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Characterization of tomato germplasm accessions for breeding research

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Although tomato is the leading vegetable crop in Kenya, not much work has been done to develop improved tomato varieties with farmer preferred and market demanded traits. This study aims to characterize ten tomato genotypes for morphological and agronomic traits and to identify potential parental lines for use in the breeding program. The experiments were conducted in Kenya during the 2017 long and short rain seasons. Trials were laid out in a randomized complete block design with three replicates. Study materials were AVTO1429, AVTO1424, AVTO1314 from World Vegetable Center, four commercial varieties namely; Riogrande, Cal J, Roma VF, UC82 and three farmer selections namely; Valoria, Danny and Eden select. Genotype effects, genotype x environment interactions and location effects for days to flowering, plant height, maturity, fruit yield and related traits were highly significant (P<0.01). Duration of flowering varied from 36 to 42 days; plant height from 66.37 to 182.57cm, duration to maturity from 85 to 100 days, and fruit yield from 18.3 to 55.7 t ha-^{1}. All the genotypes showed a determinate growth habit except AVTO1314 which had indeterminate growth habit. Genotype AVTO1429, AVTO1424 and AVTO1314 had green stem while commercial varieties and farmers' selection had purple stem. The high genetic variation observed among the test genotypes for the traits evaluated can be exploited in developing the tomato breeding program.

Key words: Tomato, accessions, characterization, flowering, morphological traits, agronomic traits.

INTRODUCTION

Tomato (*Solanum Lycopersicum* L.) has been ranked the second most important vegetable crop in Kenya (Mwangi et al*.,* 2020). The crop accounts for 14% of the total vegetable produced and 6.72% of entire horticultural crops in Kenya (Sigei et al*.,* 2014). Tomato is a commercially important crop and its production in Kenya,

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is largely relied upon by 80, 5 and 90% of small scale farmers, processing industries and consumers, respectively (Ochilo et al*.,* 2019). In Kenya, tomato is cultivated on 0.4 million hectares which produces about 280,000 tons annually against an increasing demand of 300,000 tons (FAOSTAT, 2017). This demand increase has been partly associated with the noted population growth from 29 million people in 1999 to nearly 48 million in 2019 (KNBS, 2019a). According to the Kenya National Bureau of Statistics, there has been a 41.7% increase in tomato consumption per capita, between 2017 and 2018 only (KNBS, 2019b). Fufa et al*.* (2009) stated that every homestead in sub-Saharan Africa uses at least one tomato fruit daily in the numerous dishes or in processed foods. Despite the growing demand of tomato, there has been a sharp decline in yields from 25.5 t ha-^{1} in 2006 to 18.7 t ha-^{1} in 2017 (FAOSTAT, 2017). Tomato yield decline observed in Kenya has contributed to increased tomato price and the importation of over 27, 000 tons from Ethiopia and Tanzania (Mwangi et al*.,* 2020). Adoption of outdated varieties that are susceptible to biotic stresses such as diseases and insect pests, abiotic stresses such as high temperatures, high humidity, excessive rainfall and low nutrients in the soil have negative impacts on tomato productivity (Sigei et al*.,* 2014). There has been a high dependence on expensive imported tomato seeds by Kenya farmers due to lack of local breeding programs (Ochilo et al*.,* 2019; Mwangi et al*.,* 2020). Furthermore, among these imported varieties, some, such as Cal J, Riogrande, and UC82 have been associated with poor adaptability to local conditions, low yielding and high susceptibility to biotic and abiotic stress (KCSAP, 2019).

