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Performance evaluation and variability analysis for morpho-physiological traits of orange fleshed tomato varieties introduced in Nigeria climatic conditions

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Abstract. The introduction of orange flesh tomato in Nigeria climatic conditions through characterization is the best way to understand its adaptability and fight against the lack of ß-carotene in the landraces and improved varieties currently cultivated in the country. This study was aimed to evaluate7 tomato varieties comprised of 4orange-fleshed tomato imported from New Zealand and 3 local varieties for their morphological, agronomic and chemical composition and fruit quality characters. Phenotyping was used to assess the morphological and agronomic traits and while biochemical assays was used for fruit quality characters. The four orange fleshed tomato varieties were indeterminate and the 3 local varieties were determinate. There were significant variability and differences in plant height (54.93 cm to 72.23 cm), leaf number (14 to 24), leaf length (24.10 cm to 28.53 cm), length width (15.13 cm to 16.93 cm), internode length (2.41 cm to 3.29 cm), root collar (3.46 cm to 4.53 cm), days to 1% flowering (20 to 23), days to maturity (34 to 42), number of clusters per plant (5 to 10), fruits per cluster (4 to 6), fruit weight (72.64 g to 488.58 g), fruit length (27 mm to54.89 mm), fruit diameter (23.67 mm to 28 mm), transverse fruit section (1 mm to 3 mm), moisture content (92.30 to 95.33%), protein (0.15 to 1.02%), fat (0.15 to 1.02%), fibre (0.92 to 2.37%) and carbohydrate (1.86 to 6.41%). At the time the local varieties senesced they showed higher yields than the introduced varieties, but as indeterminate they were better than the local ones because they continued fruiting after the local ones died off. Flesh color of pericarps and ripened fruit color ranged from orange to red while fruit shape varied from highly rounded to cylindrical (long oblong). Fruit size showed variation from small to moderate size.

Key words: characterization, tomato, acclimation, performance, ß-carotene.

INTRODUCTION

Tomato (*Solanumlycopersicum* L.) is a vital horticultural crop largely cultivated and consumed in Nigeria. It even ranks first among the vegetable crops in the country. In Nigeria, local varieties are known for their large and medium fruit size, fleshy texture, red color at maturity. Tomato fruits are rich in vitamins (C and E), carotenoids (lycopene, β-carotene, phytoene, and phytofluene), phenolic acids (ferulic acid, caffeic acid, and chlorogenic acid) and flavonoids (naringenin, quercetin, and kaempferol) (Beecher 1998; Slimestad & Verheulb 2009; Cooperstone et al., 2015).

Most farmers live in high poverty and therefore don't eat healthy and consume oftentimes imbalanced foods. Majority of our diets are deficient in iodine, iron, and vitamin A, leading to illness, fatigue, blindness, and memory loss and increasing in mental retardation among children. A total of 600 carotenoids are discovered in the nature, among which only three are pro-vitamin A in human being that is ß-carotene, α-carotene, and ß -cryptoxanthin. It has been revealed through research that ß -carotene is the main pro-vitamin A component of ultimate carotenoid-rich foods (Parker, 1996). Vitamin A deficiency (VAD) is prevalent especially in sub-Saharan Africa because most available food contains negligible amounts of beta carotene which fails to meet the physiological requirements resulting in the impairment by high rates of infection, especially diarrhea and measles (WHO, 2009). It has been demonstrated that VAD is very severe among children than adults due to the fact that children develop faster and therefore are much more exposed to infection and acute malnutrition than adults do and also in pregnant and breastfeeding women (Underwood, 2000; Mbabu et al., 2012). VAD results in blindness and death of 250,000–500,000 African children yearly (Wariboko & Ogidi, 2014). Vitamin A deficit can cause growth limitation, decline in immunity, blindness and rise in mortality (Sommer & West, 1996). Xerophthalmia is considered as the clinical form of vitamin A deficiency, and occurs when the eye is badly affected, and is expressed as night blindness or, at its most severe, as total, irreversible blindness. In 1995, about three million children were infested with Xerophthalmiain in the world (IVACG 1995). In the same year, i.e. 1995, 227.6 million persons were affected by pre-infection vitamin A deficiency leading to in rising of illness and death rates (IVACG 1995). However, promoting the introduction of high Beta-carotene tomato varieties will help boost the income of farmers in Nigeria and enhance vitamin A and other nutrients in the daily diet of the population. Therefore, the aim of the proposed research is to enhance agriculture and food security in Nigeria by introducing high Beta-carotene tomato varieties. High Beta-carotene tomato varieties are an excellent source of vitamin A and could be grown in Nigeria to reduce malnutrition in the region. Currently, farmers in Nigeria only grow tomato varieties, which are deficient in vitamin A. This research study supports the introduction of four new varieties that are 'fit for purpose', i.e. that provide high beta-carotene with stable and high yields while having an increased capacity for adaptation to varying biotic and abiotic conditions. This will help introduce tomato traits that respond to new challenges and demands in the country, while also taking into account the economic return of farmers. Therefore, the objective of this study was to evaluate four orange-fleshed tomato on-farm for its adaptation to Nigeria climatic condition and agronomic characters.

MATERIAL AND METHODS

Plant Materials

Four high beta-carotene tomato varieties from New Zealand and 3 most cultivated local tomato varieties were used in this experiment. The names of the 4 varieties imported from New Zealand are: (i)Golden Ellipse (ii) Eye Drop Tomato, (ii) Optical Tomato and (iii)Oracle Tomato while the names of the 3 local varieties are Alara, Alausa 1 and Alausa 2. The 3 most cultivated local tomato varieties were used as check along the three imported and introduced orange fleshed tomato varieties (Table 1).

