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Assessment of wild tomato accessions for fruit yield, physicochemical and nutritional properties under a rain forest agro-ecology

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Abstract: Tomato (*Solanum lycopersicum* L.) is a broadly consumed fruit vegetable globally. It is one of the research mandate vegetable of the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria. The institute's genebank contains diverse collections of tomato accessions and wild relatives, without utilization information for the African continent. With the decline in diversity and potential of cultivars, a robust tomato breeding pipeline with broad genetic base that eliminates redundancy in the development of lines with desired horticultural traits is paramount. This study evaluated the mean performance and variations of thirteen wild tomato accessions obtained from the C.M. Rick Tomato Genetic Resource Center, University of California, Davis, USA, evaluated for agronomic, nutritional and physicochemical traits under a rain forest agro-ecology zone in Nigeria. The accessions were planted and grown in three replications with randomized complete block design. Agronomic traits, physicochemical and nutritional parameters were measured and analyzed. There was significant ($P < 0.001$) variation among accessions for all traits measured. Accession LA0130 was separated from others by cluster analysis and was outstanding for its unique attributes which include: fruit yield parameters, total soluble solids, titratable acidity and lycopene content. The principal component analysis suggests fruit yield related traits, titratable acidity and lycopene contributed most to the variation among the 13 accessions. The results obtained can be used to breed materials adapted to a rain forest agro-ecology. These wild tomato accessions have genes with desirable agronomic, nutritional and physicochemical traits that could be introgressed into breeding lines to improve commercial tomato varieties.

Keywords: agronomic traits, breeding programme, fruit quality, variation, wild relatives

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Introduction

Tomato (*Solanum lycopersicum* L. formerly *Lycopersicon esculentum* Mill.) is one of the most famous and broadly consumed vegetable crops throughout the world (Nowicki *et al*, 2013; Ajayi and Hassan, 2019). Nigeria was ranked the largest producer of tomato in West Africa and the 16th largest producer in the World with 4.2 million metric tonnes FAO (2016). These data suggest prospects for Nigeria tomato breeding programmes to enhance production efficiency by improving the quantity and quality of tomato fruit. However, extensive breeding efforts and selection over the years have modified tomato (Blanca *et al*, 2015). The decline in diversity and potential of cultivated germplasm has been reported (Jatoi *et al*, 2008; Chen *et al*, 2009). To enlarge the gene pool of cultivars, breeders now focus on introgression of desirable genes from wild relatives (Singh, 2006) .

Wild tomato species have a rich reservoir of useful genetic traits needed to improve cultivated toma-

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toes and serve as sources of genetic variability (Hanson *et al*, 2007). Miller and Tanksley (1990) reported that the genomes of cultivated tomato contain 5 % of the genetic variation of their wild relatives. These wild tomato species are native to western South America and distributed from central Ecuador, through Peru to northern Chile, and in the Galápagos Islands (Darwin *et al*, 2003). There are 16 wild species of tomato, namely *Solanum habrochaites*, *S. pennellii*, *S. pimpinellifolium*, *S. cheesmaniae*, *S. galapagense*, *S. peruvianum*, *S. corneliomulleri*, *S. chilense*, *S. chmielewskii*, *S. arcanum*, *S. neorickii*, *S. huaylasense*, *S. lycopersicoides*, *S. ochranthum*, *S. jugandifolium*, and *S. sitiens* (Rick and Fobes, 1975; Peralta *et al*, 2008; Zuriaga *et al*, 2009). The closest wild ancestor to cultivated tomato is *S. pimpinellifolium* L. found in the centre of origin of tomato from the northern part of Chile to Colombia. Most of these wild relatives are vulnerable to extinction because of their small population sizes (Bai and Lindhout, 2007; Onyia *et al*, 2019). Therefore, wild tomato accessions stored in genebanks need to be evaluated in time and space in order to identify significant traits and valuable potential. Documented information about the performance of wild tomato accessions will aid future use in tomato breeding programmes.

Currently, the breeding programme at the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria has made diverse collections of landraces, cultivars and wild tomato accessions. Only the landraces and cultivars have been extensively studied for their agronomic performance and resistance to abiotic and biotic stresses (Olaniyi *et al*, 2010; Nnabude *et al*, 2015). However, the wild accessions obtained from the C.M. Rick Tomato Genetic Resource centre, University of California, Davis, USA have not been studied for the identification of useful agronomical traits, nutritional and physicochemical parameters in Nigeria.

