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Original Article

Evaluation of African tomato landraces (*Solanum lycopersicum*) based on morphological and horticultural traits

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A B S T R A C T

Crop landraces represent a reservoir of genetic diversity; hence understanding and utilizing the genetic variation in tomato accessions are essential for improving the crop. The objective of this study was to characterize 69 tomato landraces from the World Vegetable Centre and the National Genebank of Kenya to identify desirable morphological and horticultural traits that could be used for tomato crop improvement. Field experiments were laid out in a randomized complete block design with three replicates at the University of Nairobi's Kabete field station, Kenya, in 2014 and 2015. Principal component analysis showed that the first five components explained 78.4% of total variation among the genotypes. Traits that contributed most to variability were the presence of green shoulder, fruit size, exterior fruit color, pubescence density, flower color and fruit cross section shape. Cluster analysis grouped the accessions into two major clusters. Cluster I contained 63 accessions while cluster II had six accessions. Analysis of variance for quantitative traits indicated significant differences among the accessions for single leaf area, soil plant analysis development, days to 50% flowering, days to maturity, the number of fruits per plant, fruit width, fruit length and fruit weight per plant. Fruit weight per plant ranged from 565.0 g to 2759.0 g per plant and showed a positive significant correlation with fruit length (r = 0.28) and fruit width (r = 0.30). The study showed the existence of wide genetic diversity among the tomato accessions thus providing scope for future genetic improvement of the crop.

Introduction

Tomato (*Lycopersicon esculentum* L.) is horticultural crop widely grown in Kenya (Musyoki et al., 2005). The crop is mainly grown for the domestic market and ranks second after potato (Horticultural Crops Development Authority, 2014). Alongside other nutrients, tomato fruit contains β-carotene, vitamin C and phenolic compounds, which offer many health benefits for the consumers (Martí et al., 2016). The production area under tomato has been on the increase in the country, and this could be attributed mainly to the increased demand for the crop. Between 2011 and 2013, the area under tomato increased by 16% from 20,584 ha to 23,866 ha. In the same period, the total volume produced increased by about 24% from 396,544 t to 494,037 t (Horticultural Crops Development Authority, 2014).

Despite this substantial improvement, tomato production has continued to face major setbacks. According to Maerere et al. (2006), some biotic and abiotic factors have been attributed to low yields and the increased cost of production. In their effort to control pests and diseases, farmers use pesticide products excessively with over 40 applications per season recorded in some tomato fields (Waiganjo et al., 2006). The low diversity among commercial tomato varieties has been identified as one of the major factors that predispose the crop to biotic and abiotic constrains (Osei et al., 2014).

Crop landraces have been used widely in breeding work and are always thought to harbor valuable traits lost among cultivated varieties and the exploitation of such traits increases research findings and knowledge of the genetic variability which facilitates breeding for wider geographic adaptability (Hanson et al., 2007). In Africa, there are large numbers of tomato landraces stored in gene banks whose phenotypic and genotypic traits are largely undocumented. Knowledge of this diversity is important to broaden the genetic resource base for future tomato crop improvement

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programs. The current study aimed to evaluate and document the extent of phenotypic diversity among African tomato landraces.

Materials and methods

Description of the research site

The study was conducted during the short and long rains of 2014 and 2015, respectively, at the University of Nairobi's Upper Kabete Field Station, Kenya. The site lies at an altitude of 1940 m above sea level and between latitude 10º14′20′S and 10º15′15 ′N and longitude 360º44′E to 360º45′E and receives bimodal rainfall averaging 1000 mm annually (Mburu, 1996). The long rains last from March to December. Mean monthly maximum and minimum temperatures are 23 °C and 12 °C, respectively (Siderius, 1976). The soils at the site are reddish brown clays overlying dark and red clays and are classified as humic nitisols which are deep, fertile, well drained with thick acid top soils and have a blocky structure which allows good root penetration and development; the clay minerals are predominantly kaolinite (Karuku et al., 2012).

Experimental treatments and design

The study evaluated 69 tomato landraces (Table 1) sourced from the World Vegetable Centre and the National Genetic Resources in Kenya. These accessions were from: Ethiopia (16), Morocco (15), Madagascar (14), South Africa (10), Egypt (3), Mauritius (3) Kenya (2), Tanzania (2), Zimbabwe (2), Nigeria (1) and Zambia (1). The accessions were planted in a randomized complete block design with three replications.

Data collection and analysis

The qualitative traits studied consisted of: stem color, growth type, pubescence density, foliage density, flower color, presence of a green shoulder, fruit shape, mature fruit color, fruit size and fruit cross-sectional shape. The traits were evaluated based on the set standards for characters by the International Plant Genetic Resources Institute tomato descriptor (Darwin et al., 2003).

The quantitative traits were: single leaf area, soil plant analysis development (SPAD), and days to 50% flowering, days to maturity, the number of fruits per plant, fruit length, fruit width fruit and fruit weight per plant. Days to flowering was recorded as the number of days from sowing to when 50% of the plants in each plot had flowered. A SPAD value was determined at the flower initiation stage on a fully expanded young leaf from three plants in each stand and averaged. This value was taken at flowering using a non-destructive, hand-held chlorophyll meter (SPAD-502; Minolta Camera Co. Ltd; Tokyo, Japan). Single leaf area was determined at flowering and calculated using leaf length and leaf width measurements following the formula of Rivera et al. (2007): $SLA = 0.763L + 0.34W$, where SLA is the single leaf area, L is the leaf length, and W is the leaf width. Days to maturity was recorded from sowing until 50% of plants had at least one ripened fruit. Fruit length and fruit width were measured at physiological maturity. Fruit length was recorded from stem end to blossom end while fruit width was recorded at the largest diameter of cross-sectioned fruits. The total number of fruits per plant was determined at physiological maturity and weighing was used to obtain the total fruit weight per plant.

