RUFORUM Working Document Series (ISSN 1607-9345), 2018, No. 17 (1):791-799.
Available from *http://repository.ruforum.org*

Heterosis for fruit yield, yield components and bacterial wilt resistance of tomatoes genotypes in Kenya

Kathimba, F.K.,[1] Kimani, P.M,[2] Kiriika, L.M.[1] & Narla, R.D.[1]
[1]Department of Plant Science and Crop Protection, College of Agriculture and Veterinary Sciences, University of Nairobi, P.O Box 29053-00625, Nairobi, Kenya
[2]Department of Horticulture, Jomo Kenyatta University of Agriculture and Technology, P.O Box 6200-00620, Nairobi, Kenya
Corresponding Author: francisgath@gmail.com

Abstract

Yields of tomato (*Solanum lycopersicum*) in Kenya has continued to decrease due to biotic stresses especially bacterial wilt (*Ralstonia solanacearum*), fungal diseases, nematodes, tomato yellow leaf curl and overreliance on low yielding varieties such as UC82, Roma VF, Cal J and Riogrande. These problems stem from lack of a local breeding programme to develop new varieties suitable for fresh market and processing. The objectives of this study were to: i) determine heterosis for fruit yield, yield components and bacterial wilt in ten tomato lines; ii) select F_1 hybrids combining resistance to bacterial wilt, high fruit yield, better shelf life and other market demanded traits, and iii) develop segregating F_2 populations for further breeding. The parental lines included three elite breeding lines with resistance genes to bacterial wilt obtained from AVRDC-Taiwan, four local open pollinated commercial lines and three lines selected from tomato growers in central Kenya. The ten parental lines were crossed in a half diallele at Kabete Field Station, University of Nairobi in 2017. The 45 F_1 and their parents were evaluated in the field at Kabete Field Station, Mwea Research Station, and in a bacterial wilt infested sick plot in Kanyei location, Kirinyaga County in 2018. Data were recorded on days to flowering, days to maturity, fruits per truss, fruits diameter, fruit length, fruits per plant, number of locules per fruit, average weight of fruit, resistance to bacterial wilt diseases. Bacterial wilt disease severity was scored on 0 to 5 scale (0=no disease symptoms, 1=one leaf wilted, 2=two leaves wilted, 3=three leaves wilted, 4=all leaves wilted except the tip, 5=entire plant dead) for two seasons in wilt infested sick plot in a farmer's field in Kanyei location, Kirinyaga County and in a greenhouse at Kabete Field Station, both in Kenya. Results showed significant differences (P<0.05) for duration to 50% flowering, maturity, fruit diameter, fruit length, average fruit weight, number of fruits per plant, number of trusses per plant and fruit yield among the F1s and their parents. High parent heterosis -9% recorded on days to flowering (AVTO1429 x Cal J VF), -5% heterosis to maturity days (Roma VF x AVTO1314), 20% heterosis to plant height (AVTO1424 x UC82), 50% heterosis on vigour (AVTO1314 x Valoria select, AVTO1314 x Riogrande).