In addition to fruit yield and improved agronomical traits, the fruit quality and nutritional parameters are essential breeding objectives from a consumer's point of view and even in the processing industries (Bauchet and Causse, 2012; Bergougnoux, 2014). Fruit quality and physicochemical parameters are cultivar dependent (Riahi *et al*, 2009; Ilahy *et al*, 2011; Domínguez *et al*, 2012). Fertilization, cultural practices and postharvest storage could influence fruit quality and physicochemical parameters (Rosales *et al*, 2011; Beckles, 2012). Production of quality tomato fruits depends on the climatic conditions, sunlight availability, good agronomic practices and genetic variability among cultivars (Causse *et al*, 2003; Peixoto *et al*, 2018).

In order to identify, select and develop novel tomato lines with desired horticultural traits for a Nigerian breeding programme, it is crucial to evaluate tomato accessions which are wild to the Nigerian germplasm. These could then be subjected to diverse breeding methodologies and agronomic practices (Chitarra and Chitarra, 2005). Knowledge of desirable traits from the evaluated tomato accessions will help to identify those that could be used as parents in a tomato breeding programme, hence, promoting improved nutrition and increased production (Causse *et al*, 2003; Álvaro Toledo and Burlingame, 2006).

This study evaluated mean performance and variation among wild tomato accessions based on agronomic, nutritional and physicochemical traits under rainforest agro-ecology in Nigeria.

Materials and Methods

Germplasm

The accessions evaluated in this study are from the C.M. Rick Tomato Genetic Resource Centre (TGRC), University of California, Davis, USA (Table 1). They are part of the tomato wild relatives core collection of the NIHORT germplasm bank without previous utilization information that could be included in breeding programmes.

Nursery and field operations

Seeds were sown into perforated nursery trays filled with sterilized soil and grown for three weeks in a greenhouse at NIHORT, Ibadan, Oyo State (Rain forest zone; 3° 56'E, 7° 33' N; 168 meters above sea level). The perforated nursery trays were kept moist by regular watering on daily basis at sunrise and sunset with tap water using a watering can. Seedlings were transplanted to the field in paired rows in plots that were 2 m long with spacing of 0.5 m between rows and 0.5 m between plants within a row. Spacing between plots was 1 m. Seedlings were arranged in a randomized complete block design with three replications. N-P-K (15-15-15) fertilizer was applied at the rate of 120 kg/ha three weeks after transplanting. The plants were trellised to prevent lodging and loss of fruits due to diseases and pests. Manual weeding was carried out at two-week intervals. To protect the leaves from defoliating pests, plants were sprayed with the pyrethroid insecticide Cymbush containing cypermethrin at 2, 6, and 9 weeks after transplanting at the rate of 450 ml of active ingredients per 100 liters of water per hectare using a knapsack sprayer. No disease infestation was observed during the experiment and data were collected on five randomly selected plants per plot.

Sample preparation

Uniformly ripe, healthy fruit at the red-ripe stage were harvested (Hanson *et al*, 2004). A total of 10-15 representative fruit were collected from pre-tagged plants (from the first 3 clusters) to minimise intra-plant variability (Borja *et al*, 1998). Tomato samples (100 g) were homogenized in 50 mL of water in a water bath at 4°C and low light (to reduce antioxidant loss) for physicochemical analysis. All analyses were done in triplicate for each sample at the Product Development Laboratory of NIHORT.

Table 1. Description of the 13 species of wild tomato accessions used for the experiment

