Original Research Article

Diversity for composition in scarlet (*S. aethiopicum*) and gboma (*S. macrocarpon*) eggplants and in interspecific hybrids between *S. aethiopicum* and common eggplant (*S. melongena*)

Raquel San José [a], Mariola Plazas [b], M. Cortes Sánchez-Mata [a], Montaña Cámara [a], Jaime Prohens [b, *]

[a] Departamento de Nutrición y Bromatología II – Bromatología, Facultad de Farmacia, Universidad Complutense de Madrid, Plaza Ramón y Cajal s/n, 28040 Madrid, Spain

[b] 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

Scarlet (*Solanum aethiopicum*) and gboma (*S. macrocarpon*) eggplants are cultivated vegetable crops native to Africa for which no comprehensive reports exist on composition and its diversity. We have evaluated diversity for composition in three varieties of scarlet eggplant and four varieties of gboma eggplant as well as in four interspecific hybrids between scarlet and common eggplant (*S. melongena*) and their respective parents. With exception of moisture (range between 85.80 and 88.26 g/100 g) and pH (range between 5.32 and 5.89), there was a wide diversity among varieties within each of the species for the composition traits evaluated, revealing ample possibilities for selection of varieties with improved fruit composition. Scarlet eggplant varieties evaluated presented, on average, lower content than gboma eggplant varieties for carbohydrates (3.60 vs. 6.48 g/100 g), starch (3.18 vs. 6.15 g/100 g), vitamin C (11.63 vs. 18.92 mg/100 g), and total phenolics (24.42 vs. 144.47 mg/100 g). and higher values for soluble sugars content and for the ascorbic/dehydroascorbic acid ratio. Interspecific hybrids between scarlet and gboma eggplants presented moisture content (78.98 g/100 g) and pH (5.15) values below those of any of the parents. For the rest of traits, values were intermediate between both parents, although much more similar to the scarlet eggplant parent. Data on composition of scarlet and gboma eggplants as well as of interspecific hybrids provide valuable information for the enhancement of both crops as well as for selecting and breeding new eggplant varieties with improved composition.

Keywords: Food analysis, food composition, scarlet eggplant, gboma eggplant, *Solanum aethiopicum*, *Solanum macrocarpon*, carbohydrates, antioxidants, varietal differences, interspecific hybrids

1. Introduction

Scarlet (*S. aethiopicum* L.) and gboma (*S. macrocarpon* L.) eggplants are two neglected cultivated vegetables related to the common eggplant (*S. melongena* L.) (Schippers, 2000). The three cultivated eggplant species are phylogenetically related and form part of subgenus *Leptostemonum* within genus *Solanum* (Vorontsova et al., 2013). Interspecific hybrids between the three species can be obtained (Daunay et al., 1991), which is of interest for breeding and developing new cultivars with improved properties. Unlike common eggplant, which is of Asian origin (Meyer et al., 2012), both scarlet and gboma eggplants are native to Africa (Daunay et al., 2001a). Both scarlet and gboma eggplants are important in sub-Saharan Africa, where they are mostly used for their fruits and leaves (Schippers, 2000). Like *S. melongena* (Daunay et al., 2001b), scarlet and gboma eggplants are hypervariable (Lester et al., 1986; Bukenya-Ziraba and Bonsu, 2004; Lester and Seck, 2004). However, despite their intraspecific diversity, the three species can be easily distinguished because of their morphological differences (in size of the plant, type of leaves, hairiness, prickliness, colour of flowers and fruits) (Lester et al., 2011; Plazas et al., 2014a).

The scarlet eggplant was domesticated from the wild species *Solanum anguivi* Lam. (Lester and Niakan, 1986), which can be found in natural environments of tropical Africa. Apart from Africa, scarlet eggplant cultivation also spread to some areas of South America, mainly in Brazil and the Caribbean, where it was probably introduced through slaves trade several centuries ago (Carney, 2013). The scarlet eggplant is one of the five most important vegetables of tropical Africa, together with tomato, onion, pepper and okra (Schippers, 2000; Lester and Seck, 2004;Maundu et al., 2009). The scarlet eggplant is subdivided into four cultivar groups (Gilo, Kumba, Shum, and Aculeatum), which are characterized by different morphology and uses (Lester, 1986). The groups Gilo and Kumba are used for their fruits (used in the same way as common eggplant); groups Kumba and Shum for their leaves (used in the same way than spinach); and, group Aculeatum as an ornamental as well as a rootstock (Schippers, 2000; Lester and Daunay, 2003; Daunay, 2008). The Gilo group is the most commonly cultivated, and their fruits normally are oval or spherical, with a fruit diameter between 2.5 cm and 12 cm and have a white, green, or even purple colour at the commercial stage (physiologically immature). The Kumba group is characterized by fruits that are flattened, ribbed, and have a variable diameter from 3 to 20 cm which, like the Gilo group, are variable in colour. The Shum group has small spherical fruits, usually between 1.2 and 2.0 cm in diameter, which are very bitter and are not consumed. The three edible groups (Gilo, Kumba and Shum) are adapted to different areas depending on climatological aspects: the Gilo group is mostly found in humid areas throughout tropical Africa, the Kumba group is commonly cultivated in semi arid areas from Occidental Sahel to the north of Nigeria, and the Shum group is mainly found at high altitude and very humid areas of Africa in Uganda and south east of Nigeria (Schippers, 2000; Maundu et al., 2009; Kouassi et al., 2014; Nyadanu and Lowor, 2015). The

Aculeatum ornamental group probably arised from hybridization between the Kumba group and the wild *S. anguivi* (Lester and Daunay, 2003). Scarlet and common eggplants can be easily hybridized (Daunay et al., 1991; Prohens et al., 2012; Rotino et al., 2014), and in fact interspecific hybrids between both species are used as rootstocks for commercial cultivation of common eggplant (Gisbert et al., 2011). Also, interspecific hybrids between both species can be backcrossed to both parental species, facilitating introgression from one species into the genetic background of the other (Daunay et al., 2011; Prohens et al., 2012; Rotino et al., 2014).

The gboma eggplant was domesticated from its wild and very prickly ancestor *S. dasyphyllum* Schum. and Thonn. (Bukenya and Carasco, 1994), which can be found in non arid tropical areas of the African continent. Although it has less prominence than scarlet eggplant, it has local importance in several parts of Eastern and Central Africa (Schippers, 2000; Bukenya-Ziraba and Bonsu, 2004; Nyadanu and Lowor, 2015). Also, like scarlet eggplant, occasional cultivation of gboma eggplant can be found in South America and the Caribbean (Carney, 2013), as well as in southeast Asia (Malkanthi et al., 2014). Gboma eggplant is cultivated either for its fruits, which are flattened in shape, non-ribbed, with smooth surface and with a diameter between 3 and 10 cm, and white or green coloured at the commercially mature stage, or for its leaves, which are used in the same way as spinach (Nyadanu and Lowor, 2015). Cultivation of gboma eggplant for its fruits takes place in the more humid areas in the western coast of the African continent, while cultivation for its leaves is common in the eastern and central parts of Africa. There are no statistics related to their production, although fruits and leaves of gboma eggplant are commercially important in the rain forest regions of coastal west Africa (Lester and Daunay, 2003; Schippers, 2000; Maundu et al., 2009; Nyadanu and Lowor, 2015). Interspecific hybrids between gboma and common eggplants can be obtained although they usually are highly sterile (Daunay et al., 1991; Bletsos et al., 2004; Khan et al., 2013) and backcross breeding with common eggplant has been unsuccessful. So, gboma eggplant presents more difficulties than scarlet eggplant for introgression breeding with common eggplant (Rotino et al., 2014).

