Acosta-Quezada, P.; Raigón Jiménez, MD.; Riofrío-Cuenca, T.; García Martínez, MD.; Plazas Ávila, MDLO.; Burneo, J.; Figueroa, JG.... (2015). Diversity for chemical composition in a collection of different varietal types of tree tomato (Solanum betaceum Cav.), an Andean exotic fruit. Food Chemistry. 169:327-335. doi:10.1016/j.foodchem.2014.07.152.

Diversity for chemical composition in a collection of different varietal types of tree tomato (*Solanum betaceum* Cav.), an Andean exotic fruit

Running title: Diversity for chemical composition in tree tomato

Pablo G. Acosta-Quezada[a], María D. Raigón[b], Tania Riofrío-Cuenca[a], María D. García-Martínez[b], Mariola Plazas[c], Juan I. Burneo[a], Jorge G. Figueroa[a], Santiago Vilanova[c], Jaime Prohens[c,*]

[a] Departamento de Ciencias Agropecuarias y de Alimentos, Universidad Técnica Particular de Loja, San Cayetano Alto s/n, 1101608 Loja, Ecuador

[b] Departamento de Química, Universitat Politècnica de València, Camino de Vera 14, 46022 Valencia, Spain

[c] Instituto de Conservación y Mejora de la Agrodiversidad Valenciana, Universitat Politècnica de València, Camino de Vera 14, 46022 Valencia, Spain

[*]Corresponding author.

Tel.: +34 963879424; fax: +34 963879422

E-mail address: jprohens@btc.upv.es (J. Prohens)

Abstract

We evaluated 23 tree tomato (*Solanum betaceum*) accessions from five cultivar groups and one wild relative (*S. cajanumense*) for 26 composition traits. For all traits we found highly significant differences (P<0.001) among the materials studied. The high diversity found within *S. betaceum* for composition traits was matched by a high diversity within each of the cultivar groups. We found that sucrose and citric acid were the most important soluble sugar and organic acid, respectively, in tree tomato. Fruit in the anthocyanin pigmented (purple) group had a carotenoid content similar to that in the yellow-orange cultivar groups. Total phenolic content was significantly correlated (r=0.8607) with antioxidant activity. Analyses of mineral content showed that tree tomato is a good source of K, Mg, and Cu. Multivariate principal components analysis (PCA) confirmed that an important diversity exists within each cultivar group. The results we have obtained indicate that the high diversity found within the tree tomato could be exploited for selection and breeding for developing the tree tomato as a commercial crop.

Keywords: antioxidants, minerals, organic acids, proximate composition, soluble sugars, tree tomato

1. Introduction

The so-called exotic fruits represent an important part of the human diet in their regions of origin and are increasingly present in specialty markets in developed countries. Many exotic fruits have beneficial properties for human health due to their high levels of biologically active metabolites (Dembitsky et al., 2011), which may further enhance demand and consumption. The Andean region is the native home of many neglected exotic fruits with a high potential for developing as new high value export crops (National Research Council, 1989).

One of the Andean fruit crops to have attracted increasing interest in the last few years is the tree tomato (*Solanum betaceum* Cav., syn. *Cyphomandra betacea* (Cav.), Sendtn.), also known as tamarillo. The tree tomato is a neglected, fast-growing, small fruit tree (Prohens & Nuez, 2000). It is cultivated for its edible, fleshy, juicy, and flavourful (fresh) fruits, which have a characteristic acidic taste (Bohs, 1989). Tree tomato has been extensively studied from the taxonomy and systematics point of view (Bohs, 1991, 1994, 1995, Bohs, 2007). However, until recently, few studies have studied the diversity of the domesticated tree tomato with the aim of plant breeding and increased intake. Acosta-Quezada, Martínez-Laborde, & Prohens (2011) differentiated five cultivar groups based on fruit colour and shape: orange, orange pointed, red, red conical and purple, and found considerable morphological diversity within each of the cultivar groups. The low differentiation among cultivar groups from the morphological point of view was confirmed with molecular data (Acosta-Quezada, Vilanova, Martínez-Laborde, & Prohens, 2012). As a result of these studies, strategies for the conservation of germplasm, as well as for the breeding and development of new cultivars, were proposed.

The development of a successful tree tomato-breeding programme would benefit from improvement of fruit quality, in particular those constituents impacting taste (e.g., sugars and acids) and compounds with functional activity or nutritional relevance (El-Zeftawi et al., 1988). A number of studies have been devoted to the study of the chemical composition and bioactive constituents of tree tomato, including general composition (Dawes & Callaghan, 1970; Heatherbell, Reid, & Wrolstad, 1982; El-Zeftawi et al., 1988; Romero-Rodriguez, Vazquez-Oderiz, Lopez-Hernandez, & Simal-Lozano, 1994), sugars and organic acids (Boyes & Strübi, 1997; Ordóñez, Vattuone, & Isla, 2005; Vasco, Avila, Ruales, Svanberg, & Kamal-Eldin, 2009), carotenoids (Rodríguez-Amaya, Bobbio, & Bobbio, 1983; Mertz, Brat, Caris-Veyrat, & Gunata, 2010), phenolics (Hurtado, Morales, González-Miret, Escudero-Gilete, & Heredia, 2009; Osorio et al., 2012), or minerals (Clark, Smith, & Gravett, 1989). These studies show that tree tomato contain relatively high levels of soluble sugars and organic acids and remarkable levels of carotenoids and phenolics. Tree tomato also contain high levels of K, with values similar to those of banana (Sulaiman et al., 2011).

Although the studies performed up to now have provided considerable information about the composition and properties of tree tomato fruit, they have been performed with only one or a few (with a maximum of three) varieties. These studies have provided evidence of difference in composition among the varieties (Dawes & Callaghan, 1970; Romero-Rodriguez, Vazquez-Oderiz, Lopez-Hernandez, & Simal-Lozano, 1994; Boyes & Strübi, 1997; Vasco, Avila, Ruales, Svanberg, & Kamal-Eldin, 2009). However, the diversity of fruit composition within the species as well as within and among cultivar groups has not been explored. This information is essential for the development of selection and breeding programmes for improving the composition of tree tomato, which is seen as key for the success of new varieties (El-Zeftawi et al., 1988).