Tomatoes are used for fresh markets and in processing industries and the preferred traits differ with markets and end-users (Kenneth, 2016). Tomato fruits are consumed fresh in salad or cooked in sauce, soup, dishes and can be processed into puree, jam, paste, juice and tomato sauce (Bose et al*.,* 2002; Ochilo et al*.,* 2019). The main purpose of breeding is to develop varieties with distinct traits that satisfy producers and consumer's needs (Sacco et al*.,* 2015). Variations exhibited in yields, agronomic and commercially desirable traits in tomato are of paramount importance in understanding and improvement of potential morphological and agronomic traits (Huang et al*.,* 2012). Despite the marginal research related to tomato breeding in Kenya (Munyi and De Jonge, 2015), significant efforts have been extensively focused on breeding programs of cereals, root crops, beverage crops and pulses. Moreover, the only tomato breeding program in the East African region is the Asian Vegetable Research and Development Centre (AVRDC) program centered in Arusha, Tanzania (Fufa et al., 2009). On crop improvement programs, morphological and agronomic traits such as leaf, floral and fruit characteristics, growth habit, crop yields and yield components are of importance (Yuling and Lindhout, 2007). Regarding the analysis of genetic variability among the accessions, potential parents for hybridization and selection had been successfully identified (Valls, 2007). The earlier research on germplasm has shown that local tomato varieties present novel of traits that are key in the utilization, maintenance as well as the acquisition of germplasm resources for breeding programs (Mwirigi et al., 2009). Therefore, this study purposed to characterize ten tomato genotypes to breed for improved agronomic traits. The ten tomato genotypes used in this study were three breeding genotypes from the World Vegetable Centre (AVRDC) in Taiwan namely AVT01424, AVT01429 and AVT01314. Four commercial varieties; Riogrande, Roma VF, Cal J VF and UC82 sourced from Continental Seeds Company Limited and three selections from farmers in Kirinyaga County which were Eden, Danny and Valoria. Genotypes AVTO1424 and ATO1314 are semi-determinate; while AVTO1429 is indeterminate, early maturing and suited for open field cultivation. AVTO1424 is suitable for both processing and fresh market while AVTO1429 and AVTO1314 are only for fresh market. These three genotypes from Taiwan have traits for resistance to bacterial wilt, tomato leaf curl disease and have good tolerance to heat stress. However, the productivity of these genotypes in terms of yields is unknown (Fufa et al., 2009). Commercial varieties are popular determinate pure lines grown under rain fed or irrigation in open field and suitable for processing and fresh market. The varieties yield medium to large fruits with long shelf life of up to 3 weeks. However, these commercial varieties are low yielding, producing less than 30 tons per hectare, require staking, lack trait for resistance to bacterial wilt, Fusarium wilt and insect pests (Ochilo et al*.,* 2019). Farmers' selections are determinate varieties that require staking and are grown under rain fed or irrigation regime in open fields. These varieties have good traits for fresh market tomatoes such as good firmness and saladette fruit shape. However, the yield potential and the maturing state of these varieties have not been validated.

MATERIALS AND METHODS

Experimental sites

Field experiments were conducted at Kabete field station and Mwea research station in Kiambu and Kirinyaga counties, respectively. At Kabete field station, the experiments were conducted on both long and short rain seasons; the trials in Mwea research station were only on short rains in 2017. The Kabete Field Station is located at 01°15'S; 036°44'E with an elevation of 1820m above sea level (ASL) which is in agro- ecological zone (AEZ) III. It has a bimodal rainfall of 1059 mm per year and temperature range of 12.3 to 22.5°C. The soils at Kabete site are humic nitisols, deep and well-drained with a pH of about 5.0 to 5.4 (Lengai, 2016). The Mwea research station site is located at 0°41'S; 037°21'E with an elevation of 1159m ASL which is in Agro-ecological zone II. The area has a bimodal rainfall regime of 973 mm annually. Temperature ranges from 15.6 to 28.6°C and soils are Niti-rhodic ferrasols with a pH of about 5.1 (Waiganjo et al*.,* 2006).

Experimental design and trial management

Ten tomato genotypes were separately sown in germination trays containing a peat-moss planting media and were watered twice daily. On attaining a pencil thickness, 28 days after sowing, the seedlings were transplanted in the field.

Trials were laid out in a randomized complete block design with three replicates. Plot consisted of 2 rows each measuring 2.4m with 10 plants per plot at a spacing of 60 x 60cm. Di-ammonium phosphate (DAP) and N.P. K (17 : 17: 17) fertilizer at a rate of 12 g plant^{-1} was applied during transplanting. Manual cultivation was carried out to keep plots weed free. Metalaxyl-M and Propineb 700g/kg at the rate of 50g/20litres water was applied to manage early and late blight per fortnight alternatively. Imidaclopride+ Betacyfluthrine 100+45g/l at rate of 0.2litres/ha and Thiamethoxam at the rate of 8gm/20litres water were used to control aphids, whiteflies and leaf miners during the crop growth cycle. Water was supplemented through drip irrigation system. Irrigation management was carried out in the morning and evening for 45 min.