Key words: Combining ability, F_1 hybrids, heterosis, Kenya, tomatoes

Résumé

Les rendements de la tomate (*Solanum lycopersicum*) au Kenya ont continué de diminuer en raison de stress biotiques, en particulier du flétrissement bactérien (*Ralstonia solanacearum*), des maladies fongiques, des nématodes, de la feuille jaune de la tomate et de la dépendance excessive sur les variétés à faible rendement telles que l'UC82, Roma VF, Cal J et Rio Grande. Ces problèmes découlent de l'absence d'un programme de sélection local pour développer de nouvelles variétés adaptées au marché frais et à la transformation. Les objectifs de cette étude étaient les suivants: i) déterminer l'hétérosis pour le rendement en fruits, les composants de rendement et le flétrissement bactérien dans dix lignées de tomates; ii) sélectionner des hybrides F1 combinant une résistance au flétrissement bactérien, un rendement élevé en fruits, une meilleure durée de conservation et d'autres caractères demandés par le marché, et iii) développer des populations F2 ségrégatives pour une reproduction ultérieure. Les lignées parentales comprenaient trois lignées de sélection d'élite avec des gènes de résistance au flétrissement bactérien obtenus auprès de l'AVRDC-Taiwan, quatre lignées commerciales locales à pollinisation libre et trois lignées sélectionnées parmi des producteurs de tomates du centre du Kenya. Les dix lignées parentales ont été croisées dans un demi-diallèle à la station de Kabete, Université de Nairobi en 2017. Les 45 F1 et leurs parents ont été évalués sur le terrain à la station de Kabete, la station de recherche de Mwea, et dans une parcelle malade infestée de flétrissure bactérienne à Emplacement de Kanyei, comté de Kirinyaga en 2018. Les données ont été enregistrées sur les jours jusqu'à la floraison, les jours jusqu'à la maturité, les fruits par grappe, le diamètre des fruits, la longueur des fruits, les fruits par plante, le nombre de locules par fruit, le poids moyen des fruits, la résistance au flétrissement bactérien. La gravité de la maladie du flétrissement bactérien a été notée sur une échelle de 0 à 5 (0 = aucun symptôme de la maladie, 1 = une feuille flétrie, 2 = deux feuilles flétries, 3 = trois feuilles flétries, 4 = toutes les feuilles flétries sauf la pointe, 5 = plante entière morte) pendant deux saisons dans une parcelle malade infestée de flétrissure dans un champ d'agriculteur à Kanyei, dans le comté de Kirinyaga et dans une serre à la station de Kabete, toutes deux au Kenya. Les résultats ont montré des différences significatives (P <0,05) pour la durée à 50% de floraison, maturité, diamètre des fruits, longueur des fruits, poids moyen des fruits, nombre de fruits par plante, nombre de fermes par plante et rendement en fruits parmi les F1 et leurs parents. Hétérosis parentales élevées -9% enregistrées les jours avant la floraison (AVTO1429 x Cal J VF), -5% hétérosis jusqu'aux jours de maturité (Roma VF x AVTO1314), 20% d'hétérosis à la hauteur de la plante (AVTO1424 x UC82), 50% d'hétérosis sur vigueur (AVTO1314 x Valoria select, AVTO1314 x Riogrande).

Mots clés: capacité de combinaison, hybrides F1, hétérosis, Kenya, tomates

Introduction

Tomato (*Solanum lycopersicum*) is the second most important vegetable crop in Kenya after potato (*Solanum tuberosum*). Demand for tomatoes is increasing partly due to population growth and changing lifestyles associated with urbanization. Fufa *et al.* (2009) suggested that every homestead in sub-Saharan Africa uses at least one fruit of tomato per day in numerous dishes or processed foods making it a dietary staple food. Despite the growing demand for tomato, yields have declined from 20 t ha^{-1} in 2012 to 18.7 t ha^{-1} in 2016 (FAO, 2017). The yield decline has been associated with use of outdated varieties that are susceptible to biotic and abiotic stresses, loss of soil fertility and disease build up due to continuous cropping. Kenyan farmers rely on expensive imported seed due to lack of local breeding. Moreover, some of the imported varieties are poorly adapted to local conditions. In some cases, farmers have made local selections such as Valoria FS, Eden FS and Danny FS from popular varieties. Other varieties such as Riogrande, Roma VF, UC 82 and Cal

J VF have farmer and consumer preferred traits which can be exploited in developing improved varieties with higher levels of resistance to major diseases such as bacterial wilt and better fruit attributes including shelf life.

Combining ability analyses have proved important techniques to the breeders because they provide valuable information on the genetic potential of parental lines and development of hybrid varieties. These techniques provide information on gene effects which can also be used in developing an effective breeding strategy. Combining ability means the relative ability of a genotype to transmit or transfer genetic superiority to its offspring's when crossed with other individuals (Troyer, 2006).