This work aimed to study the chemical composition, including proximate composition traits (moisture, soluble solids content, titratable acidity, and protein), soluble sugars (glucose, fructose, and sucrose), organic acids (malic and citric acid), chlorophylls, total carotenoids, total phenolics, antioxidant activity, and minerals, in a collection of tree tomato varieties from five cultivar groups (Acosta-Quezada, Martínez-Laborde, & Prohens, 2011). The objective was to obtain information for the selection and breeding of tree tomato varieties with improved taste and nutritional quality.

2. Material and methods

2.1. Plant material and cultivation conditions

A total of 24 tree tomato accessions, 23 of which correspond to the cultivated *S. betaceum* and one to the wild relative *S. cajanumense*, were used for the analyses of composition. The cultivated accessions belonged to five cultivar groups as defined by Acosta-Quezada, Martínez-Laborde, & Prohens (2011): orange, orange pointed, red, red conical, and purple (Table 1). Most of these accessions were previously morphologically and molecularly characterized (Acosta-Quezada, Martínez-Laborde, & Prohens, 2011; Acosta-Quezada, Vilanova, Martínez-Laborde, & Prohens, 2012). Plant materials used were provided by the germplasm banks of the Universitat Politècnica de València (UPV; Spain) and the Universidad Técnica Particular de Loja (UTPL; Ecuador).

Plants from which the fruits were harvested were grown in an experimental field plot of the UTPL in Loja (Ecuador; GPS: 4º 0’ 1.59” S and 79º 10’ 48.46” W) at 2160 m of altitude. The plantation was established in October 2007.

2.2. Preparation of samples

Commercially ripe fruits, i.e., in which the final size had been attained and with fully coloured skin, were harvested between July and August 2011. A total of six samples of fruit were taken for each accession. Each sample consisted of approximately 0.5 kg, except for four accessions (A18, A27, A21, A40) in which the number of fruits available was limited and the sample was around 250 g. Fruits were washed, peeled, cut longitudinally and the seeds removed. Each sample was divided in two parts; one (fresh fruit) was analysed at UTPL while the other (lyophilised) was analysed at UPV. For the four accessions with reduced numbers of fruit, all fruits were lyophilised and no analysis of fresh fruits was performed.

Fresh fruit samples were squeezed using a domestic juice extractor and immediately analysed. Samples were frozen in liquid N_2 and stored at -80ºC prior to lyophilisation. One accession (A26) was lost due to a technical problem. Lyophilised tissue from remaining samples was shipped to UPV using a courier service. Fruit moisture, soluble solids content (SSC), and acidity (TA) were measured in fresh fruit samples only, while other analyses were performed on the lyophilised samples.

2.3. Analytical methods

Moisture was determined as (100 × (fresh weight – dry weight)/fresh weight) and expressed as g/100 g. Soluble solids content (SSC; %) was measured with a hand held refractometer. Titratable acidity (TA) was determined by titrating diluted juice with 0.1 mol/L NaOH to the phenolphthalein-end point and expressed as g/100 g of anhydrous citric acid. The SSC:TA ratio was calculated from the SSC and TA values. Protein concentration was estimated using the Kjeldahl method described by Raigón, Prohens, Muñoz-Falcón, & Nuez (2008).

Glucose, fructose and sucrose contents were determined using a commercial kit (Sucrose, D-fructose and D-glucose kit, Megazyme International Ltd., Wicklow, Ireland). Analyses of malic and citric acids were also performed with commercial enzymatic kits (MA9906 kit for malic acid and CI9920 kit for citric acid, BEN S.r.l., Milano, Italy). For both soluble sugars and organic acids, determinations were performed following the manufacturers' instructions.

Chlorophylls *a* and *b*, total chlorophylls, and total carotenoids were measured spectrophotometrically after extraction with a mixture of acetone and water (80:20 v/v) using the method described by Wellburn (1994). Total phenolics were determined according to the Folin-Ciocalteu method using the procedure indicated in Raigón, Prohens, Muñoz-Falcón, & Nuez (2008). Results were expressed as chlorogenic acid equivalents. Antioxidant activity was estimated using the colourimetric DPPH (1,1-diphenyl-2-picrylhydrazyl) assay described in Sánchez-Moreno, Larrauri, & Saura-Calixto (1998). Antioxidant capacity results were presented as Trolox equivalents (TE).

The analyses of minerals were performed as described in Raigón, Prohens, Muñoz-Falcón, & Nuez (2008). Two g of lyophilised sample were calcined in a furnace at 450 ºC for 2 h and ashes were dissolved in 2 mL HCl. The mixture was heated until the first vapours appeared and immediately 2 mL distilled water were added. Subsequently, the mixture was filtered and brought to 100 mL with distilled water. P was analysed by spectrophotometry using the molibdovanadate method, K by flame photometry using a Jemway PF7 flame photometer (Jenway, Essex, UK), and Ca, Mg, Fe, Cu, and Zn by atomic absorption spectrophotometry with a Thermo Elemental (SOLAAR AA Spectrometers, Cambridge, UK) spectrometer.

2.4. Statistical analyses

Data were subjected to factorial analyses of variance (ANOVA) using a fixed-effects model for variety. For each trait measured the least significant difference (LSD) was calculated from the corresponding ANOVA. For each cultivar group the average and standard error (SE) were calculated. Spearman rank correlations were calculated between pairs of composition traits and significance of correlations were evaluated with the Bonferroni test (Hochberg, 1988). The Spearman rank correlation was chosen instead of the commonly used Pearson correlation in order to avoid spurious correlations arising from extreme values (Little & Hills, 1978). The Bonferroni test, which is very conservative, was chosen in order to minimize the risk of false positives (Hochberg, 1988). Principal components analysis (PCA) was performed for standardized composition data using pairwise Euclidean distances among accessions. Only accessions with data for all the composition traits were included in the PCA analysis.

3. Results

3.1. Proximate composition

Highly significant differences (P<0.001) among accessions were found for all proximate composition traits (Table 2). Moisture content in the *S. betaceum* accessions ranged between 86.1% and 87.7%, while for the wild *S. cajanumense* was 93.2% (Table 2). SSC varied between 10.9% and 12.5% with an average value of 11.3%. No differences were found among the cultivar groups, although the wild accession A15 had values higher than those of the cultivated materials. TA varied widely, with wild *S. cajanumense* values much lower than that of cultivated accessions (Table 2). Also, considerable differences for TA were found within and among the different cultivar groups. Cultivar groups red conical, red and orange pointed had average TA values lower than those of the orange group. This wide variation for TA also resulted in very variable values for SSC:TA ratio (Table 2). On average the orange accessions had lower SSC:TA ratio than the other cultivar groups. Protein content ranged between 4.89 g/100 g in *S. cajanumense* and 9.58 g/100 g in the *S. betaceum* accession A41 (red conical group) (Table 2).