Table 1. List of 7 tomato varieties including 4 orange fleshed tomato and 3 local varieties

Variety name	Country of Origin	Population type	Plant growth habit
Optical tomato	New Zealand	Improved variety	Indeterminate
Golden Ellipse	New Zealand	Improved variety	Indeterminate
Eye Drop Tomato	New Zealand	Improved variety	Indeterminate
Oracle Tomato	New Zealand	Improved variety	Indeterminate
Alara	Nigeria	Local variety	Determinate
Alausa 1	Nigeria	Local variety	Determinate
Alausa 2	Nigeria	Local variety	Determinate

Field Experiments

The field experiment was carried out from July to October 2021. The land was cleared with manual labor and ridges were made for the planting of seven tomato varieties at the Teaching and Research farm, Bowen University, Iwo, Nigeria. The seven varieties were planted in a complete randomized block design with 4 blocks. The experimental unit was made up of three ridges with 12 ridges in a block. The following plant spacing 48 cm × 61 cm were observed within and between rows, respectively. There were a 1.5 m intervals between blocks. One healthy seedling was transplanted per hill. The best agronomic practices were observed in the course of the experiment. The experimental location was at a latitude of 7° 38' 6.97" N and a longitude of 4° 10' 53.62" E.

Measurement of parameters

Data on different morphological and agronomic characters were recorded on individual plant. Plant height (cm), leaf length (cm), number of leaves, days to maturity, number of clusters, fruit length, width, and fruit weight, color, and adaptability.

Phyto-chemical determination: Proximate composition of the tomato fruits including moisture, protein, lipid, crude fiber, ash contents were determined using the official method of the Association of official Analytical chemist AOAC (2005). All chemical analyses were performed in triplicates. Carbohydrate was determined by difference, 100% - (protein +ash + fat + fiber contents).

Statistical analysis

The collected data were subjected to statistical analysis with R software using analysis of variance and the means were compared by Fisher's *LSD* test. The level of significance was set at $P \leq 0.05$. The morphological, agronomic, and phytochemical traits were used for distinct clusters using Ward's coefficient of agglomerative hierarchical clustering in R program using dendextend (Galili, 2015). Multivariate analysis of PCA parameters was estimated using different R packages including ggplot2, FactoMineR and Factoextra.

RESULTS

Morphological characteristics

The four orange fleshed tomato varieties showed indeterminate as their growth habits while the three local varieties were determinate (Table 1). The 7 varieties tested displayed their growth potential at Bowen farm under Osun climatic conditions. The results of the analysis showed significant ($P \leq 0.05$) differences in plant height, number of leaves, leaf length and root collar (Table 2). Alausa 1 tomato variety demonstrated the tallest plant height (72.23 cm), followed by Alara (68.43 cm) and Oracle tomato variety (67.63 cm). Alausa 1 had the highest number of leaves (24.53) followed by Alara, Oracle and eye drop at 19.13; 18,27; 18, respectively. For leaf length, the highest was recorded with Oracle (28.53 cm), and followed by Alausa 1 (28.33 cm) and Golden Ellipse (27.83 cm), the lowest was recorded in Optical tomato (24.10 cm). The highest root collar was observed with Alausa 1, Alara, Aluasa 2, Oracle and Eye drop recording 4.53 cm, 4.38 cm, 4.17 cm, 4.12 cm and 4.04 cm, respectively. However, there were no significant ($P \leq 0.05$) differences in leaf width and internode length, though the highest leaf width was recorded in Eye drop and Oracle at 16.93 cm and 16.43 cm, respectively.

Yield and yield components

The results indicated significant ($P \leq 0.05$) differences in number of clusters per plant, fruits per cluster, fruit weight, fruit length, fruit diameter; and transverse fruit section (Table 3). The average fruit weight of the varieties ranged from 72.64 g to 488.58 g. The variety Alara was significantly the highest yielding variety with 488.52 g followed by Alausa 2 (444.06 g), Alausa 1 (411.99 g) and Golden Ellipse (169.39 g). The lowest (72.64 g) yielding variety was Eye drop. It should be noted that two growth habits (determinate and indeterminate) were observed among the 7 varieties used in this study and the harvest of the fruits was performed twice after which the local varieties senesced completely and died off while the 4 imported varieties were still flowering. This is the reason why the four orange fleshed tomato varieties had the lowest yields compared to the local varieties at the moment when they local varieties died off.

The mean fruits per cluster ranged from 4 to 6 (Table 3). The highest mean fruit number per cluster was recorded in Oracle (6.67) followed by Alausa 1 (6), Alara (5.67) and Optical tomato (5.33). The lowest number of fruits per cluster was harvested from Alausa 2 (4 fruit per cluster). The number of cluster ranged from 5 to 10. The highest mean cluster number was recorded in Aluasa 2 (10.33) followed by Alara (9.67) and Oracle Tomato. The lowest number of clusters was observed with Optical tomato (4.67). Golden Ellipse were superior in producing the longest fruit compared to other varieties. This indicates that the highest fruit length was recorded in Golden Ellipse (54.89) followed by Alausa 1 (52.92), Aluasa 2 (45.17), Alara (39.42) and Optical tomato (35.33); while the highest fruit diameter was recorded in Alara (34.33 mm), followed by Optical tomato (29.33 mm), Alausa 2 (28 mm) and Oracle (27.58 mm). However, non-significant ($P \leq 0.05$) differences were observed for average thickness of pericarp and number of locules among all 7 tomato varieties studied.

Table 2. Mean performance and the comparisons of tomato varieties for morphology traits