Data collection

Morphological and agronomic data were collected at various growing stages for quantitative traits. This followed the International Plant Genetic Resources Institute (IPGRI, 2003) tomato descriptor for plant height, days to 50% flowering, days to maturity, fruit diameter, fruit length, average fruit weight, number of locules, number of fruits per truss and yield per plant. Qualitative traits like presence of green shoulders, stem color and growth type were also recorded.

Quantitative traits

Quantitative traits were evaluated following the protocol of International Plant Genetic Resources Institute (IPGRI, 2003). Duration to 50% flowering was determined as a period from planting to when half the population per plot showed at least one flower. Days to maturity were determined as an average number of days taken from transplanting to 50% ripening of fruits per plant from a sample size of six plants evaluated randomly per plot. Plant height (cm) from soil base of the plant to the apex of the main stem at harvesting stage was recorded using a tape measure from a sample of six plants per plot. Six randomly tagged plants in each plot were assessed on the number of fruits per truss from fruits harvested. Average fruit weight per plant was determined by weighing random sample of 6 red ripe fruits per plant and mean calculated.

Marketable fruits per plot were harvested at physiological maturity and their yield weighed using electronic weighing balance model AG64-100, (Wagtech International, New York). The yields were converted to tons per hectare. Fruit length or equatorial diameter (mm) was measured on six fruits harvested per plant at physiological maturity using a Vanier caliper from pistil scar to blossom end and mean calculated. Number of locules per fruit was determined by cutting the fruits at the middle transversely and counting the locules on six fruits collected from six random plants per plot.

Qualitative traits

Qualitative traits are characterization descriptors that are highly heritable. The qualitative traits were measured following the descriptions of tomato (IPGRI, 2003). Stem color was determined as either green or purple when the seedling lower leaves were fully opened with a 5mm terminal bud. Plant growth habit: scored as determinate, semi- determinate and indeterminate was observed on the plant, after admixtures had been removed. Stem pubescent and foliage densities were measured as intermediate, dense, or sparse for all the genotypes assessed. In flower color, an average of 10 petals from six random flowers of a plant was assessed for white, yellow, or orange Corolla color. Mature fruit color was assessed by observing the color of all the 3rd fruit of all the 2nd and 3rd truss at full maturity stage for the 10 genotypes. An average of 10 fruits from six random plants was recorded and the color score was green, yellow, orange, pink or red. Fruit cross- section shape was determined as either round, angular or irregular. The genotypes were assessed for either jointed or jointless pedicels. The presence of green (shoulder) trips on the fruit was scored as either absent (uniform ripening) or present (fruit shoulders- upper part of the fruit, around calyx- are green while pistil area of the fruit is red). Mature tomato fruits harvested at physiological maturity were classified into five categories based on cross-section diameter (IPIGRI, 2003). The categories were; very small (<3cm), small (3-5cm), intermediate (5.1-8cm), large (8.1-10cm) and very large (> 10cm).

Statistical analysis

Quantitative trait data for the 10 genotypes was subjected to analysis of variance (ANOVA) with environments as the main plots and genotypes as the subplots. Fisher’s protected least significant difference (LSD) test was used to compare and separate means of the genotypes, environment effects and environment x genotype interactions at 5% significance P-value.

RESULTS AND DISCUSSION

Qualitative traits analysis

The study showed no genotypic variation across the 3 environments (Kabete long and short rains and Mwea short rains) for the qualitative traits assessed (Table 1). Based on the results, the 3 varying environments had no effects on the assessed qualitative traits. Hence, our findings concur with the study of Yuling and Lindhout (2007) where tomato and other solanaceous crops exhibited common qualitative trait loci despite them being domesticated in different continents.

This study revealed that tomato seedlings for genotypes AVTO1429, AVTO1424 and AVTO1314 had green stem color whereas all other genotypes which represent 70% of genotypes evaluated had purple stem color (Table 1). Similar findings were noted by Kenneth, (2016) where out of 69 genotypes evaluated, 91.3% had purple stem color while green stems were only 8.7%. Moreover, the trend of our results, is in agreement with IPGRI descriptors for tomato that gives similar variations of the seedling stem color being either green or purple for all tomato varieties (IPGRI, 2003). Interestingly, stem

Table 1. Qualitative traits data of 10 tomato parental lines grown in three environments in Kenya, 2017.