Despite the increasing interest in markets for the scarlet and gboma eggplant few information exists on their nutritional composition (Stommel and Whitaker, 2003; Sánchez-Mata et al., 2010; Chinedu et al., 2011; Plazas et al., 2014b; Nyadanu and Lowor, 2015). Information on the main nutritional properties and the composition diversity is of interest for selecting and developing new varieties with improved composition. In this respect, development of new varieties with a higher content of nutritional and functional constituents is an important breeding objective (Diamanti et al., 2011; Plazas et al., 2013a). Therefore, the study of the diversity for chemical and nutritional composition in different types of cultivars will be useful for the selection and breeding of improved varieties of scarlet and gboma eggplant. Also, given the feasibility of reciprocal introgression between scarlet and common eggplant (Toppino et al., 2008; Prohens et al., 2012; Khan et al., 2014; Rotino et al., 2014), the evaluation of interspecific hybrids of these two cultivated eggplants can also provide information of interest for breeding.

In order to contribute to the knowledge on nutritional composition of scarlet and gboma eggplant, we have evaluated proximate traits, carbohydrate and antioxidant contents in a set of scarlet and gboma eggplants varieties. In addition, we have evaluated the composition of interspecific hybrids between scarlet and common eggplants, which may provide information of interest for reciprocal breeding between these two species for improved quality.

2. Material and methods

2.1. Plant material

2.1.1. Composition diversity of scarlet and gboma eggplants

Three varieties of scarlet eggplant and four of gboma eggplant with different characteristics were used in the present study (Table 1 and Fig. 1). These varieties were obtained from the COMAV germplasm bank and represent materials originally coming from the Richard N. Lester collection from the University of Birmingham collection. Varieties were chosen so that they were representative of the diversity of the African groups of eggplants. In the case of scarlet eggplant, one of the accessions belongs to the to the Gilo group (BBS157), one to the Aculeatum group (RNL187), and another one to the Shum group (BBS116). In the case of gboma eggplant, three varieties are flattened, of which two have green fruit (BBS196 and RNL371) and one has white fruit (RNL374), and one has an odd elongated fruit shape (BBS178). Ten plants of each accession were grown during the summer season in an open-air field plot at the facilities of the Universitat Politècnica de València (Valencia, Spain) following the standard cultivation techniques for eggplant. Plants were spaced 1 m between rows and 0.8 m within the row, were drip irrigated and pruned. Fertilization was provided with the drip irrigation system and phytosanitary treatments against spider mites and whiteflies were performed when necessary.

2.1.2. Composition of interspecific hybrids between scarlet and common eggplant

Two scarlet eggplant (A1=PI413783 and A2=PI413784) and two common eggplant (M1=PI263727 and M2=PI470273) varieties obtained from the USDA National Plant Germplasm System were used as parents for obtaining the four possible interspecific hybrids *S. melongena* × *S. aethiopicum* (Table 1 and Fig. 2). Ten plants of each parental and interspecific hybrid were grown in an experimental open field of the Unió de Llauradors i Ramaders in Sagunto (Spain). Plants were grown on raised beds spaced 1.2 m between rows and 0.8 m within the row and were flood irrigated. No pruning was applied and fertilization consisted in a mixture of sheep and goat manure at a rate of 15 t/ha. No phytosanitary treatments were needed. Beehives were included in the experimental field to facilitate fruit set.

2.2. Sample preparation and analytical methods

Three samples of fruits, with a total sample weight of >500 g and at least five fruits, were used for each accession or interspecific hybrid. Fruits of each variety were harvested in bulk and the three samples were extracted from the fruits bulk. Fruits were harvested during the summer season at the commercially ripe stage (i.e, physiologically immature, with seeds not fully developed; Figs. 1 and 2) and were immediately sent to the Universidad Complutense de Madrid (Madrid, Spain) for analysis. Fruits were kept under refrigeration for no more than 24 h until analysed.

Fruits were peeled, except for gboma eggplant variety BBS116 because of its small size and thin skin, and processed. Preliminary tests made with BBS116 revealed no influence of the presence of skin in the values for the composition traits studied. For the scarlet and gboma eggplant composition diversity study, each fruit was cut into two portions. For each sample, one of the halves of each fruit were bulked and homogenised in a laboratory blender for the analysis of pH, titratable acidity, moisture, and vitamin C content. The other bulk of halves of each sample was freeze-dried and stored for the analysis of proteins, soluble sugars, total available carbohydrates, fibre content, and total phenolics. In the case of the study of the interspecific *S. melongena* × *S. aethiopicum* hybrids and parents, analyses were performed only for fresh samples and the following traits were measured: pH, titratable acidity, moisture, vitamin C content, and total phenolics.

The following determinations were carried out on fresh homogenized samples: pH, which was measured using a Crison MicropH-2000 (Crison Instruments, Alella, Spain) pH meter (method 981.12 AOAC, 2005); titratable acidity (TA) was determined by titration with 0.1 N NaOH until pH of 8.1 was reached, and the results were expressed as meq NaOH needed to neutralize 100 g of sample (method 942.15 AOAC, 2005); moisture was evaluated by desiccation at 105 ± 2º C to constant weight (method 984.25 AOAC, 2005); vitamin C was determined by

HPLC-UV after the extraction of the samples in metaphosphoric acid (Sánchez et al., 2000); and, ascorbic acid (AA) was quantified before and after a reduction with L-Cysteine in order to determine AA, dehydroascorbic acid (DHA) and total vitamin C fractions (Sánchez et al., 2000), and expressed in mg/100 g of fresh product.

Freeze-dried samples were used for the following determinations: proteins, which were quantified as total nitrogen by Kjeldahl method, using the value of 6.25 as conversion factor of nitrogen to protein (method 920.125 AOAC, 2005); soluble sugars were identified and quantified by HPLC differential refractive index detection, after extraction in 80% methanol (Mollá et al., 1994); total available carbohydrates were determined by the anthrone colorimetric method, after hydrolysis with $HClO_4$ (Osborne and Voogt, 1986); starch was determined as the difference between total available carbohydrates and soluble sugars; fibre content was evaluated by an enzymatic-gravimetric method (m. 985.29 y 960.52 AOAC, 1997). Results of the analyses of these freeze-dried samples were expressed as g/100 g of fresh product.