Variety	Plant height (cm)	Leaf No	Leaf length (cm)	Leaf width (cm)	Internode length (cm)	Root collar (cm)
Optical tomato	54.93 ± 16.76c	14.07 ± 4.91c	24.10 ± 7.93b	15.39 ± 6.04a	3.13 ± 2.32a	3.46 ± 1.22c
Golden Ellipse	66.07 ± 8.67ab	16.47 ± 4.85bc	27.83 ± 2.94ab	16.43 ± 3.80a	2.61 ± 1.57a	3.90 ± 0.48bc
Eye Drop Tomato	64.0 ± 12.02ab	18.0 ± 5.37b	25.67 ± 4.70ab	16.93 ± 4.26a	2.98 ± 1.77a	4.04 ± 0.56ab
Oracle Tomato	67.63 ± 9.14ab	18.27 ± 4.35b	28.53 ± 5.84a	16.47 ± 4.10a	2.41 ± 1.40a	4.12 ± 0.49ab
Alara	68.43 ± 10.27ab	19.13 ± 6.10b	26.90 ± 6.90ab	15.43 ± 6.18a	2.65 ± 1.12a	4.38 ± 0.75ab
Alausa 1	72.23 ± 9.73a	24.53 ± 6.70a	28.33 ± 3.88a	15.13 ± 91a	3.29 ± 1.88a	4.53 ± 1a
Alausa 2	63.17 ± 12.19bc	14.13 ± 3.74c	26.47 ± 6.51ab	15.31 ± 3.36a	3.26 ± 1.75a	4.17 ± 0.95ab
Mean	65.21	17.8	26.83	15.87	2.91	4.09
Mean sq	443.9	191.33	37.78	10.16	1.82	1.79
Pr(>F)	0.00425 **	4.13e-07 ***	0.0453*	0.895	0.576	0.008068 **
LSD	8.26	3.52	4.20	3.30	1.10	0.55
CV	17.48	27.26	21.58	28.70	29.26	18.61
Min	12	5	2	0.80	1.00	0.30
Max	95	40	40	29.50	7.50	6.50

Table 3. Mean performance of tomato varieties for fruit traits

Variety	NC	NF	FW	FL (mm)	FD (mm)	TP (mm)	NL	TFS (mm)
Optical tomato	4.67 ± 1.15c	5.33 ± 1.53abc	109.62 ± 16.96b	35.33 ± 5.08bcd	29.33 ± 2.67ab	2.42 ± 0.29a	4.00 ± 1.73a	2.33 ± 1.15ab
Golden Ellipse	6.33 ± 1.53bc	4.50 ± 1.32bc	169.39 ± 38.43b	54.89 ± 5.96a	24.78 ± 3.27b	2.45 ± 0.39a	2.67 ± 0.58a	1.0 ± 0b
Eye Drop Tomato	5.33 ± 1.53c	4.42 ± 1.42bc	72.64 ± 42.32b	27.0 ± 4.67d	23.67 ± 3.99b	2.02 ± 0.04a	3.67 ± 1.15a	3.0 ± 0a
Oracle Tomato	8 ± 1abc	6.67 ± 0.58a	129.47 ± 20.0b	28.58 ± 3.40cd	27.58 ± 3.8ab	2.08 ± 0.14a	2.67 ± 0.58a	1.0 ± 0 b
Alara	9.67 ± 4.04ab	5.67 ± 0.58ab	488.52 ± 153.99a	39.42 ± 6.64bc	34.33 ± 6.08a	2.06 ± 0.33a	3.67 ± 1.15a	2.33 ± 1.15ab
Alausa 1	10.33 ± 1.57a	6 ± 0.0a	411.99 ± 18.76a	52.92 ± 2.16a	26.8 ± 2.04ab	2.2 ± 0.20a	3.00 ± 0a	1.0 ± 0b
Alausa 2	7.67 ± 0.58abc	4 ± 0.0c	444.06 ± 301a	45.17 ± 10.50ab	28.00 ± 8.76ab	2.44 ± 0.27a	4.33 ± 1.15	2.33 ± 1.15ab
Mean	7.43	5.22	260.81	40.47	27.79	2.24	3.43	1.86
Mean sq	13.52	2.78	96082	367.5	36.13	0.11	1.302	2.0952
Pr(>F)	0.0217*	0.0484*	0.0107*	0.000638 ***	0.0242*	0.217	0.367	0.0433 *
LSD	3.61	1.38	240	11.22	9.06	0.45	2.01	1.45
CV	27.32	14.87	26.78	15.58	18.33	11.33	17.57	13.74
Min	4	3.25	33.27	22.00	19.00	1.67	2.00	1
Max	12	7.00	750.48	58.33	39.75	2.75	5.00	3

Table 4. Mean performance of tomato varieties for phenological traits and fruit phyto-chemical composition

Variety	DFL1 (days)	DFL50 (days)	DMT50 (days)	Ash (%)	Moisture content (%)	Protein (%)	Fat (%)	Fiber (%)
V1	23.53 ± 2.77 b	27.27 ± 0.70b	42.27 ± 0.88b	0.50 ± 0.10a	94.60 ± 0.00ab	0.01 ± 0.00de	1.02 ± 0.00a	1.20 ± 0.00d
V2	23.33 ± 1.95b	27.87 ± 0.35a	44.06 ± 1.22a	-	92.30 ± 0.10d	0.00 ± 0.00e	-	-
V3	22.67 ± 2.16b	26.87 ± 0.35b	42.53 ± 0.52b	0.53 ± 0.11a	91.67 ± 1.02d	0.00 ± 0.00e	0.47 ± 0.04b	0.92 ± 0.11d
V4	25.47 ± 1.68a	27.87 ± 0.64a	40.86 ± 0.74c	0.97 ± 0.38a	93.40 ± 0.20c	0.11 ± 0.04a	0.15 ± 0.00d	1.89 ± 0.24bc
V5	20.33 ± 1.046c	25.07 ± 0.26d	34.13 ± 0.99f	0.77 ± 0.12a	93.67 ± 0.12bc	0.09 ± 0.01b	0.21 ± 0.01d	1.05 ± 0.04c
V6	20.80 ± 0.94c	26 ± 0.37c	36.60 ± 0.73d	1.00 ± 0.61a	93.93 ± 1.03bc	0.02 ± 0.03d	0.19 ± 0.04c	2.37 ± 0.18a
V7	20.20 ± 0.77c	25.13 ± 0.91d	35 ± 0.00e	0.47 ± 0.12a	95.33 ± 0.12a	0.05 ± 0.01c	0.15 ± 0.00c	2.14 ± 0.52ab
Mean	22.33	26.58	39.35	0.71	93.55	0.03	0.37	1.60
Mean sq	58.18	21.460	242.22	0.17	4.83	0.01	0.35	1.25
Pr(>F)	$1.7x10^{-14}$ ***	$<2x10^{-16}$ ***	$<2x10^{-16}$ ***	0.21	0.00013 ***	$1.43x10^{-9}$ ***	$9.28x10^{-13}$ ***	0.0014***
LSD	1.27	0.41	0.59	0.57	1.09	0.02	0.04	0.07
CV	7.86	2.11	2.06	28.07	0.66	23.31	5.62	3.56
Min	20	24	32	0.4	90.8	0.00	0.15	0.9
Max	27	29	45	0.6	95.4	0.13	1.02	2.4

V1 = Optical tomato; V 2= Golden Ellipse; V3 = Eye Drop Tomato; V4 = Oracle Tomato; V5 = Alara; V6 = Alausa 1, V7 = Alausa 1; V8 = Alausa 2. DFL1 = days to 1% flowering, DFL50 = Days to 50% flowering; DMT50 = Days to 50% maturity.