No.	Accession ID	Species	Origin (Area of collection)
1	LA0103	*Solanum peruvianum* (L.) Miller	Cajamarquilla Lima, Peru
2	LA0130	*Solanum chilense* Dunal	Moquegua, Peru
3	LA0411	*Solanum pimpinellifolium* (L.) Miller.	Pichilingue, Los Rios, Ecuador
4	LA1028	*Solanum chmielewskii* (C.M. Rick et al.)	Casinchichua, Apurimac, Peru
5	LA1041	*Solanum cheesmanii* L. Riley	Santa Cruz, El Cascajo, Galapagos Islands, Ecuador
6	LA1136	*Solanum cheesmanii* L. Riley	Gardner st, Floreana Islet, Galapagos Islands, Ecuador
7	LA1208	*Solanum esculentum* var. *cerasiforme* Dunal	Sierra Nevada, Colombia
8	LA1272	*Solanum pennellii* (Correll) D'Arcy	Pesquera, Lima, Peru
9	LA1293	*Solanum peruvianum* f. *glandulosum* (C.F. Mull)	Matucana, Lima, Peru
10	LA2641	*Solanum parviflorum* (C.M. Rick et al.)	Apurimac, Peru
11	LA4113	*Solanum sitiens* I.M. Johnst.	Estación Ceres, Antofagasta Chile
12	LA4115	*Solanum sitiens* I.M. Johnst.	Quebrada Desde Cerro, Oeste De Paqui, Antofagasta, Chile
13	LA4138	*Solanum pimpinellifolium* (L.) Miller	El Corregidor, La Molina, Lima, Peru

Physicochemical and nutritional analyses

Total soluble solid (°Brix) (g 100 g^{-1}) of the juice was measured using the Eclipse hand-held refractometer [PN# 45-01 (0-15 °Brix)] and the pH of the fruit juice was measured using a benchtop pH meter (Sper scientific benchtop) with the pH meter calibrated with standard buffers pH 4 or 9. For determination of titratable acidity (g 100 g^{-1}) and vitamin C content (mg 100 g^{-1}), 10 mL of juice from 10 fruits was diluted in 100 mL of distilled water and titrated with NaOH (0.1 N) to pH 8.2. For vitamin C, the solution was titrated with iodine (0.1 N) until a colour change was observed (International Plant Genetic Resources Institute, 1996) .

To determine lycopene content (mg 100 g^{-1}), 5 mL of acetone-n-hexane mixture in the ratio 4:6 was added to 0.8 g of tomato pulp for each sample and mixed well. The mix was centrifuged at 5000 rpm for 5 min at 4°C; the supernatant was extracted and absorbance measured with a spectrophotometer (model 6400, Jenway) at 503 nm using the acetone-n-hexane mix as blank (Rosales *et al*, 2006). Lycopene content was calculated using an extinction coefficient ($E^{\%}$) of 3150.

Agronomic data collection

Data were collected on the following traits: number of leaves at maturity (NLM), plant height at maturity (PH), number of clusters per plant (NCP), number of fruits per cluster (NFC), fruit weight (FW), fruit length (FL), fruit circumference (FC), number of fruits per plant (NFP) and fruit size index (FSI). Fruit yield of tomato was adjusted to t ha^{-1}using the following formula: Fruit yield (t ha^{-1}) = fruit yield per plot (kg) x 10,000 / plot area (m^2) x 1,000.

Statistical analysis

The data was subjected to analysis of variance (ANOVA) using PROC GLM in SAS (SAS Institute, 2010) . Means were separated using Fisher's least significant difference (LSD) test ($P < 0.05$). A rank summation index (RSI) (Mulumba and Mock, 1978) was constructed to create the aggregate trait by ranking accessions with regard to high fruit weight, fruit yield, improved agronomics, nutritional and physicochemical traits. Ranks were summed for each accession to select the top five. Pearson's correlation analysis was done to determine associations among all traits measured with SAS. Hierarchical cluster analysis was performed using SAS PROC CLUSTER based on centroid distance and a dendrogram constructed by PROC TREE in SAS to identify divergent groups. To identify patterns of morphological variation, principal component analysis (PCA) was conducted. Those PCs with Eigen values >1 were selected (Jeffers, 1967). The PCA analysis reduces dimensions of a multivariate data to a few principal axes, generates an Eigen vector for each axis and produces component scores for characters (Sneath and Sokal, 1973).