Total phenolics were determined in freeze-dried (diversity of scarlet and gboma eggplants) or in fresh samples (*S. melongena* × *S. aethiopicum* hybrids and parents) with the Folin-Ciocalteu assay (Singleton and Rossi, 1965) using chlorogenic acid as standard. Results of the analyses of both types of samples were expressed as mg/100 g of fresh product.

2.3. Analytical equipment and conditions

A HPLC chromatographer (Micron Analítica, Madrid, Spain) equipped with an isocratic pump model PU-II (Jasco, Tokyo, Japan), an automatic injector (model AS-1555, Jasco), an Spectra Series UV100 UV-Vis detector (Thermo Separation Products, Riviera Beach, FL, USA), a R401 differential refractometer detector (Waters Associates, Milford, MA, USA), and Biocrom 2000 v. 3.0. Software (Micron Analitica, Madrid, Spain) was used. For vitamin C analysis, a Sphereclone ODS (2), 5 µm; 4.6 x 300 mm column (Phenomenex, Torrance, CA, USA) was used, working at the following conditions: water acidified to pH 2.5 with H_2SO_4 as mobile phase, flow-rate of 0.9 ml/min and detection at 245 nm wavelength. For soluble sugar analysis by HPLC, an amino bonded column µBondapak Carbohydrate Analysis Column, 300 x 3.9 mm (Waters Associates) was used. The following analysis conditions were used for sugar analysis: acetonitrile/water 80/20 as mobile phase, and flow-rate of 0.9 ml/min.

2.4. Statistical analysis

For each variety, the mean and standard errors of the mean were obtained for the composition traits analysed. Also, the means for each species and for interspecific hybrids as well as their respective coefficients of variation were calculated from variety means. When necessary, *t* tests were performed at a significance level of P=0.05 to evaluate the significance of differences among varieties for individual traits. All analyses were carried out using the Statgraphics plus version 5.1 software (Statistical Graphics Corp., Rockville, MD, USA).

3. Results

3.1. Composition diversity of scarlet and gboma eggplants

3.1.1. Proximate composition

Moisture content in the scarlet and gboma eggplants ranged between 85.80% (gboma eggplant BBS116) and 88.26% (scarlet eggplant RNL374). Although significant differences ($P<0.05$, according to *t* tests) exist among several cultivars (Table 2), the range of the average moisture content among the seven cultivars was of less than 3%, and the CV values were the lowest of all traits analysed, with a maximum value of CV=1.1% for gboma eggplant (Table 2). Protein content was variable (CV=11.1% for scarlet eggplant and CV=24.6% for gboma eggplant) and ranged between 0.86 g/100 g (gboma eggplant BBS196) and 1.67 g/100 g (scarlet eggplant BBS116) (Table 2), with somewhat larger average values in scarlet eggplant than in gboma eggplant. The pH values displayed a small range of variation (with CV values below 4%), with a maximum difference of 0.57 pH units between gboma eggplant RNL 374 (5.32) and scarlet eggplant BBS 157 (5.89) (Table 2). The titratable acidity (TA) was more variable (CV=52.4% for scarlet eggplant and CV=17.0% for gboma eggplant) than the pH values, with values ranging from 0.99 meq NaOH/100 g (scarlet eggplant RNL 187) to 2.34 meq NaOH/100 g (scarlet eggplant BBS116). As a consequence of this wide range of variation in scarlet eggplant the coefficient of variation was much higher in this species than in the gboma eggplant. No significant differences were observed between the global values for scarlet and gboma eggplants for any of the proximate composition traits.

3.1.2. Carbohydrates

Total available carbohydrates fraction ranged between 2.89 g/100 g (scarlet eggplant BBS116) and 8.04 g/100 g (gboma eggplant BBS178) (Table 3). Scarlet and gboma eggplants presented considerable differences in the average content for total carbohydrates, with significantly higher average values in the gboma eggplant (6.48 g/100 g) than in the scarlet eggplant (3.60 g/100 g). Total soluble sugars ranged between 0.21 g/100 g (gboma eggplant RNL371), and 0.55 g/100 g (scarlet eggplant BBS157) (Table 3), and presented higher total CV than the total available carbohydrates (Table 3). Scarlet eggplant presented higher CV values than gboma eggplant for both total available carbohydrates and total soluble sugars (Table 3).

The main soluble sugars present in the analyzed samples were glucose and fructose (Table 3) representing on average 57.1% and 31.0%, respectively, of the total soluble sugars content. Sucrose was not detected in two of the gboma eggplant varieties (BBS196 and RNL371). For the rest of varieties sucrose concentrations were much lower than those of glucose and fructose and accounted for 15.5% of the total soluble sugars content. Maltose was not detected in any of the samples analyzed. The profile obtained with the proportion of soluble sugars in each cultivar shows some differences among varieties (Fig. 3). For example, gboma eggplant BBS 196 does not present sucrose, and is the only cultivar that presents fructose contents above 40%. Also, it is remarkable that the four varieties of gboma eggplant varieties present considerable differences in the profile of soluble sugars; on the contrary, the three scarlet eggplant cultivars show a similar proportion of soluble sugars (Fig. 3). In consequence, scarlet eggplant presented lower values for CV for the soluble sugars analyzed individually than gboma eggplant (Table 3). The CV for individual soluble sugars ranged between 12.5% for sucrose and 44.6% for fructose in the scarlet eggplant and between 23.5% for glucose and 120.0% for sucrose in the gboma eggplant. Although no significant differences between both species were detected between scarlet and gboma eggplant average values for soluble sugars, the former presents higher average values for all soluble sugars than the latter (Table 3).

Starch content ranged between 2.46 g/100 g (scarlet eggplant BBS116) and 7.68 g/100 g (gboma eggplant BBS178), and the CV values were of 26.1% for scarlet eggplant and 20.5% for gboma eggplant (Table 3). Average starch values of gboma eggplant (6.15 g/100 g) were significantly higher than those of scarlet eggplant (3.18 g/100 g). The seven varieties analyzed presented a content in starch content much higher than the total soluble sugars content and therefore, the ratio total soluble sugars/starch was in all cases lower than 1. Fibre content ranged from 2.39 g/100 g (gboma eggplant BBS178) to 5.58 g/100 g (scarlet eggplant RNL187). The two species differ, according to a *t* test at $P<0.05$, with scarlet eggplant displaying a higher average content (4.51 g/100 g) of fibre than gboma eggplant (2.86 g/100 g) (Table 3).