Mean performance of tomato varieties for carbohydrate content in the fruits is showed in Fig. 1. The variety Eye drop tomato showed significantly ($P \leq 0.05$) higher carbohydrate content (6.41) followed by Alara (4.21), Oracle tomato (3.48), Optical tomato (2.67) and Alausa (2.49).

Phyto-chemical composition and phenological traits of tomato varieties

The results indicated significant ($P \leq 0.05$) differences in proximate composition such as moisture contents, proteins, and fats among the 7 varieties (Table 4). Moisture contents ranged from 91.67 to 95.33%. Alausa 2 had the highest moisture content (95.33%), followed by Optical (94.60%), Alausa 1 (93.93%), Alara (93.67%) and Oracle (93.40%). Golden Ellipse had the lowest moisture percentage (91.67%) among the tomato varieties. The fat percentage ranged from 0.15 to 1.02%. Optical tomato had the highest fat percentage (1.02%), followed by Eye Drop tomato (0.47%) and Alara (0.21%). The variety Oracle tomato had the highest protein percentage (0.11), followed by Alara (0.09) and Alausa (0.05). The fiber percentage ranged from 0.92 to 2.37 for the 7 varieties. the varieties Alausa 1 (2.27%) and Alausa 2(2.14%) had the highest fibre percentage, followed by Oracle and Optical (1.89 and 1.20, respectively. The lowest percentage was recorded for Eye Drop and Alara (0.92 and 1.05%, respectively). However, no significant ($P \leq 0.05$) differences were observed for average ash percentage among all tomato varieties. Alausa 1 and Oracle tomato had the highest ash percentage (1% and 0.97, respectively), followed by Alara and Eye Drop at 0.77% and 0.53%, respectively.

Significant differences were observed among the 7 tomato varieties in days to 1% flowering, days to 50% flowering and days to 50% maturity. Alara, Alausa 1 and Alausa 2 flowered a little bit early as they took 20 days to flower after transplanting. Alara, Alausa 2 and Alausa maturity (ripening), with an average of 35 days after transplanting (Table 4).

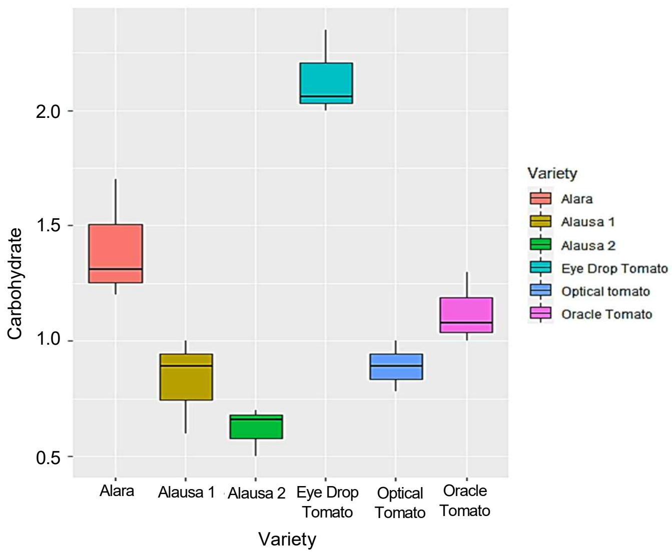

Figure 1. Mean performance and the comparisons of tomato varieties for carbohydrate content in the fruits.

The varieties Optical, Gloden Ellipse, Eye dropand Oracle exhibited orange colour at maturity and the fruit shape were rounded except for Golden Ellipse which were long oblong shape (Table 5). For the local varieties, fruits from Alara, Alausa 1 and Alausa 2 were red internally and externally and were rounded with long oblong shape except Alara with flattened shape.

Table 5. Description for qualitative traits of fruits of different tomato varieties

Variety	Ripened Fruit Colour	Flesh color of pericarp	Color of immature fruits	Predominant fruit shape	Fruit blossom end	Texture
Optical tomato	Orange	Yellow	Green	Highly rounded	Flat	Firm
Golden Ellipse	Orange	Orange	Dark Green	Cylindrical (long oblong)	Pointed	Firm
Eye Drop Tomato	Orange	Orange	Dark Green	High rounded	Flat	Firm
Oracle Tomato	Orange	Yellow	Light Green	Rounded	Flat	Firm
Alara	Red	Red	Greenish-white	Flattened (oblate)	Flat	soft
Alausa 1	Light red	Light red	Greenish-white	Cylindrical (long oblong)	Indented	Firm
Alausa 2	Red	Red	Greenish-white	Cylindrical (long oblong)	Indented	Soft/firm

Principal component analysis

The individual varieties are presented in Fig. 3 and Fig. 4 while morphological, proximate composition and agronomic variables are represented in Fig. 2 and Fig. 4.