Table 1
List of the African tomato accessions evaluated in the study and their country of origin.

S/no	Acc Name	Species name	Origin	S/no	Acc Name	Species name	Origin
1	GBK 050580	*S.lycopersicum*	Kenya	36	VI006481-A	*S.lycopersicum*	Zimbabwe
2	GBK 050589	*S.lycopersicum*	Kenya	37	VI006825	*S.lycopersicum*	Ethiopia
3	RV02114	*S.lycopersicum*	Tanzania	38	VI006826	*S.lycopersicum*	Ethiopia
4	RV101884	*S.lycopersicum*	Madagascar	39	VI006827	*S.lycopersicum*	Ethiopia
5	RVI01885	*S.lycopersicum*	Madagascar	40	VI006828	*S.lycopersicum*	Ethiopia
6	RVI01887	*S.lycopersicum*	Madagascar	41	VI006832	*S.lycopersicum*	Ethiopia
7	RVI01888	*S.lycopersicum*	Madagascar	42	VI006833	*S.lycopersicum*	Ethiopia
8	RVI01896	*S.lycopersicum*	Madagascar	43	VI006837	*S.lycopersicum*	Ethiopia
9	RVI01983	*S.lycopersicum*	Madagascar	44	VI006838	*S.lycopersicum*	Ethiopia
10	RVI02098	*S.lycopersicum*	Madagascar	45	VI006840	*S.lycopersicum*	Ethiopia
11	RVI02100	*S.lycopersicum*	Madagascar	46	VI006841	*S.lycopersicum*	Ethiopia
12	RVI02102	*S.lycopersicum*	Madagascar	47	VI006842	*S.lycopersicum*	Ethiopia
13	RVI02104	*S.lycopersicum*	Madagascar	48	VI006847	*S.lycopersicum*	Ethiopia
14	RVI02107	*S.lycopersicum*	Madagascar	49	VI006848	*S.lycopersicum*	Ethiopia
15	RVI02109	*S.lycopersicum*	Madagascar	50	VI006864	*S.lycopersicum*	Ethiopia
16	RVI02111	*S.lycopersicum*	Madagascar	51	VI006865	*S.lycopersicum*	Ethiopia
17	RVI02112	*S.lycopersicum*	Madagascar	52	VI006869	*S.lycopersicum*	Ethiopia
18	VI005871	*S.lycopersicum*	Morocco	53	VI006881-B	*S.lycopersicum*	Zimbabwe
19	VI005872	*S.lycopersicum*	Morocco	54	VI006892	*S.lycopersicum*	South Africa
20	VI005873	*S.lycopersicum*	Morocco	55	VI006972	*S.lycopersicum*	Tanzania
21	VI005874	*S.lycopersicum*	Morocco	56	VI007108	*S.lycopersicum*	South Africa
22	VI005875	*S.lycopersicum*	Morocco	57	VI007539	*S.lycopersicum*	South Africa
23	VI005876	*S.lycopersicum*	Morocco	58	VI007540	*S.lycopersicum*	South Africa
24	VI005877	*S.lycopersicum*	Morocco	59	VI008098	*S.lycopersicum*	South Africa
25	VI005878	*S.lycopersicum*	Morocco	60	VI008099	*S.lycopersicum*	South Africa
26	VI005889-A	*S.lycopersicum*	Egypt	61	VI008234	*S.lycopersicum*	Nigeria
27	VI005895	*S.lycopersicum*	Egypt	62	VI008916	*S.lycopersicum*	South Africa
28	VI005905	*S.lycopersicum*	Morocco	63	VI030375	*S.lycopersicum*	South Africa
29	VI005986	*S.lycopersicum*	Morocco	64	VI030379	*S.lycopersicum*	Mauritius
30	VI005987	*S.lycopersicum*	Morocco	65	VI030380	*S.lycopersicum*	Mauritius
31	VI005988	*S.lycopersicum*	Morocco	66	VI030381	*S.lycopersicum*	Mauritius
32	VI005989	*S.lycopersicum*	Morocco	67	VI030852	*S.lycopersicum*	South Africa
33	VI005990	*S.lycopersicum*	Morocco	68	VI035028	*S.lycopersicum*	South Africa
34	VI005991	*S.lycopersicum*	Morocco	69	VI037948	*S.lycopersicum*	Zambia
35	VI006480	*S.lycopersicum*	Egypt				

S/no = serial number; Acc name = accession name.

Table 2
Qualitative variation at vegetative and flowering stages among the 69 tomato accessions.

Trait	Observation	Frequency	Percentage
Growth type	Determinate	22	31.9
	Indeterminate	47	68.1
Foliage density	Dense	42	60.9
	Intermediate	22	31.9
	Sparse	5	7.2
Flower color	White	1	1.4
	Yellow	68	98.6
Stem color	Green	6	8.7
	Purple	63	91.3
Pubescence density	Dense	24	34.8
	Intermediate	45	65.2

Table 3
Qualitative variation in fruit characteristics among the 69 tomato accessions.