3.1.3. Vitamin C and total phenolics

Vitamin C content in the scarlet and gboma eggplant varieties considered in this study ranged between 9.24 mg/100 g (scarlet eggplant RNL187) and 22.03 mg/100 g (gboma eggplant RNL374), with a CV value of 11.6% for scarlet eggplant and 15.3% for gboma eggplant (Table 4). The gboma eggplant varieties presented higher vitamin C content than that of scarlet eggplant, with average values of 18.92 mg/100 g and 11.63 mg/100 g, respectively. Regarding ascorbic acid (AA), values ranged between 2.70 mg/100 g (gboma eggplant BBS196) and 9.43 mg/100 g (gboma eggplant RNL374), with much higher variation in gboma eggplant varieties (CV=45.1%) than in scarlet eggplant varieties (CV=13.1%) (Table 4). For dehydroascorbic acid (DHA), the values ranged between 4.73 mg/100 g (for scarlet eggplant RNL187) and 16.77 mg/100 g (for gboma eggplant BBS196). Average values were higher ($P<0.05$) in gboma eggplant (11.71 mg/100 g) than in the scarlet eggplant (6.82 mg/100 g) (Table 4). In all cultivars, the content of DHA was always higher than the AA content, which resulted in values for the ratio AA/DHA ranging between 0.16 (BBS 196) and 0.96 (RNL 187).

Total phenolics concentration ranged between 18.55 mg/100 g (scarlet eggplant RNL187) and 167.24 mg/100 g (gboma eggplant RNL371). Although differences among accessions existed within each species, the gboma eggplant varieties presented much higher values than scarlet eggplant varieties, with average differences of almost six-fold in the total phenolics content of both species (24.42 mg/100 g for scarlet eggplant vs. 144.47 mg/100 g for gboma eggplant). Within gboma eggplant, considerable differences were found among accessions, so that the accession RNL371 (167.24 mg/100 g) presented values almost three times higher than those of BBS178 (60.31 mg/100 g) (Table 4). Also, in scarlet eggplant the accession BBS116 (34.34 mg/100 g) presented values significantly higher than the two other accessions (BBS157 and RNL187, with values of 20.36 and 18.55 mg/100 g, respectively).

3.2. Composition of interspecific hybrids between scarlet and common eggplants

3.2.1. Proximate composition

Common eggplant parents had higher moisture content (above 80%) than scarlet eggplant parents (below 80%) (Table 5). Interspecific hybrids presented values similar or lower than those of the scarlet eggplant parents, and ranged from 74.61 (interspecific hybrid M2×A2) to 79.99 (M1×A1). The CV for moisture content was low (3.3 %) in all cases, with a maximum value of 3.3% in interspecific hybrids. Regarding pH values, despite the small range of variation with a maximum difference of 0.28 pH units between the interspecific hybrid M2×A1 (5.10) and scarlet eggplant A2 (5.38) (Table 5), interspecific hybrids presented pH values (average of 5.15) significantly lower than those of both parents (5.36 and 5.30, respectively for scarlet eggplant and common eggplant averages). Interspecific hybrids derived from common eggplant M2 parental presented the lowest pH. Titratable acidity (TA) was more variable than the pH values, with values between 1.65 meq NaOH/100 g (common eggplant M1) and 2.54 meq NaOH/100 g (interspecific hybrid M2×A2). Interspecific hybrids presented average titratable acidity values (2.33 meq NaOH/100 g) significantly higher than the ones of common eggplant (average of 1.81 meq NaOH/100g).

3.2.2. Vitamin C and total phenolics

Vitamin C content in the materials studied was very variable and ranged between 16.45 mg/100 g (common eggplant M1) and 27.53 mg/100 g (scarlet eggplant A2), with low CV values in parental groups (3.5% in common eggplant and 4.3% in scarlet eggplant) and considerably higher (17.0%) in the interspecific hybrids (Table 6). The vitamin C values of scarlet eggplant and the interspecific hybrids were significantly higher than those of common eggplant. In contrast to what occurred for vitamin C content, the ascorbic acid (AA) content of common eggplant varieties was significantly higher (average of 7.50 mg/100 g) than those of scarlet eggplant (average of 4.83 mg/100 g) or the insterspecific hybrids (average of 5.22 mg/100 g). Regarding dehydroascorbic acid (DHA), scarlet eggplant parentals and the interspecific hybrids presented significantly higher values (average values of 21.90 mg/100 g and 17.71 mg/100 g, respectively), than those of common eggplant (average value of 9.45 mg/100 g) (Table 6). In all materials, the content of DHA was higher than the AA content, which resulted in values between 0.17 (scarlet eggplant A2) and 0.80 (common eggplant M2) for the ratio AA/DHA ranging. It is remarkable that the ratio

AA/DHA was higher in common eggplant parentals (average of 0.80) than in scarlet eggplant or in the interspecific hybrids (average values of 0.22 and 0.31, respectively).

The total phenolics concentration was much higher in common eggplant than in scarlet eggplant parents (with average values of 50.90 mg/100 g and 14.10 mg/100 g, respectively) (Table 6). The interspecific hybrids presented intermediate values (between 17.85 mg/100 g and 24.83 mg/100 g), although they were much closer to those of the scarlet eggplant parents than to the common eggplant parents.

4. Discussion

Development and expansion of the scarlet and gboma eggplant crops will benefit from an improved knowledge of their composition and properties and from the selection and breeding of new cultivars with improved fruit composition, which will depend on the demands of society and consumers. This will require the study of the variation and identification of sources of variation for the traits of interest and also will benefit from hybridization for obtaining new genetic combinations with enhanced values for the target traits (Diamanti et al., 2011). Many studies have been devoted to the composition of common eggplant and its diversity (Stommel and Whitaker, 2003; Hanson et al., 2006; Raigón et al., 2008; San José et al., 2013; Kaur et al., 2014). Regarding scarlet and gboma eggplants, which are important crops in Africa and have a potential interest for common eggplant breeding, few studies deal with their composition (Sánchez-Mata et al., 2010; Chinedu et al., 2011; Plazas et al., 2014b;

Nyadanu and Lowor, 2015). Although some studies have focused on diversity and breeding of specific compounds like glycoalkaloids (Sánchez-Mata et al., 2010) and phenolics content (Plazas et al., 2014b), there is a lack of comprehensive studies on the composition of scarlet and gboma eggplants and its variation. Our study represents an initial contribution to the study of diversity and use of scarlet and gboma eggplant for selection and improvement of fruit composition.

4.1. Composition diversity of scarlet and gboma eggplants

Our results show that the fruits of the scarlet and gboma eggplant varieties evaluated present a high moisture content, similar to common eggplant, and a low content of protein, although with greater values than the latter (Raigón et al., 2008; Chinedu et al., 2011; San José et al., 2013, 2014). pH is a trait of interest in eggplants as it may affect the eggplant PPO activity (Concellón et al., 2004; Todaro et al., 2011) and in consequence fruit flesh browning (Plazas et al., 2013b). However, the values obtained in this study do not present much variation, and will not have much effect on PPO activity (Concellón et al., 2004; Todaro et al., 2011). The variation for titratable acidity was much greater than for pH, suggesting that there is diversity in the buffer capacity among the varieties studied. In this respect, titratable acidity in our scarlet and gboma eggplant materials was considerably higher than values found for common eggplant (San José et al., 2013, 2014).