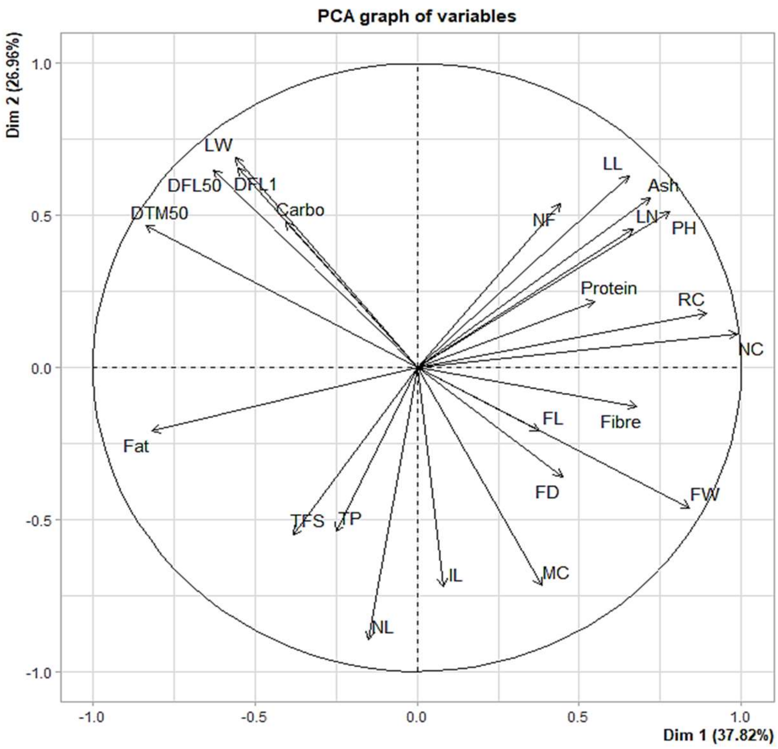

Figure 2. Individual variables at the vegetative and reproductive stage of plant growth. MC = moisture content; NC = Number of clusters per plant; NF = Fruits per cluster; FW = Fruit weight; FL = Fruit length; FD = Fruit diameter; TP = Thickness of pericarp; NL = Number of locules; TFS = transverse fruit section; DTM50 = Days to 50% maturity; PH = Plant height; Carbo = Carbohydrate; LL = Leaf length; LN = leaf number.

The principal component analysis showed that PC1 explained most of the variation observed in the traits and describes 37.81% of the original information. PC 1 includes individual varieties Alara (5) and Alausa2 (7) on the lower right portion of the graph which is characterized by a strongly positive coordinate on the axis; and while Optical tomato (1) on the lower left of the graph is characterized by a strongly negative coordinate on the axis (Fig. 3 and Fig. 4). Alara (5) and Alausa 2 (7) are characterized by: (i) high values for the variables fruit length, fiber, fruit diameter, fruit weight, moisture content and internode length and (ii) low values for the variable Thickness of pericarp, transverse fruit section, fat, number of locules. While the individual variety such as Optical tomato (1) is characterized by high values for the variables transverse fruit section, Fat, number of locules and Thickness of pericarp (Figs 2 and 4).

The PC2 accounted for 29.96% particularly distinguishes individuals such as Golden Ellipse (2), Eye Drop Tomato (3), Oracle Tomato (4), Alausa 1 (6) on the upper side of the graph, which are characterized by a strongly positive coordinate on the axis. The individual varieties such as Golden Ellipse (2) and Eye Drop Tomato (3) are characterized by high values for the variables carbohydrates, DMT50 and DFL whereas Oracle Tomato (4), Alausa 1 (6) are characterized by high values for the variables protein, NF, LL, RC, NC, PH and ash (Figs 2; 3; 4).

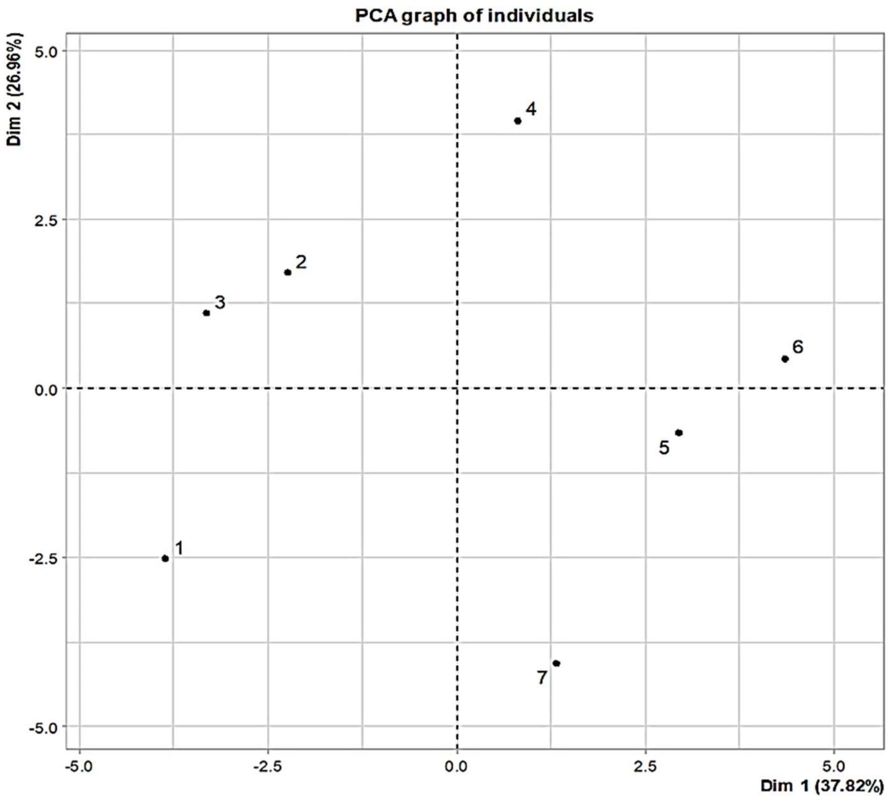

Figure 3. Individual Varieties at the vegetative and reproductive stage of plant growth. 1 = Optical tomato; 2 = Golden Ellipse; 3 = Eye Drop Tomato; 4 = Oracle Tomato; 5 = Alara; 6 = Alausa 1; 7 = Alausa 2.