Heterosis breeding offers a huge potential in improving productivity of tomatoes in Kenya. Presence of adequate heterosis is a pre-requisite for breeding tomato hybrids. Breeding hybrids and production of hybrids seeds is gaining popularity in many programs globally. Heterosis in tomatoes is mainly exhibited through increased vigour, hastened growth and development, early maturity, notable yield increase and high resistances to biotic and abiotic stresses (Yordanov, 1983). Heterosis levels of local varieties are not known, which is pre-requisite for the development of new disease resistant hybrid varieties in Kenya.

Tomato breeding has received very little research attention in Kenya. There is no documented effort on tomato improvement in Kenya at present. A tomato improvement programme is therefore a priority if farmers and processors are to expect high performing, locally adapted varieties with market demanded traits. Seeds merchants including commercial private and public companies in East Africa have not allocated much resources towards tomato breeding programmes leaving a big gap on crop improvement initiatives (Fufa *et al.,* 2009). As a result, all tomato seeds commercial in Kenya are imported and expensive to resource poor farmers. Most of the available commercial varieties are low yielding, have short shelf-life and are susceptible to widely prevalent diseases such as bacterial wilt. The only tomato breeding programme in the East African region is the Asian Vegetable Research and Development Centre (AVRDC) programme centred in Arusha, Tanzania. Through this program several varieties with resistance to late blight and other resistances like Fusarium wilt, nematodes and tomato mosaic virus were released namely Tengeru 97, Tanya, Meru and Kiboko. Tanya and Tengeru were introduced in Kenya year 2006 by East African Seeds Company (Fufa *et al.,* 2009). However, these two varieties have not been widely adopted in Kenya because they are susceptible to bacterial wilt. The objective of this study was to determine the combining ability and heterosis for yield and yield related traits in local and introduced tomato lines, and reaction of their F_1 hybrids to bacterial wilt infection.

Materials and Methods

The crossing block was established at Kabete Field Station, University of Nairobi in 2017. Kabete Field Station experiences bimodal rainfall (1059 mm per year) and temperature range 12.3°C to 22.5°C. Soils are humic nitisols, deep and well-drained with pH of about 5.0 to 5.4.

Forty-five F_1 hybrids were developed from crosses among ten parental tomato lines. Five of the parental lines were susceptible to bacterial wilt but with high yield potential. The other five parental lines had moderate to high levels of resistance to bacterial wilt and better marketable fruits attributes.

The mating design was half-diallele (Griffin 1956b). The experiment was conducted at, Kabete Field Station, the University of Nairobi. The ten tomato accessions used in the crossing block included four commercial cultivars, three farmer selections and three elite breeding accessions obtained from AVRDC, Taiwan. The F1 hybrid seeds were produced through hand emasculation and subsequent hand pollination in October to November 2017. The 45 F1's and their parents were evaluated at Kabete Field Station and at Mwea Research Station. The F1's and their parents were evaluated for reaction to infection by bacterial in sick plot in Kirinyaga County. The experimental design at the three sites was randomized complete block with three replicates.

The parental lines were sown in germination trays and transplanted in the field following normal agronomic practices to ensure healthy crop. Diammonium phosphate (DAP) and N:P:K (17% nitrogen: 17% phosphorus: 17% potassium) were each applied at a rate of 12gm plant-1. Plots were kept weed free by manual cultivation. Metalaxyl-M and Propineb 700g/kg at the rate of 50g / 20 litres water were used to control early and late blight per fortnight alternatively. Imidaclopride+Betacyfluthrine100+45g/L at rate of 0.2L/Ha and Thiamethoxam at the rate of 8gm / 20 litres water used to control aphids, whiteflies and leaf miners during the crop growth cycle. Supplemental irrigation was provided with drip irrigation.

