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Nutritional quality, fruit shape and relationships among exotic and local *Capsicum* pepper genotypes in Uganda

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Summary: Twenty-one hot pepper genotypes comprising of local (15) and exotic (6) types (*C. annuum, C. frutescens* and *C. chinense*) were characterized for selected fruit traits after propagation in a glasshouse at the Makerere University Agricultural Research Institute Kabanyolo in Central Uganda using a completely randomized design with three replicates. Ripe fruits were harvested and analyzed; traits evaluated were all significantly different at P<0.05 with variations in quality attributes. The genotype OHA-B305-10 had the highest ascorbic acid content (128.86 mg/100 g) and is recommended for improvement of both local and exotic genotypes targeting the fresh market. Genotypes CAP0408-12 and UG2 WE0511-22, with highest total soluble solids (16.17 ºBrix) and dry matter content (28.59%), respectively should be used in improvements for industrial use or processing to products such as chilli powder or flakes. BRS-M205-04 with highest titratable acidity (1.04%) can be used in enhancing shelf life of genotypes with low titratable acids as well as for the fresh market. In spite of the intraspecific relationships among genotypes, significant differences were observed in their quantitative traits. These genotypes will, therefore, be useful in improving the quality of hot pepper fruit in Uganda.

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Key words: ascorbic acid, crop improvement, hot pepper, total soluble solids

Introduction

Capsicum peppers are one of the top ten spices in world trade, accounting for 3-5% global exports between 1991 and 2015 (Jambor et al., 2018). Of the 38 species in the genus, five were domesticated: *C. annuum, C. chinense, C. frutescens, C. baccatum,* and *C. pubescens* (Bosland & Votava, 2000; Delelegn, 2011) in Mesoamerica or South America (Perry et al., 2007). Many *Capsicum* varieties have been developed though genotypes that are more related to the centres of origin are useful as sources of genes for crop improvement.

Globally, *Capsicum* peppers are grown for income generation among smallholder farmers for both local and export markets (Beyene & David, 2007; Ayodele et al., 2016). Peppers also have nutritional and medicinal value. They are used as spices, vegetables and condiments in sauces and pickles (Ali et al., 2018). The peppers contribute towards the vitamins A, C, E, B6 and thiamine dietary requirements. Beta-carotene is an especially important form of pro-vitamin A with antioxidant properties. Other carotenoids are also used as natural colorants in both animal and human foodstuff. Vitamin C, capsaicin, and flavonoids in peppers have also been shown to prevent blood clot formation and reduce risks of heart attack and stroke (Bridgemohan et al., 2018). Vitamin C enables neutralization of harmful free radicals in the body, wound healing, iron assimilation, defense against bacterial and viral infections and build collagen that aids skin strength, elasticity and hydration (Medina-Juarez et al., 2012; Orobiyi et al., 2015). The different fruit colours, sizes and shapes enhance the ornamental potential of peppers especially when grown in gardens or in pots; this has a double purpose when the ornamental peppers are used for decoration and consumption (Padilha & Barbieri, 2016). In Uganda, commercial production of hot pepper began in the 1990s (Tusiime et al., 2010). The crop is mainly grown in the districts of Mukono, Wakiso, Luwero and Mpigi (Central region); Kiboga and Hoima (Western region) (Muzira, 2015) and Kisoro and Kasese (South-western region) (Nsabiyera et al., 2013). Prominent cultivars include: Bird's eye chilies (Buyinza & Mugagga, 2010), Scotch Bonnet (Caribbean type), Long Cayenne and Habanero (Afedraru, 2018), which are grown primarily from farm-saved seed (Buyinza & Mugagga, 2010). As such, diseases are a constant challenge for farmers. Morphological characteristics of hot pepper landraces were described by Nsabiyera et al. (2013) as a prelude to breeding for various desirable traits including tolerance to viral disease. However there is limited information on quality attributes of both local and exotic genotypes in Uganda. No research has been done on characterization of fruit quality attributes, yet these are among the important qualities in the hot pepper markets. This study characterized fruit quality attributes among selected *Capsicum* genotypes with promising resistance to pests and diseases in order to identify desirable traits for improvement of farmer-preferred varieties.

