric Cracking	0.60 ab	0.00 b	1.31 ab	0.09 b	2.29 ab	0.00 b	0.86 ab	3.08 a	<0.001
Fruit Fasciation	1.40 bc	0.00 c	3.00 b	0.45 c	5.57 a	0.00 c	2.08 bc	3.00 b	<0.001
Puffiness Appearance	2.48 a	0.00 b	0.00 b	0.72 b	0.71 b	2.13 a	0.11 b	0.00 b	<0.001
Number of Days to Maturity	135 ab	118 b	129 ab	147 a	136 ab	143 a	141 a	138 ab	0.030

[a]Means within rows separated by different letters are significantly different at P<0.05, according to the Student-Newman-Keuls test

Table 4 Mean values for each cultivar group for the Tomato Analyzer descriptors for which significant (P<0.05) differences were found among cultivar group means

Trait	Borseta[a]	Cherry	Cor	Penjar	Plana	Pruna	Redona	Valenciana	Prob. F
N	5	2	7	11	7	5	19	13	
Perimeter (mm)	227 bc	77 e	247 ab	181 d	274 a	202 cd	232 abc	254 ab	<0.001
Area (mm^2)	3327 ab	421 d	3760 a	2083 c	4259 a	2604 bc	3440 ab	3873 a	<0.001
Width Mid-Height (mm)	65.1 b	23.0 d	74.0 b	54.3 c	86.9 a	47.0 c	70.9 b	72.1 b	<0.001
Maximum Width (mm)	65.6 b	23.1 d	74.8 b	54.9 c	87.6 a	47.8 c	71.4 b	73.6 b	<0.001
Height Mid-Width (mm)	59.3 ab	20.7 e	56.4 abc	42.3 d	48.2 cd	65.8 a	52.4 bc	60.9 ab	<0.001
Maximum Height (mm)	62.4 a	21.4 c	62.8 a	46.2 b	60.1 a	67.5 a	58.4 a	68.4 a	<0.001
Curved Height (mm)	64.0 a	23.1 c	65.6 a	48.4 b	66.6 a	68.1 a	60.6 a	71.6 a	<0.001
Fruit Shape Index External I	0.96 b	0.92 b	0.85 bc	0.85 bc	0.69 c	1.42 a	0.82 bc	0.95 b	<0.001
Fruit Shape Index External II	0.92 b	0.89 b	0.77 b	0.79 b	0.56 c	1.40 a	0.75 b	0.87 b	<0.001
Curved Fruit Shape Index	0.99 b	1.01 b	0.90 bc	0.90 bc	0.77 c	1.45 a	0.86 bc	1.01 b	<0.001
Proximal Fruit Blockiness	0.70 c	0.74 abc	0.77 ab	0.78 a	0.76 ab	0.71 bc	0.76 ab	0.74 abc	<0.001
Distal Fruit Blockiness	0.70 a	0.65 ab	0.58 b	0.63 ab	0.62 ab	0.63 ab	0.64 ab	0.52 c	<0.001
Fruit Shape Triangle	1.00 c	1.14 bc	1.35 ab	1.25 b	1.24 b	1.14 bc	1.20 bc	1.50 a	<0.001
Ellipsoid	0.03 cd	0.03 d	0.05 b	0.04 bc	0.08 a	0.04 bcd	0.05 b	0.06 b	<0.001
Circular	0.06 bc	0.04 c	0.09 bc	0.07 bc	0.17 a	0.11 b	0.09 bc	0.09 bc	<0.001
Rectangular	0.55 a	0.55 a	0.53 a	0.55 a	0.55 a	0.53 a	0.55 a	0.50 b	<0.001
Shoulder Height	0.03 bc	0.02 c	0.05 abc	0.05 abc	0.07 a	0.02 ca	0.06 ab	0.05 ab	<0.001
Proximal Angle Micro (º)	224 abc	199 c	236 ab	245 a	241 a	209 bc	235 ab	239 c	0.002