Results

The ANOVA produced significant mean squares for all agronomic, nutritional and physicochemical traits of the tomato accessions indicating genetic variations for all measured traits (Table 2). The coefficient of variation (CV) used to measure the precision of the experiment indicated the data was reliable (Table 2). Phenotypic variation in the biological growth stages of tomato accessions revealed that LA4113 was tallest and LA2641 shortest (Table 3). The most fruits per cluster were observed for accession LA0103 and least for LA1041. The most fruits per plant were observed for accession LA0411, the least for LA4138. For fruit yield related

Table 2. Mean squares from analysis of variance of agronomic, nutritional andphysicochemical traits of wild tomato accessions

Source	df	NLM	PH (cm)	NCP	NFC	FW (g)	Fruit yield (t/ha)	FL (cm)	FC (cm
Replication	2	752.03	65.89	4.58	31.57**	57571.79**	1.44**	0.19*	0.15
Accessions	12	3254.65***	148.54***	31.89**	28.52***	24458.12*	0.61*	0.37***	0.65***
Error	24	408.16	37.18	10.53	4.80	11010.68	0.28	0.05	0.11
CV		17.77	13.67	33.11	29.22	68.32	68.32	13.20	19.79

Source	df	NFP	FSI	VIT C (mg/100 g)	TSS (°Brix) (g/100 g)	TA (g/100g)	Fruit juice pH	Lycopene (mg/100 g)
Replication	2	1381.87	0.02	2.3	0.0004	0.0003	0.003	0.51
Accessions	12	4605.24***	0.08***	147.40***	0.51***	0.17***	0.08***	106.12***
Error	24	841.79	0.02	2.54	0.03	0.002	0.002	0.31
CV		42.25	12.37	4.94	4.14	4.74	0.95	2.38

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.
CV = Coefficient of variation, NLM = Number of leaves at maturity, PH = Plant height at maturity, NCP = Number of cluster per plant, NFC = Number of fruits per cluster, FW = Fruit weight, FL = Fruit length, FC = Fruit circumference, NFP = Number of fruits per plant, FSI = Fruit size index, VIT C = Vitamin C, TSS = Total soluble solids, TA = Titratable acidity.

traits, tomato accession LA0130 had the heaviest fruit and most fruit yield, LA1293 had the lowest fruit weight and least fruit yield. Accession LA0411 had the highest concentration of vitamin C. LA1028 had the highest levels of total soluble solids while accessions LA4113, LA4138, LA1041 had the lowest levels. Accessions LA1208 and LA4133 had the lowest titratable acidity, LA2641, LA1293 and LA0130 had the lowest fruit juice pH. Lycopene content was highest in tomato accession LA0130 and lowest in LA1208 (Table 3).

Based on a rank summation index (RSI) of 13 accessions, LA0130 was identified as best performing among all tested accessions, with the best fruit yield performance, desirable agronomic, nutritional and physicochemical traits. Tomato accession LA0130 was characterized by moderate plant height, highest number of fruits per cluster, fruit weight and fruit yield (Table 3). Accession LA0130 also had the highest titratable acidity and lycopene content, but moderate fruit juice pH (Table 4).

Pearson's correlation coefficient was calculated to determine associations among traits and showed variation for some trait combinations (Table 5). Fruit yield was significantly positively correlated with fruit weight coupled with a significant negative correlation with number of leaves at maturity. Fruit size index was significantly negatively correlated with fruit circumference and significantly positively correlated with vitamin C content. Total soluble solid was significantly positively correlated with number of leaves at maturity and vitamin C content. Titratable acidity was significantly positively correlated with number of fruit per plants and total soluble solid. Fruit juice pH was significantly negatively correlated with number of fruit per plant, total soluble solid and titratable acidity. Lycopene content was positively significantly correlated with vitamin C content and titratable acidity.

All agronomic traits, nutritional and physicochemical parameters measured which showed significant variations were adopted to construct a hierarchical cluster based on the centroid distances among the 13 tomato accessions as in Figure 1. Cluster analysis differentiated the accessions into 4 distinct groups, where LA0130 differed from the other three groups. Cluster I consisted of five accessions, cluster II had four accessions, and clusters III and cluster IV had three and one accessions, respectively indicating variation among the accessions.

Additionally, contribution of each measured trait to the total variation within the accession was further determined through Principal Component Analysis (PCA) based on correlation matrix of the variables. The Scree plot of the PCA indicated six eigenvalues corresponding to the entire percent variance with eigenvalues >1. PCA1 accounted for about 22 % of variation, PCA2 for 19 %, PCA3 for 15 %, PCA4 for 11 %, PCA5 for 10 % and PCA6 for 6 % (Table 6). The first principal component axis (PCA1) was mainly loaded positively by fruit yield, fruit yield related traits and titratable acidity. In PCA2 traits which had positive contribution were number of leaves at maturity, plant height at maturity, titratable acidity and lycopene. Fruit length, fruit circumference, total soluble solids and lycopene had positive contributions in PCA3. In PCA4 plant height at maturity, number of clusters per plant, fruit weight, fruit yield and fruit juice pH had positive contributions were. In PCA5 number of clusters per plant, number of fruits per cluster, fruit length, fruit circumference and total soluble solids had positive contributions. In PCA6 traits which had positive contributions were fruit length, fruit size index and Vitamin C content.