Total available carbohydrates content of scarlet and gboma eggplants was similar to that found in previous studies with common eggplant (Esteban et al., 1989; Boo et al., 2010; Hernández-Hernández et al., 2011; San José et al., 2013, 2014; Nyadanu and Lowor, 2014), although gboma eggplant had higher contents than scarlet eggplant. The soluble sugars, which are responsible for a sweet taste in fruits and vegetables (Nookaraju et al., 2010), presented a different profile among the species studied although values were higher in scarlet eggplants, which may result in a sweeter taste for the latter species. The most common sugars in scarlet and gboma eggplants are fructose and glucose, while sucrose content is very low, suggesting that there is a considerable invertase activity in the scarlet and gboma eggplant fruits (Boo et al., 2010). Contrary to what occurs in common eggplant (San José et al., 2013, 2014), maltose was not detected in any of the scarlet and gboma eggplant varieties studied. Starch content of scarlet and gboma eggplants is considerably higher than the total soluble sugars suggesting that the hydrolysis of starch has not been completed at the physiologically unripe harvesting stage (Singh et al., 2000). Fibre content in the scarlet and gboma eggplant varieties studied was much higher than values observed for common eggplant grown under similar conditions (San José et al., 2013, 2014), with *S. aethiopicum* presenting higher values than *S. macrocarpon*. This result is important as eggplants are considered as a good source of fibre for reducing cholesterol (Jenkins et al., 2003) and are also used for producing high fibre content food products (Perez and Germani, 2007). In consequence, scarlet eggplant could represent a good source of variation for this trait. In addition, scarlet and gboma eggplants present glycoalkaloids and saponins (Aubert et al., 1989; Sánchez-Mata et al., 2010), which could also contribute to reducing cholesterol.

We have found that African eggplant varieties evaluated, and in particular the gboma eggplant, present higher values for vitamin C than those found for common eggplant (Hanson et al., 2006; Raigón et al., 2010; San José et al., 2013, 2014). As occurs in common eggplant (San José et al., 2013, 2014), the oxidized form of vitamin C (dehydroascorbic acid; DHA) generally prevails over the reduced form (ascorbic acid; AA). Although vitamin C is thermolabile, in the case of common eggplant it has been demonstrated that around two thirds of the vitamin C activity remain after grilling (Das et al., 2011). An important aspect of increasing the content in AA content in eggplants is that it may prevent fruit flesh browning by protecting phenolic compounds from oxidation mediated by polyphenol oxidases (PPO) (Nicolas et al., 1994). This is an important aspect in breeding programmes (Prohens et al., 2007; Plazas et al., 2013b) and, in consequence, scarlet and gboma eggplant varieties with high AA content may be desirable.

Our results show that the concentration of phenolics in scarlet and common eggplant is higher than the content in AA. However, it has to be taken into account that the Folin-Ciocalteu reagent reacts with other compounds, like AA (Ainsworth and Gillespie, 2007), which in our case may result in an overestimation of the total phenolics compound. In any case, our results confirm what was observed in common eggplant (Prohens et al., 2007; Niño-Medina et al., 2014) indicating that, as in common eggplant (Plazas et al., 2013b) phenolics are the main antioxidants of scarlet and gboma eggplants. Furthermore, in contrast to what occurs with vitamin C, eggplant phenolics have a high stability and their bioavailability increases after cooking (Lo Scalzo et al., 2010). Our results are in agreement with other studies, which indicate that gboma eggplants present much higher contents in total phenolics than scarlet eggplants (Stommel and Whitaker, 2003; Prohens et al., 2007; Plazas et al., 2014b) and therefore represent a source of variation for selection and breeding programmes for improving the bioactive properties of eggplants (Plazas et al., 2013a).

The high diversity found for African scarlet and gboma eggplants for many of the chemical and nutritional traits studied, in particular for carbohydrates, vitamin C and total phenolics, indicates that they are amenable to selection and that varieties with higher content in nutritional and bioactive compounds can be selected with a limited effort (Diamanti et al., 2011). Also, given that both species can be crossed with *S. melongena* (Daunay et al., 1991; Oyelana and Ugborogho, 2008; Prohens et al., 2012; Khan et al., 2013; Rotino et al., 2014), they may represent a valuable genetic resource for common eggplant breeding. In this respect, the results of this study indicate that scarlet eggplants are a source of variation of great interest for the improvement of eggplant cultivars, for higher content of proteins, total soluble sugars and fibre, while gboma eggplants are a good source of variation for total carbohydrates, vitamin C, and total phenolics.

4.2 Composition of interspecific hybrids between scarlet and common eggplants

Obtaining interspecific hybrids between scarlet and/or gboma eggplants and common eggplant is a key step on the way of reciprocal improvement of these three crops, as backcrosses of the hybrids to both species have been obtained (Toppino et al., 2008; Prohens et al., 2012; Khan et al., 2014; Rotino et al., 2014). In the case of gboma eggplant, interspecific hybrids with common eggplant are highly sterile (Bletsos et al., 2004; Khan et al., 2013) and no backcross generations to any of the parents have been reported, which limits the use of interspecific hybridization between both eggplants for breeding new gboma or common eggplant varieties. In the first part of our study, scarlet eggplant proved of interest as a source of variation for breeding programmes directed to improve several quality traits of common eggplant. As occurs for morphological characters (Prohens et al., 2012), interspecific hybrids between scarlet and common eggplants are generally, with the exception of moisture content and pH, intermediate between both parents for chemical and nutritional composition traits, but with values generally more similar to scarlet eggplant parents.

Scarlet eggplant parents had less moisture content than common eggplant parents, indicating that the former species may be of interest to increase the dry matter content of common eggplant, which is a trait of interest for the processing industry (Raigón et al., 2008; Puig et al., 2012). In addition the interspecific hybrids were transgressive, with moisture values below those of the scarlet eggplant parents, suggesting that the introgression of this trait in the genetic background of common eggplant will be facilitated. The pH values for parental materials were similar to those found by Prohens et al. (2007) and San José et al. (2013, 2014) for parental varieties, but interspecific hybrids presented considerably lower levels than any of the parents. For high acidity values, which may have a negative impact on taste (Nookaraju et al., 2010), the dominance of scarlet eggplant may represent a disadvantage.