Descriptors	Parents									
	Eden Select	Roma VF	AVTO1429	CAL J VF	AVTO1424	Danny Select	AVTO1314	UC82	Valoria Select	Riogrande
Hypocotyl (stem) colour	Purple	Purple	Green	Purple	Green	Purple	Green	Purple	Purple	Purple
Growth type (growth habit)	Determinate	Determinate	Determinate	Determinate	Determinate	Determinate	Indeterminate	Determinate	Determinate	Determinate
Stem pubescence density	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
Foliage density	Dense	Dense	Intermediate	Dense	Intermediate	Dense	Intermediate	Dense	Dense	Dense
Corolla (fruit) colour	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Exterior colour of immature fruit	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Exterior colour of mature fruit	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
Presence of green (shoulder) trips	Absent	Absent	Present	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Fruit size	Large (8.1-10 cm)	Large (8.1-10 cm)	Large (8.1-10 cm)	Large (8.1-10 cm)	Large (8.1-10 cm)	Large (8.1-10 cm)	Small (3-5 cm)	Small (3-5 cm)	Large (8.1-10 cm)	Large (8.1-10 cm)
Fruit cross-section shape	Angular	Angular	Irregular	Angular	Angular	Angular	Round	Angular	Angular	Angular
Predominant fruit shape	Cylindrical	Pyriform	Flattened	Rounded	High rounded	Rounded	Slightly flattened	Rounded	Pear-shaped	High rounded
Jointed or joint less pedicel	Joint less	Jointed	Jointed	jointed	Jointed	jointed	Jointed	jointed	Joint less	Joint less

color is an important morphological trait that can be largely employed in differentiating varying genotypes. The field observation revealed that all the genotypes (90%) had a determinate growth habit except genotype AVTO1314 that showed the indeterminate growth habit indicated in Table 1. Owing to these results, it is indeed evident that most tomato varieties in Africa have determinate growth habit. These finding trends are consistent with those reported by Sacco et al. (2015) that out of the 125-tomato accession characterized, 77.2% were determinate.

Marginal diversity was demonstrated within the ten genotypes evaluated with respect to flower and fruit color. The ten genotypes had yellow flower petals with green fruit color that turned red at full maturity. All the genotypes had a uniform green color on the fruits except genotype AVTO1429 that had green shoulders on the fruits. Kenneth (2016) reported a similar trend that 66 accessions out the 69 evaluated had yellow flowers and produced red fruit at full maturity. There were no variations in the pigments such as carotenoids, chlorophyll and anthocyanin in the ten genotypes. The green shoulder disorder exhibited by genotype AVTO1429 in this study was characterized by persistent, firm green area around the calyx end as the fruit ripened. According to Nguyen (2015), the green shoulder disorder is genetically controlled and can be eliminated by adding the uniform ripening gene. Therefore, high yielding genotypes such as AVTO1429 expressing green shoulder traits have potential of improvement through breeding to introgress the uniform ripening gene.

Stem pubescence density in the ten genotypes was intermediate (Table 1). Stem hairiness facilitates coating on stems, fruits and leaves hence potentially reducing transpiration, reflects sunlight and protects the delicate tissues during adverse weather conditions (Subhash, 2010). Field observation on the foliage density, among the 10 genotypes, revealed that genotypes Eden, Danny, Valoria selection, Roma VF, Cal J, UC82 and Riogrande had dense canopy while AVTO1429, AVTO1424 and AVTO1314 had intermediate canopy. The fruit shape, fruit cross-section shape and fruit size were each in distinct variations. Fruits cross-section of the genotypes revealed that AVTO1429 had irregular fruit shape, AVTO1314 had round while other genotypes had angular fruit shape. Of the 10 genotypes, seven had jointed pedicels while Eden select, Valoria select and Riogrande displayed jointless pedicels

Table 2. Duration to flowering, maturity, and plant height of ten genotypes grown at Kabete and Mwea, 2017.