Discussion

Significant phenotypic variations among the accessions for all agronomic, nutritional and physicochemical traits validate availability of genetic diversity in the collection from the C.M. Rick Tomato Genetics

Table 3. Mean ranking of agronomic traits of wild tomato accessions evaluated under the rainforest agro-ecology zone in Nigeria

S/N	Accession	PH (cm)	NFC	NFP	FW (g)	Fruit yield (t/ha)	NLM	NCP	FL (cm)	FC (cm)	FSI	RSI
1	LA0130	44.14	11.72	95.42	380.00	1.90	99.67	9.72	2.30	2.05	1.15	30
2	LA0411	52.97	8.64	143.78	113.33	0.57	137.67	9.78	1.22	1.17	1.05	51
3	LA1136	45.22	8.50	79.33	236.67	1.18	109.67	8.44	1.33	1.20	1.13	63
4	LA2641	29.64	10.94	106.72	140.00	0.70	96.00	7.28	1.67	1.40	1.19	65
5	LA0103	48.39	10.20	86.23	143.33	0.72	108.00	18.39	1.85	1.90	0.98	67
6	LA1272	35.96	9.39	94.50	156.67	0.78	107.00	7.73	1.60	1.90	0.86	69
7	LA1208	39.74	4.28	28.95	220.00	1.10	49.00	8.55	1.50	2.27	0.67	71
8	LA1028	46.29	5.67	28.83	93.33	0.47	171.67	8.89	2.35	2.79	0.84	79
9	LA1293	50.92	6.34	95.72	40.00	0.20	145.00	10.11	1.38	1.45	0.99	80
10	LA4115	44.96	3.95	27.94	200.00	1.00	138.33	9.39	1.58	1.67	0.95	83
11	LA4138	40.85	3.67	20.72	90.00	0.45	138.33	7.16	1.78	1.37	1.31	83
12	LA1041	44.91	3.33	30.50	130.00	0.65	68.00	7.17	1.71	1.69	1.02	84
13	LA4113	56.00	10.89	53.98	53.33	0.27	110.00	14.78	1.32	1.40	0.95	85
	Minimum	17.92	2.67	11.25	10.00	0.05	34.00	5.83	1.20	1.00	0.66	
	Maximum	62.08	15.83	205.83	500.00	2.50	176.00	29.17	2.41	2.90	1.46	
	Mean of Top 5	44.07	10.00	102.30	202.67	1.01	110.20	10.72	1.67	1.54	1.10	
	Grand mean	44.61	7.50	68.66	153.59	0.77	113.72	9.80	1.66	1.71	1.01	
	Sel. Differential (%)	-1.22	33.32	48.98	31.95	31.95	-3.09	9.41	0.78	-9.83	9.40	
	LSD (5 %)	10.28	3.69	48.89	176.83	0.88	34.05	5.47	0.37	0.57	0.21	

PH = Plant height at maturity, NFC = Number of fruits per cluster, NFP = Number of fruits per plant, FW = Fruit weight, NLM = Number of leaves at maturity NCP = Number of cluster per plant, FL = Fruit length, FC = Fruit circumference, FSI = Fruit size index. RSI = Rank Summation Index. Sel. Differential = Selection differential is estimated as a proportion (%) of mean of all accessions

Table 4. Ranking of the mean performance of nutritional and physicochemical parameters of wild tomato accessions evaluated under the rainforest agro-ecology zone in Nigeria