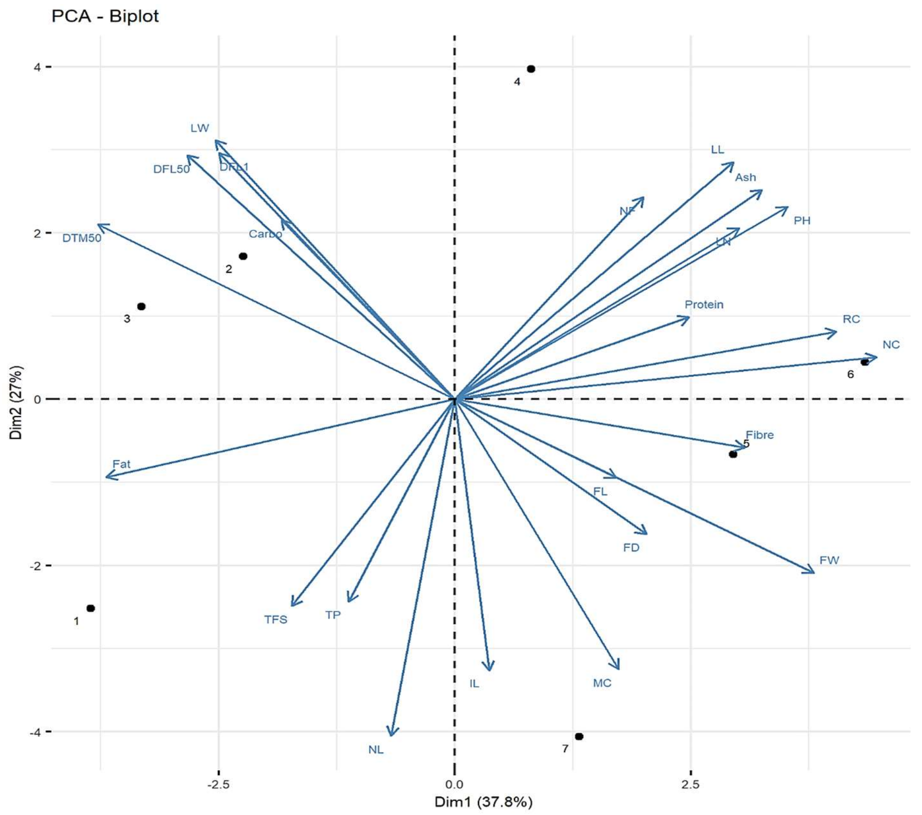

Figure 4. Contribution of individual variables and individual Varieties. 1 = Optical tomato; 2 = Golden Ellipse; 3 = Eye Drop Tomato; 4 = Oracle Tomato; 5 = Alara; 6 = Alausa 1; 7 = Alausa 2.

Fig. 5 show the contributions of the agro-morphological and phytochemical traits to form the first 6 dimensions (PCAs). Dim1, Dem2, Dem3, Dem4, Dim5 and Dim6 accounted for 37.8%, 27%, 13.7%, 11%, 5.7% and 4.7%, respectively.

The varieties were categorized into 3 groups based on the morphological, agronomic and phytochemical traits (Fig. 6), with the clusters in red and blue having the highest number of varieties (3varieties each) and the green cluster with only one variety. The clusters in red is composed of local varieties i.e. Alara, Alausa 1 and Alausa 2 while the blue cluster is made up of Optical tomato, Eye Drop Tomato, Oracle Tomato and the green cluster consisted of Golden Ellipse. Varieties in the red cluster were characterized by high mean values for Protein, RC, NC,

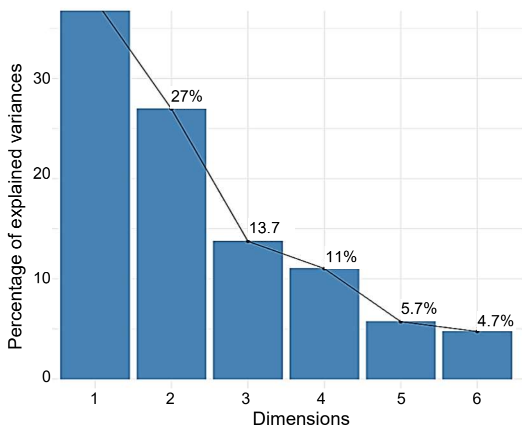

Figure 5. Contribution of the variables to the formation of the first 6 PCA (Dimensions).

Fiber, FL, FD, FW, MC and IL while those in the blue and green clusters were characterized by high mean values for Fat, TFS, TP, NL, DTM50, DFL50, carbohydrate and LW.

There were many significant correlations among the characters used for score (Fig. 7). The level of significance of the correlations at $p < 0.05$ is shown by the red and brown rounds. Either positive or negative correlations, the rounds indicate if it is statistically significant or not. The brown colors showed negative correlations while the blue colors showed positive correlations. The deeper the colors, the stronger the correlations. The correlation matrix showed that PH had a positive correlation with LN($r = 0.96$, $p < 0.001$); LL($r = 0.79$, $p < 0.05$); RC($r = 0.75$, $p < 0.05$); NC($r = 0.89$, $p < 0.01$); NF($r = 0.68$, $p > 0.05$); FW($r = 0.46$, $p > 0.05$); FL($r = 0.29$, $p > 0.05$); Protein ($r = 0.38$, $p > 0.05$); Ash($r = 0.89$, $p < 0.01$), and carbohydrate ($r = 0.14$, $p > 0.05$) but negatively correlates with IL, LW, DFL1, DFL50, DTM50, FD, TP, NL, TFS, MC and Fat.

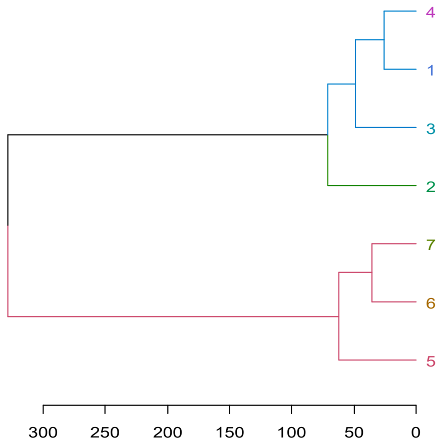

Figure 6. Hierarchical clustering dendrogram analysis; Euclidean distance was used and the associations between groups were done by the Ward method for agro-morphological and phytochemical traits.