Our results also reveal that the scarlet eggplant varieties studied have a higher content in vitamin C, but much lower phenolics content than common eggplant (Prohens et al., 2007; Raigón et al., 2010; San José et al., 2013, 2014) and demonstrate the dominance of scarlet eggplant for vitamin C and total phenolics contents in hybrids. In this respect, for both vitamin C and total phenolics contents, values of hybrids are more similar to those of the scarlet eggplant parents than to those of common eggplant. This same result was already observed by Prohens et al. (2012) for total phenolics content in interspecific hybrids between scarlet and common eggplant. Regarding the AA and DHA results, again the values observed for hybrids were more similar to the ones corresponding to scarlet parental varieties. In this case, although total vitamin C contents were higher in scarlet eggplant than in common eggplant, revealing a higher antiescorbutic activity in the former (Tsujimura et al., 2008), the content in the reduced form of vitamin C (AA) was higher for common eggplant parents, indicating an increased antioxidant capacity derived from this compound in common eggplant (Atkinson et al., 2005). Interspecific hybrids again presented AA amounts similar to the ones of scarlet parental varieties, and so lower levels than the ones of common eggplant parents; however, interspecific hybrids presented an improvement in the AA/DHA ratio compared to scarlet eggplant parentals, which is of interest in breeding for antioxidant activity (Diamanti et al., 2011; San José et al., 2013). Regarding phenolics, the values have been much higher in common eggplant than in scarlet eggplant, confirming previous results (Stommel and Whitaker, 2003; Prohens et al., 2007, 2012; Kaur et al., 2014). In this respect, phenolics are the main antioxidants of common eggplant (Plazas et al., 2013a, 2013b; Kaur et al., 2014), and the high values observed confirm that common eggplant is one of the vegetables with higher antioxidant capacity (Cao et al., 1996).

Overall, the results of the interspecific hybrids between scarlet and common eggplants reveal a clear dominance of scarlet eggplant for most traits. This has important implications for breeding, as it may suggest that introgression of traits of interest from scarlet eggplant into the genetic background of common eggplant will be facilitated.

5. Conclusions

Our results provide the first comprehensive study of the fruit composition in a set of varieties representing the diversity of scarlet and gboma eggplants. We have found that the varieties evaluated of both eggplant species are diverse for composition, making them amenable to selection and have found some differences among species, like the lower content in total carbohydrates, starch, vitamin C and total phenolics and the higher values for soluble sugars and fibre in scarlet eggplant eggplant compared to gboma eggplant. We have also found that interspecific hybrids between scarlet and common eggplant present a composition profile much more similar to scarlet eggplant parents than to common eggplant parents, suggesting dominance of scarlet eggplant for most of the traits studied. The results obtained provide information of interest regarding chemical and nutritional composition traits of the scarlet and gboma eggplants as well as on the diversity of these traits. Data on composition of interspecific hybrids between scarlet and common eggplant is also of interest for introgression breeding for developing eggplant varieties with improved nutritional and functional quality. All this information will contribute to the enhancement of the scarlet and gboma eggplant crops and to the selection and development of new varieties of scarlet, gboma, and common eggplants with improved quality.

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Table 1

Varieties used for the study of the diversity of composition of scarlet and gboma eggplants and of interspecific hybrids between scarlet and common eggplants.

Variety	Origin	Varietal group	Fruit shape	Fruit colour	Fruit weight (g)[a]
		Composition diversity of scarlet and gboma eggplants			
Scarlet eggplant (*Solanum aethiopicum*)					
BBS116	Ivory Coast	Shum	Spherical	Dark green	2.9±1.4
BBS157	Ivory Coast	Gilo	Spherical	Green	21.9±5.1
RNL187	Burkina Faso	Aculeatum	Flattened and ribbed	Green/pale green	19.33±2.9
Gboma eggplant (*Solanum macrocarpon*)					
BBS178	Ivory Coast	---	Oval	Pale green	26.22±9.3
BBS196	Ivory Coast	---	Flattened	Dark green	81.4±30.8
RNL371	Ghana	---	Flattened	Green	38.3±7.8
RNL374	Ghana	---	Flattened	White	29.43±5.7
		Composition of interspecific hybrids between scarlet and common eggplants			

Scarlet eggplant (*Solanum aethiopicum*)					
PI413783 (A1)	Burkina Faso	Kumba	Flattened and ribbed	Green	118.2±53.3
PI413784 (A2)	Burkina Faso	Kumba	Flattened and ribbed	Green	125.5±48.9
Common eggplant (*Solanum melongena*)					
PI263727 (M1)	Puerto Rico	---	Semi-long	Pale purple	273±74.0
PI470273 (M2)	Indonesia	---	Oval	Dark purple	179.5±59.3
Interspecific hybrids *S. melongena* × *S. aethiopicum*					
M1×A1	---	---	Lightly flattened and ribbed	Pale purple, white and green	62.7±23.7
M1×A2	---	---	Lightly flattened and ribbed	Pale purple, white and green	36.1±12.4
M2×A1	---	---	Spherical and lightly ribbed	White and green	20.8±12.5
M2×A2	---	---	Spherical and lightly ribbed	White and green	23.4±10.5

[a]Average±SE of individual fruits used for the analyses.

Table 2

Proximate composition traits (moisture, proteins, pH, and titratable acidity; average±SE) in three scarlet and four gboma eggplant varieties studied.

Variety	Moisture (g/100g)[a]	Proteins (g/100g)[a]	pH	Titratable acidity (meq NaOH/100g)[a]
Scarlet eggplant (*Solanum aethiopicum*)				
BBS116	85.80±1.19	1.67±0.02	5.45±0.08	2.34±0.08
BBS157	87.55±0.25	1.35±0.02	5.89±0.03	1.04±0.10
RNL187	86.42±0.35	1.61±0.03	5.75±0.06	0.99±0.02
Mean	86.59±0.66	1.54±0.10	5.70±0.13	1.46±0.44
CV (%)	1.0	11.0	3.9	52.4
Gboma eggplant (*Solanum macrocarpon*)				
BBS178	85.99±0.15	1.51±0.04	5.62±0.06	1.96±0.09
BBS196	87.53±0.74	0.86±0.09	5.82±0.08	1.92±0.39
RNL371	86.94±0.54	1.37±0.01	5.71±0.04	1.42±0.21
RNL374	88.26±0.22	1.59±0.02	5.32±0.08	2.16±0.13
Mean	87.18±0.48	1.33±0.16	5.61±0.11	1.87±0.16
CV (%)	1.1	24.6	3.8	17.0

[a]For varietal means, values represent average±SE of three replicates, with each replicate consisting of at least 500 g of fruit and five fruits; for species means values represent average±SE of varietal means.

Table 3

Carbohydrates content (total available carbohydrates, soluble sugars, starch, and fibre; average±SE) in three scarlet and four gboma eggplant varieties studied.