S/N	Accession	Vit C (mg/100 g)	TSS (°Brix)	TA (g/100 g)	Fruit juice pH	Lycopene (mg/100 g)	RSI
1	LA0130	42.46	4.50	1.38	4.85	32.54	30
2	LA0411	46.28	4.50	1.26	4.9	31.02	51
3	LA1136	29.21	3.75	0.76	5.3	24.42	63
4	LA2641	32.07	3.88	0.98	4.8	15.11	65
5	LA0103	33.63	3.75	0.74	5.15	21.57	67
6	LA1272	21.02	3.75	0.95	5.00	16.13	69
7	LA1208	26.01	4.00	0.63	5.30	13.43	71
8	LA1028	34.56	4.85	0.82	5.05	22.16	79
9	LA1293	25.53	4.50	1.31	4.85	26.16	80
10	LA4115	25.38	3.75	1.02	5.10	27.65	83
11	LA4138	40.21	3.50	0.70	5.05	26.51	83
12	LA1041	31.38	3.50	0.85	5.30	31.24	84
13	LA4113	30.64	3.50	0.69	5.15	18.63	85
	Minimum	20.90	3.25	0.6	4.80	12.64	
	Maximum	46.29	5.20	1.39	5.30	32.81	
	Mean of Top 5	36.73	4.08	1.02	5.00	24.93	
	Grand mean	32.18	3.98	0.93	5.06	23.58	
	Sel. Differential (%)	14.13	2.42	10.01	-1.22	5.73	
	LSD (5 %)	2.95	0.31	0.08	0.09	1.04	

VIT C = Vitamin C, TSS = Total soluble solids, TA = Titratable acidity. RSI = Rank Summation Index. Sel. Differential = Selection differential is estimated as a proportion (%) of mean of all accessions

Table 5. Pearson's correlation coefficient (r) of agronomic, nutritional and physicochemical traits of wild tomato accessions evaluated under a rainforest agro-ecology in Nigeria

	NLM	FW (g)	Fruit yield (t/ha)	FC (cm)	NFP	FSI	VIT C (mg/100 g)	TSS (°Brix)	TA (g/100 g)	pH
FW	-0.32*									
Fruit yield	-0.32*	1.00***								
FC	0.03	0.01	0.01							
NFP	-0.05	0.18	0.18	-0.34*						
FSI	0.18	0.05	0.05	-0.60***	0.18					
VIT C	0.19	0.08	0.08	-0.07	0.22	0.40*				
TSS	0.37*	0.08	0.08	0.30	0.30	-0.10	0.38*			
TA	0.24	0.15	0.15	-0.08	0.50***	0.18	0.32	0.66***		
pH	-0.35*	0.04	0.04	0.03	-0.49***	-0.21	-0.31	-0.51***	-0.76***	
Lycopene	0.27	0.15	0.15	-0.14	0.10	0.35*	0.58***	0.32*	0.57***	-0.14

*, *** Significant at 0.05 and 0.001 probability levels, respectively.
NLM = Number of leaves at maturity, FW = Fruit weight, FC = Fruit circumference, NFP = Number of fruits per plant, FSI = Fruit size index, VIT C = Vitamin C, TSS = Total soluble solids, TA = Titratable acidity, pH = Fruit juice pH.

Table 6. Eigenvalue, proportion of variability and estimated traits of wild tomato accessions contributing to first six principal components

Traits	PC1	PC2	PC3	PC4	PC5	PC6
NLM	-0.08	0.31	0.20	-0.04	0.00	-0.07
PH (cm)	-0.16	0.34	0.06	0.32	-0.07	-0.20
NCP	-0.08	0.18	-0.12	0.48	0.21	0.13
NFC	0.29	0.07	-0.28	0.12	0.24	0.15
FW (g)	0.37	-0.26	0.06	0.27	-0.06	-0.08
Fruit yield (t/ha)	0.37	-0.2	0.06	0.27	-0.06	-0.08
FL (cm)	0.03	-0.05	0.41	0.07	0.30	0.51
FC (cm)	-0.09	-0.13	0.32	0.09	0.54	0.09
NFP	0.32	0.22	-0.21	-0.05	0.06	-0.08
FSI	0.14	0.11	0.03	-0.10	-0.48	0.53
VIT C (mg/100 g)	0.16	0.25	0.22	0.16	-0.16	0.33
TSS (°Brix)	0.19	0.21	0.31	-0.11	0.24	-0.29
TA (g/100 g)	0.30	0.26	0.20	-0.18	0.02	-0.24
Fruit juice pH	-0.24	-0.27	-0.10	0.29	-0.17	-0.08
Lycopene (mg/100 g)	0.13	0.19	0.34	0.12	-0.34	-0.11
Eigenvalue	4.15	3.68	2.82	2.12	1.98	1.08
Proportion (%)	22	19	15	11	10	6
Cumulative (%)	21	41	56	67	78	83

NLM = Number of leaves at maturity, PH = Plant height at maturity, NCP = Number of cluster per plant, NFC = Number of fruits per cluster, FW = Fruit weight, FL = Fruit length, FC = Fruit circumference, NFP = Number of fruits per plant, FSI = Fruit size index, VIT C = Vitamin C, TSS = Total soluble solids, TA = Titratable acidity.