Materials and methods

Description of the experimental site

A glasshouse trial was established at Makerere University Agricultural Research Institute Kabanyolo (MUARIK). MUARIK is in Wakiso district, 5 km from Gayaza town and about 14km north of Kampala city. The institute is located on spatial coordinates 0˚27'60"N, 32˚36'24"E at an elevation range of 1250 m to 1320 m above sea level (Yost & Eswaran, 1990; Okiror et al., 2017). MUARIK receives a bi-modal rainfall pattern with two wet seasons, one season is from April to May and the other from October to November. The drier periods are January to February and July to August. The institute is in the Lake Victoria basin that receives mean annual precipitation of 1218 mm (Okiror et al., 2017), an annual average temperature range of 18-28˚C and annual average relative humidity of 46-88% (Djaman et al., 2017). Soils in Kabanyolo are mainly formed on residuum and colluvium from quartzite, gneiss and basement complex rocks and the side slopes of MUARIK mostly have Colluvium enriched with lateritic gravel (Yost & Eswaran, 1990; Okiror et al., 2017), they are also clayey, acidic (pH range of 6.08 to 6.12), deficient in minerals such as P, Ca, K, Mg, Na and N, and have low organic matter content (Okiror et al., 2017).

Genotypes

Twenty-one hot pepper genotypes (*C. annuum*, *C. frutescens* and *C. chinense*) were evaluated in this study (***Table 1***). These included six exotic genotypes from USA, China and Brazil. The rest were a mix of genotypes from farmers' fields in Mbarara, Ntungamo, Mayuge, Kisoro, Gulu, Ibanda, Kasese, Kabale, Buikwe and Mukono districts in the Western, Northern, Eastern and Central regions of Uganda.

Table 1. Source, type and species of the studied Capsicum pepper genotypes

Germplasm code	Source/origin	Type	Species
UG-WE05-0607	Mbarara, Uganda	Scotch bonnet	*C. chinense*
UG-WE02-0711	Ntungamo, Uganda	Bullet chili	*C. annuum*
UG-EA06-0515	Mayuge, Uganda	Bird eye chili	*C. frutescens*
UG2-WE0106-01	Kisoro, Uganda	Cayenne	*C. annuum*
UG2-WE0102-02	Kisoro, Uganda	Bullet chili	*C. annuum*
UG2-WE0119-03	Kisoro, Uganda	Habanero	*C. chinense*
UG2-WE0103-05	Kisoro, Uganda	Bullet chili	*C. annuum*
UG2-NO0211-09	Gulu, Uganda	Bullet chili	*C. annuum*
UG2-WE0318-15	Ibanda, Uganda	Habanero	*C. chinense*
UG2-WE0419-17	Kasese, Uganda	Scotch bonnet	*C. chinense*
UG2-WE0502-20	Kabale, Uganda	Bird eye chili	*C. frutescens*
UG2-WE0511-22	Kabale, Uganda	Bird eye chili	*C. frutescens*
UG2-WE0505-23	Kabale, Uganda	Bullet chili	*C. annuum*
UG2-EA0604-24	Buikwe, Uganda	Cayenne	*C. annuum*
UG2-CE0706-25	Mukono, Uganda	Scotch bonnet	*C. chinense*
NSR0105-01	USA	Habanero	*C. chinense*
BRS-M205-04	Brazil	Biquinho	*C. chinense*
RHA-T305-07	USA	Habanero	*C. chinense*
OHA-B305-10	USA	Habanero	*C. chinense*
RHA0307-11	USA	Habanero	*C. chinense*
CAP0408-12	China	Cayenne	*C. annuum*

Experimental design and management

A one-year experiment was set up using a completely randomized design with genotypes replicated three times. Genotypes were planted from seed in trays with a mixture of black forest soil and sand. Forty-five-day-old seedlings were transplanted into plastic buckets with drainage holes; every bucket had one plant. The media used was mixed in the ratio of 2:1 (black forest soil: cow dung). Plants were watered once a day and the weeds were hand pulled. Fertilizers were applied one month after transplanting and Nitrogen-Phosphorous-Potassium, NPK (17:17:17) was applied at a rate of 200 kg/ha (two times in the growing season) and Vegimax (5 ml/20 litres of water) at an interval of 2 weeks. Mancozeb (application rate: 50 g/20 litres of water) was applied every after two weeks to control fungal infection. Fruits were harvested at the ripe stage for each species (Lim et al., 2009) from two plants in each replicate for each genotype using a simple random sampling approach **(**Aminifard et al., 2012) and taken to the Food Chemistry laboratory at the School of Food Technology, Nutrition & Bio-Engineering (Makerere University) for further analysis.