Parents	Days to 50% flowering			Days to maturity			Final plant height (cm)		
	Kabete LR2017	Kabete SR2017	Mwea SR2017	Kabete LR2017	Kabete SR2017	Mwea SR2017	Kabete LR2017	Kabete SR2017	Mwea SR2017
Eden select	41	42	33	85	113	82	71.3	105.3	111.7
Roma VF	45	43	34	86	124	85	70	99.7	105.6
AVTO1429	38	43	35	82	122	81	126.1	204.7	217.0
Cal J VF	47	43	35	92	115	77	52.4	96.1	101.4
AVTO1424	38	42	35	83	118	85	70.4	121.8	128.5
Danny select	37	41	32	80	108	74	59.5	99.7	105.1
AVTO1314	38	42	35	82	118	89	87.1	110.5	117.1
UC82	37	40	31	79	105	71	50.1	72.3	76.7
Valoria select	47	42	34	92	118	90	69.4	107.2	113.7
Riogrande	48	43	34	91	114	85	69.6	87.4	92.7
Grand mean	42	42	34	85	116	82	72.6	110.5	116.9
CV (%)	2.80	2.80	2.80	4.03	4.03	4.03	5.60	5.60	5.60
LSD (5%)	1.78	1.78	1.78	2.50	2.50	2.50	9.11	9.11	9.11

LSD= Least significant differences of means at (P≤0.05), CV = Coefficient of variation. Environments were Kabete LR2017, Kabete SR2017 and Mwea SR2017. LR is long rain season and SR is short rain season.

(Table 1). The present study showed eight of the ten studied genotypes had large fruits size categorized in the range of 8.1 to 10cm while AVTO1314 and Valoria select had small sized fruits in the range 3 to 5cm following the IPGRI descriptors for fruit size. These findings are similar to those reported by Luna-Guevara et al. (2014) who found significant variations for fruit size, shape and cross-section shape in Spanish local tomato varieties. In addition, Kenneth (2016)'s findings support the results of our present study where it was demonstrated that majority of accession 81.2% evaluated had angular fruit cross-section shape and the large fruit sizes ranging from 8.1 to 10cm.

Quantitative traits analysis

Days to flowering and maturity

The ten tomato genotypes evaluated had significant differences in the days to flowering and maturity at P≤0.05. Tomato genotype UC82 was the earliest flowering at 37, 40 and 31 days recorded at Kabete long rain, short rain and Mwea short rain respectively. Riogrande that took 48 days to 50% flowering at Kabete long rain was the latest flowering genotype (Table 2). Similarly, the earliest maturing genotype was UC82 recording, 79 days at Kabete long rain, 105 days for short rain and 71 days at Mwea short rain. The latest maturing genotype at Kabete long rain and Mwea short rain was Valoria select, and Roma VF was the latest during the short rain at Kabete recording 92, 90 and 124 days, respectively. In the 10 genotypes assessed for days to flowering and maturity, Kabete short rain recorded significantly higher days compared to long rains and Mwea short rain. The average number of days to 50% flowering recorded at Kabete long and short rain and Mwea short rain was 42 , 42 and 34 days, respectively while days recorded for maturity were 85, 116 and 82 days respectively. Of concern, environment significantly influenced duration to 50% flowering and maturity during the experimental period. These findings were consistence with those reported by Samach and Lotan (2007) where the environment affects the timing of transition from vegetative to reproductive development of tomato which is the flowering stage. Genotypes showed differential responses to changes in environmental condition for the number of days to maturity. This was indicated by the significant difference in days recorded at Kabete field station, on short rains at an average of 116 days compared to Mwea short rain at 82 days. These results showed significant genotype x environment interactions. Similar findings were observed by Kenneth (2016) after characterizing 69 African tomato landraces under field and greenhouse conditions and noted variations in the days to 50% flowering and maturity across the accessions. Accession grown in the field recorded a range of 38 to 64 days to 50% flowering while greenhouse had a range of 36 to 68 days. In addition, days to maturity ranged from 79 to 127 and from 84 to 131 days for accession in the field and greenhouse, respectively. The findings support the results of the current study.

The days to flowering provides important information in determining either earliness or lateness of a variety. Days to flowering had been reported to have a close association to maturity of the tomato genotypes (Sacco et al., 2015). Herein, genotype UC82 was earliest to 50% flowering recording an average of 36 days and was also the earliest genotype to mature recording an average of 85 days in all the sites. Similarly, Riogrande that was latest to 50% flowering was also a late maturing genotype. With this positive correlation between days to flowering and maturity, it is inferred that crop improvement for early maturity of tomato should focus on reducing the number of days to flowering. Notably, early maturity of tomato had been an important attribute demanded by growers especially on these perpetual erratic weather patterns of nowadays.