3.2. Soluble sugars and organic acids

Differences among accessions for all soluble sugars and organic acids were highly significant (P<0.001). Glucose and fructose values were similar (average values of 9.1 and 9.3 g/100 g, respectively), and lower than those of sucrose (average value of 23.5 g/100 g) (Table 3). Glucose contents were very variable ranging from 2.0 g/100 g in the *S. cajanumense* accession to 12.4 g/100 g in *S. betaceum* accession A17 (Table 3). Differences within the cultivated species were less; A23 had the lowest value at 6.3 g glucose/100 g. Few differences were found for average values among the cultivar groups, the most significant being the low value for the red conical group compared with the orange and orange pointed groups. For fructose contents, the results were comparable to those obtained for glucose, with the lowest values being found in *S. cajanumense* (1.1 g/100 g), and the highest in accession A19 (13.2 g/100 g) (Table 3). Sucrose contents were less variable than those for glucose or fructose. Although important differences were found within each cultivar group, average values in orange cultivar group and the wild *S. cajanumense* were highest (Table 3). Average total sugars was 41.9 g/100 g, and ranged between 28.1 g/100 g and 52.0 g/100 g in accessions A23 and A17 (both of the orange pointed group). As with individual sugars, the orange group had higher total sugars than the other cultivar groups, which in turn were higher the wild *S. cajanumense* (Table 3).

Average malic acid content (0.70 g/100 g) was much lower than that of citric acid (6.07 g/100 g). Malic acid content was highest in *S. cajanumense* (2.11 g/100 g); the highest and lowest contents in *S. betaceum* were found in accessions A24 (0.99 g/100 g) and A17 (0.34 g/100 g) (Table 3). For citric acid, the highest and lowest values were found within *S. betaceum*, ranging from 4.01 g/100 g (A18) to 7.54 g/100 g (A16). For both malic and citric acids wide differences were found within cultivar groups but not among groups. For total acids content, the results were similar to those of the predominant citric acid (Table 3). The average value for the sugars:acids ratio was 6.43, and the values varied between 4.38 (A39) and 9.37 (A18). On average, the cultivated *S. betaceum* groups have higher values for the sugars:acids ratio than those of the wild *S. cajanumense* (Table 3).

3.3. Pigments and antioxidants

All the pigment and antioxidant traits measured presented highly significant ($P<0.001$) differences among accessions. Chlorophyll *b* content was higher than chlorophyll *a* content with mean values of 1.53 and 0.66 mg/100 g, respectively (Table 4). The only exception was *S. cajanumense* which had a chlorophyll *b* content higher than that of chlorophyll *a*. Chlorophyll *a* content was much higher in the wild *S. cajanumense* (4.50 mg/100 g) than in the cultivated *S. betaceum*, which had values ranging from 0.19 mg/100 g (A34) to 0.97 mg/100 g (A21 and A40) (Table 4). Despite wide differences within cultivar group, the purple, red and red conical groups had higher average values than those of the orange and orange pointed groups. For chlorophyll *b* the content ranged between 0.42 mg/100 g (A31) and 6.57 mg/100 g (A40). Wide variation for chlorophyll *b* content was found within cultivar groups (Table 4). Total chlorophyll content was maximal in *S. cajanumense* (8.64 mg/100 g) and minimal in *S. betaceum* A31 (0.67 mg/100 g). *Solanum betaceum* A40 had much higher total chlorophyll content (7.54 mg/100 g) than the rest of cultivated accessions. Purple, red conical and red groups had higher contents of total chlorophylls than the orange and orange red groups.

The content in carotenoids varied between 2.60 mg/100 g (A24) and 11.20 mg/100 g (A40) (Table 4). Again there were important differences within cultivar groups; the red conical and purple groups had higher average values than the rest of groups. The total phenolic content was much higher than that of the chlorophylls and carotenoids, with an average value of 3.78 g/100 g (Table 4). Individual accession values ranged from 2.82 g/100 g (A35) to 6.18 g/100 g (A19) (Table 4). As with chlorophylls and carotenoids wide differences were found within groups, but the differences among groups were not significant. The antioxidant activity varied considerably among accessions with values ranging from 12.2 μmol TE/g (A23) to 48.7 μmol TE/g (A40) (Table 4). Also, wide differences were found within groups, but not among groups.

3.4. Minerals

As with the other traits studied, highly significant differences ($P<0.001$) were found among accessions for the concentration of all minerals studied. By far, the mineral with highest concentration was K, with an average value of 2511 mg/100 g, followed by Mg (141 mg/100 g), P (124 mg/100 g), Ca (60 mg/100 g), Fe (1.39 mg/100 g), Zn (0.97 mg/100 g) and Cu (0.57 mg/100 g) (Table 5). For all minerals, a wide range of variation was found. In the case of P, the red conical accession A41 had much higher values (226 mg/100 g) than the rest of accessions, and differences among the rest of cultivar groups were not significant (Table 5). Conversely to what occurred for P, accession A41 had the lowest content in K, with values considerably lower than those of the rest of cultivar groups. For Ca the wild *S. cajanumense* had much higher values (117 mg/100 g) than the cultivated accessions (Table 5). In the case of Mg, accession A41 had the lowest value (48 mg/100 g); also, some of the purple accessions had low Mg values (Table 5). For microelements Fe, Cu, and Zn, very important differences were found among the accessions, in particular for Cu (Table 5). However, the differences among cultivar groups were non-significant in most cases.

3.5. Correlations between traits

Ten out of 378 Spearman rank correlations between traits were significant according to the Bonferroni significance test at $P\leq0.05$. A negative correlation was found between TA and the SSC:TA ratio ($r=-0.9304$); the rest of significant correlations had positive values. Out of the nine significant positive correlations, four involve content in sugars (glucose and fructose, r=0.9745; glucose and total sugars, r=0.9607; fructose and total sugars, r=0.9565; sucrose and total sugars, r=0.8238), one content in acids (citric acid and total acids, r=0.9338), three the content in chlorophylls (chlorophyll *a* and chlorophyll *b*, r=0.8310; chlorophyll *a* and total chlorophylls, r=0.9042; chlorophyll *b* and total chlorophylls, r=0.9792), and the last one involves total phenolic content and antioxidant activity (r=0.8607).