Data collection and analysis

Data were collected from July to September 2019 on fruit shape, moisture content, total soluble solid content, Vitamin C (ascorbic acid), dry matter content and titratable acidity.

Shape was scored on plants from an average of 10 fruits per genotype using the descriptive values scored at the pedicel attachment (1= Acute, 2= Obtuse, 3= Truncate, 4= Cordate, 5= Lobate), and at blossom end (1= Pointed, 2= Blunt, 3= Sunken, 4= Sunken and pointed) according to *IPGRI* et al. (1995). For moisture content (%) and dry matter content (%), the fruit pedicel was removed and whole fruit dried in an oven at 70ºC for 24 hours. The loss of weight was used to calculate moisture content (Nielsen, 2010) while the percentage difference between fresh and dry weights was used to calculate dry matter content (Bozokalfa et al., 2009). In order to determine total soluble solids, fruit pericarp and pulp tissues were crushed with a pestle and mortar to obtain one drop of juice that was used to read the ºBrix in a hand refractometer (do Rêgo et al., 2011). Ascorbic acid was determined using the 2, 6-dichloroindophenol titration method (Antoniali et al., 2007; Samira et al., 2013). Titratable acidity was measured as described by Edusei & Ofosu-Anim (2013) with a few changes, 2-3 grams of pepper fruits were manually crushed and the extract was diluted with distilled water up to 100 ml. Five millilitres of this solution were titrated against 0.116M NaOH using phenolphthalein as indicator and the results were expressed as percentage citric acid.

Data was entered in Excel and subjected to Analysis of Variance (ANOVA) using GenStat statistical software (12th Edition). Least significant difference (LSD) at 95% confidence interval ($\alpha = 0.05$) was used to separate means. The data were also evaluated by linear regression analysis for total soluble solids, moisture content and ascorbic acid. Hierarchical cluster analysis was done using XLSTAT 2015 and Euclidean distance was estimated.

Results

There were significant differences between evaluated genotypes for total soluble solid content, ascorbic acid, titratable acidity, moisture and dry matter content. The highest total soluble solid content was observed in genotype CAP0408-12 and the lowest in UG2-WE0511-22. Genotypes OHA-B305-10 and RHA0307-11 had the highest ascorbic acid content while the lowest content was in UG2-WE0103-05. Highest TA was observed in BRS-M205-04 and the lowest in OHA-B305-10. Genotype UG-WE05-0607 contained the highest moisture and lowest dry matter content; the lowest moisture and highest dry matter content was recorded in UG2-WE0511-22 (***Table 2***). Total soluble solid content was negatively correlated with moisture content (R^2=0.49). In contrast, there was a positive correlation between ascorbic acid content and total soluble solid content (R^2=0.204).

The genotypes were grouped into three clusters basing on five quantitative parameters (***Figure 1***). Cluster 2 was the largest with 11 genotypes (3 exotic and 8 local), the dominant species was *C. chinense* with 8 genotypes followed by *C. annuum* (2 genotypes) and *C. frutescens* (1 genotype). Cluster 3 was the second largest with 8 genotypes (7 local and 1 exotic), *C. annuum* was a dominant species in this cluster with 6 genotypes, followed by *C. frutescens* that had 2 genotypes. Cluster 1 was the smallest with only two exotic genotypes, all belonging to *C. chinense*. Genotypes in clusters 2 and 3 were from different geographical origins while the ones in cluster 1 were from the same geographical origin.

Based on the descriptors for *Capsicum* used, the genotypes evaluated exhibited variation in fruit shape at both the blossom end and pedicel attachment. Most of them were, however, pointed at the blossom end and obtuse at the pedicel attachment (***Table 3*** and ***Figure 2***). The genotypes were grouped into three clusters by fruit shape (***Figure 1***). Cluster 1 was the largest with 11 genotypes (2 exotic and 9 local), which were a mixture of the species evaluated (*C. annuum, C. frutescens* and *C. chinense*). Cluster 2 was the second largest and had 7 genotypes with 4 exotic and 3 locals. Cluster 3 was the smallest with two local genotypes that belonged to *C. annuum*. Exotic genotypes were grouped together with local genotypes and each cluster had genotypes from different origins.