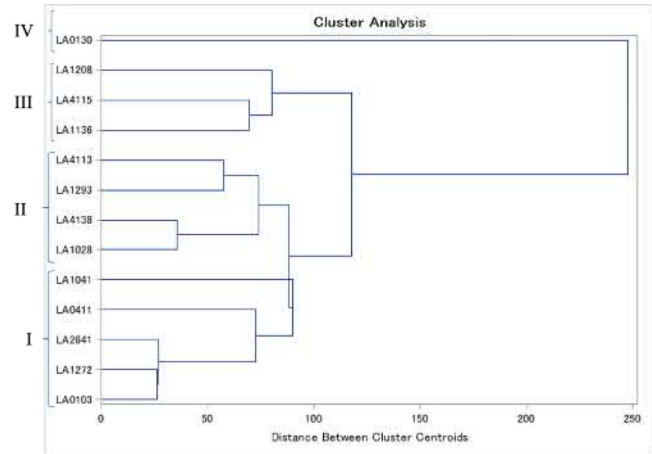

Figure 1. Dendrogram of 13 wild tomato accessions based onagronomic traits, nutritional and physicochemical parameters generated by centroid hierarchical cluster analysis

Resource Center (Chetelat, 2004, 2006). Previous research reported significant variations for agronomic traits for cultivated tomato varieties grown in various environments in Africa (Chernet and Zibelo, 2014; Shiberu, 2016; Regassa *et al*, 2016). This study indicates a wealth of genetic variability for fruit quality traits of wild tomato accessions. Accessions LA0411 and LA2641 had the highest number of fruit per plant which could be ascribed to genetic variation in flower abortion (Kanneh *et al*, 2017). Numbers of fruit per plant from this study were higher than the values reported by Ceballos-Aguirre and Vallejo-Cabrera (2012), but similar with the report of Agong *et al* (2001). The mean performances for fruits per cluster and fruit weight in our study were higher than the results presented by Ceballos-Aguirre and Vallejo-Cabrera (2012) who worked on wild tomato accessions from the Tomato Genetics Resources Center (TGRC), University of California-Davis. Disparities in the results from this study may be due to difference in the accessions evaluated, number of days before transplanting, agronomic practices used, and the environment.

Important quality traits that determine flavor, shelf life and market-related attributes of tomato are total soluble solids, fruit juice pH, titratable acidity, lycopene and Vitamin C content. The quality of tomato fruit for industrial processing and paste production depends on a high value of total soluble solids. Total soluble solids recorded in this present study ranged from 3 to 5 °Brix which is comparable to the minimum value of total soluble solids (4.5 °Brix) reported by Campos *et al* (2006) but considered low for industrial tomatoes. Previous studies have reported a range from 4 to 6 °Brix for total soluble solids of tomato fruits (Alcántar *et al*, 1999; Cramer *et al*, 2001; Pascale *et al*, 2001). High total soluble solid increases tomato paste efficiency and must be between 5.0 and 6.5 % in industrial tomatoes (Teka, 2013). The range of 4.80 – 5.30 for tomato fruit juice pH reported in this study is considerably high. Tomato fruit juice pH values can vary from 4.25 to 4.78 and fruits with high pH values may not be recommended for fresh tomato consumption or industrial processing (Paulson and Stevens, 1974; Anthon *et al*, 2011; Rajae *et al*, 2018). A pH below 4.50 is desirable because it reduces proliferation of microorganisms and indicates quality (Mohammed *et al*, 1999; Tigist *et al*, 2013). However, the pH of ripe tomatoes may exceed 4.50 because a higher pH value is associated with flavor (Stevens, 1972). Titratable acidity in this study was higher than previously reported (George *et al*, 2004; Tigist *et al*, 2013; Rajae *et al*, 2018). Tomatoes are considered the main source of lycopene compounds and a major source of carotenoids in the human diet (Willcox *et al*, 2003). Lycopene imparts the red color to tomato and affects quality. The range for lycopene content reported in the literature is between 0.58-6.50 mg 100 g^{-1} (Rickman *et al*, 2007; Saha *et al*, 2010), which is lower than reported in this study. The Vitamin C concentrations reported in this study for all accessions were higher than reported by Aoun *et al* (2013), but consistent with the range reported by Franke *et al* (2004) and Saha *et al* (2010). Our results show that wild tomato accessions contain significant antioxidants and may be useful for nutritional improvement in tomato breeding programmes (Tigchelaar, 1986) . All fruit quality and nutritional traits measured in this study reveal the value of the wild tomato accession as a source of useful alleles and their utilization as interesting donor parents in cultivar development.