Preparation of Sick plot for open field screening. The *Ralstonia solanacearum* sick plot was developed at Kirinyaga county in a farmer's field with history of wilt problem by incorporating chopped debris of diseased plants collected from different farms in the region to build up the inoculum load of the pathogen. Susceptible check variety Roma VF was used to test the pathogen load and establish the location severity index (Jitendra *et al.,* 2004). The dead plant parts after the disease infection were chopped and incorporated back to the soil to further prepare the sick plot for germplasm evaluation. Random samples were taken from the diseased plants for laboratory confirmation of *R. solanacearum.* Enough infestation of the sick plot was maintained by continuous recycle of *R. solanacearum* plant debris throughout the research period. The sick plot was considered ideal for *Ralstonia solanacearum* evaluation after attaining location severity index of over 76 % with the susceptible check varieties. The bacterial wilt disease incidence score of 0-5 scale was used to rank the germplasm resistance reaction (Jitendra *et al.,* 2004).

Data collection and analysis. Data on plant height, days to 50% flowering, days to maturity, fruit diameter, fruit length, average fruit weight, number of locules, number of truss per plant and yield per plant were collected at the appropriate growing stage. Bacterial wilt disease incidence was scored on 0 to 5 scale, where 0 – no disease symptoms, 1-resistant, 2-moderately resistant, 3-moderately susceptible, 4-susceptible, 5-highly susceptible. Genstat statistical software (15^{th} edition) was used for data analysis. Fisher's protected least significant difference was used for mean separation at 5% probability level.

Heterosis. Better parent heterosis was calculated as: Better parent heterosis (%) = F1 – BP x 100

$$(\%) = \frac{F1 - BP}{BP} \times 100$$

where: F1 = mean performance of a single cross, and BP= mean performance of the better parent.

Results

Significant variations were noted in the 45 F_1 hybrids and 10 parent's genotypes for all traits (Table 1).

Days to 50% flowering and maturity. The means varied across the genotypes at 5% P-value threshold from 36.67 days for the hybrid Eden FS x Danny FS becoming the earliest flowering selection while the hybrid Roma VF x Riogrande recorded the latest days to flowering at average of 43.67 days.

Days to maturity was measured on the days taken to achieve 50% harvesting across the plants. The mean ranged between 80.33 days for hybrid Cal J VF x AVTO1314 to 124.33 days for Roma VF. Earliness is an important factor for growers especially in areas with no reliable rainfall and absence of irrigation.

Plant vigour. Plant vigour determines the ability of plant to register significant growth energy enabling it overcome growing challenges including pests and diseases. Significant variation was noted across the parents and the F_1 hybrids with a mean of five in tomato Roma VF, Danny FS and in hybrids Eden FS x Danny FS, Roma VF x Danny FS, Roma VF x Valoria FS, Cal J VF x AVTO1424, Danny FS x UC82. Mean value of 3.33 was recorded in the hybrid combination Cal J VF x UC82.

Bacterial wilt incidences. Significant variation was recorded across the parental genotypes and their hybrids for resistence to *Ralstonia solanacearum*. High resistance with mean of less than one was noted in the parental genotypes AVTO1429, AVTO1424 and AVTO1314 respectively plus their hybrids namely Eden FS x AVTO1424, Roma VF x AVTO1429, AVTO1429 x AVTO1314, AVTO1429 x UC82, AVTO1429 x Valoria FS, AVTO1424 x AVTO1314, AVTO1424 x UC82, AVTO1424 x Valoria FS, AVTO1424 x Riogrande, and Danny FS x AVTO1314.

Other plant attributes. Plant height means across the parental genotypes and their F_1 hybrids ranged between 218.17 cm for AVTO1429 x AVTO1314 to 83.33 cm for the hybrid Cal J VF x UC82. On the other hand for fruit length, a mean value of 5.66 for the F_1 hybrid cross Eden FS x Riogrande and 3.00 for Eden FS x Valoria FS were recorded for fruit length. Also, means for the fruit diameter varied across the parents and their cross combinations with Eden select x AVTO1429 recording 7.77 cm of beef type tomato and the lowest mean of 3.90 cm noted in UC82.

In terms of number of fruits per truss, the mean values for the fruits per truss was 5.33 for tomato Danny, UC82 and Roma VF x Danny select. The lowest mean number of fruit per truss of 3.0 was recorded on AVTO1314 and in hybrid crosses Eden select x Valoria select and AVTO1429 x AVTO1314.