Trait	Observation	Frequency	Percentage
Greening shoulder	Absent	14	20.3
	Present	55	79.7
Fruit color	Red	66	95.7
	Yellow	3	4.3
Fruit shape	Cylindrical	2	2.9
	Ellipsoid	2	2.9
	Flattened	9	13.0
	Heartshaped	3	4.3
	High rounded	4	5.8
	Pyriform	2	2.9
	Rounded	47	68.1
Fruit cross-section shape	Angular	1	1.4
	Irregular	9	13.0
	Round	59	85.5
Fruit size	Intermediate	29	42.0
	Large	19	27.5
	Small	10	14.5
	Very large	11	15.9

Dissimilarities for qualitative traits were estimated based on Euclidean distance matrix and hierarchical clustering analyses using the unweighted pair group method of arithmetic averaging performed in the DARwin 6.0 software (available from: http://darwin.cirad.fr/product.php). The MINITAB software package (version 18; Minitab Inc; State College, PA, USA) was used to perform multivariate-principal component analysis (PCA). The analysis was used to identify the most significant descriptors in capturing the qualitative variation within the accessions. Analysis of variance for quantitative traits was performed using the Genstat software package (version 15; Numerical Algorithms Group Ltd; Oxford, UK). Mean separation for a treatment that was significant was tested using Fisher's protected least significant difference (LSD) test at $p = 0.05$.

Results

Qualitative traits

Most of the study accessions had indeterminate growth type (68.1%) with only 31.9% being determinate (Table 2). Foliage density of 62.3% accessions was dense while 37.7% were intermediate. The study revealed that 98.5% of the accessions produced yellow flowers while white flowers were observed with only one accession. The majority of the accessions had a purple stem (91.3%) while only 8.7% were green. Stem hairiness was mainly intermediate for 65.2% accessions while 34.8% were dense.

A large proportion of the accessions recorded the presence of greening shoulder (79.7%) while only 20.3% showed uniform greening (Table 3). Fruit color at maturity indicated the predominance of red (95.6%) with only 4.4% of the accessions being yellow. Fruit shape varied being: round (66.7%), flattened (14.5%), highly rounded (5.8%), heart shaped (4.4%), ellipsoid (2.9%), pyriform (2.9%) and cylindrical (2.9%). The shape of the fruit cross-section ranged being: round (85.51%), irregular (13.04%) and angular (1.45%). Fruit size varied being: very small (10.1%), small (17.4%), intermediate (42.0%), large (24.6%) and very large (42.0%).

Cluster analysis

Cluster analysis identified two major clusters (Cluster I and II) as shown in Fig. 1. Cluster I had 63 accessions that were grouped into seven sub-clusters while cluster II had only six accessions all of

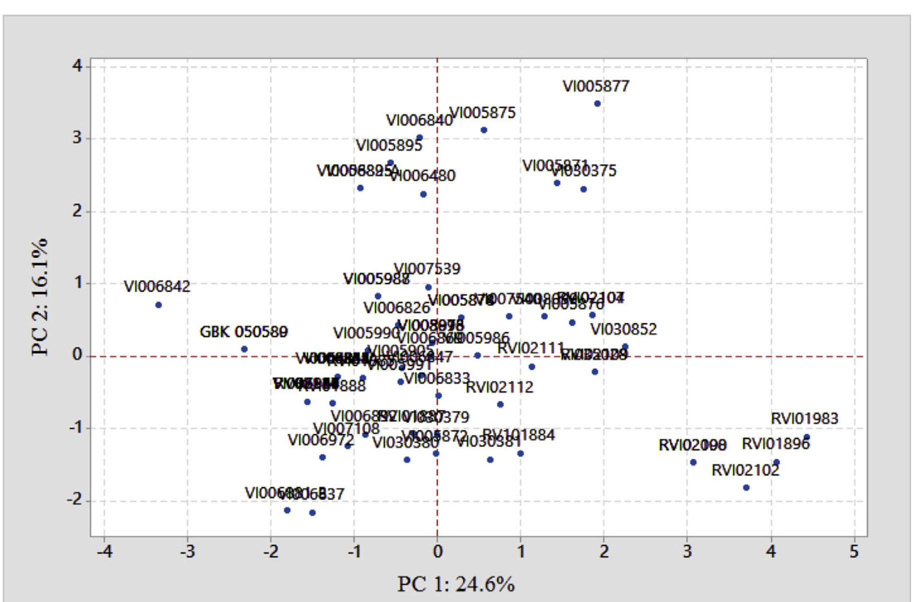

Fig. 1. Distribution of tomato accessions for first two principal components based on 10 qualitative traits.

which came from Madagascar. Accessions in clusters I and II all had purple and green stems, respectively. Sub-cluster 'a' had 17 accessions with the majority originating from South Africa and Madagascar. Most of the accessions in sub-cluster 'b' were from South Africa and Morocco while sub-cluster 'c' was dominated with accessions from Ethiopia. Sub-clusters'd', 'e', 'f' and 'g' had the least number of accessions evaluated grouped together. Sub-clusters, 'd', and 'g' had accessions from different origins while accessions from Morocco and Kenya dominated sub-clusters 'e' and 'f', respectively (see Fig. 2).

Principal component analysis

The first five components of the PCA explained 78.4% of total variations among the accessions, with the first two PCs contributing 40.7% (Fig. 1). PCA identified six traits, namely presence of green shoulder, fruit size, exterior fruit color, pubescence density, flower color and fruit cross section shape as the main traits that contributed positively to PC1. However, presence of green shoulder (0.414) and fruit size (0.336) contributed more positively to this PC compared to the rest of the traits. It was also observed that foliage density, growth type, stem color and fruit shape had negative loadings to this component at −0.478, −0.445, −0.406 and −0.091, respectively (Table 4).