Proximal Angle Macro (º)	187 cd	168 cd	224 b	211 b	249 a	154 d	221 b	219 b	<0.001
Proximal Indentation Area	0.06 bcd	0.03 d	0.10 abcd	0.08 abcd	0.15 a	0.04 cd	0.12 ab	0.12 abc	<0.001
Distal Angle Micro (º)	170 abc	166 abc	168 abc	173 abc	181 a	153 c	176 ab	155 bc	<0.001
Distal Angle Macro (º)	160 a	155 a	150 ab	159 a	171 a	128 c	160 a	135 bc	<0.001
Distal Indentation Area	0.00 b	0.00 b	0.00 b	0.01 b	0.02 a	0.00 b	0.01 b	0.01 a	0.003
Distal End Protrusion	0.01 ab	0.01 ab	0.01 ab	0.01 ab	0.03 ab	0.00 b	0.01 ab	0.04 a	0.014
Obovoid	0.10 a	0.00 c	0.00 c	0.00 c	0.01 c	0.06 b	0.01 c	0.01 c	<0.001
Ovoid	0.03 d	0.14 bc	0.18 ab	0.17 ab	0.15 b	0.10 c	0.14 bc	0.20 a	<0.001
V.Asymmetry	0.11 abc	0.03 d	0.13 ab	0.07 cd	0.20 a	0.08 bc	0.10 bc	0.16 ab	<0.001
H.Asymmetry.Ob	0.07 a	0.00 d	0.01 cd	0.00 cd	0.03 bc	0.06 ab	0.01 cd	0.01 cd	<0.001
H.Asymmetry.Ov	0.04 e	0.04 e	0.26 b	0.16 cd	0.24 bc	0.12 de	0.18 bcd	0.36 a	<0.001
Width Widest Pos	0.52 a	0.47 bc	0.45 c	0.44 c	0.45 c	0.50 ab	0.47 bc	0.43 c	<0.001
Eccentricity	0.77 ab	0.78 a	0.72 c	0.74 bc	0.65 d	0.78 a	0.73 c	0.71 c	<0.001
Distal Eccentricity	0.89 a	0.88 b	0.89 ab	0.89 a	0.89 a	0.89 a	0.89 a	0.88 ab	0.010
Fruit Shape Index Internal	0.93 b	0.90 ab	0.79 ab	0.80 ab	0.57 c	1.40 a	0.76 b	0.88 ab	<0.001
Eccentricity Area Index	0.41 c	0.42 bc	0.44 b	0.44 b	0.49 a	0.40 c	0.45 b	0.44 b	<0.001
Average L*	42.9 a	34.5 d	38.2 c	42.5 ab	40.6 abc	40.5 abc	39.5 bc	39.6 bc	<0.001
Average Hue	53.2 ab	49.8 bc	42.6 d	56.7 a	43.2 d	42.8 d	45.4 cd	42.4 d	<0.001
Average Chroma	26.6 d	28.5 bcd	31.5 ab	27.1 cd	32.3 a	32.0 a	30.0 abc	32.2 a	<0.001

[a]Means within rows separated by different letters are significantly different at P<0.05, according to the Student-Newman-Keuls test

Table 5 Number of significant (P<0.05) differences among cultivar group means for 64 conventional descriptors (above the diagonal) and for 38 Tomato Analyzer descriptors (below the diagonal)

	Borseta	Cherry	Cor	Penjar	Plana	Pruna	Redona	Valenciana
Borseta		14	8	6	17	10	9	13
Cherry	14		15	14	22	16	16	20
Cor	13	15		14	6	14	1	1
Penjar	15	15	12		17	8	12	16
Plana	24	27	10	16		26	8	5
Pruna	11	19	16	18	25		14	20
Redona	13	17	0	8	11	16		2
Valenciana	16	23	5	17	20	21	8	

Table 6 Correlation coefficients between conventional and Tomato Analyzer descriptors and the two first principal components. Only those correlations with absolute values above 0.15 have been listed

