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African Journal of Plant Science

Full Length Research Paper

Performance of cotton genotypes (*Gossypium hirsutum* L.) for yield and yield component traits under irrigated climatic conditions of Ethiopia

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The present study was conducted to test the performance of cotton genotypes for yield and yield components from 2011 to 2013 cropping season at different cotton growing agro-ecologies in the country. Eleven cotton genotypes along with three check varieties were examined at three locations in RCBD under three replications. The genotypes manifested highly significant differences ($p \leq 0.01$) for plant height, bolls per plant, boll weight, seed cotton yield, ginning outturn and lint yield. The data indicated that higher seed cotton yield, lint yield and ginning outturn were obtained from cotton genotype Arba × Cucurova 1518 F5#1-3/3 at Weyto. Guru F5#1-2 genotype performed higher bolls per plant and seed cotton yield at Weyto but the value of seed cotton yield was lower than that of best performed check varieties. And also, the maximum seed cotton yield was recorded in Stam 59A × ICA 01 bulk and Sanju F5#9-2-1 cotton genotypes at Werer. It is concluded that the higher mean performance of seed cotton yield and more lint yield were obtained in cotton genotypes Guru F5#1-2, Sanju F5#9-2-1 and Arba × Cucurova 1518 F5#1-3/3 than that of check varieties. Moreover, Arba × Cucurova 1518 F5#1-4/3 genotype performed maximum boll weight, ginning outturn and lint yield than the check varieties. Therefore, genotypes Guru F5#1-2, Sanju F5#9-2-1, Arba × Cucurova 1518 F5#1-4/3 and Arba × Cucurova 1518 F5#1-3/3 recommended to use for their performed traits.

Key words: Seed cotton yield, plant height, lint yield, Genotypes, mean performance.

INTRODUCTION

Cotton is the most important fiber crop of Ethiopia. The cotton plant provides raw material to all textile mills, ginning factories, cottage industries and oil mills. It is also used for edible oil production, which when quantified makes a huge contribution to the national oil production (https://www.cotton.org/pubs/cottoncounts/story/importance.cfm). The crop is also used as an important source of cash for the growers and it offers considerable employment opportunity on the farms, in ginneries, oil mills, and knitting, textile and garment factories. At present, cotton is produced

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under both rain-fed and irrigated conditions by private commercial farms and small holders. Commercial cotton is produced in the lowland irrigated areas at elevations below 1300 m. The major growing areas are the Upper, Middle and Lower Awash Rift Valley areas in the East, and the Abaya, Arba Minch, Sille, Weyto and Omorate areas in the South part of the country; while the rain-fed cotton production centres are located in the medium altitude ranging from 1000 to 18000 m above sea level, mainly in Gambella, Beneshangul Gumuz, Amhara, Tigray, and SNNP regions. According to a study report of Minister of Agriculture and Rural Development, there are some 3,000,810 ha of land suitable for cotton production, which is far above that of Pakistan, the fourth largest producer of cotton in the world that harvests around 2.5 to 3.5 million tons of cotton per annum. Despite this immense potential, Ethiopia currently produces only about 214,786 tons of seed cotton from a total cultivated land amount of about 111,886 ha which accounts for about 3.7% of the total potential area of the country (Ministry of Agriculture and Rural Development (MoARD), 2010).

Ethiopian cotton productivity is 860 to 1800 kg/ha in rain fed and 2200 kg/ha in irrigated farms. These low yields may be attributed to several factors like poor management practices, diseases and pests and lack of knowhow by growers about the advanced package of technology concerning cotton production. However, most common cause of low productivity in Ethiopia is lack of improved varieties in form of seed cotton yield and yield components. The new variety CIM-608 has been developed through interspecific hybridization, that is, (*Gossypium hirsutum* × *Gossypium anomalum*) × *G. hirsutum* and produced significantly higher yield in varietal trials compared with the standard variety, that is, MNH-786 (Zahid et al ., 2014). Significant differences were observed in yield and yield contributing traits with the development of new varieties of Upland cotton (Singh et al., 1973). Arshad et al. (2003) found significant variation for various characters like ginning out percentage, staple length, number of bolls and boll weight due to the use different genotypes.

Therefore, various parents have been involved in crosses of intraspecific crosses at Werer Agricultural Research Center to improve seed cotton yield and yield components and many of the crosses have passed through a series of evaluations and the best ones are now at the National yield trial and have almost reached homozygosity and the present study was conducted to evaluate these genotypes in form of seed cotton yield and yield components at different cotton growing agro-ecologies of Ethiopia to release as new varieties if found to be superior to the varieties under cultivation.

MATERIALS AND METHODS

The experiment was carried out from 2011 to 2013 main growing season at three locations (Werer, Sille and Weyto) of cotton growing regions. Werer is located at 9° 34’12” N latitude and 40° 17’22”E longitude and 740 m above sea level (masl), Sille is located at 5° 51’42” N latitude and 37° 28’32” E longitude at an elevation of 1120 masl, and Weyto is located at 5° 23’31” N latitude and 36° 58’41” E longitude at an elevation of 550 masl. Eleven cotton genotypes (Table 1) with three check varieties (Deltapine-90, Stam 59 A and Ionia) were obtained from Werer Agricultural Research Center. The experiment was carried out in randomized complete block design with three replications. Sowing was carried out in five rows each 5-m long with plant to plant distance of 20 cm and row to row distance of 90 cm (plot size of 5 m × 5 rows × 0.9 = 22 m^2). Three seeds per hole were hand sown on the top of the ridges. Thinning was done fifteen days after emergence to have the required population of 125 plants per plot. Appropriate agronomic practice and field evaluations were also implemented as per the schedule. The central three rows with net plot size of 5 m × 3 rows × 0.9 = 13.5 m^2 were used for harvesting seed cotton yield to avoid border effect, and other data were taken from fifteen selected plants from central rows of a plot. Agronomic traits, namely: plant height, number of bolls per plant, mature boll weight (g), seed cotton yield, ginning outturn and lint yield, were collected. The data collected were statistically analyzed according to Steel and Torrie (1984) by using SAS software for analysis of variance (ANOVA).

RESULTS AND DISCUSSION

According to analysis of variance (Table 2), the overall mean values of fourteen cotton genotypes manifested highly significant differences ($p \leq 0.01$) for plant height, bolls per plant, boll weight, seed cotton yield, ginning outturn and lint yield. The differences among locations were found significant for all characters while the location × genotype interactions were non-significant for all characters except seed cotton yield and lint yield. Therefore, the results revealed significant variations among the genotypes and locations for all of the traits studied.

Plant height

Data regarding the plant height is shown in Table 3. On average, the plant heights were varied from 107.72 to 132.05 cm among fourteen cotton genotypes. The tallest plant height was observed in Sanju F5#9-2-1 (132.05 cm) followed by Arba × GL-7 F5#1-2/3 (129 cm) and Indam 206 F5#6-1-1 (126.05 cm) genotypes. The shortest plant height was observed in Deltapine-90 (107.72 cm) and it was statistically at par with seven genotypes with plant height from 111.39 to 118.07 cm. The differences among genotypes for plant height might have been due to the difference in genetic makeup of genotypes considered in the experiment. These results are in confirmation with those of Premalatha et al. (2020) and Nikhil et al. (2018) who reported that plant height is affected due to genetic makeup of genotypes.