3.6. Multivariate analysis

The first and second components of the PCA performed with all the accessions accounted for 37.1 and 15.8% of the total variation, respectively. This PCA analysis (not shown) basically separates the wild *S. cajanumense* accession A15 from the cultivated tree tomato accessions. Therefore, we performed another PCA including only cultivated accessions. In this PCA the first and second components accounted, respectively. for 26.1% and 19.2% of the total variation. The first principal component was positively correlated to moisture content, acidity (TA, malic acid, citric acid, and total acids), and chlorophylls (chlorophyll *a*, chlorophyll *b*, and total chlorophylls), and negatively correlated to sugars content (glucose, sucrose, fructose, and total sugars) and ratio sugars:acids (Figure 1). The second component was positively correlated to Fe and negatively correlated to sugars (glucose, sucrose, fructose, and total sugars), total phenolic content, antioxidant activity and minerals P, Ca, and Zn (Figure 1). The projection of individual accessions in the PCA plot shows that accessions of cultivar groups are intermingled (Figure 1). However, most of the accessions of the orange pointed group are characterized by low values of both the first and second components (i.e., associated to high content in sugars and sugars:acids ratio). In this respect, no accessions from any of the other groups had negative values for both the first and second principal components (Figure 1). Also, no accessions of the orange pointed group are found in the PCA graph quadrant having positive values for the first component and negative values for the second one (i.e., associated to high content in acids, chlorophylls, carotenoids, and minerals P, K, Ca, and Zn).

4. Discussion

Tree tomato is an emerging exotic fruit crop (Acosta-Quezada, Martínez-Laborde, & Prohens, 2011). The successful build-up as a commercially important crop requires the development of improved cultivars with good fruit quality. In this respect, selection and breeding of new cultivars requires the identification of sources of variation for the traits of interest. Although the composition of tree tomato fruit had been already studied (Dawes & Callaghan, 1970; Heatherbell, Reid, & Wrolstad, 1982; Rodríguez-Amaya, Bobbio, & Bobbio, 1983; El-Zeftawi et al., 1988; Clark, Smith, & Gravett, 1989; Romero-Rodriguez, Vazquez-Oderiz, Lopez-Hernandez, & Simal-Lozano, 1994; Boyes & Strübi, 1997; Ordóñez, Vattuone, & Isla, 2005; Hurtado, Morales, González-Miret, Escudero-Gilete, & Heredia, 2009; Vasco, Avila, Ruales, Svanberg, & Kamal-Eldin, 2009; Osorio et al., 2012; Mertz, Brat, Caris-Veyrat, & Gunata, 2010), the results obtained here are the first to examine the diversity of chemical composition in sufficient tree tomatoes, including different cultivar groups and one wild relative (*S. cajanumense*).

We have shown that cultivated tree tomato and wild *S. cajanumense* have different composition profiles. For example, *S. cajanumense* fruits have greater moisture content, lower TA and soluble sugars, higher SSC:TA ratio, malic acid, chlorophylls, and Ca than those of cultivated *S. betaceum*. These differences in composition profile can be exploited for the introgression of favourable traits from the wild species into the genetic background of the cultivated species. The lower TA of *S. cajanumense* could be a trait of great interest for the improvement of cultivated tree tomato, as tree tomato fruit are generally perceived as acidic (Bohs, 1989; Boyes & Strübi, 1997; Vasco, Avil, Ruales, Svanberg, & Kamal-Eldin, 2009).

Tree tomato fruit display statistically significant differences for all the composition traits studied. Although for moisture content and SSC the range of variation was quite narrow, for all the other traits measured a wide range of variation was found. Our study is in agreement with previous works that used a limited genetic diversity (two or at the most three accessions) in this crop, in which differences among varieties for composition traits were reported (Dawes & Callaghan, 1970; Romero-Rodriguez, Vazquez-Oderiz, Lopez-Hernandez, & Simal-Lozano, 1994; Boyes & Strübi, 1997; Vasco, Avila, Ruales, Svanberg, & Kamal-Eldin, 2009). In particular, for the microminerals studied (Fe, Cu, Zn) differences of several-fold were found among the varieties having the lowest and the highest content. The wide differences for composition traits affecting flavour (sugars and acids), colour (chlorophylls, carotenoids, phenolics), and functional quality (carotenoids, phenolics, antioxidant activity) reveal improvement of tree tomato fruit quality can be achieved through selection and breeding.

As occurs with morphological and molecular diversity (Acosta-Quezada, Martínez-Laborde, & Prohens, 2011; Acosta-Quezada, Vilanova, Martínez-Laborde, & Prohens, 2012), we have found a wide diversity for composition traits within each of the cultivar groups. Also, differences have been observed among cultivar groups for some relevant composition traits. For example, the orange group had higher TA and lower SSC:TA ratio than the rest of cultivar groups. This is in agreement with the results obtained by Boyes & Strübi (1997) who, in a study with two red and one yellow-orange cultivars found the red cultivars had a sweeter taste than the yellow-orange one. These results suggest the orange cultivar group varieties will have a more acidic taste than the rest of cultivars.

When considering soluble sugars, we found that the most abundant sugar was sucrose. Glucose and fructose were present at similar levels. For organic acids, citric acid content was much higher than malic acid. These results are in agreement with previous results (Heatherbell, Reid, & Wrolstad, 1982; Romero-Rodríguez, Vazquez-Oderiz, Lopez-Hernandez, & Simal-Lozano, 1984; Boyes & Strübi, 1997; Vasco, Avila, Ruales, Svanberg, & Kamal-Eldin, 2009), but differ from those obtained by Dawes and Callaghan (1970) and by Ordóñez, Vattuone, & Isla (2005), who found higher levels of fructose and glucose than of sucrose. The wide variation among varieties for the sugars:acids ratio, with differences up to two-fold among accessions, indicates that selection for a sweeter taste could be achieved (El-Zeftawi et al., 1988; Mwithiga, Mukolwe, Shitanda, & Karanja, 2007). Correlations among the three soluble sugars studied, on one hand, and between the two organic acids, on the other, werehigh, indicating variation in the composition profile of both sugars and acids was low.