Selection of the top outstanding five accessions with RSI may be useful as donor parent through intra and interspecific hybridization (Ghani *et al*, 2020) and may result in a significant increase in tomato fruit weight and fruit yield. This gain in fruit weight and yield could also be associated with improvement in number of fruits per cluster, number of fruits per plant, titratable acidity, lycopene content and fruit juice pH. To improve breeding efficiency and selection indices in crop improvement, knowledge about correlation among traits is essential (Nzuve *et al*, 2014). Results from Pearson's correlation coefficients indicate that as tomato fruit yield increases, number of leaves at maturity decreases significantly. Selection based on fruit weight and reduction in number of leaves at maturity could lead to tomato fruit yield improvement. There were significant negative correlations between fruit juice pH and titratable acidity. This implies that increased fruit juice pH was accompanied by a decrease in titratable acidity and acid concentrations and is associated with maturity (Teka, 2013). Significant positive correlations between total soluble solids and titratable acidity in this study corroborate findings of Aoun *et al* (2013), and also indicated that plants with high sugar content have more free organic acids than plants with low sugar content (Saliba-Colombani *et al*, 2001; Georgelis, 2002; Getinet *et al*, 2008). With positive correlations, genes controlling these traits could be linked to, or be under control of, pleiotropic effects (Boćanski *et al*, 2009). Positive and/or negative desirable relationships among some agronomic, nutritional and physicochemical traits indicate that desirable genes in these wild accessions could be exploited in further breeding activities for cultivar improvement (Sujiprihati *et al*, 2003).

Furthermore, the wild tomato accessions were arranged in 4 clusters; with cluster IV appearing as the most phenotypically diverse. The best performing accession LA0130 in cluster IV has the highest number of fruits per cluster; highest fruit weight, fruit yield, vitamin C concentration, lycopene content, and moderate total soluble solids, titratable acidity and fruit juice pH. This accession might harbor novel traits that are lacking in cultivated tomato and may be used as potential parent in tomato breeding to develop high yielding cultivars with desirable nutritional and physicochemical traits. The eigenvalue from PCA indicates importance of each principal component axis and its contribution to variability in traits of the tomato accessions. Fruit size index and vitamin C concentration play a role in explaining the variation but are less important than the first four factors.

Conclusion

This study identifies variability among the 13 wild tomato accessions evaluated. Accession LA0130 was outstanding for its unique attributes which included high number of fruits per cluster, fruit weight, fruit yield, total soluble solids, titratable acidity and lycopene content amongst others. Thus, this wild tomato accession may be considered promising to broaden the genetic variability for tomato improvement programmes. Consequently, this accession may be incorporated into the tomato breeding programme in the national institutes and could be used in hybridization for developing lines with desirable horticultural traits. Documentation of the agronomic, nutritional and physicochemical performance of the evaluated wild tomato accessions is informative for their utilization in breeding programmes. These results are useful for breeders working on the development and improvement of tomato, as desirable traits from these wild tomatoes can be transferred into the commercial tomato varieties suitable for the growth conditions in the rainforest agro-ecology zone of Nigeria and to boost production and diversity.

Conflicts of Interest:

The authors declare no conflict of interest.

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Author contributions

D.O.I. designed the experiment. D.O.I., A.O.K. and R.T.F. executed the experiment. A.O.K. performed the data analysis. A.O.K. and D.O.I. wrote the manuscript. All the authors contributed to writing the article, read and approved its submission.

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