Bolls per plant

The highest bolls per plant were picked from Indam 2194

Table 1. Experimental materials consisted of eleven cotton genotypes with three check varieties (Deltapine-90, Stam 59 A and Ionia).

Treatment
Stam 59A × ICA 01 bulk
Indam 2194 F5#2-1-2
Sanju F5#9-2-1
Indam 206 F5#6-1-1
Guru F5#1-2
Polaris F5#3-2-2
Del Cero × Cucurova 1518 F5#1-3
Del Cero × GL-7 F5#1-4-1
Arba × Cucurova 1518 F5#1-3/3
Arba × Cucurova 1518 F5#1-4/3
Arba × GL-7 F5#1-2/3
Ionia
Deltapine-90
Stam 59 A

Table 2. Analysis of Variance of different cotton genotypes for seed cotton yield and its components.

Source of variation	Mean square					
	Plant height (cm)	Boll no/plant	Boll weight (g)	Seed cotton yield (kg/ha)	Ginning outturn (%)	Lint yield (kg/ha)
Rep(Year*Location)	546.06	28.19	2.21	139.49	4.88	15.99
Locations	110592.49**	726.88**	17.34**	8083.34**	188.01**	1074.94**
Genotypes	1247.37**	110.98**	3.62**	217.69**	142.86**	71.01**
Genotypes × locations	308.15	12.08	0.54	98.67*	6.55	17.29*
Error	285	12.56	0.58	56.68	5.83	9.73
CV	14.17	19.49	15.51	18.24	6.31	19.79

* and ** showing significance at 5 and 1% levels, respectively. CV = Coefficient of variation.

F5#2-1-2, Guru F5#1-2 and Delcero × GL-7 F5#1-4-1 cotton genotypes at all locations (Weyto (24.79 bolls plant^{-1}), (23.24 bolls plant^{-1}) and (23.43 bolls plant^{-1}), Sille (18.78 bolls plant^{-1}), (21.29 bolls plant^{-1}) and (18.56 bolls plant^{-1}) and Werer (19.28 bolls plant^{-1}), (20.33 bolls plant^{-1}) and (20.6 bolls plant^{-1})), respectively. The lowest bolls per plant were picked from Ionia cotton genotype at Werer (13.37 bolls plant^{-1}) and Sille (15.45 bolls plant^{-1}). Overall locations, bolls per plant gave that the maximum value from Guru F5#1-2 (21.62 bolls plant^{-1}) followed by Indam 2194 F5#2-1-2 (20.95 bolls plant^{-1}) and Delcero × GL-7 F5#1-4-1 (20.87 bolls plant^{-1}). Seven genotypes had bolls plant^{-1} higher than that of the best check variety Deltapine-90 (18.1395 bolls plant^{-1}). The minimum bolls per plant were picked from check variety Stam 59 A (15.72 bolls plant^{-1}) and were found statistically at par with five genotypes (15.93 to 17.31 bolls plant^{-1}) (Table 3). The differences among genotypes for number of bolls per plant might have been due to the difference in genetic potential of the genotypes and environment. The significant differences among varieties for number of bolls per plant had also been reported by Shakeel et al. (2015). The results were also in accordance with the findings of Chaudhari et al. (2017) who also reported variable number of bolls per plant for different genotypes.

Boll weight

Two cotton genotypes (namely, Arba × Cucurova 1518 F5#1-4/3 and Ionia) produced biggest boll weight at all locations (Sille (5.82 g) (5.54 g), Weyto (5.46 g) (5.53 g) and Werer (5.14 g) (5.22 g)). Indam 206 F5#6-1-1 cotton genotype produced biggest boll weight at Sille (5.64 g) and Werer (5.08 g). Delcero × GL-7 F5#1-4-1 (3.87 g) and Guru F5#1-2 (3.89 g) cotton genotypes produced the smallest boll weight at Weyto and Werer, respectively. Average boll weight of the cotton genotypes revealed that

Table 3. Mean performances of cotton genotypes for plant height, number of bolls per plant and boll weight.

Treatment	Plant height				Number of bolls per plant				Boll weight			
	Werer	Sille	Weyto	Mean	Werer	Sille	Weyto	Mean	Werer	Sille	Weyto	Mean
Stam 59A × ICA 01 bulk	96.24^{ab}	144.82^{abc}	117.22^{a}	119.43^{bcde}	18^{cb}	19^{ab}	23^{ab}	20^{ab}	4.02^{cd}	4.67^{b}	4.25^{cd}	4.31^{f}
Indam 2194 F5#2-1-2	87.56^{bc}	143.39^{abc}	121.73^{a}	117.56^{cdef}	19^{ab}	19^{ab}	25^{a}	21a	4.11^{cd}	5.24^{ab}	4.64^{abcd}	4.66^{def}
Sanju F5#9-2-1	101.61^{a}	165.07^{a}	129.45^{a}	132.05^{a}	16^{cd}	19^{ab}	20^{abc}	18^{bc}	4.72^{abc}	5.06^{ab}	4.97^{abc}	4.92^{cde}
Indam 206 F5#6-1-1	95.00^{ab}	161.67^{a}	121.47^{a}	126.05^{abc}	14^{d}	17^{b}	19^{bc}	17^{cde}	5.08^{a}	5.64^{ab}	4.68^{abcd}	5.14^{abcd}
Guru F5#1-2	91.31^{abc}	136.95^{c}	119.35^{a}	115.87^{cdef}	20^{a}	21^{a}	23^{ab}	22a	3.89^{d}	5.18^{ab}	4.56^{bcd}	4.54^{ef}
Polaris F5#3-2-2	92.30^{abc}	147.39^{abc}	113.01^{a}	117.57^{cdef}	15^{cd}	19^{ab}	22^{abc}	18^{bc}	4.31^{bcd}	5.59^{ab}	4.38^{bcd}	4.76^{cde}
Del Cero × Cucurova 1518 F5#1-3	84.90^{bc}	139.11^{bc}	111.67^{a}	111.89^{def}	15^{cd}	17^{b}	20^{abc}	17^{cde}	5.08^{a}	5.44^{ab}	4.56^{bcd}	5.03^{abcd}
Del Cero × GL-7 F5#1-4-1	93.89^{bc}	144.67^{abc}	121.13^{a}	116.78^{cdef}	21^{a}	19^{ab}	23^{ab}	21^{a}	4.17^{cd}	4.81^{ab}	3.87^{d}	4.29^{f}
Arba × Cucurova 1518 F5#1-3/3	93.89^{abc}	146.31^{abc}	127.99^{a}	122.73^{abc}	16^{cd}	19^{ab}	21^{abc}	19^{bc}	4.68^{abc}	5.34^{ab}	5.11^{abc}	5.04^{abcd}
Arba × Cucurova 1518 F5#1-4/3	82.33^{cd}	153.01^{abc}	118.85^{a}	118.07^{cdef}	13^{d}	17^{b}	18^{c}	16^{e}	5.14^{a}	5.82^{a}	5.46^{a}	5.47^{a}
Arba × GL-7 F5#1-2/3	91.26^{abc}	164.70^{a}	131.04^{a}	129.00^{ab}	15^{d}	16^{b}	17^{c}	16^{e}	4.76^{abc}	5.54^{ab}	5.19^{ab}	5.17^{abc}
Ionia	82.70^{cd}	133.57^{c}	117.89^{a}	111.39^{ef}	13^{d}	15^{b}	20^{bc}	16^{ed}	5.22^{a}	5.54^{ab}	5.53^{a}	5.43^{ab}
Deltapine-90	72.49^{d}	135.73^{c}	114.93^{a}	107.72^{f}	16^{cd}	17^{b}	22^{abc}	18^{bcd}	4.68^{abc}	5.33^{ab}	4.88^{abc}	4.96^{bcde}
Stam 59 A	91.39^{abc}	160.33^{ab}	115.48^{a}	122.40^{abcd}	16^{d}	17^{b}	17^{c}	16^{e}	5.02^{ab}	5.52^{ab}	4.78^{abc}	5.11^{abcd}
Mean	89.11	148.34	120.09	119.18	15.94	17.88	20.71	18.18	4.64	5.34	4.78	4.92