Descriptor	First principal component	Second principal component
Fruit Weight (g)	0.163	
Fruit Length (cm)		0.171
Fruit Width (cm)	0.186	
Fruit Shoulder Shape	0.165	
Width of Pedicel Scar (mm)	0.177	
Colour (Intensity) of Core	0.176	
Size of Core (cm)	0.176	
Number of Locules	0.193	
Fruit Fasciation	0.162	
Perimeter	0.175	
Area	0.167	
Width Mid-Height	0.191	
Maximum Width	0.192	
Height Mid-Width		0.246
Maximum Height		0.217
Curved Height		0.201
Fruit Shape Index External I		0.225
Fruit Shape Index External II		0.216
Curved Fruit Shape Index		0.226
Distal Fruit Blockiness		-0.166
Ellipsoid	0.169	
Rectangular		-0.214
Proximal Angle Macro	0.170	
Distal Angle Micro		-0.209
Distal Angle Macro		-0.240
V.Asymmetry	0.157	
Eccentricity	-0.178	
Fruit Shape Index Internal		0.215
Variance explained (%)	22.6	11.8

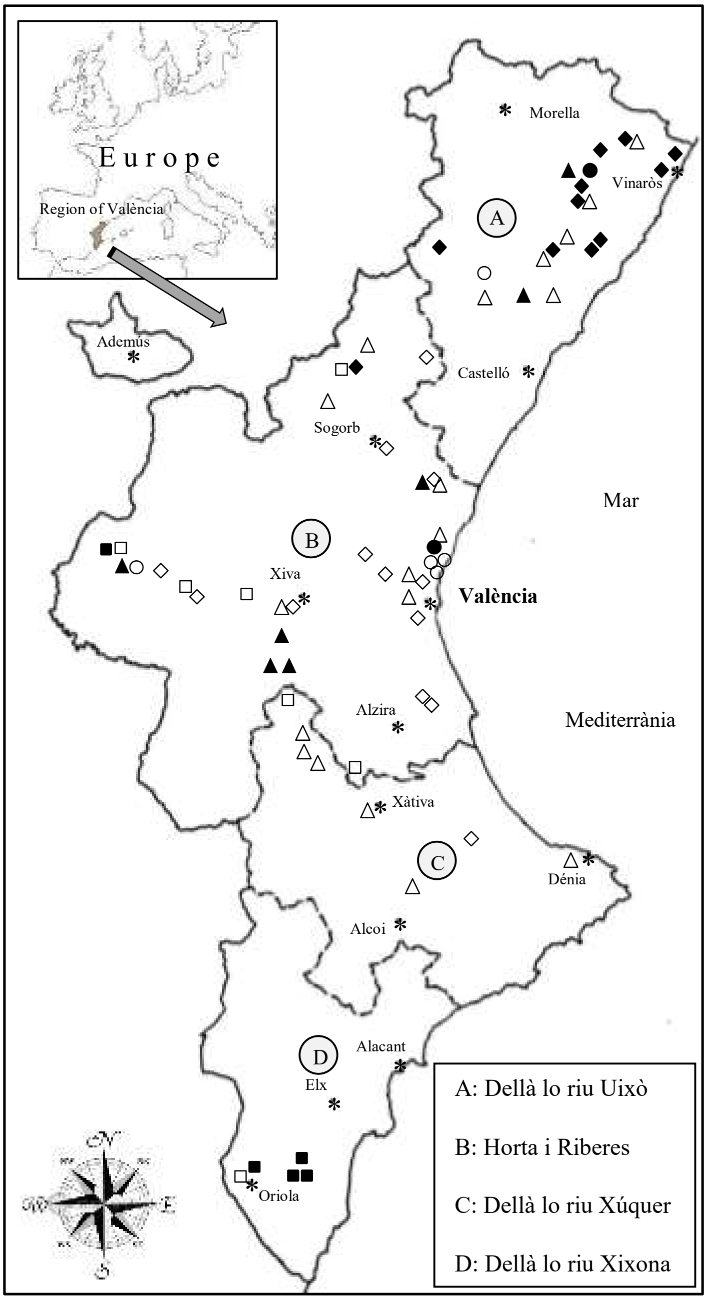

Fig. 1 Map of the Region of València, showing the geographical origin of the accessions used. The four foral demarcations (A=Dellà lo riu Uixò; B=Horta i Riberes; C=Dellà lo riu Xúquer; D=Dellà lo riu Xixona) and major cities (marked with an asterisk) of the region of València are indicated. The different cultivar groups are represented by different symbols: Borseta (filled square), Cherry (filled circle), Cor (filled triangle), Penjar (filled rhombus), Plana (open square), Pruna (open circle), Redona (open triangle), and Valenciana (open rhombus)