Quantitative traits

Significant differences were observed for all the growth and fruit traits evaluated (Tables 5 and 6). Single leaf area was in the range 3.8–8.7 cm^2 in accessions RV102107 and VI005895, respectively, while SPAD value ranged from 45.1 (VI030380) to 62.7 (VI030852) (Table 5). Days to flowering ranged between 39 d in accession VI005905 and 64 d in VI030375. Similarly, days to maturity ranged between 79.3 d and 127.3 d with accession VI005905 being the earliest to mature while accession VI030375 the latest. Accessions with the shortest and the longest fruit length recorded means of 3.3 cm (GBK 050580) and 11.9 cm (VI005986), respectively (Table 6). The average number of fruits per plant

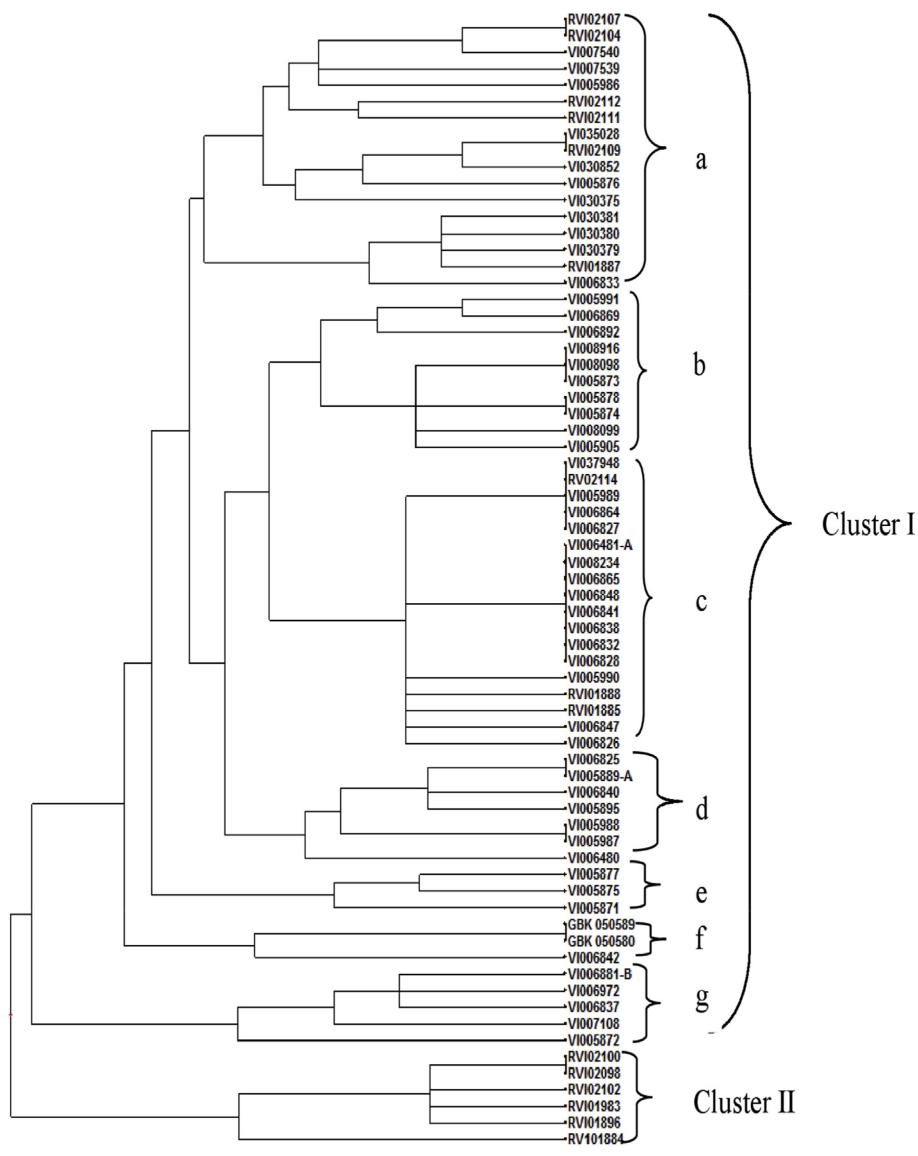

Fig. 2. Unweighted pair-group method using arithmetic averages cluster analysis phenogram showing the relationships among the 69 tomato accessions.

Table 4
Eigen values, proportion of variability and qualitative traits that contributed to the five principal components (PC) in 69 tomato genotypes.

Variable	PC1	PC2	PC3	PC4	PC5
Stem color	−0.406	0.281	0.115	−0.525	−0.095
Flower color	0.166	−0.054	0.661	−0.155	0.282
Growth type	−0.445	0.191	0.117	0.202	0.400
Foliage density	−0.48	0.047	0.104	−0.26	−0.46
Pubescence density	0.178	0.256	−0.193	−0.589	0.500
Green shoulder	0.414	0.006	−0.135	−0.277	−0.018
Exterior fruit color	0.232	−0.040	0.664	−0.022	−0.180
Fruit shape	−0.091	−0.555	0.015	−0.350	−0.074
Fruit cross section shape	0.049	0.631	0.144	0.172	−0.039
Fruit size	0.336	0.326	−0.090	−0.116	−0.504
Eigen values	2.464	1.609	1.519	1.297	0.947
% variation	24.6	16.1	15.2	13	9.5
Cumulative	24.6	40.7	55.9	68.9	78.4

ranged from 8.3 (VI007539) to 442.8 (GBK 050580). Similarly, the mean fruit weight per plant ranged between 565.0 g (RVI02098 and VI006827) and 2759.0 g (VI006826). Correlation analysis among the quantitative traits showed that fruit weight per plant had a positive and significant association with fruit length (r = 0.28), fruit width (r = 0.30) and single leaf area (r = 0.16). However, number of fruits per plant had a significant but negative correlation with days to maturity (r = −0.30), fruit length (r = −0.71) and fruit width (r = −0.66) (see Table 7).