the biggest boll weight was noticed in genotypes Arba × Cucurova 1518 F5#1-4/3 (5.47 g) and Ionia (5.43 g), followed by Arba × GL-7 F5#1-2/3 (5.17 g), Indam 206 F5#6-1-1 (5.14 g) and Stam 59 A (5.11 g). The smallest boll weight was noticed in genotypes Delcero × GL-7 F5#1-4-1 (4.29 g) and Stam 59A × ICA 01 bulk (4.31 g). The variation was due to the use of different genotypes. These results are also in line with those of Ahsan et al. (2015) and Farooq et al. (2017) who reported that average boll weight varies significantly among the varieties studied.

Seed cotton yield

In Table 4, it can be seen that the maximum seed cotton yield was recorded in Stam 59A × ICA 01 bulk and Sanju F5#9-2-1 cotton genotypes at Werer (5099 and 5021 kg ha^{-1}) and recorded in Guru F5#1-2, Arba × Cucurova 1518 F5#1-3/3 and Arba × GL-7 F5#1-2/3 genotypes at Weyto (5112, 5052, and 5019 kg ha^{-1}); but there, the results were exceeded by check variety Ionia (5188 kg ha^{-1}). The minimum seed cotton yield was observed at Sille in all varieties, rather than other locations. The overall mean values of seed cotton yield ranged from 3485 to 4618 kg ha^{-1} among cotton genotypes. The highest seed cotton yield was obtained from Guru F5#1-2 (4618 kg ha^{-1}) and Sanju F5#9-2-1 (4541 kg ha^{-1}) cotton genotypes, followed by Arba × Cucurova 1518 F5#1-3/3 (4304 kg ha^{-1}) and Deltapine-90 (4297 kg ha^{-1}) cotton genotypes. The lowest seed cotton yield was obtained from Indam 206 F5#6-1-1 (3485 kg ha^{-1}) genotype; but was found statistically at par with two other genotypes, whose seed cotton yields were 3883 and 3896 kg ha^{-1}. These results are in line with those of Premalatha et al. (2020) who reported seed cotton yield traits in cotton vary depending on the genotypic structure of cultivar and environmental conditions.

Lint yield

The data pertaining to lint yield is presented in Table 4. The highest lint yield was produced in Arba × Cucurova 1518 F5#1-3/3, Arba × GL-7 F5#1-2/3 and Arba × Cucurova 1518 F5#1-4/3 genotypes at Weyto (namely, 2086, 2022, and 2021 kg ha^{-1}, respectively); and produced in Stam 59A × ICA 01 bulk, Indam 2194 F5#2-1-2, Delcero × Cucurova 1518 F5#1-3 and Guru F5#1-2 at Werer (namely, 1902, 1849, 1835, and 1829 kg ha^{-1}, respectively). Cotton genotypes Indam 206 F5#6-1-1 and Polaris F5#3-2-2 revealed the lowest lint yield at all locations; namely, Sille (1016 and 1145 kg ha^{-1}), Weyto (1220 and 1458

Table 4. Mean performances of cotton genotypes for seed cotton yield, lint yield and ginning outturn.

Treatment	Seed cotton yield				Lint yield				Ginning outturn			
	Werer	Sille	Weyto	Mean	Werer	Sille	Weyto	Mean	Werer	Sille	Weyto	Mean
Stam 59A × ICA 01 bulk	5099^{a}	3081^{abc}	4555^{ab}	4245^{abc}	1902^{a}	1194^{abcdef}	1854a	1650^{ab}	37.30^{bc}	39.15^{cd}	40.46^{abcd}	38.97^{bcd}
Indam 2194 F5#2-1-2	4727^{abcd}	3087^{abc}	4202^{bc}	4006^{c}	1849^{ab}	1229^{abcdef}	1672^{ab}	1583^{ab}	39.08^{a}	39.95^{abc}	39.84^{abcd}	39.62^{bc}
Sanju F5#9-2-1	5021^{ab}	3878^{a}	4724^{ab}	4541^{ab}	1777^{abc}	1443^{abc}	1729^{ab}	1649^{ab}	35.10^{d}	37.67^{de}	36.64^{de}	36.47e
Indam 206 F5#6-1-1	3990^{e}	2865^{bc}	3601^{c}	3485^{d}	1268^{d}	1016^{E}	1220^{c}	1168^{d}	31.77^{e}	35.49^{f}	33.79^{e}	33.68^{f}
Guru F5#1-2	4848^{abc}	3895^{a}	5112^{ab}	4618^{a}	1829^{abc}	1523^{a}	1867^{a}	1740^{a}	37.64^{b}	39.61^{abc}	37.34^{cde}	38.20_{cd}
Polaris F5#3-2-2	4244^{de}	3157^{abc}	4289^{abc}	3896^{cd}	1345^{d}	1145^{bcde}	1458^{bc}	1316^{cd}	31.50^{e}	36.24^{ef}	33.95^{e}	33.90f
Del Cero × Cucurova 1518 F5#1-3	4862^{abc}	2988^{abc}	4561^{ab}	4137^{bc}	1835^{abc}	1179^{abcde}	1812^{ab}	1609^{ab}	37.53^{b}	39.40^{bcd}	39.82^{abcd}	38.92^{bcd}
Del Cero X GL-7 F5#1-4-1	4518^{bcde}	2800^{bc}	4329^{abc}	3883^{cd}	1609^{c}	1089^{cde}	1671^{ab}	1456^{bc}	35.98^{cd}	39.14^{cd}	38.65^{abcd}	37.92d
Arba × Cucurova 1518 F5#1-3/3	4524^{bcde}	3335^{abc}	5052^{ab}	4304^{abc}	1680^{abc}	1291^{abcde}	2086^{a}	1686^{a}	36.84^{bc}	39.01^{cd}	41.07^{abc}	38.97^{bcd}
Arba × Cucurova 1518 F5#1-4/3	4518^{de}	3563^{ab}	4774^{ab}	4210^{abc}	1741^{abc}	1468^{ab}	2021^{a}	1743^{a}	40.50^{a}	41.07^{ab}	42.42^{a}	41.33^{a}
Arba × GL-7 F5#1-2/3	4524^{de}	2925^{bc}	5019^{ab}	4072^{c}	1677^{abc}	1196^{abcde}	2022^{a}	1632^{ab}	39.15^{a}	41.25^{ab}	40.58^{abc}	40.33^{ab}
Ionia	4292^{cde}	2580^{c}	5188^{a}	4052^{c}	1630^{bc}	1025^{de}	1988^{a}	1548^{ab}	36.98^{bc}	39.59^{abc}	38.23^{bcd}	38.27^{cd}
Deltapine-90	4597^{abcd}	3365^{abc}	4928^{ab}	4297^{abc}	1656^{bc}	1291^{abcde}	1923^{a}	1623^{ab}	36.12^{bde}	38.66^{cd}	38.86^{abcd}	37.88^{d}
Stam 59 A	4032^{e}	3362^{abc}	4747^{ab}	4047^{c}	1637^{bc}	1386^{abcd}	1978^{a}	1667^{a}	40.52^{a}	41.31^{a}	41.60^{ab}	41.14^{a}
Mean	4530	3206	4649	4128	1674	1248	1807	1576	36.86	39.11	38.8	38.26