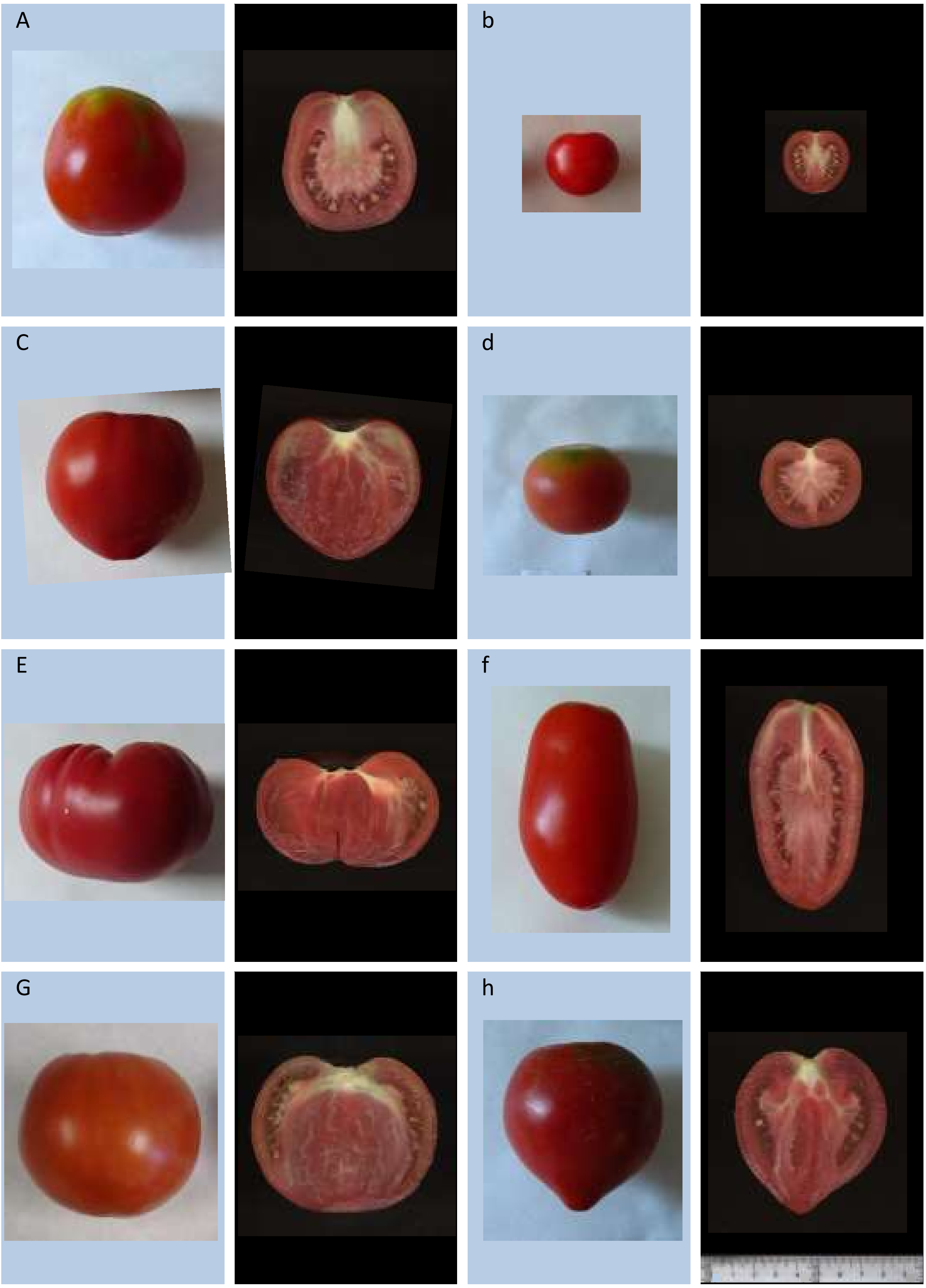

Fig. 2 Representative fruits and longitudinal sections of each of the eight cultivar groups of local tomato evaluated: a) Borseta; b) Cherry, c) Cor; d) Penjar; e) Plana; f) Pruna; g) Redona; h) Valenciana. All pictures are at the same scale (shown below right; in cm)