Discussion

From the dendrogram, it was not possible to group all the tomato accessions from the same collection sites or location into their specific groups, but it was clear that most of the study accessions are quite related. It is also likely that continuous recycling of tomato seeds by farmers and selections leading to massive segregation have contributed to the wide phenotypic variability of the tomato crop. However, stem color clearly separated the accessions into two major clusters, being those with a purple stem and those with a green stem.

Significant differences were observed among the 69 accessions for all the quantitative traits evaluated. This was in agreement with the findings of Kumar et al. (2013) who reported significant variation in days to maturity, the number of fruits per plant and average fruit weight among tomato accessions. Several authors have shown a relationship between SPAD value and the nitrogen content in plant leaves (Sexton and Carol, 2002; Wang et al., 2004). This implies that accessions with high SPAD values have higher levels of nitrogen. Variations in the current study could have been attributed to the differences in genetic and environmental conditions from which the accessions were obtained. This was expected since different genotypes perform differently in the same environment (Blay et al., 1999).

The positive and significant association of fruit weight with leaf area showed that plants with a large leaf area tend to have higher yields compared to those with a smaller leaf area. Similar findings were reported by Wali and Kabura (2014). This may be explained by the greater number of photosynthetic products available for partitioning to fruit production in plants with large leaf area. Similarly, fruit weight, which is a function of fruit size, had a predictably positive and significant association with fruit length and fruit diameter. Similar findings were reported by Islam et al. (2010). The authors concluded that yield had a significant positive correlation with fruit diameter.

The significant but negative correlations observed for number of fruits per plant with days to maturity, fruit length and fruit width

Table 5
Quantitative traits (mean ± SE) among the 69 tomato accessions.