Discussion

The traits evaluated showed reasonable variability among genotypes studied, which is a pre-requisite for selection of materials for breeding. Nsabiyera et al. (2013) characterized several morphological traits in local and exotic pepper genotypes. The current study, however, presents the first attempt at characterizing fruit quality traits. Quality traits such as high dry matter and total soluble solid content are considered important for processing peppers (Li et al., 2009) as they lower pepper powder processing costs (do Rêgo et al., 2011). Do Rêgo et al. (2011) also reported a negative relationship between total soluble solid content and moisture content in the fruit, which matches the results of this study. Genotypes with high TSS content such as CAP0408-12, UG2-WE0103-05, UG2-WE0502-20, RHA0307-11 and UG2-WE0505-23 have the potential for improving varieties desired by the dry pepper processing industry.

The highest ascorbic acid content values recorded in this study were still lower than the 191.4mg/g reported by do Rêgo et al. (2011) and 192.6 mg/g by Orobiyi et al. (2015). Ascorbic acid concentrations in green pepper in the range of 46.6 - 243.0 mg/100g of dry weight have been reported by other studies (Nisperos-Carriedos et al., 1992; Howard et al., 1994; Lee et al., 1995; Gibbis & O'Garro, 2004) as indicated by Samira et al. (2013). Medina-Juárez et al. (2012) also reported an ascorbic acid content range of 121.14 - 251.60mg/100g in various peppers. While the levels observed among the genotypes studied fall within this general range, it is evident that ascorbic acid may not have been a key attribute considered in genotypic selection. Traditionally, hot peppers are not popular within Uganda and are largely grown for export markets that value their intense heat and aroma. This would explain why varieties grown by farmers are mainly of the Scotch bonnet and Habanero types that are very hot and rated from 100,000 - 350,000 on the Scoville scale (Hommel, 2019). Kantar et al. (2016) reported a positive relationship between ascorbic acid and heat in *Capsicum* peppers. Selection for high ascorbic acid content should, therefore, not compromise heat intensity in improvement of Ugandan pepper.

Ascorbic acid content also varies with cultivar and light intensity (Lee & Kader, 2000). The difference observed among *C. chinense* genotypes in this study is, thus, not surprising. Evaluation of genotypes in areas with high light intensity should, however, allow for selection closer to their true genetic potential. Ascorbic acid showed a positive relationship with total soluble solids in this study, which agrees with what Niklis et al. (2002) found out at different ripening stages of pepper and has been attributed to glucose being a precursor for ascorbic acid synthesis. Since *Capsicum* fruits can contribute 50% to over 100% of the recommended daily intake (RDI) and the current RDI for vitamin C is 90 mg/day and 75 mg/day for men and women respectively (Howard & Wildman, 2007; Food and Nutrition Board, 2011; Wahyuni, 2014), then genotype OHA-B305-10 with ascorbic acid content greater than 112mg/100g can be a potential source of vitamin C. Improvement of local *C. annuum* genotypes would especially be relevant since this species is more widely consumed in Uganda.

The highest titratable acidity observed in this study was lower than the 1.45% reported by Edusei & Ofosu-Anim (2013) and the range of 0.86-3.31% by Jarret et al. (2007). Higher fruit acidity enhances shelf life. Fruit taste has also been linked with titratable acidity (Edusei & Ofosu-Anim, 2013). Fruits and vegetables with low levels of organic acids may lack characteristic flavor (taste) (Kader, 2008; Edusei & Ofosu-Anim, 2013). Variations in titratable acidity among genotypes in this study could be attributed to their genetic differences especially since they also belong to different species.

Moisture content has a detrimental effect on fruit shelf life since water enhances microbial activity that causes food spoilage (Emmanuel-Ikpeme et al., 2014). Genotypes with higher moisture content, therefore, have a short shelf life and are not good for the export market. These genotypes can, however, be sold in dehydrated form. Genotypes with high dry matter content are good for industrial use (processing dry pepper products) as they lower fruit dehydration costs (Lannes et al., 2007; do Rêgo et al., 2011).