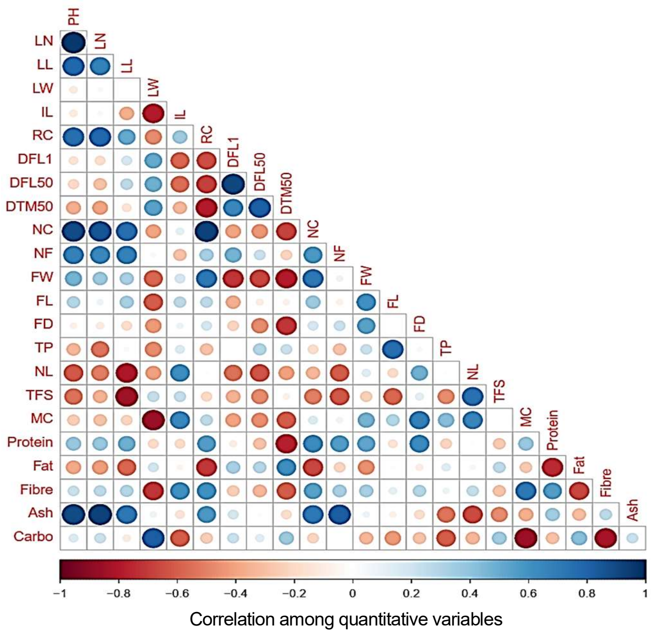

Figure 7. Correlations among the traits scored; Pearson's rank correlation matrix and performance analytic chart of the variables showing the relationship among the variables scored on the 7 tomato varieties grown. (Blue color indicates a significant positive correlation and brown color indicates a significant negative correlation among different traits.

Among the variables, NC (11.20%), RC (9.18%), FW (8.13%), DTM50 (8.05%), and Fat (7.67%) were the major contributing traits in Dim1 while NL (12.93%), IL(8.39%), MC (8.32%), and LW (7.65%) had the highest contributions to Dim2 (Table 6).

DISCUSSION

Lack of vitamin A in most of our diets has been a big challenge in developing countries due to its severe effect on our health. Providing tomato varieties rich in beta-carotene will help bridging the gaps and help preventing this condition. Thus, the assessment of four orange fleshed tomato varieties introduced in Nigeria climatic conditions for their adaptability, yields and yield components and fruit quality. Our study corroborates that of Alsina et al. (2019) who investigated β-carotene and lycopene contents on 27 varieties of tomatoes in Latvia.

Table 6. Principal component analysis showing relative contribution of characters towards divergence

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
PH	6.97	4.22	0.04	4.92	0.44
LN	5.09	3.34	0.015	3.80	10.50
LL	4.89	6.41	2.33	0.85	3.34
LW	3.62	7.65	2.19	1.68	0.75
IL	0.07	8.39	1.00	4.50	24.91
RC	9.18	0.52	1.63	4.33	0.04
DFL1	3.51	6.92	1.49	7.76	0.52
DFL50	4.52	6.80	4.86	1.15	0.19
DTM50	8.05	3.49	2.36	0.14	0.28
NC	11.20	0.20	0.02	0.05	0.21
NF	2.24	4.66	0.07	14.04	5.52
FW	8.13	3.44	0.19	0.54	4.21
FL	1.63	0.71	13.85	8.59	8.24
FD	2.31	2.07	3.28	12.81	6.99
TP	0.71	4.67	18.34	0.07	4.85
NL	0.26	12.93	4.49	0.18	1.06
TFS	1.68	4.87	16.70	0.26	1.22
MC	1.69	8.32	2.55	9.09	0.59
Protein	3.46	0.77	3.04	16.94	4.57
Fat	7.67	0.69	1.75	0.55	0.47
Fibre	5.29	0.265	4.83	0.55	14.15
Ash	5.95	4.99	0.04	2.38	6.97
Carbo	1.895997	3.66	14.94	4.84	0.01

Plant growth is expressed by its morphological and agronomic traits as a results of efficient partitioning and allocation of assimilates through efficient photosynthesis and adequate absorption of nutrients. The four orange fleshed tomato varieties tested demonstrated their growth potential at Bowen University farm under Osun climatic conditions while the 3 local varieties served as controls and checks. Phenotypic diversity was observed in the morphological and agronomic traits among the 7 varieties studies. This was exhibited through ANOVA and mean separation using Fisher's *LSD* test at 5% probability. Plant heights and root collar were very significant, and number of leaves was highly significant among the varieties. No significant differences ($P < 0.05$) were observed with internode length, leaf length and leaf width though there were slight differences in values. This finding is in congruence with many studies on phenotypic assessment of tomato accessions using morphological and agronomic traits which demonstrated large variability and variations as observed in this study (Frankel 1984; Grozeva et al., 2021). Mavromatis et al. (2013), Omar et al. (2019), Salim et al. (2020) and Kocsis et al. (2022) also showed that there was agro-morphological variation among the tomato accessions used in their studies.

We observed that the orange fleshed tomato varieties took 27 days after transplanting to reach days to 50% flowering and a maximum of 44 days for 50% ripening/maturity revealing a slight difference when compared to the local varieties used as checks. Thein (1999) in his study conducted in Thailand using 17 tomato accessions obtained from The World Vegetable Center recorded 49 days of flowering after transplanting. In another studies, the results obtained by Grozeva et al. (2021) were different to ours as the recorded days of maturity varied from 93 days to 107 days while Al Said et al. (2014) reported 34 days to flowering and between 71 to 85 days to maturity after transplanting, though they pointed out that it took some accessions 100 days to maturity after transplanting. Flower initiation is characterized by the last period of fast crop growth and development and plant preferentially and differentially translocate assimilates to the reproductive organs for better yield performance and quality. Discrepancies in days to flowering and repining are recorded in several studies and countries, which could due to the growth and development cycle of each variety and environmental conditions as each environment shows its temperature, light, moisture content, wind and relative humidity. It was revealed that individual abiotic factor with their combined effects or/and interactions significantly affect the days to flowering and maturity in tomato (Kinet, 1977). Furthermore, Hurd & Graves (1985) reported that fruit ripening is dependent on temperature as under15°C night temperature it took tomato fruits 66 days to ripen when compared to74 days at a nominal 11°C night temperature.