s/n	ACC.NO.	SLA	SPAD	DTF	DTM
1	GBK 050580	4.7 ± 0.1	54.0 ± 0.5	50.5 ± 0.9	92.5 ± 0.3
2	GBK 050589	4.3 ± 0.1	53.5 ± 0.4	44.0 ± 0.9	109.8 ± 0.5
3	RV02114	4.4 ± 0.1	50.8 ± 0.5	49.0 ± 0.6	91.2 ± 0.5
4	RV101884	6.1 ± 0.1	52.8 ± 0.2	49.7 ± 0.8	122.0 ± 0.6
5	RVI01885	5.2 ± 0.2	52.2 ± 0.5	51.2 ± 0.6	98.2 ± 0.7
6	RVI01887	8.1 ± 0.2	53.4 ± 0.3	54.5 ± 0.4	102.0 ± 1.0
7	RVI01888	5.6 ± 0.2	58.1 ± 0.3	62.3 ± 1.0	116.7 ± 0.7
8	RVI01896	6.5 ± 0.2	55.6 ± 0.3	53.8 ± 0.6	113.3 ± 0.6
9	RVI01983	7.1 ± 0.2	55.8 ± 0.2	61.5 ± 0.4	113.3 ± 0.4
10	RVI02098	6.6 ± 0.1	60.4 ± 0.4	42.0 ± 0.6	120.5 ± 1.0
11	RVI02100	6.1 ± 0.1	57.9 ± 0.4	42.0 ± 0.7	112.3 ± 0.7
12	RVI02102	5.7 ± 0.1	51.4 ± 0.2	42.7 ± 0.4	116.7 ± 0.8
13	RVI02104	6.8 ± 0.2	55.2 ± 0.4	52.2 ± 0.7	109.2 ± 1.0
14	RVI02107	3.8 ± 0.1	52.8 ± 0.3	40.3 ± 0.6	92.8 ± 0.9
15	RVI02109	5.6 ± 0.3	51.3 ± 0.5	41.8 ± 0.6	103.5 ± 1.3
16	RVI02111	4.3 ± 0.1	51.1 ± 0.3	39.8 ± 0.5	114.2 ± 1.2
17	RVI02112	5.1 ± 0.1	56.6 ± 0.6	49.3 ± 0.4	113.3 ± 0.9
18	VI005871	5.3 ± 0.1	54.8 ± 0.5	48.8 ± 0.8	92.7 ± 0.9
19	VI005872	5.8 ± 0.2	49.9 ± 0.4	52.7 ± 0.5	94.2 ± 0.9
20	VI005873	5.3 ± 0.3	45.9 ± 0.4	53.2 ± 0.6	112.7 ± 0.7
21	VI005874	5.8 ± 0.1	52.3 ± 0.4	57.2 ± 0.5	104.2 ± 1.1
22	VI005875	6.3 ± 0.3	56.7 ± 0.3	49.5 ± 0.6	101.0 ± 1.0
23	VI005876	5.4 ± 0.2	51.9 ± 0.6	45.7 ± 0.6	96.0 ± 1.0
24	VI005877	5.5 ± 0.2	54.4 ± 0.3	51.0 ± 0.7	81.8 ± 0.6
25	VI005878	4.8 ± 0.1	57.1 ± 0.4	57.5 ± 0.6	114.5 ± 0.8
26	VI005889A	5.6 ± 0.2	57.9 ± 0.4	40.7 ± 0.7	113.8 ± 0.9
27	VI005895	8.7 ± 0.2	56.1 ± 0.4	40.8 ± 0.7	108.5 ± 0.8
28	VI005905	4.1 ± 0.2	51.2 ± 0.2	37.5 ± 0.9	79.3 ± 0.7
29	VI005986	5.9 ± 0.2	51.4 ± 0.4	59.8 ± 0.6	119.5 ± 0.8
30	VI005987	5.5 ± 0.3	52.6 ± 0.4	49.5 ± 0.6	114.5 ± 0.8
31	VI005988	5.8 ± 0.2	51.4 ± 0.5	45.5 ± 0.6	105.7 ± 0.7
32	VI005989	4.5 ± 0.2	50.9 ± 0.5	49.5 ± 0.9	109.3 ± 0.7
33	VI005990	6.5 ± 0.2	58.8 ± 0.2	51.0 ± 0.6	115.0 ± 1.0
34	VI005991	5.1 ± 0.1	55.3 ± 0.2	53.8 ± 0.7	112.0 ± 1.1
35	VI006480	5.2 ± 0.1	56.7 ± 0.4	50.0 ± 0.7	97.8 ± 1.1
36	VI006481-A	4.0 ± 0.1	54.6 ± 0.3	54.3 ± 0.6	114.3 ± 0.9
37	VI006825	6.2 ± 0.1	61.4 ± 0.5	53.2 ± 0.6	92.5 ± 1.0
38	VI006826	6.6 ± 0.1	58.5 ± 0.4	53.5 ± 0.6	111.3 ± 1.4
39	VI006827	4.4 ± 0.2	51.4 ± 0.2	53.2 ± 0.5	105.2 ± 0.7
40	VI006828	4.7 ± 0.1	55.3 ± 0.1	53.5 ± 0.6	94.8 ± 1.0
41	VI006832	4.5 ± 0.1	54.0 ± 0.3	49.3 ± 0.5	114.7 ± 1.3
42	VI006833	7.5 ± 0.1	51.3 ± 0.1	51.8 ± 0.7	96.8 ± 0.7
43	VI006837	5 ± 0.3	57.0 ± 0.2	55.0 ± 0.6	104.3 ± 0.8
44	VI006838	5.5 ± 0.1	50.0 ± 0.1	45.3 ± 0.7	108.3 ± 0.8
45	VI006840	5.7 ± 0.2	56.2 ± 0.3	53.7 ± 1.0	88.7 ± 1.1
46	VI006841	5.4 ± 0.1	52.8 ± 0.5	55.0 ± 0.4	118.0 ± 1.9
47	VI006842	5.8 ± 0.2	57.9 ± 0.4	53.8 ± 0.7	89.2 ± 0.9
48	VI006847	5.5 ± 0.1	51.1 ± 0.4	51.8 ± 0.7	116.2 ± 0.5
49	VI006848	5.3 ± 0.2	54.8 ± 0.4	47.3 ± 0.7	103.7 ± 1.1
50	VI006864	4.8 ± 0.1	51.5 ± 0.4	51.3 ± 0.8	101.5 ± 0.8
51	VI006865	5.1 ± 0.1	54.6 ± 0.4	51.7 ± 0.7	93.3 ± 0.7
52	VI006869	6.8 ± 0.1	46.9 ± 0.3	52.8 ± 0.8	103.2 ± 0.9
53	VI006881-B	5.5 ± 0.1	48.6 ± 0.7	54.7 ± 0.8	109.2 ± 0.7
54	VI006892	4.6 ± 0.2	51.3 ± 0.3	61.2 ± 1.2	108.2 ± 0.6
55	VI006972	5.1 ± 0.1	53.3 ± 0.4	52.0 ± 0.6	108.7 ± 0.3
56	VI007108	4.8 ± 0.1	54.5 ± 0.2	39.0 ± 0.4	113.3 ± 0.7
57	VI007539	6.4 ± 0.1	52.3 ± 0.3	54.2 ± 1.3	114.7 ± 0.5
58	VI007540	5.6 ± 0.2	56.4 ± 0.3	56.7 ± 0.5	118.8 ± 0.6
59	VI008098	6.8 ± 0.3	56.1 ± 0.2	58.5 ± 0.9	119.2 ± 0.4
60	VI008099	4.5 ± 0.1	53.0 ± 0.4	50.2 ± 0.6	105.0 ± 0.6
61	VI008234	6.0 ± 0.2	55.6 ± 0.3	38.2 ± 0.2	94.8 ± 0.4
62	VI008916	5.3 ± 0.2	54.0 ± 0.5	50.3 ± 0.7	115.3 ± 0.7
63	VI030375	6.5 ± 0.2	60.8 ± 0.3	63.8 ± 1.1	127.3 ± 0.6
64	VI030379	5.7 ± 0.2	51.4 ± 0.3	51.5 ± 0.8	100.3 ± 0.7
65	VI030380	5.7 ± 0.3	45.1 ± 0.5	48.0 ± 0.5	106.3 ± 0.5
66	VI030381	4.4 ± 0.3	48.1 ± 0.4	50.8 ± 0.5	109.8 ± 0.6
67	VI030852	8.5 ± 0.3	62.7 ± 0.4	60.0 ± 0.4	115 ± 0.5
68	VI035028	5.3 ± 0.2	53.6 ± 0.4	49.3 ± 0.5	91.5 ± 0.6
69	VI037948	4.4 ± 0.1	58.7 ± 0.4	49.5 ± 0.6	91.2 ± 0.8
	Lsd($p < 0.01$)	0.51**	1.01**	1.85**	2.31**

S/no = serial number; ACC NO = accession number; SLA = single leaf area (cm^2); SPAD = soil plant analysis development; DTF = days to 50% flowering; DTM = days to maturity; ** = highly significant.