Fruit shapes at pedicel attachment and blossom end were relatively diverse and should be considered in planning for improvement as market specifications may vary. The Habanero and Scotch bonnet types currently grown are clearly different, being hat-shaped and lantern-shaped, respectively. Grouping of

Table 2. Means of quantitative fruit attributes in the studied selected *Capsicum* genotypes

Germplasm code	Species	MC (%)	DM (%)	TSS (°Brix)	Ascorbic acid (mg/100g)	TA (%)
OHA-B305-10	*C. chinense*	86.63	13.37	11.17	128.86	0.04
RHA0307-11	*C. chinense*	84.25	15.75	12.33	109.91	0.05
RHA-T305-07	*C. chinense*	88.18	11.82	7.33	11.95	0.38
NSR0105-01	*C. chinense*	86.70	13.30	11.50	32.46	0.32
BRS-M205-04	*C. chinense*	90.39	9.61	7.50	23.28	1.04
UG2-WE0119-03	*C. chinense*	86.74	13.26	9.33	20.46	0.42
UG-WE05-0607	*C. chinense*	90.63	9.37	7.67	19.84	0.35
UG2-CE0706-25	*C. chinense*	84.95	15.05	10.17	33.92	0.41
UG2-WE0419-17	*C. chinense*	89.66	10.34	7.83	31.31	0.32
UG2-WE0318-15	*C. chinense*	89.53	10.47	7.50	14.82	0.41
CAP0408-12	*C. annuum*	75.44	24.56	16.17	18.45	0.39
UG-WE02-0711	*C. annuum*	77.12	22.88	7.67	17.77	0.23
UG2-WE0106-01	*C. annuum*	83.22	16.78	10.00	35.28	0.28
UG2-WE0102-02	*C. annuum*	72.22	27.78	10.17	13.72	0.41
UG2-WE0103-05	*C. annuum*	81.92	18.08	12.83	10.66	0.28
UG2-WE0505-23	*C. annuum*	77.72	22.28	12.17	13.67	0.42
UG2-NO0211-09	*C. annuum*	85.08	14.92	9.50	18.08	0.53
UG2-EA0604-24	*C. annuum*	72.45	27.55	7.50	21.11	0.47
UG2-WE0502-20	*C. frutescens*	78.42	21.58	12.33	29.67	0.42
UG2-WE0511-22	*C. frutescens*	71.41	28.59	6.17	20.61	0.41
UG-EA06-0515	*C. frutescens*	85.94	14.06	7.33	12.68	0.51
Grand mean		82.79	17.21	9.72	30.40	0.38
Standard error		1.781	1.781	0.267	7.273	0.068
CV (%)		2.2	10.4	2.7	23.9	17.8
LSD (0.05)		2.935	2.935	0.4404	11.984	0.113
F-probability		<.001	<.001	<.001	<.001	<.001

MC: moisture content, DM: dry matter content, TSS: total soluble solids, TA: titratable acidity, UG: Ugandan accessions

Table 3. Distribution of variations in *Capsicum* fruit shape at blossom end and pedicel attachment

Blossom end		Pedicel attachment	
Fruit shape	Number of genotypes	Fruit shape	Number of genotypes
Blunt	2	Acute	1
Pointed	11	Cordate	1
Sunken	4	Obtuse	10
Sunken and pointed	4	Truncate	9
Grand total	21		21