kg ha^{-1}) and Werer (1268 and 1345 kg ha^{-1}), respectively.

On average, the lint yields of the genotypes varied between 1168 and 1743 kg ha^{-1}. The maximum lint yield was observed in Arba × Cucurova 1518 F5#1-4/3 (1743 kg ha^{-1}) and Guru F5#1-2 (1740 kg ha^{-1}) genotypes, followed by genotypes Arba × Cucurova 1518 F5#1-3/3 (1686 kg ha^{-1}), Stam 59 A (1667 kg ha^{-1}), Stam 59A × ICA 01 bulk (1650 kg ha^{-1}) and Sanju F5#9-2-1 (1649 kg ha^{-1}); and the minimum lint yield was observed in Indam 206 F5#6-1-1 (1168 kg ha^{-1}) genotype.

Ginning outturn (%)

The difference between genotypes in the ratio of lint to the seed cotton was analyzed for ginning outturn percentage. In Table 4, it can be seen that cotton genotype Arba × Cucurova 1518 F5#1-4/3 gave the highest ginning outturn at Weyto (42.42%), Sille (41.07%) and Werer (40.5%). However, the entry value at Sille and Werer was nearly equivalent with the best check variety. Arba × GL-7 F5#1-2/3 genotype gave the highest lint percentage at Sille (41.25%); but the entry value was nearly equivalent with check variety Stam 59 A (41.31%). Cotton genotypes Polaris F5#3-2-2 and Indam 206 F5#6-1-1 gave the lowest ginning outturn at Werer (31.5 and 31.77%) and Weyto (33.95 and 33.79%). Overall, lint percentage of the genotypes showed that the highest lint percentage was noticed in genotypes Arba × Cucurova 1518 F5#1-4/3 (41.33%) and Stam 59 A (41.14%) followed by Arba × GL-7 F5#1-2/3 (40.33%) and Indam 2194 F5#2-1-2 (39.62%) genotypes. The lowest lint percentage was noticed in genotypes Indam 206 F5#6-1-1 (33.68%) and Polaris F5#3-2-2 (33.9%). The aforementioned findings are well supported by published results of Nikhil et al. (2018) and Premalatha et al. (2020) who reported differences in the ginning outturn percentage (% GOT) due to differences among varieties. Huseyin et al. (2017) studied the comparison of mean yield components and fiber quality parameters of advanced bulk generations in f2, f3 and f4 interspecific and intraspecific cotton populations, and observed varied ginning % for different genotypes.

Conclusion

It can be concluded that considerable variability was observed among traits. The test varieties with high seed cotton yield and lint yield can be recommended for their desirable performance. The genotypes Guru F5#1-2, Sanju F5#9-2-1 and Arba × Cucurova 1518 F5#1-3/3 performed better than the check varieties in terms of both seed cotton and lint yield. Arba × Cucurova 1518 F5#1-4/3 genotype gave maximum boll weight, ginning % and lint yield compared to the check varieties. On the basis of these results, it is recommended that the cotton genotypes Guru F5#1-2, Sanju F5#9-2-1, Arba × Cucurova 1518 F5#1-3/3 and Arba × Cucurova 1518 F5#1-4/3 can be released to be used for their performed traits.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of storage temperature on fruit firmness and weight loss of nine tomato lines

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This study aimed to determine effect of three temperature levels on fruit firmness and weight in nine tomato lines in Kenya. Fruit firmness and weight loss were evaluated in a split plot design, temperature levels as main plots and tomato lines as sub-plots at the University of Nairobi, Pilot Seed Processing Plant. Fruits stored at 16°C showed the lowest average decrease in fruit firmness (58.19%) followed by 4°C (61.11%) while the highest loss of 73.34% was at 25°C. An average firmness loss of <47.59% was recorded in tomato lines after three weeks storage at 4°C and <50.62% after four weeks at 16°C. More than 50.31% loss was recorded after two weeks at 25°C. Tomato lines stored at 4°C recorded a weight loss of <38.76% throughout the storage period. More than 50.00% weight loss at 16°C was recorded after three weeks while at 25°C, the same loss was recorded after one week of storage. At 4°C, loss in fruit weight varied from 0.98% (AVTO1424) to 3.11% (Roma VF x AVTO1314) in week one and from 22.85% (AVTO1424) to 38.76% (AVTO1314) in week five. AVTO1424 had the lowest loss in fruit firmness and weight while Valoria selects had the highest.

Key words: Shelf-life, quality attributes, genotypes, fruit mass, storage conditions.

INTRODUCTION

Fresh market and processing tomato are based on key quality traits that need to be focused by most growers since they influence tomato purchase price (Humphrey, 2007). Grading of tomatoes follows the quality attributes that are external -such as fruit colour, firmness, size, shape, absence of green shoulders (uniformity in ripening) and skin defects- whereas internal are locule number, total soluble sugars and texture (Kenneth, 2016). A study by Ochilo et al. (2019) showed immense horticultural development and expansion in Kenya due to the production of tomato (*Solanum lycopersicum* Mill). For instance, production of tomato represents 14% of the total vegetables grown and about 7% of the total horticultural crops grown (Mwangi et al., 2020). Tomato varieties such as Roma VF, Valoria select, Eden F_1, and Cal J are widely cultivated in Kenya either for processing or fresh market (Kathimba et al., 2021). However, information on varying the storage temperatures on

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postharvest shelf life of newly developed lines are limited (Kenneth, 2016).