Variety	Total available carbohydrates (g/100 g)[a]	Soluble sugars					Starch (g/100g)[a]	Fibre (g/100g)[a]
		Total soluble sugars (g/100g)[a]	Glucose (g/100g)[a]	Fructose (g/100g)[a]	Sucrose (g/100g)[a]	Maltose (g/100g)[a]		
Scarlet eggplant (*Solanum aethiopicum*)								
BBS116	2.89±0.06	0.43±0.01	0.23±0.00	0.12±0.00	0.08±0.00	nd[b]	2.46±0.06	4.61±0.46
BBS157	4.64±0.39	0.55±0.04	0.24±0.01	0.21±0.02	0.09±0.00	nd[b]	4.09±0.39	3.35±0.68
RNL187	3.28±0.22	0.28±0.07	0.17±0.03	0.09±0.02	0.07±0.00	nd[b]	3.00±0.22	5.58±0.88
Mean	3.60±0.53	0.42±0.08	0.21±0.02	0.14±0.04	0.08±0.01	---	3.18±0.48	4.51±0.65
CV (%)	25.5	32.2	17.8	44.6	12.5	---	26.1	24.8
Gboma eggplant (*Solanum macrocarpon*)								
BBS178	8.04±0.31	0.36±0.05	0.19±0.03	0.08±0.00	0.09±0.02	nd[b]	7.68±0.31	2.39±0.25
BBS196	6.71±0.31	0.35±0.09	0.22±0.03	0.16±0.03	0.00±0.00	nd[b]	6.36±0.31	2.72±0.21

RNL371	6.22±0.42	0.21±0.01	0.14±0.02	0.07±0.01	0.00±0.00	nd[b]	6.01±0.42	3.70±0.63
RNL374	4.94±0.56	0.34±0.02	0.25±0.02	0.05±0.01	0.06±0.00	nd[b]	4.60±0.56	2.65±0.31
Mean	6.48±0.64	0.31±0.04	0.20±0.02	0.09±0.02	0.04±0.02	---	6.15±0.63	2.86±0.29
CV (%)	19.8	22.4	23.5	53.7	120.0	---	20.5	20.1

[a]For varietal means, values represent average±SE of three replicates, with each replicate consisting of at least 500 g of fruit and five fruits; for species means values represent average±SE of varietal means.

[b]Not detected.

Table 4

Vitamin C and total phenolics; average±SE) in three scarlet and four gboma eggplant varieties studied.

Variety	Vitamin C			Total phenolics (mg/100g)[a]
	Total vitamin C (mg/100g)[a]	Ascorbic acid (mg/100g)[a]	Dehydroascorbic acid (mg/100g)[a]	

Scarlet eggplant (*Solanum aethiopicum*)				
BBS116	14.14±0.93	4.38±0.51	9.75±0.98	34.34±1.25
BBS157	11.50±0.39	5.53±0.29	5.97±0.41	20.36±1.09
RNL187	9.24±0.11	4.51±0.15	4.73±0.26	18.55±1.23
Mean	11.63±1.41	4.80±0.36	6.82±1.51	24.42±4.99
CV (%)	21.1	13.1	38.3	35.4
Gboma eggplant (*Solanum macrocarpon*)				
BBS178	15.02±0.48	7.00±0.65	8.02±0.56	60.31±3.50
BBS196	19.47±4.94	2.70±0.26	16.77±4.82	115.93±5.92
RNL371	19.18±0.16	5.73±0.21	13.45±0.34	167.24±7.30
RNL374	22.03±2.43	9.43±0.47	12.60±2.51	114.40±4.77
Mean	18.92±1.45	6.21±1.40	11.71±1.80	144.47±21.83
CV (%)	15.3	45.1	21.3	43.7

[a]For varietal means, values represent average±SE of three replicates, with each replicate consisting of at least 500 g of fruit and five fruits; for species means values represent average±SE of varietal means

Table 5

Proximate composition traits (moisture, pH, and titratable acidity; average±SE) in two scarlet eggplant and two common eggplant parents and their four interspecific hybrids.

	Moisture (g/100g)[a]	pH	Titratable acidity (meq NaOH/100g)[a]
Scarlet eggplant (*Solanum aethiopicum*) parents			
PI413783 (A1)	78.01±1.40	5.34±0.03	2.20±0.14
PI413784 (A2)	79.95±0.96	5.38±0.03	2.01±0.10
Mean	78.98±0.97	5.36±0.02	2.10±0.10
CV (%)	1.7	0.5	6.5
Common eggplant (*Solanum melongena*) parents			
PI263727 (M1)	83.94±1.85	5.34±0.01	1.65±0.24
PI470273 (M2)	80.22±0.99	5.26±0.01	1.98±0.12
Mean	82.08±1.86	5.30±0.04	1.81±0.17

CV (%)	3.2	1.1	12.8
Interspecific hybrids *S. melongena* × *S. aethiopicum*			
M1×A1	79.99±1.48	5.17±0.01	2.00±0.15
M1×A2	75.23±0.49	5.19±0.01	2.48±0.05
M2×A1	75.13±3.60	5.10±0.02	2.29±0.19
M2×A2	74.61±0.47	5.12±0.05	2.54±0.05
Mean	76.24±1.26	5.15±0.02	2.33±0.12
CV (%)	3.3	0.8	10.4

[a]For varietal means, values represent average±SE of three replicates, with each replicate consisting of at least 500 g of fruit and five fruits; for species means values represent average±SE of varietal means.

Table 6

Vitamin C and total phenolics; average±SE) in two scarlet eggplant and two common eggplant parents and their four interspecific hybrids.

Variety	Vitamin C			Total phenolics
	Total vitamin C (mg/100g)[a]	Ascorbic acid (mg/100g)[a]	Dehydroascorbic acid (mg/100g)[a]	(mg/100g)[a]

Scarlet eggplant (*Solanum aethiopicum*) parents				
PI413783 (A1)	25.92±0.71	5.74±0.50	20.18±0.64	12.31±0.55
PI413784 (A2)	27.53±1.12	3.91±0.06	23.62±1.06	15.88±1.15
Mean	26.73±0.81	4.83±0.92	21.90±1.72	14.10±1.79
CV (%)	4.3	26.8	11.1	17.9
Common eggplant (*Solanum melongena*) parents				
PI263727 (M1)	16.45±0.38	7.26±0.43	9.19±0.05	56.91±3.94
PI470273 (M2)	17.28±0.49	7.73±0.38	9.70±0.11	44.88±4.19
Mean	16.86±0.42	7.50±0.24	9.45±0.26	50.90±6.02
CV (%)	3.5	4.4	3.8	16.7
Interspecific hybrids *S. melongena* × *S. aethiopicum*				
M1×A1	17.28±1.37	5.60±0.39	11.68±1.03	17.85±0.83
M1×A2	23.46±1.15	4.96±0.54	18.50±0.93	19.70±0.66
M2×A1	25.66±0.49	4.74±0.10	20.91±0.40	18.33±1.42
M2×A2	25.30±0.47	5.57±0.06	19.73±0.50	24.83±2.77

Mean	22.92±1.94	5.22±0.22	17.71±2.07	20.18±1.80
CV (%)	17.0	8.2	23.4	15.9

[a]For varietal means, values represent average±SE of three replicates, with each replicate consisting of at least 500 g of fruit and five fruits; for species means values represent average±SE of varietal means.