Table 6
Quantitative fruit traits (mean ± SE) among the 69 tomato accessions.

s/n	ACC.NO.	FL	FW	NFPP	FWPP
1	GBK 050580	3.3 ± 0.0	1.9 ± 0.1	442.8 ± 4.6	1212.0 ± 18.0
2	GBK 050589	3.9 ± 0.0	2.4 ± 0.0	230 ± 2.4	571.0 ± 9.0
3	RV02114	4.8 ± 0.1	3.0 ± 0.0	107.7 ± 1.4	618.0 ± 14.3
4	RV101884	5.5 ± 0.1	3.2 ± 0.0	135.0 ± 3.4	1143.0 ± 48.4
5	RVI01885	8.9 ± 0.0	5.4 ± 0.0	42.7 ± 1.2	2351.0 ± 67.6
6	RVI01887	7.4 ± 0.8	4.3 ± 0.3	47.7 ± 1.2	1636.0 ± 64.0
7	RVI01888	7.3 ± 0.0	4.4 ± 0.0	19.7 ± 1.1	789.0 ± 44.3
8	RVI01896	9.4 ± 0.2	5.6 ± 0.0	28.7 ± 1.2	1719.0 ± 39.9
9	RVI01983	10.2 ± 0.1	5.0 ± 0.0	36.0 ± 0.6	2186.0 ± 24.0
10	RVI02098	8.2 ± 0.1	4.4 ± 0.0	13.0 ± 0.9	565.0 ± 44.0
11	RVI02100	9.1 ± 0.1	5.8 ± 0.1	18.8 ± 0.8	1325.0 ± 63.2
12	RVI02102	6.3 ± 0.1	4.0 ± 0.1	35.0 ± 1.3	802.0 ± 43.3
13	RVI02104	10.2 ± 0.0	7.1 ± 0.1	20.3 ± 0.8	1210.0 ± 40.7
14	RVI02107	10.5 ± 0.1	6.0 ± 0.1	27.2 ± 1.3	2638.0 ± 160.5
15	RVI02109	7.7 ± 0.4	5.0 ± 0.3	65.2 ± 1.9	1857.0 ± 70.9
16	RVI02111	6.8 ± 0.5	5.8 ± 0.1	43.0 ± 0.6	1124.0 ± 48.8
17	RVI02112	6.2 ± 0.1	3.3 ± 0.1	97.7 ± 1.7	934.0 ± 51.4
18	VI005871	9.3 ± 0.3	6.1 ± 0.5	29.8 ± 0.7	2674.0 ± 69.4
19	VI005872	9.0 ± 0.3	5.6 ± 0.3	24.0 ± 1.0	1427.0 ± 67.0
20	VI005873	7.3 ± 0.0	4.5 ± 0.0	23.2 ± 1.9	1202.0 ± 124
21	VI005874	8.5 ± 0.3	5.8 ± 0.2	28.7 ± 0.8	2253.0 ± 74.2
22	VI005875	9.9 ± 0.3	6.9 ± 0.2	25.7 ± 0.8	1727.0 ± 51.1
23	VI005876	10.4 ± 0.4	7.3 ± 0.5	28.0 ± 1.7	2108.0 ± 106.7
24	VI005877	10.1 ± 0.0	6.9 ± 0.1	31.7 ± 0.6	2222.0 ± 36.4
25	VI005878	8.5 ± 0.1	5.3 ± 0.1	14.3 ± 0.8	763.0 ± 53.4
26	VI005889A	8.0 ± 0.1	5.7 ± 0.1	19.0 ± 0.9	816.0 ± 34.5
27	VI005895	9.3 ± 0.2	7.6 ± 0.2	26.7 ± 0.6	1613.0 ± 39.6
28	VI005905	3.5 ± 0.0	2.2 ± 0.0	38.5 ± 1.1	1203.0 ± 36.9
29	VI005986	11.9 ± 0.1	7.4 ± 0.0	11.0 ± 0.6	1018.0 ± 53.4
30	VI005987	8.6 ± 0.2	5.7 ± 0.1	25.3 ± 0.8	1052.0 ± 21.7
31	VI005988	8.8 ± 0.3	6.0 ± 0.2	47.3 ± 2.0	1823.0 ± 93.1
32	VI005989	5.0 ± 0.1	3.2 ± 0.1	145.7 ± 2.3	871.0 ± 31.0
33	VI005990	8.9 ± 0.1	5.4 ± 0.1	21.7 ± 1.5	1020.0 ± 68.9
34	VI005991	7.5 ± 0.5	4.6 ± 0.4	34.3 ± 0.4	1253.0 ± 15.0
35	VI006480	5.6 ± 0.2	3.7 ± 0.1	125.8 ± 2.8	1718.0 ± 171.6
36	VI006481-A	6.9 ± 0.1	4.5 ± 0.0	192.3 ± 0.8	1223.0 ± 17.2
37	VI006825	4.3 ± 0.1	2.2 ± 0.1	146.8 ± 1.9	622.0 ± 10.8
38	VI006826	7.7 ± 0.2	5.8 ± 0.2	40.5 ± 1.0	2759.0 ± 58.9
39	VI006827	10.6 ± 0.5	7.7 ± 0.2	31.5 ± 1.1	1637.0 ± 75.3
40	VI006828	3.8 ± 0.2	2.1 ± 0.0	237.2 ± 2.6	565.0 ± 23.7
41	VI006832	5.3 ± 0.1	3.2 ± 0.1	115.5 ± 1.0	2341.0 ± 59.7
42	VI006833	5.5 ± 0.2	3.6 ± 0.1	54.8 ± 1.3	954.0 ± 42.6
43	VI006837	8.4 ± 0.0	3.9 ± 0.0	64.8 ± 1.2	1777.0 ± 36.9
44	VI006838	7.9 ± 0.0	3.6 ± 0.1	23.8 ± 0.6	812.0 ± 17.1
45	VI006840	5.6 ± 0.1	3.9 ± 0.2	129.3 ± 1.2	1101.0 ± 10.4
46	VI006841	11.1 ± 0.5	7.6 ± 0.1	12.3 ± 0.7	1606.0 ± 90.9
47	VI006842	5.1 ± 0.1	3.2 ± 0.1	162.2 ± 1.7	2125.0 ± 145.2
48	VI006847	9.2 ± 0.1	6.0 ± 0.1	15.8 ± 0.6	1018.0 ± 37.6
49	VI006848	5.4 ± 0.1	3.3 ± 0.1	106.5 ± 2.0	1433.0 ± 105.4
50	VI006864	5.6 ± 0.1	3.5 ± 0.1	91.7 ± 0.8	1258.0 ± 41.6
51	VI006865	5.0 ± 0.1	4.1 ± 0.4	126.5 ± 1.1	2477.0 ± 26.2
52	VI006869	5.2 ± 0.2	3.2 ± 0.1	104.3 ± 0.8	1409.0 ± 9.6
53	VI006881-B	9.3 ± 0.4	6.1 ± 0.2	13.3 ± 0.8	1114.0 ± 66.0
54	VI006892	4.9 ± 0.0	2.4 ± 0.0	102.7 ± 1.0	887.0 ± 37.0
55	VI006972	7.0 ± 0.1	2.7 ± 0.1	108.5 ± 1.1	1192.0 ± 30.0
56	VI007108	5.9 ± 0.2	3.8 ± 0.2	89.8 ± 1.1	1416.0 ± 25.1
57	VI007539	11.1 ± 0.2	7.4 ± 0.0	8.3 ± 0.4	663.0 ± 36.5
58	VI007540	10.4 ± 0.1	7.4 ± 0.1	10.8 ± 0.5	1323.0 ± 61.9
59	VI008098	7.7 ± 0.1	4.5 ± 0.0	41.8 ± 0.7	1175 .0 ± 42.2
60	VI008099	8.4 ± 0.1	5.5 ± 0.0	53.2 ± 1.0	1269.0 ± 23.4
61	VI008234	7.5 ± 0.1	4.5 ± 0.1	48.2 ± 0.5	1369.0 ± 22.1
62	VI008916	7.3 ± 0.1	4.5 ± 0.0	65.7 ± 1.3	1589.0 ± 95.2
63	VI030375	10.1 ± 0.0	5.2 ± 0.1	30.7 ± 0.6	1841.0 ± 45.7
64	VI030379	8.9 ± 0.5	6.0 ± 0.1	17.3 ± 0.6	1110.0 ± 29.9
65	VI030380	7.0 ± 0.4	4.3 ± 0.3	53.5 ± 1.1	2115.0 ± 74.4
66	VI030381	7.5 ± 0.2	4.3 ± 0.2	42.0 ± 0.9	1539.0 ± 38.4
67	VI030852	10.2 ± 0.2	6.3 ± 0.1	49.2 ± 0.5	1941.0 ± 17.4
68	VI035028	6.3 ± 0.3	3.4 ± 0.1	28.0 ± 1.0	881.0 ± 49.2
69	VI037948	3.6 ± 0.1	2.1 ± 0.1	212.7 ± 0.7	1222.0 ± 24.5
	LSD($p < 0.01$)	0.69**	0.48**	3.96**	182.69**