Earlier developed genotypes such as AVTO1429, AVTO1424 and AVTO1314 are characterised with low levels of respiration and ethylene production upon stored in low temperatures that beneficially slows ripening and increases their shelf life. Newly developed and characterised genotypes namely Roma VF x AVTO1429, Roma VF x AVTO1424, Roma VF x AVTO1314 and Roma VF x Valoria (Kathimba et al., 2022), effect of different storage temperatures on their shelf life have not been determined.

In tomato, shelf life as determined by the degree of softening, shrivelling and rotting of fruit extends to a maximum of 4 weeks, whereby the stored fruits are considered suitable for consumption (Thole et al., 2020). One of the most important traits for commercially grown tomatoes is post-harvest shelf life. This is an essential trait that can be shortened by accelerating ripening induced by exposure to infections by pathogens after harvesting and unsuitable temperature and humidity (Dean et al., 2012; Petric et al., 2018). Fresh market demand tomatoes with the following quality traits: good flavour, high acids, high sugars, weight, colour, aroma and shelf life (Turhan and Seniz, 2009). Tomato qualities such as high dry matter, firm fruits and high total soluble sugars are highly demanded for the processing industries (DePascale et al., 2001). However, shelf-life is affected upon changing in the aforementioned tomato quality attributes during post-harvest handling (Rodriguez et al., 2010). In improving tomato shelf, conventional breeding is mostly preferred to genetic engineering that uses the ripening mutants (Boyazoglu, 2002). For example, LA722 which is recombinant inbred tomato line developed from the hybridization of *Solanum lycopersicum* and *S. pimpinellifolium* was shown to have a longer shelf life its wild parents (Rodriguez et al., 2006). The objective of this study was to determine the effect of three storage temperature levels on key tomato quality attributes that affect shelf-life regarding fruit weight and firmness in five tomato lines and four newly developed hybrids. These newly developed hybrids of tomato were a result of tomato breeding program in Kenya initiated by Kathimba et al. (2022).

MATERIAL AND METHODS

Experimental site

Experiment was conducted at the Pilot Seed Processing Plant, Department of Plant Science and Crop Protection, University of Nairobi, Kenya in 2019. The plant is located at 01° 15'S; 036° 44'E and an elevation of 1820m above sea level with temperature range between 12.3 to 22.5°C. The soils with a pH of about 5.0 to 5.4 are humic nitisols, deep and well-drained.

Plant materials

This study used nine tomato lines from different sources. Three lines namely AVT01424, AVT01429 and AVT01314 were from the World Vegetable Centre (AVRDC). Four F_1 hybrids namely Roma VF x AVTO1429, Roma VF x AVTO1424, Roma VF x AVTO1314 and Roma VF x Valoria select that are newly developed lines in Kenya by Kathimba et al. (2022). Roma VF was a commercial variety from Continental Seeds Company Limited whereas Valoria selects were from farmers' selection.

Planting patterns

A split plot design was used in this experiment. The main plots were different temperature levels and sub-plots were the nine tomato lines. The treatment was replicated three times. The experiment was conducted from September, 2018 to April, 2019.

Harvesting stage

Six tomato fruits were randomly hand harvested at mature green stage based on the "Colour Classification Requirement in United States Standards for Grades of Fresh Tomatoes" chart (USDA, 2007). Harvested fruits were uniform in size and shape, with no physical defects. Fruits were placed 2 cm apart in round (diameter of 30.48 cm) mudeela plastic trays from Amazon, Kenya.

Storage temperatures

Storage temperature levels were 4, 16 and 25°C. Cold storage rooms were fixed with LG air conditioners (model BSQ1865NAO18KBTU Gencool Inverter) to maintain the aforementioned storage temperatures with modifications as described by Pinheiro et al. (2013).

Data collection

Average fruit firmness was determined using digital hand-held Lutron fruit hardness tester (Model FR 5105 from Taiwan, manufactured by Italy Lutron electronic). Fruits were punctured using a 1cm diameter plunger and the pressure used to penetrate fruit pericarp shown on the digital reader of the penetrometer recorded and expressed in Ncm^{-2} following a modified procedure of (Tigist et al., 2013). Fruit weight was measured using an electronic balance (Model AG64-100 manufactured by Wagtech International, New York). Data was collected from week 0 to week 5 at 7 days interval following a modified protocol of Tadesse et al. (2012).

Percent weight and firmness loss was determined following procedure described by Pinheiro et al. (2013). That is, % loss = (Weight or Firmness at week 0 - Weight or Firmness at a given week) / Weight or Firmness at week 0 x 100.

Data analysis

Fruit firmness and fruit weight data were subjected to analysis of variance (ANOVA) using GenStat software (15th edition) in a split plot design with three replicates. Means of tomato lines and storage temperatures were compared and separated using Fisher's protected Least significant difference (LSD) at 5% significance P-value thresholds.

RESULTS

Fruit firmness (Ncm^{-2})

Significant differences ($P \leq 0.05$) among storage

Table 1. Fruit firmness (Ncm^{-2}) loss at 4, 16 and 25°C in five weeks storage duration.

Genotype	4°C					16°C					25°C				
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1	Week 2	Week 3	Week 4	Week 5
AVTO1429	12.92	33.36	42.15	48.66	58.98	15.05	33.63	41.90	46.73	51.69	41.42	45.83	61.11	69.49	73.37
Roma VF	4.81	33.50	43.26	51.36	56.93	8.97	38.93	49.04	54.46	63.49	37.82	48.11	60.00	65.74	70.84
Roma VF x AVTO1429	7.10	30.62	40.82	50.15	56.30	10.13	37.35	46.98	52.68	58.72	40.24	45.24	59.79	68.89	74.27
AVTO1424	4.23	29.64	40.18	46.32	51.62	10.45	31.88	39.88	44.26	52.04	30.79	35.64	55.04	63.57	68.37
Roma VF x AVTO1424	10.85	39.24	47.55	51.80	56.87	21.48	40.74	48.22	52.50	60.48	40.94	48.28	59.98	66.63	71.60
AVTO1314	13.03	43.79	53.31	60.69	69.51	22.49	32.95	37.57	39.42	45.31	46.77	60.27	67.58	74.45	79.54
Roma VF x AVTO1314	12.89	33.87	44.08	51.80	58.48	23.32	7.73	43.40	49.14	55.77	39.11	51.19	59.34	64.71	70.25
Valoria selects	22.92	51.37	62.74	68.26	73.43	18.32	45.39	51.92	54.75	66.75	47.34	59.01	64.31	68.97	73.01
Roma VF x Valoria selects	20.70	45.54	54.25	61.27	67.86	19.93	48.65	56.04	61.65	69.53	49.89	59.18	66.49	70.79	78.76
Grand mean	12.16	37.88	47.59	54.48	61.11	16.68	35.25	46.11	50.62	58.19	41.59	50.31	61.51	68.14	73.34