The flesh colour of tree tomato depends on the content in chlorophylls, carotenoids, and anthocyanins. The presence of chlorophyll in the fruit flesh is a negative trait for fruits of the orange or red fleshed cultivars, as it reduces the chroma and luminosity of the fruit flesh colour (McGhie & Ainge, 2002). However, for the purple-fleshed cultivars, the presence of chlorophyll may be favourable, as chlorophylls may contribute to a darker flesh colour. In this respect, we have found that the purple group, on average, had higher content in chlorophylls than the rest of accessions. Carotenoids, which are responsible of the yellow or orange colour of the flesh of the orange, orange pointed, red, and red conical cultivars (Mertz, Brat, Caris-Veyrat, & Gunata, 2010), display wide variation in the collection tested. However, on average, yellow- or orange-fleshed cultivars did not have more carotenoid than purple cultivars (Mertz et al., 2009; Vasco, Avila, Ruales, Svanberg, & Kamal-Eldin, 2009). This indicates that anthocyanins in the purple-fleshed cultivars mask the yellow or orange colour conferred by carotenoids.

Phenolic content was much greater (several hundred-fold) than carotenoids (Mertz et al., 2009). The high correlation value (r=0.8607) observed by us between phenolics content and antioxidant activity indicates that, as in other crops (Plazas et al., 2013), phenolics are the major antioxidants in the fruit flesh of tree tomato. Although the tree tomato also contains appreciable quantities of ascorbic acid (Romero-Rodriguez, Vazquez-Oderiz, Lopez-Hernandez, & Simal-Lozano, 1994; Vasco, Avila, Ruales, Svanberg, & Kamal-Eldin, 2009), the levels found are much lower than those of phenolics. Furthermore, given than tree tomato is mostly consumed in juices, ascorbic acid is quickly oxidized and lost (Mertz, Brat, Caris-Veyrat, & Gunata, 2010), and in practice will not represent a significant contribution to the antioxidant intake.

As with other *Solanum* fruit crops (Raigón, Prohens, Muñoz-Falcón, & Nuez, 2008; Giuffrida, Martorna, & Leonardi, 2009), the tree tomato has only moderate levels of minerals. Nonetheless, the important variation observed indicates that selection and breeding could result in improvements in the content of nutritionally important minerals. In this respect, one serving (100 g) of tree tomato would provide relevant amounts of the minerals K (up to 8.8% of the recommended dietary allowance; RDA), Mg (up to 7.6% of the RDA), and Cu (up to 50% of the RDA) (Institute of Medicine, 2000, 2001; Vasco, Avila, Ruales, Svanberg, & Kamal-Eldin, 2009).

The multivariate PCA analysis reflected the wide diversity existing within cultivar groups in composition profile, and allowed varieties that are more or less similar in composition to be identified. It also showed that the accessions belonging to different cultivar groups intermingle, suggesting that chemometric classification using PCA may not be a realiable tool to assign accessions to cultivar groups. However, the PCA analysis showed some orange-pointed accessions had similar composition profile, characterised by high contents of sugars and ratio sugars:acids, and were different from the rest of cultivars. These accessions could be considered of interest for improving the flavour of this cultivar group, and also could be sources of variation for improving these traits in other cultivar groups (El-Zeftawi et al., 1988; Mwithiga, Mukolwe, Shitanda, & Karanja, 2007).

Overall, our results indicate that wide variation exists among tree tomato accessions for composition traits. But, there are good prospects for the selection of tree tomato with better organoleptic, nutritional, and functional quality. This may help in developing the tree tomato as a commercially important crop.

Acknowledgements

This work was partially financed by the Ecuadorian Secretaría Nacional de Educación Superior, Ciencia, Tecnología e Innovación from Ecuador (SENESCYT).

References

Acosta-Quezada, P. G., Martínez-Laborde, J. B., & Prohens, J. (2011). Variation among tree tomato (*Solanum betaceum* Cav.) accessions from different cultivar groups: implications for conservation of genetic resources and breeding. *Genetic Resources and Crop Evolution, 58,* 943-960.

Acosta-Quezada, P. G., Vilanova, S., Martínez-Laborde, J. B., & Prohens, J. (2012). Genetic diversity and relationships in accessions from different cultivar groups and origins in the tree tomato (*Solanum betaceum* Cav.). *Euphytica, 187,* 87-97.

Bohs, L. (1989). Ethnobotany of the genus *Cyphomandra* (Solanaceae). *Economic Botany, 43,* 143-163.

Bohs, L. (1991). Crossing studies in *Cyphomandra* (Solanaceae) and their systematic and evolutionary significance. *American Journal of Botany, 78,* 1683-1693.

Bohs, L. (1994). *Cyphomandra (Solanaceae)*. Bronx, New York: The New York Botanical Garden.

Bohs, L. (1995). Transfer of *Cyphomandra* (Solanaceae) and its species to *Solanum*. *Taxon, 44*, 583-587.

Bohs, L. (2007). Phylogeny of the *Cyphomandra* clade of the genus *Solanum* (Solanaceae) based on ITS sequence data. *Taxon, 56,* 1012-1026.

Boyes, S., & Strübi, P. (1997). Organic acid and sugar composition of three New Zealand grown tamarillo varieties (*Solanum betaceum* (Cav.)). *New Zealand Journal of Crop and Horticultural Science, 25,* 79-83.

Clark, C. J., Smith, G. S., & Gravett, I. M. (1989). Seasonal accumulation of mineral nutrients by tamarillo 2. Fruit. *Scientia Horticulturae, 40,* 203-213.

Dawes, S. N., & Callaghan, M. E. (1970). Composition of New Zealand fruit 1. Tamarillo (*Cyphomandra betacea* (Cav.) Sendtn.). *New Zealand Journal of Science, 13,* 447-451.

Dembitsky, V. M., Poovarodom, S., Leontowicz, H., Leontowicz, M., Vearasilp, S., Trakhtenberg, S., & Gorinstein, S. (2011). The multiple nutrition properties of some exotic fruits: biological activity and active metabolites. *Food Research International, 44,* 1671-1701.

El-Zeftawi, B. M., Brohier, L., Dooley, L., Goubran, F. H., Holmes, R., & Scott, B. (1988). Some maturity indices for tamarillo and pepino fruits. *Journal of Horticultural Science, 63,* 163-169.

Giuffrida, F., Martorana, M., & Leonardi, C. (2009). How sodium chloride concentration in the nutrient solution influences the mineral composition of tomato leaves and fruits. *HortScience, 44,* 707-711.