Finally, the highest mean number of trusses per plant of 29.5 was recorded on tomato UC82 while the lowest (9.28) was from cross Cal J VF x Riogrande.

Discussion

Heterosis breeding has been used over several decades across the globe in developing hybrid tomatoes and performance of F_1 over better in several traits (Jinks and Jones, 1958). Table 2 shows that performance of F_1 hybrids over better parents heterosis ranged between -9% (AVTO1429 x Cal J VF) to 3% (AVTO1429 x Danny select, AVTO1424 x Valoria select, Eden select x AVTO1314). Lower percentage of days to flowering is desirable because it signifies earliness to fruit formation. Magnitude of heterosis (Table 2) of F1 over better parent ranged from -5% (Roma VF x AVTO1314) to 17% (AVTO1429 x UC82) for days to maturity. The lowest negative percentage shows early maturing F_1 hybrid variety representing an important trait desirable to many farmers. Table 2 also shows heterosis magnitude for plant height. This ranged from -41% (AVTO1429 x Cal J VF) to 20% (AVTO1424 x UC82). High Negative heterosis magnitude shows that the F1 hybrid is short determinate while higher positive heterosis denoted an indeterminate growth type. The growth type determinate the cropping practice a farmer will follow like need for cropping support or pruning. Heterosis magnitude for plant vigour ranged from -20% (Eden select x AVTO1314) to 50% (AVTO1314 x Valoria select, AVTO1314 x Riogrande). The maximum positive heterosis shows the best vigorous F_1 hybrids in the crosses which is an important trait in variety selection from early germination energy to full maturity vigour that enables the variety to overcome both biotic and abiotic stresses. For number of fruits per truss, heterosis magnitude ranged between -20% (AVTO1429 x Danny select, AVTO1429 x UC82, AVTO1424 x Danny select, AVTO1314 x UC82, and Cal J VF x AVTO1314) to 25% (AVTO1424 x Riogrande). High positive heterosis is desired because farmers relate the number of flowers per truss to variety production.

Conclusion

Significant heterosis was noted for the traits under consideration and these points out potential varieties that can be exploited for further development into commercial cultivars. There is therefore opportunity for Kenyan and regional breeders to utilize heterosis and combining ability for different traits breeding in tomatoes that will culminate into local breeding programme commercializing locally adapted varieties that are easily accessible to growers, at affordable price and with improved traits.

Acknowledgment

The financial support provided by Continental Seeds Company and The University of Nairobi is gratefully acknowledged. Great appreciation also goes to the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for providing a platform to showcase results of this study. This paper is a contribution to the 2018 Sixth African Higher Education Week and RUFORUM Biennial Conference.

Table 1 Mean performance of parental genotypes and selected F_1 hybrids for key growth and yield attributes