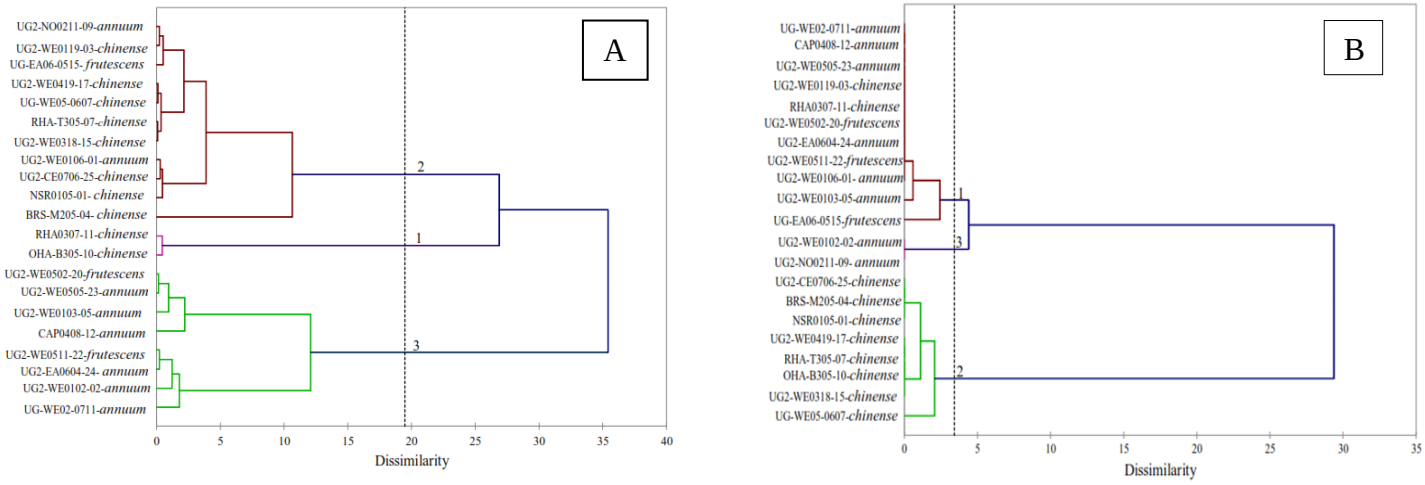

Figure 1. Dendrogram of 21 Capsicum genotypes generated by hierarchical cluster analysis A: Quantitative traits, B: Fruit shape

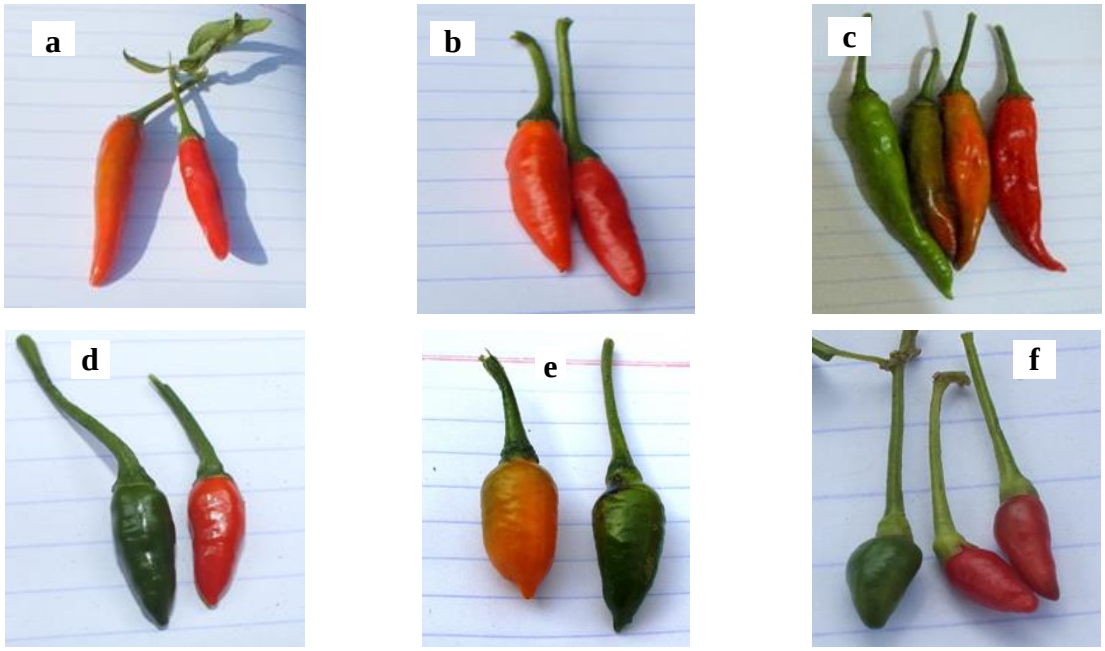

Figure 2. Fruit from selected Capsicum pepper genotypes evaluated. UG2-WE0106-01 (a), UG2-WE0103-05 (b), UG2-NO0211-09 (c), UG2-WE0502-20 (d), UG2-WE0511-22 (e) and UG-EA06-0515 (f)

genotypes by fruit shape based on species is expected since sweet and hot peppers in the *Capsicum* genus shows intra- and inter-specific diversity in fruit shape (Dagnoko et al., 2013). Quantitative traits also supported intra-specific diversity as in the case of genotypes OHA-B305-10 and RHA0307-11. The close clustering of *C. annuum*, *C. frutescens*, and *C. chinense* genotypes was also expected since the three species belong to a species complex and share the same ancestral gene pool (Tripodi & Greco, 2018).

Conclusions

Nutritional attributes varied more than fruit shape among the local and exotic *Capsicum* genotypes evaluated. Intraspecific relationships were evident, irrespective of sources of origin. Genotypes OHA-B305-10, CAP0408-12 and UG2-WE0511-22, and BRS-M205-04 should be used to improve ascorbic acid, total soluble solids and titratable acidity, respectively. Further characterization of all genotypes evaluated for capsaicin content is recommended for prioritization based on hotness.

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