Heatherbell, D. A., Reid, M. S., Wrolstad, R. E. (1982). The tamarillo: chemical composition during growth and maturation. *New Zealand Journal of Science, 25,* 239-243.

Hochberg, Y. (1988). A sharper Bonferroni procedure for multiple tests of significance. *Biometrika, 75,* 800-802.

Hurtado, N. H., Morales, A. L., González-Miret, M. L., Escudero-Gilete, M. L., & Heredia, F. J. (2009). Colour, pH stability and antioxidant activity of anthocyanin rutinosides isolated from tamarillo fruit (*Solanum betaceum* Cav.). *Food Chemistry, 117,* 88-93.

Institute of Medicine. (2000). Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride. Washington, DC: National Academy Press.

Institute of Medicine. (2001). Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington, DC: National Academy Press.

Little, T., Hills, J. (1978). Agricultural experimentation: design and analysis. New York: Wiley.

McGhie, T. K., & Ainge, G. D. (2002). Color in fruit of the genus *Actinidia*: carotenoid and chlorophyll compositions. *Journal of Agricultural and Food Chemistry, 50,* 117-121.

Mertz, C., Brat, P., Caris-Veyrat, C., & Gunata, Z. (2010). Characterization and thermal lability of carotenoids and vitamin C of tamarillo fruit (*Solanum betaceum* Cav.). *Food Chemistry, 119,* 653-659.

Mertz, C., Gancel, A. L., Gunata, Z., Alter, P., Dhuique-Mayer, C., Vaillant, F., Perez, A. M., Ruales, J., & Brat, P. (2009). Phenolic compounds, carotenoids and antioxidant activity of three tropical fruits. *Journal of Food Composition and Analysis, 22,* 381-387.

Mwithiga, G., Mukolwe, M. I., Shitanda, D., & Karanja, P. N. (2007). Evaluation of the effect of ripening on the sensory quality and properties of tamarillo (*Cyphomandra betaceae*) fruits. *Journal of Food Engineering, 79,* 117-123.

National Research Council. (1989). *Lost crops of the Incas: little-known plants of the Andes with promise for worldwide cultivation*. Washington, DC: National Academy Press.

Ordóñez, R. M., Vattuone, M. A., & Isla, M. I. (2005). Changes in carbohydrate content and related enzyme activity during *Cyphomandra betacea* (Cav.) Sendtn. fruit maturation. *Postharvest Biology and Technology, 35,* 293-301.

Osorio, C., Hurtado, N., Dawid, C., Hofmann, T., Heredia-Mira, F. J., & Morales, A. L. (2012). Chemical characterisation of anthocyanins in tamarillo (*Solanum betaceum* Cav.) and Andes berry (*Rubus glaucus* Benth.) fruits. *Food Chemistry, 132,* 1915-1921.

Plazas, M., Andújar, I., Vilanova, S., Hurtado, M., Gramazio, P., Herraiz, F.J., & Prohens, J. (2013). Breeding for chlorogenic acid content in eggplant: Interest and prospects. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 41(1),* 26-35.

Prohens, J., & Nuez, F. (2000). The tamarillo (*Cyphomandra betacea*): a review of a promising small fruit crop. *Small Fruits Review, 1(2),* 43-68.

Raigón, M. D., Prohens, J., Muñoz-Falcón, J. E., & Nuez, F. (2008). Comparison of eggplant landraces and commercial varieties for fruit content of phenolics, minerals, dry matter and protein. *Journal of Food Composition and Analysis, 21,* 370-376.

Rodriguez-Amaya, D. B., Bobbio, P. A., & Bobbio, F. O. (1983). Carotenoid composition and vitamin A value of the Brasilian fruit *Cyphomandra betacea*. *Food Chemistry, 12,* 61-65.

Romero-Rodriguez, M. A., Vazquez-Oderiz, M. L., Lopez-Hernandez, J., & Simal-Lozano, J. (1994). Composition of babaco, feijoa, passion-fruit and tamarillo produced in Galicia (NW Spain). *Food Chemistry, 49,* 251-255.

Sánchez-Moreno, C., Larrauri, J. A., & Saura-Calixto, F. (1998). A procedure to measure the antiradical efficiency of polyphenols. *Journal of the Science of Food and Agriculture, 76,* 270-276.

Sulaiman, S. F., Yusoff, N. A. M., Eldeen, I. M., Seow, E. M., Sajak, A. A. B., Supriatno, & Ooi, K. L. (2011). Correlation between total phenolic and mineral contents with antioxidant activity of eight Malaysian bananas (*Musa* sp.). *Journal of Food Composition and Analysis, 24,* 1-10.

Vasco, C., Avila, J., Ruales, J., Svanberg, U., & Kamal-Eldin, A. (2009). Physical and chemical characteristics of golden-yellow and purple-red varieties of tamarillo fruit (*Solanum betaceum* Cav.). *International Journal of Food Sciences and Nutrition, 60,* 278-288.

Wellburn, A.R. (1994). The spectral determination of chlorophylls *a* and *b*, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. *Journal of Plant Physiology, 144,* 307-313.

Table 1

Tree tomato accessions used for the present study and information on the cultivar group they belong to and origin, including province or department and country.

Accession	Germplasm bank	Accession code in germplasm bank	Origin
Orange			
A16	UPV	ECU-1134	Morona Santiago (Ecuador)
A22	UTPL	ECUt-002	Azuay (Ecuador)
A29	UTPL	ECUt-008	Cotopaxi (Ecuador)
Orange pointed			
A17	UPV	ECU-1221	Azuay (Ecuador)
A19	UPV	ECU-1295	Carchi (Ecuador)
A23	UTPL	ECUt-003	Azuay (Ecuador)
A31	UPV	UNT-08	Lima (Peru)
A32	UPV	PT-087	Chachapoyas (Peru)
A33	UPV	PT-221	Cajamarca (Peru)
A34	UPV	PT242	Cajamarca (Peru)
A35	UPV	BOL-14	Cochabamba (Bolivia)
A36	UPV	BOL-116	Santa Cruz (Bolivia)
Red			
A18	UPV	ECU-1248	Tungurahua (Ecuador)
A24	UTPL	ECUt-004	Azuay (Ecuador)
A26	UTPL	ECUt-006	Tungurahua (Ecuador)
A27	UTPL	ECUt-007	Tungurahua (Ecuador)
Red conical			
A41	UTPL	ECUt-009	Saraguro (Ecuador)
Purple			
A21	UTPL	ECUt-001	Loja (Ecuador)
A25	UTPL	ECUt-005	Azuay (Ecuador)
A30	UPV	QB-54	Boyacá (Colombia)
A37	UPV	EUR-CY-1	Lisboa (Portugal)
A39	UPV	NZ-1	New Zealand
A40	UPV	NZ-2	New Zealand
Wild (S. cajanumense)			
A15	UTPL	ECUts-100	Loja (Ecuador)

Table 2

Mean values, probability of the *F*-test for differences among accessions and least significant difference (LSD; P=0.05) for proximate composition traits measured in 24 tree tomato accessions, and average values±SE for each of the four cultivar groups containing two or more accessions.