S/no = serial number; ACC NO = accession number; FL = fruit length; FW = fruit width; NFPP = number of fruits per plant; FWPP = fruits weight per plant (g); LSD = least significant difference; ** = highly significant.

Table 7
Correlation table for the quantitative traits among the 69 accessions.

	DTF	DTM	FL	FW	NFPP	SLA	FWPP	SPAD
DTF	–							
DTM	0.24**	–						
FL	0.20**	0.35**	–					
FW	0.09	0.27**	0.90**	–				
NFPP	−0.02	−0.30**	−0.71**	−0.66**	–			
SLA	0.23**	0.30**	0.49**	0.43**	−0.37**	–		
FWPP	0.04	−0.20**	0.28**	0.30**	−0.13*	0.16*	–	
SPAD	0.10	0.32**	0.24**	0.21**	−0.12*	0.28**	0.066	–

DTF = days to 50% flowering; DTM = days to maturity; FL = fruit length; FW = fruit width; NFPP = number of fruits per plant; SLA = single leaf area (cm^2); FWPP = fruits weight per plant (g); SPAD = soil plant analysis development; ** = highly significant.

could be explained by the fact that with the increased number of days to 50% fruit maturity, the yield decreased, and this demonstrated that early maturing cultivars had higher yields than late maturing cultivars. Similarly, the number of fruits per plant had a significant correlation with fruit weight per plant (r = −0.13) because the accessions which had the highest numbers of fruits per plant had relatively small-sized fruits.

In summary, the variation observed in this study provides a potential source of genetic diversity for tomato crop improvement. However, a comparatively high level of similarity was also revealed among accessions from the same region for most of the characters studied. This suggests avoiding the use of material with a similar genetic background, as well as avoiding resource use on materials with the least relevant traits.

Competing interests

The authors declare there are no conflicts of interest.

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