Genotypes	Days to 50% flowering	Days to maturity	Plant vigour	Bacterial incidences	wilt Plant height (cm)	Fruit length (cm)	Fruit diameter (cm)	No. of fruits per truss	No. of trusses per plant
Eden select	42.00	113.00	4.67	3.44	105.61	5.55	4.45	4.00	24.28
Roma VF	42.67	124.33	5.00	3.67	99.67	5.53	3.91	5.00	24.37
AVTO1429	42.67	121.67	4.33	0.00	204.67	4.54	4.21	3.33	22.39
Cal J VF	42.67	115.00	3.67	3.50	96.11	5.17	4.41	3.67	20.83
AVTO1424	42.00	117.67	3.33	0.00	121.78	4.33	4.30	3.33	18.44
Danny select	40.67	108.00	5.00	1.35	99.67	5.02	4.63	5.33	22.72
AVTO1314	42.33	118.33	4.00	0.14	110.50	4.30	5.16	3.00	19.94
UC82	40.33	105.00	4.33	3.07	72.33	4.76	3.90	5.33	29.50
Valoria select	42.33	118.33	4.00	1.83	107.22	5.37	4.38	4.00	22.50
Riogrande	43.00	114.33	4.00	3.15	105.61	5.59	4.44	4.00	21.05
Eden select x AVTO1429	39.00	114.67	4.00	0.80	108.33	4.89	5.35	4.00	20.86
Eden select x AVTO1424	38.67	114.00	4.33	2.85	107.5	5.15	7.77	4.00	20.89
Eden select x AVTO1314	38.33	111.33	4.00	1.20	110.72	4.45	4.92	4.00	23.33
Roma VF x AVTO1429	37.33	117.00	3.67	1.32	211.45	4.98	4.25	4.67	19.00
Roma VF x AVTO1424	40.67	117.67	3.67	0.66	120.28	5.10	4.19	4.33	26.94
Roma VF x AVTO1314	38.67	112.33	4.33	1.06	105.67	4.90	4.68	3.67	27.00
AVTO1429 x Cal J VF	40.67	123.00	4.67	1.23	206.61	4.98	4.50	4.33	16.33
AVTO1429 x AVTO1424	39.67	119.00	4.00	1.49	208.28	4.79	5.51	3.33	15.89
AVTO1429 x Danny select	41.33	122.33	4.67	0.25	157.22	4.44	5.36	3.67	19.28
AVTO1429 x AVTO1314	43.33	119.00	4.00	0.19	218.17	4.26	5.60	3.00	24.28
AVTO1429 x UC82	41.67	123.00	4.67	1.18	152.06	4.62	4.95	4.00	16.73
AVTO1429 x Valoria select	42.33	121.33	4.67	0.47	167.56	4.75	5.16	4.33	20.94
AVTO1429 x Riogrande	41.67	122.33	4.33	1.50	150.72	4.71	5.53	4.00	13.39
Cal J VF x AVTO1424	42.67	118.67	5.00	1.22	119.72	4.94	4.20	4.67	16.78
Cal J VF x Danny select	40.67	116.67	4.00	2.56	93.17	5.08	4.37	4.00	18.83
Cal J VF x AVTO1314	42.33	80.33	4.00	1.86	110.11	4.56	4.50	4.00	25.37
Cal J VF x UC82	43.00	113.00	3.33	4.03	83.33	4.80	4.52	4.00	20.16
Cal J VF x Valoria select	40.67	114.67	4.00	3.85	99.05	5.43	4.33	4.67	12.55
Cal J VF x Riogrande	42.67	116.33	3.67	3.65	94.33	5.45	4.59	3.67	9.28
AVTO1424 x Danny select	41.67	120.67	4.67	1.37	122.61	4.93	4.53	4.33	20.28
AVTO1424 x AVTO1314	39.00	118.00	4.67	0.71	128.50	4.93	5.41	3.67	19.11
AVTO1424 x UC82	37.00	121.00	4.67	0.83	114.28	4.84	4.64	4.67	23.61

AVTO1424 x Valoria select	40.00	117.67	4.00	0.11	131.56	5.20	4.52	4.00	14.66
AVTO1424 x Riogrande	39.67	116.00	4.00	0.60	116.56	5.04	4.61	4.67	20.94
Danny select x AVTO1314	38.33	114.00	4.33	0.86	106.72	4.82	5.00	4.33	20.66
Danny select x Riogrande	41.00	113.33	4.33	1.33	89.83	5.02	4.35	4.67	23.39
AVTO1314 x UC82	37.00	107.33	4.00	0.36	102.00	4.88	5.01	4.00	29.28
AVTO1314 x Valoria	39.67	116.67	5.00	0.32	116.33	4.60	5.08	3.67	19.44
AVTO1314 x Riogrande	42.33	117.33	4.00	0.94	107.28	4.76	5.27	4.00	22.33
UC82 x Valoria select	39.33	84.33	4.00	4.60	95.06	4.71	4.42	4.67	18.55
UC82 x Riogrande	38.33	113.67	3.67	4.44	76.33	5.13	4.24	4.00	21.33
Valoria select x Riogrande	42.33	117.67	4.33	2.75	97.01	5.38	4.21	4.00	22.44
Mean	40.56	115.39	4.28	2.07	118.73	5.02	4.66	4.16	20.26
$LSD_{0.05}$	2.84	8.92	1.01	1.21	11.93	4.14	11.99	1.20	4.49
CV (%)	4.3	10.1	14.6	36.0	14.9	12.2	37.4	17.9	32.8