Standard deviation of ± 5.5.
Source: Authors.

temperatures, storage weeks and tomato lines were recorded for fruit firmness. Among the temperatures, fruits stored at 16°C had the lowest average loss of 58.19% in fruit firmness followed by 4°C with a loss of 61.11% while the highest loss of 73.34% was recorded at 25°C (Table 1). Loss in firmness of <47.59% was recorded in tomato lines stored at 4°C after three weeks storage duration and <50.62% at 16°C after four weeks while >50.31% firmness loss was recorded after two weeks storage duration in lines stored at 25°C. Firmness loss varied from 4.23% (AVTO1424) to 22.92% (Valoria selects) in week one and from 29.64% (AVTO1424) to 51.37% (Valoria selects) in week two (Table 1). After five weeks, AVTO1424 had the lowest firmness loss of 51.62%, followed by Roma VF (56.93%) and the newly developed lines Roma VF x AVTO1424 (56.87), Roma VF x AVTO1429 (56.30%). Tomato lines AVTO1424, Roma VF x AVTO1424, AVTO1429 and Roma VF x AVTO1429 had the highest fruit firmness in five weeks storage duration while Valoria selects had the lowest firmness (Figure 1).

At 16ºC, loss in fruit firmness varied from 45.31% (AVTO1314) to 69.53% (Roma VF x Valoria select) during the five weeks storage duration (Table 1). Newly developed lines Roma VF x AVTO1314, Roma VF x AVTO1429 and Roma VF x AVTO1424 recorded loss in fruit firmness of 55.77, 58.72 and 60.48%, respectively. This percentage was similar to fruit firmness loss of 58.40, 56.30 and 56.87%, respectively recorded on the lines at 4°C. Tomato line AVTO1314 which recorded 69.51% firmness loss at 4°C had lower loss of 45.31% at16°C. Similarly, loss in fruit firmness recorded by lines AVTO1429 (51.69%), Roma VF x AVTO1314 (55.77%) and Valoria selects (66.75%) at 16°C was lower than the loss of 58.98, 58.48 and 73.43%, respectively recorded at 4°C. Line AVTO1314 had the highest fruit firmness while Roma VF x Valoria selects had the lowest fruit firmness throughout the storage period (Figure 2). Fruit firmness of Roma VF x AVTO1314 decreased sharply between weeks two and three. At 25°C, loss in fruit firmness varied from 68.37% (AVTO1424) to 79.54% (AVTO1314). Tomato lines recorded an increase in percentage loss of fruit firmness at 25°C compared to loss at 4 at 16°C. Line AVTO1314, which had the lowest loss (45.31%) at 16°C recorded the highest firmness loss of 79.54% at 25°C. Line Valoria selects had the highest firmness loss of 73.43% and 73.01% at both 4 and 25°C temperature levels, respectively. Line AVTO1424 had the highest fruit firmness throughout the storage duration at 25°C (Figure 3). There was measurable significant difference in the percentage loss recorded at 4 and 25°C. At 4°C, an average loss of 61.11% was recorded among the tomato lines by the end of storage duration while at 25°C; an average loss of 61.51% was recorded by week three.

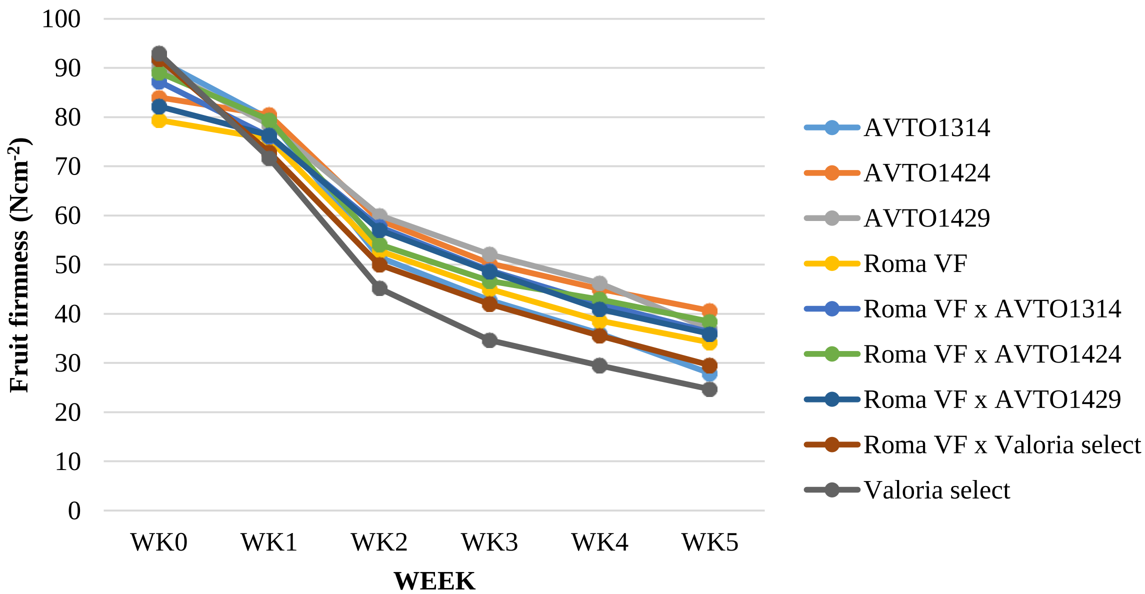

Figure 1. Fruit firmness (Ncm^{-2}) in nine tomato lines at 4°C temperature level during five weeks storage duration.
Source: Authors.