Cultivar group and accession	Moisture (g/100 g f.w.)	SSC (%)	TA (g/100 g f.w.)	Ratio SSC:TA	Protein (g/100 g d.m.)
Orange					
A16	86.1	11.2	1.50	7.48	7.13
A22	87.1	12.1	1.68	7.22	4.41
A29	86.2	11.2	1.52	7.40	6.88
Average	86.46±0.32	11.5±0.3	1.56±0.06	7.37±0.08	6.14±0.87
Orange pointed					
A17	86.2	11.0	1.24	8.88	7.41
A19	86.1	11.0	1.47	7.49	7.21
A23	86.2	11.7	1.54	7.64	6.82
A31	86.3	10.9	1.43	7.64	7.43
A32	86.2	12.0	1.31	9.15	6.23
A33	86.4	11.2	1.49	7.50	6.81
A34	86.1	11.1	1.40	7.92	5.60
A35	86.1	11.1	1.45	7.65	4.92
A36	86.3	11.0	1.41	7.84	6.13
Average	86.21±0.03	11.2±0.1	1.41±0.03	7.97±0.20	6.51±0.29
Red					
A18	---	---	---	---	6.31
A24	87.0	11.0	1.37	8.03	5.05
A26	86.9	11.1	1.39	8.01	---
A27	---	---	---	---	7.12
Average	86.95±0.03	11.1±0.1	1.38±0.01	8.02±0.01	6.16±0.60
Red conical					
A41	87.2	11.3	1.33	8.55	9.58
Purple					
A21	---	---	---	---	6.70
A25	87.1	11.1	1.29	8.61	6.53
A30	87.1	11.1	1.24	8.96	6.34
A37	87.4	11.9	1.55	7.73	7.26
A39	87.7	11.3	1.75	6.45	6.13
A40	---	---	---	---	7.15
Average	87.34±0.13	11.3±0.2	1.46±0.12	7.94±0.56	6.69±0.18
Wild (S. cajanumense)					
A15	93.2	12.5	0.70	18.78	4.89
Global mean	86.95±0.35	11.3±0.1	1.40±0.05	8.45±0.56	6.52±0.23
Prob. *F*-test	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (P=0.05)	0.4	0.2	0.07	0.48	1.25

Table 3

Mean values, probability of the *F*-test for differences among accessions and least significant difference (LSD; P=0.05) for soluble sugars and organic acids measured in 23 tree tomato accessions, and average values±SE for each of the four cultivar groups containing two or more accessions.

	Soluble sugars				Organic acids			
Cultivar group and accession	Glucose (g/100 g d.m.)	Fructose (g/100 g d.m.)	Sucrose (g/100 g d.m.)	Total (g/100 g d.m.)	Malic acid (g/100 g d.m.)	Citric acid (g/100 g d.m.)	Total (g/100 g d.m.)	Ratio sugars: acids
Orange								
A16	10.9	11.7	27.1	49.7	0.53	7.54	8.06	6.18
A22	10.9	10.9	27.0	48.8	0.74	7.28	8.02	6.20
A29	8.8	8.8	24.3	41.8	0.58	5.80	6.39	6.56
Average	10.1±0.7	10.4±0.9	26.1±0.9	46.8±2.5	0.61±0.06	6.87±0.54	7.49±0.55	6.31±0.12
Orange pointed								
A17	12.4	13.0	26.7	52.0	0.34	5.42	5.76	9.10
A19	11.1	13.2	26.9	51.2	0.78	5.88	6.65	8.23
A23	6.3	6.3	15.5	28.1	0.46	6.13	6.59	4.86
A31	9.1	8.9	21.2	39.2	0.59	4.92	5.51	7.16
A32	9.9	9.8	25.1	44.9	0.68	6.53	7.21	6.31
A33	8.9	8.8	19.8	37.5	0.72	6.91	7.63	5.07
A34	11.0	11.0	23.6	45.5	0.53	5.51	6.03	7.85
A35	9.7	9.8	25.6	45.1	0.43	6.54	6.97	6.54
A36	10.9	10.9	26.4	48.1	0.48	6.22	6.70	7.19
Average	9.9±0.6	10.2±0.7	23.4±1.3	43.5±2.5	0.56±0.04	6.01±0.21	6.56±0.23	6.92±0.47
Red								
A18	8.9	8.8	24.1	41.8	0.46	4.01	4.46	9.37
A24	10.2	9.9	24.0	44.2	0.99	5.98	6.97	6.43
A27	8.0	8.4	20.8	37.2	0.69	5.97	6.66	5.67
Average	9.0±0.6	9.0±0.5	23.0±1.1	41.1±2.0	0.71±0.15	5.32±0.66	6.03±0.79	7.16±1.13
Red conical								
A41	8.4	8.8	22.2	39.4	0.59	6.39	6.97	5.72
Purple								
A21	8.3	8.4	19.8	36.5	0.76	6.91	7.67	4.99
A25	9.4	10.1	23.1	42.6	0.74	5.50	6.24	6.90
A30	9.6	9.5	23.5	42.6	0.55	6.03	6.59	6.64
A37	9.0	9.0	23.6	41.6	0.88	6.38	7.25	5.74
A39	7.4	7.4	18.3	33.1	0.88	6.64	7.53	4.38
A40	9.5	9.6	25.8	44.8	0.53	6.56	7.10	6.32
Average	8.9±0.3	9.0±0.4	22.4±1.1	40.2±1.8	0.73±0.06	6.34±0.21	7.06±0.22	5.83±0.40
Wild (S. cajanumense)								
A15	2.0	1.1	25.6	28.6	2.11	4.51	6.62	4.52
Global mean	9.1±0.4	9.3±0.5	23.5±0.6	41.9±1.3	0.70±0.07	6.07±0.18	6.76±0.17	6.43±0.28
Prob. F-test	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (P=0.05)	2.1	2.0	4.8	8.3	0.23	0.88	0.95	1.66

Table 4

Mean values, probability of the *F*-test for differences among accessions and least significant difference (LSD; P=0.05) for pigments and antioxidants measured in 23 tree tomato accessions, and average values±SE for each of the four cultivar groups containing two or more accessions.