CV: coefficient of variation; LSD: Least significant difference at 5% P-value threshold

Table 2. Heterosis for selected F_1 hybrids for key growth and yield attributes

Genotypes	Days to 50% flowering	Better parent	Days to maturity	Better parent	Plant height (cm)	Better parent	Plant vigour	Better parent	No. of fruits per truss	Better parent
AVTO1429 x Cal J VF	-9%	34	7%	115	-41%	205	25%	4	0%	4
AVTO1429 x AVTO1424	-3%	34	8%	118	-29%	205	0%	4	0%	3
AVTO1429 x Danny select	3%	32	13%	108	-25%	205	0%	5	-20%	5
AVTO1429 x AVTO1314	-3%	34	1%	118	-38%	205	0%	4	0%	3
AVTO1429 x UC82	0%	31	17%	105	-38%	205	25%	4	-20%	5
AVTO1424 x Danny select	-3%	32	12%	108	21%	100	20%	5	-20%	5
AVTO1424 x AVTO1314	-6%	34	0%	118	5%	111	25%	4	0%	3
AVTO1424 x UC82	-6%	31	15%	105	20%	93	25%	4	0%	5
AVTO1424 x Valoria select	3%	33	0%	118	15%	107	25%	4	0%	4
AVTO1424 x Riogrande	0%	33	2%	114	12%	93	25%	4	25%	4
AVTO1314 x UC82	-3%	31	2%	105	-9%	111	25%	4	-20%	5
AVTO1314 x Valoria	-3%	33	0%	118	5%	111	50%	4	0%	4
AVTO1314 x Riogrande	0%	33	3%	114	-4%	111	50%	4	0%	4
Eden select x AVTO1314	3%	32	-2%	113	0%	111	-20%	5	0%	4
Roma VF x AVTO1314	0%	33	-5%	118	-10%	111	-20%	5	-20%	5

References

Food and Agricultural Organization (FAO). 2017. Statistical Database. Retrieved from http://www.faostat.fao.org

Fufa, F P., Hanson, Dagnoko, S. and Dhaliwal, M. 2015. AVRDC – The world vegetable centre tomato breeding in Sub-Saharan Africa: Lessons from the past, present work, and future. *Acta Hort.* 911, ISHS 2011.

Griffing, B. 1956b. Concept of general and specific combining ability in relation to diallel system. *Aust. J. Biol. Sci.* 9: 463-493.

Jinks, J.L. and Jones, R.M. 1958. Estimation of the components of hetrosis. *Genetics* 43: 223-34.

Jitendra, K.T., Nandan, M., Singh, M.K. and Prem, S.T. 2012. Screening of tomato genotypes against bacterial wilt (*Ralstonia solanacearum*) under field condition for Chhattisgarh. *G.J.B.B*. 1 (2): 168-170.

Rick, C.M. and Holle, M. 1990. Andean *Lycopersicon* esculentum var. cerasiformie: Genetic variation and its evolutionary significance. *Journal of Economic Botany* 44:69-78.

Sigei, K. G., Ngeno, K. H., Kibe, M. A., Mwangi, M. M. and Mutai, C. M. 2014. Challenges and strategies to improve tomato competitiveness along the tomato value chain in Kenya. *International Journal of Business and Management* 9 (9): 230-245.

Troyer, A.F. 2006. Adaptedness and Heterosis in corn and mule hybrids. *Crop Sci.* 46:529-543.

Yordanaov, 1983. Parent selection in tomato based on morpho-physiological traits. *HortScience* 14: 458.