The results indicated significant ($P \leq 0.05$) differences in number of clusters per plant, fruits per cluster, fruit weight, fruit length, fruit diameter; and transverse fruit section (Table 3). Mrema et al (2014) reported significant differences in number of clusters which ranged from 5 to 7 in the field varies significantly The average fruit weight of the varieties ranged 72.64 g to 488.58 g. The variety Alara was significantly the highest yielding variety with 488.52 g followed by Alausa 2 (444.06 g), Alausa 1 (411.99 g) and Golden Ellipse (169.39 g). The lowest (72.64 g) yielding variety was Eye drop. It should be noted that two growth habits (determinate and indeterminate) were observed among the 7 varieties used in this study and the harvest of the fruits was performed twice after which the local varieties senesced completely and died off while the 4 imported varieties were still flowering. This is the reason why the four orange fleshed tomato varieties had the lowest yields compared to the local varieties. The Local varieties were harvested for less than a month and they senesced, whereas the improved varieties were harvested for at least two months, which was not taking into consideration for yield performance.

Our results revealed significant variations among the varieties in terms of in number of clusters per plant, fruits per cluster, fruit weight, fruit length, fruit diameter; and transverse fruit section. The variety Alara was significantly the top yielding variety with 488.52 g followed by Alausa 2 (444.06 g), Alausa 1 (411.99 g) and Golden Ellipse (169.39 g) for the two fruit harvests carried out. The 4 orange fleshed tomato varieties could not perform better than the local one at this stage as their growth habit are indeterminate and could have been superior in terms of yield and yield components over the local ones if they were harvested for the third and fourth harvest. The lowest (72.64 g) yielding variety was Eye drop. The ability of adaptability and yield performance showed by these 4 varieties under Osun climatic conditions is an evidence that they can be grown in Nigeria without problems. The highest mean fruit number per cluster was recorded in Oracle (6.67) followed by Alausa 1 (6), Alara (5.67) and Optical tomato (5.33). The lowest number of fruits per cluster was harvested from Alausa 2 (4 fruit per cluster). Thus, one of the imported varieties showed promising potential regarding fruits per cluster over the local ones. Moreover, the results obtained also demonstrated a rich diversity in terms of fruit length, fruit width. Golden Ellipse produced the longest fruits compared to other varieties. This indicates that the highest fruit length was recorded in Golden Ellipse (54.89) followed by Alausa 1 (52.92), Aluasa 2 (45.17), Alara (39.42) and Optical tomato (35.33); while the highest fruit diameter was recorded in Alara (34.33 mm), followed by Optical tomato (29.33 mm), Alausa 2 (28 mm) and Oracle (27.58 mm). Similar results with significant diversity about fruit characteristics were also observed in previous tomato studies and these findings also substantiate with our findings (Mazzucato et al., 2010; Al Said et al., 2014; Cortés-Olmos et al., 2015; Grozeva et al., 2021).

In the current study, the results for moisture contents, proteins, fats and carbohydrate among all 7 varieties indicate significant ($P \leq 0.05$) differences. Grozeva et al. (2021) in their study found that TSS, Vitamin C, AA, and TP were used to show high variability between accessions used. Many studies (Lavelli et al., 2000; Tyssandier et al., 2004; Grozeva et al., 2021) also reported that tomato fruits are rich in ascorbic acid, polyphenols, carotenoids, and other secondary metabolites.

PCA and hierarchical clustering dendrogram analysis have been used to evaluate genetic diversity and variability in many crops such as tomato (Grozevaet al., 2021), Pyrus (Zarei et al., 2019), wheat (Munir et al., 2020), Bambara (Olanrewaju et al., 2021). The agro-morphological and phytochemical traits are represented in PCA biplot as vectors, and the longer the vectors the higher the contribution of the traits to the biplot (Figs 2 and 4). Dim1 (PCA1) demonstrated higher percentage of the variation observed than the other 5 components i.e. from Dim 2 to 6. Similar results were observed by different authors in their studies (Iezzoni & Pritts, 1991; Farhad et al., 2008; Usman et al., 2014; Atoyebi et al., 2017a; Mohammed et al., 2020; Grozeva et al., 2021; Khan et al., 2021). Adeoti et al. (2021) have shown that among the dimensions, Dim1 is the always the best to use for crop improvement in terms of yield. In this study, FL, fiber, FD, FW, MC, IL TP, TPS, fat, NL, Fat, NL and TP had more influence on PC1 where yield trait is. It was also supported by Stoilova & Pereira (2013), Ridzuan et al. (2019), Grozeva et al. (2021) Olanrewaju et al. (2021) and Khan et al. (2021).

A multiple location experiments are ideal platforms and methods to understand the stability of the introduced orange fleshed tomato varieties in term of yield performances, fruit qualities and diseases and pest resistance. Moreover, the multiple location experiments will also help apprehend the genotype by environment interaction of these varieties as a one-year phenotypic assessment is not enough to draw a final conclusion on these varieties.

CONCLUSION

The results obtained from the 4 orange fleshed tomato demonstrated great potentials and yield performance during the growth and development period under Nigeria climatic conditions. Golden Ellipse, Oracle tomato and Optical tomato did better than Eye Drop tomato. Alara was significantly the highest yielding variety followed by Alausa 2 Alausa 1 and Golden Ellipse. Although the three local varieties were determinate while the four introduced were indeterminate, and the harvest of the fruits was performed twice after which the local varieties senesced completely and died off while the 4 imported varieties were still fruiting. The imported varieties have advantages over the local ones on the basis of indeterminate growth habit. A multiple location experiments are ideal platforms to understand the stability of the introduced orange fleshed tomato varieties in term of yield performances, fruit qualities and diseases and pest resistance.

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