	Chlorophylls			Total	Total	Antioxidant
Cultivar group and accession	Chlorophyll *a* (mg/100 g d.m.)	Chlorophyll *b* (mg/100 g d.m.)	Total (mg/100 g d.m.)	carotenoids (mg/100 g d.m.)	phenolics (g/100 g d.m.)	activity (μmol TE/g d.m.)
Orange						
A16	0.40	0.78	1.18	4.11	5.26	34.2
A22	0.51	0.98	1.49	4.05	2.98	16.4
A29	0.25	0.87	1.12	3.68	4.24	28.2
Average	0.39±0.07	0.87±0.06	1.26±0.11	3.95±0.14	4.16±0.66	26.3±5.2
Orange pointed						
A17	0.52	1.25	1.77	4.60	3.69	15.1
A19	0.37	1.36	1.73	6.21	6.18	37.6
A23	0.68	1.36	2.04	3.30	2.84	12.2
A31	0.25	0.42	0.67	4.16	3.55	16.6
A32	0.26	0.66	0.92	4.48	4.15	25.3
A33	0.47	1.09	1.57	6.59	4.19	21.5
A34	0.19	0.71	0.90	3.08	2.98	17.6
A35	0.27	1.03	1.29	4.75	2.43	14.7
A36	0.38	1.08	1.47	5.16	2.54	13.2
Average	0.38±0.05	1.00±0.11	1.37±0.15	4.70±0.39	3.62±0.39	19.3±2.7
Red						
A18	0.56	1.32	1.88	4.66	4.39	23.4
A24	0.67	1.52	2.19	2.60	2.94	17.7
A27	0.46	0.93	1.38	4.53	3.91	20.9
Average	0.56±0.06	1.26±0.17	1.82±0.23	3.93±0.67	3.75±0.43	20.6±1.7
Red conical						
A41	0.56	1.84	2.40	7.35	3.65	23.6
Purple						
A21	0.97	2.27	3.24	4.80	3.66	17.7
A25	0.46	1.23	1.68	4.97	4.67	31.2
A30	0.54	1.00	1.54	3.84	2.82	15.4
A37	0.30	1.27	1.57	4.68	2.58	12.5
A39	0.59	1.63	2.22	6.14	4.05	29.8
A40	0.97	6.57	7.54	11.20	6.12	48.7
Average	0.64±0.11	2.33±0.87	2.97±0.95	5.94±1.09	3.98±0.53	25.9±5.5
Wild (S. cajanumense)						
A15	4.50	3.94	8.64	4.00	3.19	28.8
Global mean	0.66±0.18	1.53±0.27	2.19±0.41	4.91±0.37	3.78±0.22	22.7±1.9
Prob. F-test	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (P=0.05)	0.38	0.59	0.98	1.43	0.78	6.1

Table 5

Mean values, probability of the *F*-test for differences among accessions and least significant difference (LSD; P=0.05) minerals traits measured in 23 tree tomato accessions, and average values±SE for each of the four cultivar groups containing two or more accessions.

Cultivar group and accession	P (mg/100 g d.m.)	K (mg/100 g d.m.)	Ca (mg/100 g d.m.)	Mg (mg/100 g d.m.)	Fe (mg/100 g d.m.)	Cu (mg/100 g d.m.)	Zn (mg/100 g d.m.)
Orange							
A16	173	2848	70	230	0.68	0.57	1.13
A22	106	2430	48	145	1.00	0.23	0.94
A29	93	2397	35	103	1.95	0.07	0.64
Average	124±25	2558±145	51±10	159±37	1.21±0.38	0.29±0.15	0.90±0.14
Orange pointed							
A17	125	2003	66	195	1.47	1.13	1.07
A19	160	2466	66	182	1.21	0.93	1.24
A23	108	2264	57	158	1.15	0.26	1.44
A31	57	1958	34	87	2.32	0.11	0.21
A32	118	2195	54	155	1.08	0.15	0.82
A33	115	2596	66	184	1.71	0.32	1.00
A34	130	2477	60	187	1.30	0.60	1.11
A35	142	2467	62	160	2.01	3.25	1.25
A36	112	2939	80	58	1.01	0.34	0.87
Average	118±9	2374±102	61±4	152±16	1.47±0.15	0.79±0.33	1.00±0.12
Red							
A18	133	2005	66	221	1.12	0.82	1.83
A24	118	2814	70	197	1.23	0.36	1.06
A27	70	2489	42	113	1.54	0.06	0.46
Average	107±19	2436±235	60±9	177±33	1.30±0.12	0.41±0.22	1.12±0.40
Red conical							
A41	226	1868	63	48	1.64	0.59	1.31
Purple							
A21	124	2203	53	214	1.18	0.63	0.71
A25	130	3211	78	149	1.00	0.28	1.11
A30	56	2231	16	124	2.43	0.07	0.35
A37	130	2975	73	59	1.13	0.70	0.91
A39	159	3114	65	60	1.36	0.52	1.04
A40	172	2998	44	54	1.75	0.54	1.13
Average	129±16	2789±184	55±9	110±26	1.47±0.22	0.46±0.10	0.88±0.12
Wild (S. cajanumense)							
A15	104	2805	117	161	0.75	0.58	0.64
Global mean	124±8	2511±82	60±4	141±12	1.39±0.10	0.57±0.14	0.97±0.08
Prob. F-test	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (P=0.05)	33	384	25	51	0.76	0.37	0.47

Figure 1. Diagram showing the relationships among the 26 composition traits (above) and among 18 accessions of cultivated tree tomato (*S. betaceum*) (below) based on the two first principal components of PCA (26.1 and 19.2% of the total variation, respectively). The different cultivar groups are represented in the accessions plot (below) by different symbols: orange (open circle), orange pointed (filled circle), red (open triangle), red conical (filled triangle), and purple (open square). Results are based on the data obtained from 18 accessions of the cultivated tree tomato (*S. betaceum*) for which data were available for all composition traits studied.