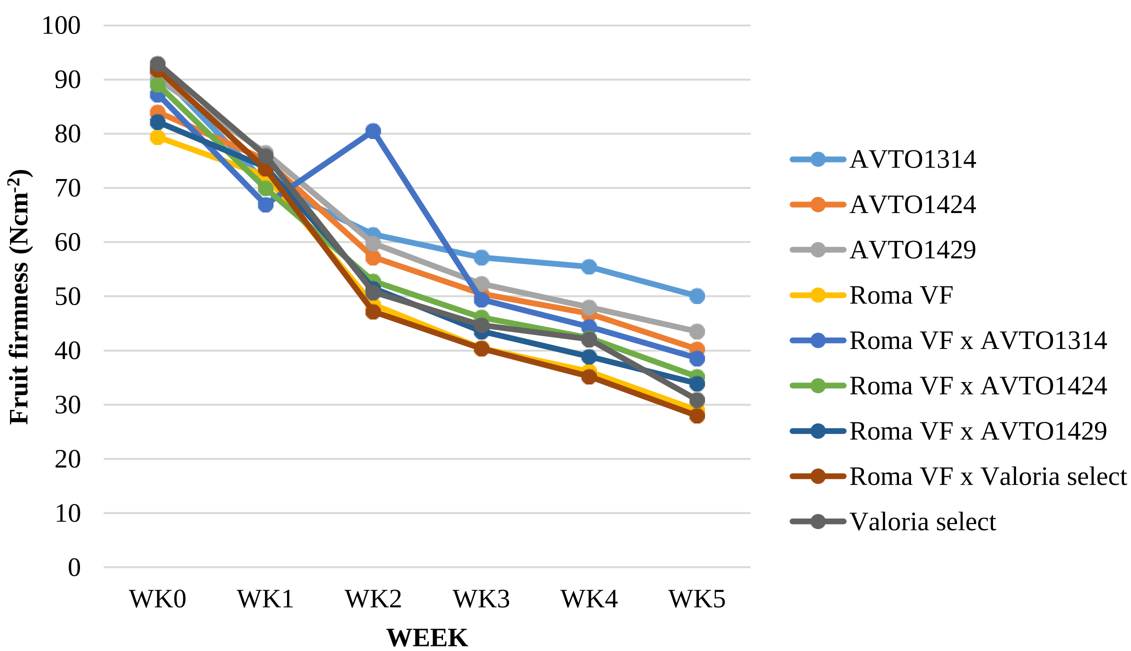

Figure 2. Fruit firmness (Ncm^{-2}) in nine tomato lines at 16°C temperature level during five weeks storage duration.
Source: Authors:

Fruit weight (g)

Significant differences (P≤0.05) among storage temperatures, storage weeks and tomato lines were recorded for fruit weight. Among the temperatures, fruits stored at 4°C had the lowest percentage average weight loss of 33.10% followed by fruits stored at 25°C with 65.31% while loss in weight for fruits store 16°C was the highest at 68.17% during the five weeks storage period (Table 2). Average weight loss of <38.76% was recorded

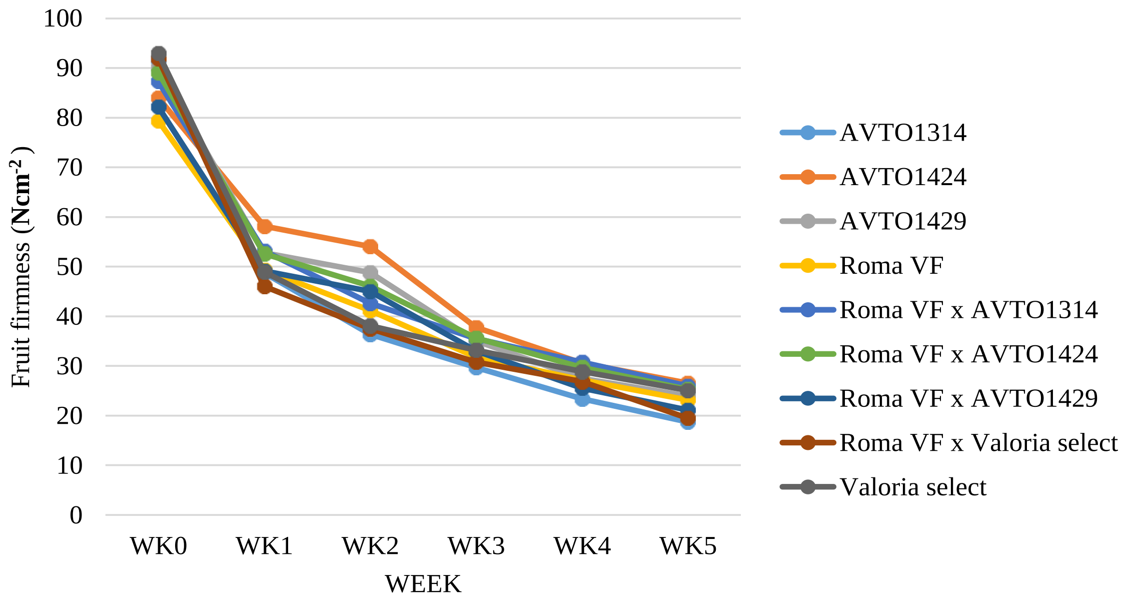

Figure 3. Fruit firmness (Ncm^{-2}) in nine tomato lines at 25°C temperature level during five weeks storage duration.
Source: Authors

Table 2. (%) Fruit weight (g) loss at 4, 16 and 25°C in five weeks storage duration.

Genotype	4°C					16°C					25°C				
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1	Week 2	Week 3	Week 4	Week 5
AVTO1429	1.75	6.21	14.90	22.93	29.92	36.10	43.13	54.35	65.44	71.74	61.98	63.65	65.48	67.32	69.17
Roma VF	2.25	9.07	16.88	23.83	29.77	47.21	53.12	56.21	64.01	71.23	55.85	58.82	60.03	61.64	64.10
Roma VF x AVTO1429	0.99	8.20	16.62	25.50	35.02	35.99	46.10	51.80	61.25	67.54	53.85	55.94	57.53	59.79	62.11
AVTO1424	0.98	7.49	11.69	18.29	22.85	40.03	55.61	57.52	66.76	74.98	58.97	60.71	62.70	64.02	65.39
Roma VF x AVTO1424	1.82	7.64	16.84	23.96	32.39	44.79	50.02	54.93	60.54	66.88	61.42	63.31	64.52	66.23	67.93
AVTO1314	2.67	12.29	22.50	30.85	38.76	25.63	38.55	44.14	53.65	59.52	56.28	59.14	61.17	62.21	63.86
Roma VF x AVTO1314	3.11	11.68	21.10	29.25	37.70	37.44	44.78	51.67	60.40	65.97	57.19	59.11	60.76	62.39	64.17
Valoria selects	2.29	7.35	15.88	26.42	35.52	34.99	37.73	47.49	56.57	66.33	60.66	61.83	62.80	63.56	64.91
Roma VF x Valoria selects	2.07	10.49	17.57	26.89	35.94	44.45	46.91	56.62	62.43	69.32	60.77	62.84	64.10	65.13	66.14
Grand mean	1.99	8.94	17.11	25.33	33.10	38.51	46.22	52.75	61.23	68.17	58.55	60.59	62.12	63.59	65.31