Plant height

Plant height for all the genotypes did not vary with location or season. These results implied that the trait for plant height was consistent across all locations (Kabete and Mwea) and seasons (long and short rains) for all the genotypes studied. Genotype AVTO1429 which exhibited indeterminate growth habit was the tallest measuring 126, 204.7 and 217cm at Kabete long rain, short rain and Mwea short rain, respectively. Genotype UC82 which had determinate growth habit was the shortest variety at Kabete long rain, short rain and Mwea short rain measuring 50.1, 72.3 and 76.7cm, respectively (Table 2). Plant height is an important trait in a tomato breeding program because it is an alternative determinant of whether the tomato variety is determinate or indeterminate (Ochilo et al., 2019). Plant height as a trait determines the variety requirement for support and training during growth (Kenneth, 2016). The significant difference (P≤0.05) observed in this study among the genotypes for the plant height implies an existence in variation among the African tomato landraces for the trait. Similar findings have been reported by Kenneth (2016) of plant height ranging from 25.5 to 81.2cm. Mohanty (2003) also reported significant differences in plant height among tomato accession. International Plant Genetic Resources Institute (IPGRI, 2003) uses same categorization of tomatoes as determinate or indeterminate based on their height and continuation of growth.

Fruit traits

There was significantly high difference in, fruit length, fruit diameter, number of fruits per truss and number of locules per fruit at P≤0.05 (Table 3). The result implies that tomato genotypes grown in Africa have variations in the fruit traits. Riogrande had the largest fruit length of 58.42 at Kabete long rain, 55.89 mm during short rain and 60.23 mm at Mwea short rain. The smallest fruit length of 46.54mm was recorded in genotype UC82 at Kabete long rain, 43 and 50.08 mm for AVTO1314 during short rain and at Mwea short rain respectively. Genotype AVTO1429 had the largest fruit diameter of 71.17 and 61.68mm at Kabete long rain and Mwea short rain, respectively while AVTO1314 recorded the largest diameter of 51.60 mm at Kabete short rain. Danny select and UC82 had the highest fruit number per truss of 5 fruits in all the environments (Table 3) while AVTO1429 had the highest number of locules per fruit of 7 locules (Table 4). These findings are similar to those reported by Shushay et al. (2014) and Mohanty (2003) where significant variations in fruit shape, fruit length/diameter and other fruit traits among the tomato accession were observed. Fruit shape, is an important attribute when developing a variety for the market. Consumer had been associating round or angular shape with durability or firmness of fruits. Therefore, results revealed Roma VF had the lowest fruit shape index and fruit firmness. Genotypes AVTO1314 and AVTO1429 recorded highest values of both fruit shape index and fruit firmness of more than 90Nmm^{-1}.

Fruit yield

The study showed significant variations on tomato yields across the ten genotypes evaluated (Table 4). Genotypes AVTO1429, AVTO1424 and AVTO1314 recorded low yields compared to local commercial varieties. Hence, with these variations, the genotypes have potential to be improved through breeding program. Valoria and Danny select were the highest yielding genotypes with more than 50,000kg/ha while genotypes AVTO1429 and AVTO1424 had the lowest yields below 20,000 kg/ha. In addition, the study revealed a positive association of the fruit yields per plant with traits such as plant height, number of primary branches, leaf length, leaf width, single leaf area and stem girth. These results showed that tall plants, with many branches, large leaf area and wide stem girths such as Danny select have higher yields as compared to shorter plants. Therefore, these findings are comparable with those reported by Kenneth (2016) that tall plants with many primary branches and large leaf area yield higher than shorter plants. This association may be explained by the availability of photosynthetic material for partitioning to fruit production (Singh et al., 2006; Gosh et al., 2010).

CONCLUSION

The genotypes with outstanding performance included UC82 for days to flowering, maturity and plant height, Valoria select for yield trait and AVTO1314 for fruit weight trait. In addition, the correlation between the number of days to 50% flowering and the number of days to maturity

Table 3. Fruit length, diameter, and fruits per truss of ten genotypes grown at Kabete and Mwea, 2017.