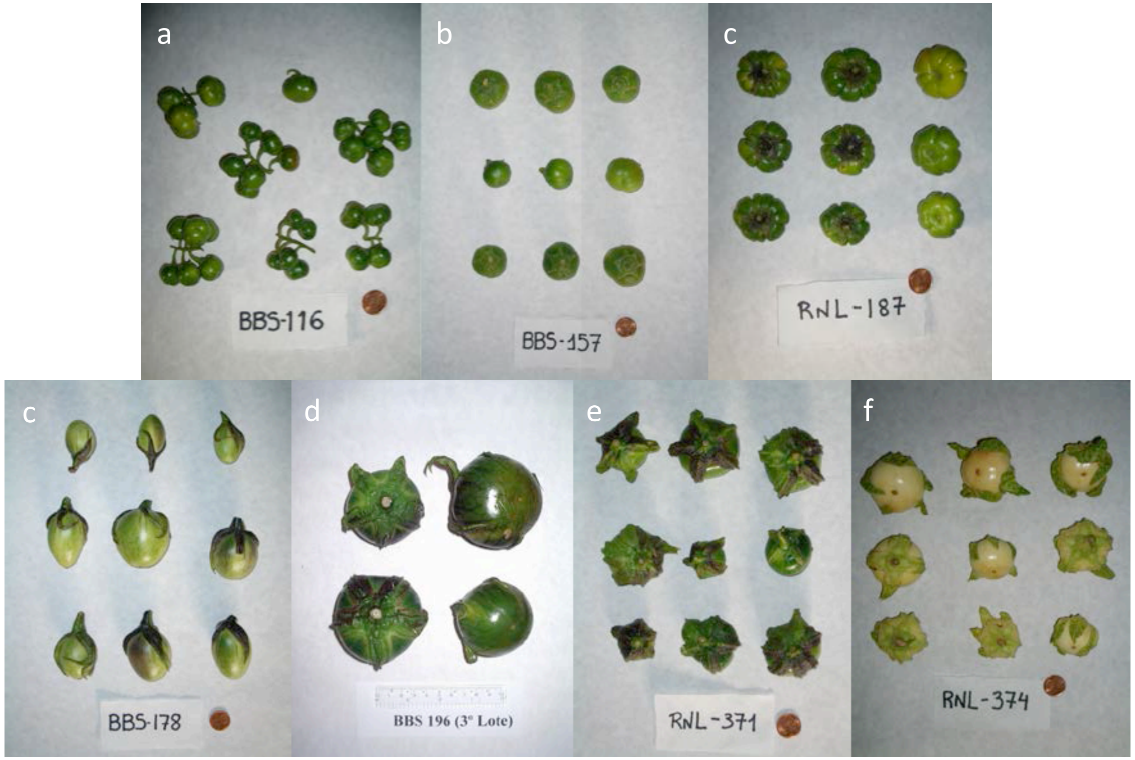

Fig. 1

Representative fruits of the varieties of scarlet (*S. aethiopicum*; above) and gboma (*S. macrocarpon*; below) eggplants varieties evaluated. *Solanum aethiopicum* varieties are BBS116 (a), BBS157 (b), and RNL187 (c); *S. macrocarpon* varieties are: BBS178 (d), BBS196 (e), RNL371 (f), and RNL374 (g). Fruits are not displayed at the same scale; the coin for reference has a diameter of 21.25 mm, while for BBS116 the scale is in cm.

Fig. 2

Representative fruits of the scarlet (*S. aethiopicum*) and common (*S. melongena*) parents and interspecific hybrids evaluated. *Solanum aethiopicum* parents are PI413783 (A1; a), and PI413784 (A2; b); *S. melongena* parents are: PI263727 (M1; c), and PI470273 (M2;

d); interspecific hybrids are M1xA1 (e), M1xA2 (f), M2xA1 (g), and M2xA2 (h). Fruits are not displayed at the same scale; the coin for reference has a diameter of 23.25 mm.

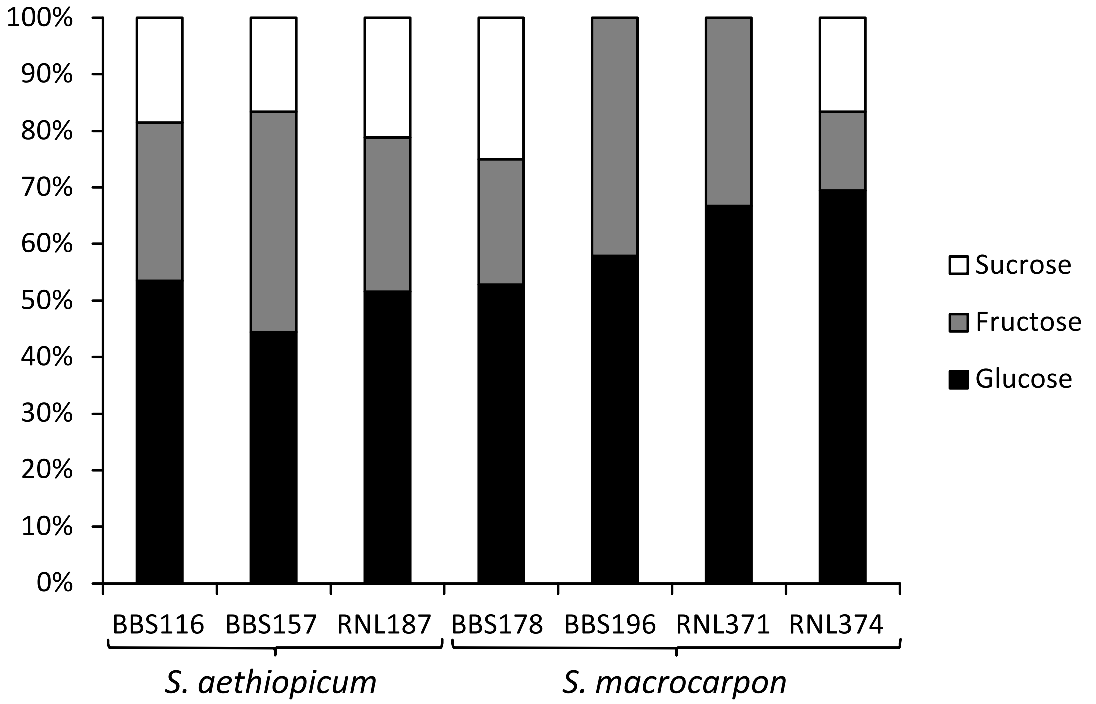

Fig. 3

Relative contents (%) for each of the individual soluble sugars (glucose, fructose and sucrose) over total soluble sugars in the three scarlet (*S. aethiopicum*) and four gboma (*S. macrocarpon*) eggplant varieties analysed.