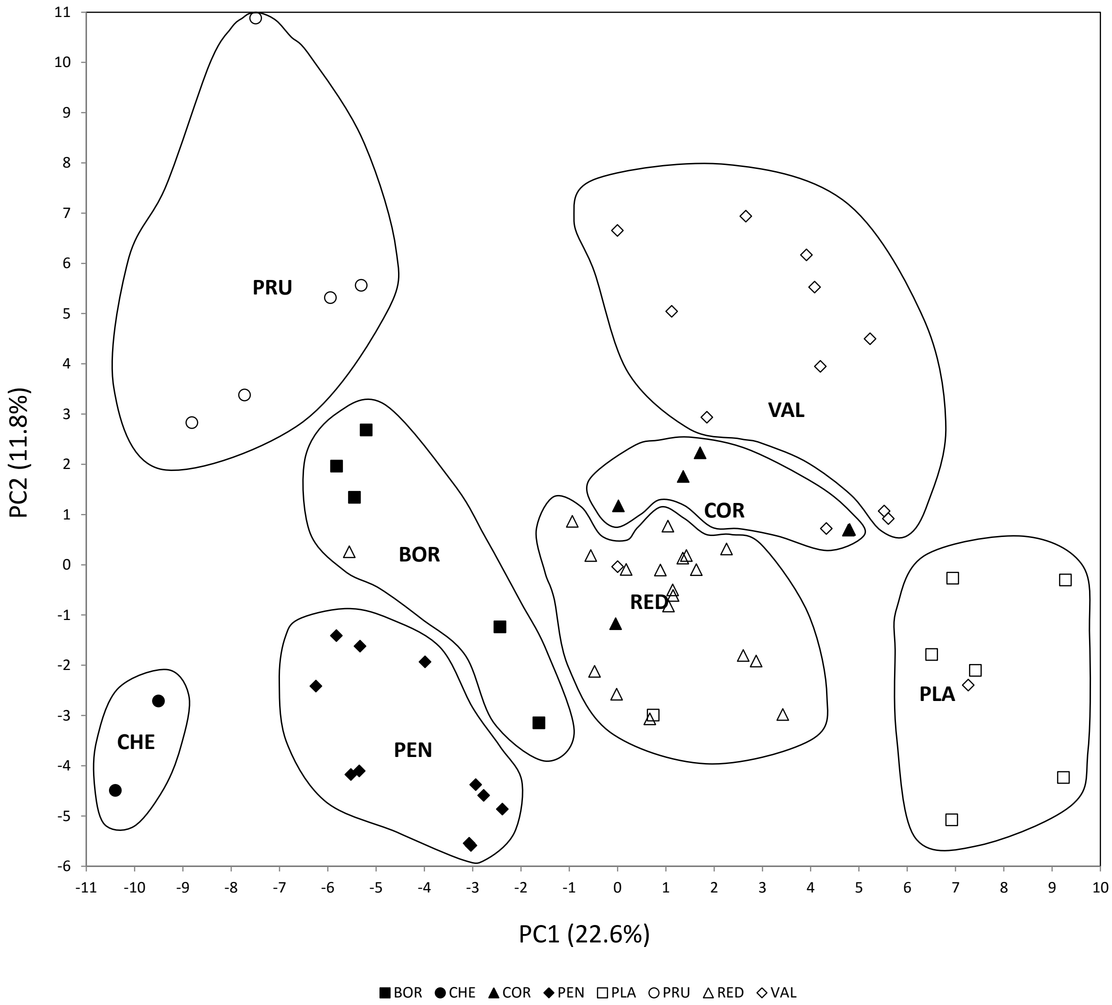

Fig. 3 Similarities based on 64 conventional and 38 Tomato Analyzer descriptors among 69 tomato accessions from the region of València (Spain) represented on the two first principal components of PCA (accounting for 22.6% and 11.8% of the total variation, respectively). The different cultivar groups are represented by different symbols: Borseta (BOR; filled square), Cherry (CHE; filled circle), Cor (COR; filled triangle), Penjar (PEN; filled rhombus), Plana (PLA; open square), Pruna (PRU; open circle), Redona (RED; open triangle), and Valenciana (VAL; open rhombus). First and second component centroids for each of the cultivar groups are indicated using the group code