Parents	Fruit length (mm)			Fruit diameter (mm)			Number of fruits truss^{-1}		
	Kabete LR2017	Kabete SR2017	Mwea SR2017	Kabete LR2017	Kabete SR2017	Mwea SR2017	Kabete LR2017	Kabete SR2017	Mwea SR2017
Eden select	53.67	55.42	58.96	44.99	44.52	51.64	4	4	3
Roma VF	59.83	55.26	51.56	42.69	39.16	38.85	5	5	3
AVTO1429	51.86	45.32	52.03	71.17	42.12	61.68	3	3	4
Cal J VF	49.85	51.67	51.55	43.74	44.10	46.66	4	4	3
AVTO1424	51.88	43.82	58.06	46.86	41.63	48.84	3	3	4
Danny select	49.50	50.19	51.75	48.18	46.29	45.99	5	5	4
AVTO1314	49.40	43.00	50.08	56.26	51.60	59.69	3	3	3
UC82	46.54	47.53	50.20	41.17	38.99	44.40	5	5	4
Valoria select	55.49	53.67	55.88	51.62	43.75	47.39	4	4	4
Riogrande	58.42	55.89	60.23	48.41	44.37	48.78	4	4	3
Grand mean	52.64	50.18	54.03	49.51	43.65	49.39	4	4	3
CV (%)	6.40	6.40	6.40	5.80	5.80	5.80	11.30	11.30	11.30
LSD (5%)	5.73	5.73	5.73	5.18	5.18	5.18	0.70	0.70	0.70

LSD= Least significant differences of means at (P≤0.05), CV = Coefficient of variation. Environments were Kabete LR2017, Kabete SR2017 and Mwea SR2017. LR is long rain season and SR is short rain season.

Table 4. Locules per fruit, fruit weight and yield per hectare of ten genotypes grown at Kabete and Mwea, 2017.

Parents	Number of locules fruit^{-1}			Fruit weight (g)			Yield ha^{-1} (kg)		
	Kabete LR2017	Kabete SR2017	Mwea SR2017	Kabete LR2017	Kabete SR2017	Mwea SR2017	Kabete LR2017	Kabete SR2017	Mwea SR2017
Eden select	3	3	4	74	66	85	36,021	35,210	43,812
Roma VF	3	2	2	41	48	50	45,125	43,221	45,049
AVTO1429	11	3	6	115	47	119	13,130	12,118	29,789
Cal J VF	2	2	3	52	60	61	36,570	33,927	39,667
AVTO1424	3	3	3	42	45	77	13,086	10,959	37,326
Danny select	3	3	3	52	62	63	67,444	47,763	43,346
AVTO1314	5	6	6	60	80	112	25,426	18,130	19,374
UC82	3	3	3	35	51	51	47,102	44,800	30,489
Valoria select	2	2	2	66	63	73	56,870	48,463	61,888
Riogrande	2	2	2	66	68	75	57,938	41,969	37,224
Grand mean	4	3	3	60	59	77	39,871	33,656	38,796
CV (%)	19.0	19.0	19.0	531.5	531.5	531.5	26.30	26.30	26.30
LSD (5%)	1.0	1.0	1.0	129.7	129.7	129.7	16,571	16,571	16,571

LSD= Least significant differences of means at (P≤0.05), CV = Coefficient of variation. Environments were Kabete LR2017, Kabete SR2017 and Mwea SR2017. LR is long rain season and SR is short rain season.

was observed in this study. Such associations help in identification of important traits that can be useful for yield improvement through introgression of multiple trait selection. This study also revealed the influence of environment in expression of some traits such as number of days to maturity. This implies that enhancement of the tomato should also focus on the adaptation of the genotype to an environment where the breeding program is intended. The positive and significant correlation between yield and yield components such as fruit length, fruit width, single fruit weight observed in this study indicates clearly that crop improvement for yields in tomato should focus of these traits. Therefore, the ten genotypes were selected as potential parental lines for tomato breeding program research in Kenya.

ABBREVIATIONS

AVRDC: Asian Vegetable Research and Development Centre; ha: Hectares; t: tons; cm: centimeter; mm: millimeter; AEZ: Agro-ecological zones; ASL: Above Sea Level; AVRDC: World Vegetable Centre; IPGRI: International Plant Genetic Resources Institute; ANOVA: Analysis of Variance

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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