Standard deviation of ± 8.5.
Source: Authors

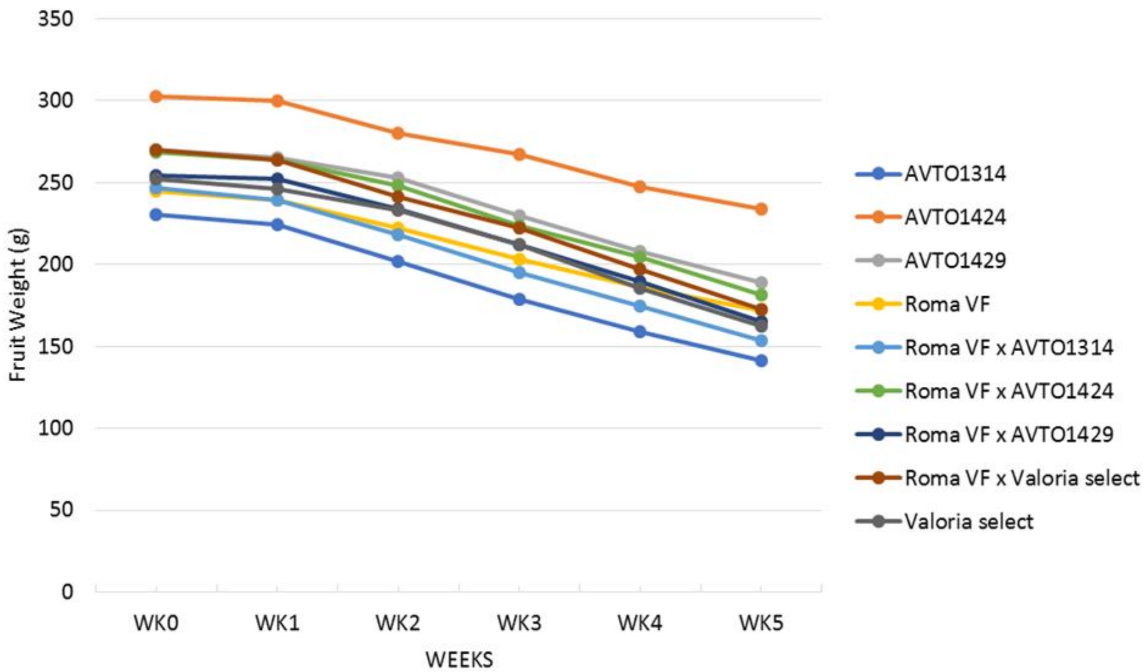

Figure **4.** Fruit weight (g) in nine tomato lines at 4°C temperature level during five weeks storage duration.
Source: Authors

in tomato lines throughout the storage period at 4°C.

More than 50.00% weight loss was recorded in tomato lines after three weeks of storage at 16°C while at 25°C, >50.00% loss in fruits weight was recorded after one week of storage. At 4°C, loss in fruit weight varied from 0.98% (AVTO1424) to 3.11% (Roma VF x AVTO1314) in week one and from 22.85% (AVTO1424) to 38.76% (AVTO1314) in week five (Table 2). Weight loss in newly developed hybrids Roma VF x AVTO1424, Roma VF x AVTO1429, Roma VF x AVTO1424, Roma VF x Valoria selects and Roma VF x AVTO1314 during the five weeks storage duration was 32.39%, 35.02%, 35.94% and 37.70%, respectively. At 16°C, loss in fruit weight varied from 59.52% (AVTO1314) to 74.98% (AVTO1424) while at 25°C loss varied from 62.11% (Roma VF x AVTO1429) to 69.17% (AVTO1429) after five weeks storage period (Table 2). Hybrid Roma VF x AVTO1429 had lower loss in weight than parent AVTO1429 at this temperature. Lines Roma VF x AVTO1429, Roma VF x AVTO1424, and Roma VF x AVTO1314 had 67.54, 66.88 and 65.97% loss in weight at 16°C while at 25°C the line recorded 62.11, 67.93 and 64.17%, loss respectively. Line AVTO1424 had the highest fruit weight throughout the storage period at 4°C while AVTO1314 had the lowest (Figure 4). Fruit weight at 16°C ranged between 55 to 100 g and Roma VF had the lowest weight (Figure 5). There was a sharp decline in fruit weight during the first week of storage (Figure 6) followed by a stable decline during week 3 to 5 storage period. Line AVTO1424 had the highest fruit weight throughout the storage period followed by Roma VF x AVTO1429 at 25°C (Figure 6).

DISCUSSION

Results showed that storage temperature influenced fruit firmness. Fruits stored at 16°C had the lowest loss in firmness (58.19%) during the five weeks storage, followed fruits stored at 4°C (61.11% loss) while the highest loss (73.34%) was recorded at 25°C (Figure 6). Highest storage temperature of 25°C recorded the highest loss in tomato firmness compared to other assessed temperatures in this study; partly follow the argument of Mwendwa et al. (2016) that higher temperature during storage accelerates ripening by increasing production of ethylene. According to Tigisi et al. (2013), both the increase in hydrolytic enzymatic activities and changes in hydrostatic pressure of tomato fruit progressively lower the fruit firmness, hence resulting to ripening. Since lowering storage temperatures consequently minimise ripening, therefore, this study conforms to this trend whereby lowering temperatures from 25°C to 4°C had lowest loss in firmness that partly contribute to ripening. Whereas ambient temperature of 25°C had lowest firmness, low temperatures at 16°C had considerable firmness hence the ideal storage temperature for fresh market. In this study, fruit firmness in all the tomato lines progressively decrease from first to the fifth week of storage. A study by Tran et al. (2017)

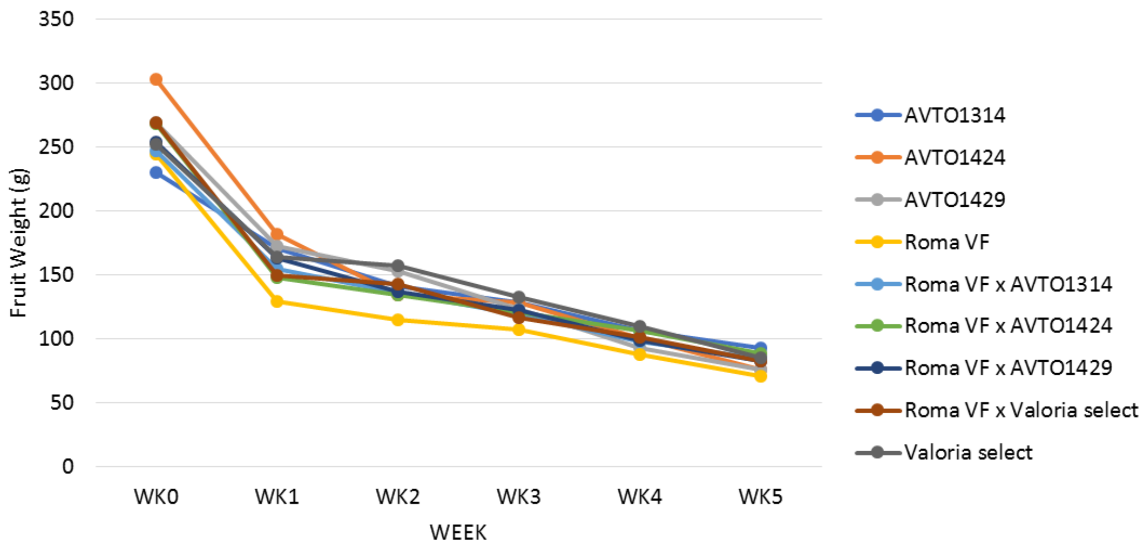

Figure 5. Fruit weight (g) in nine tomato lines at 16°C temperature level during five weeks storage duration.
Source: Authors

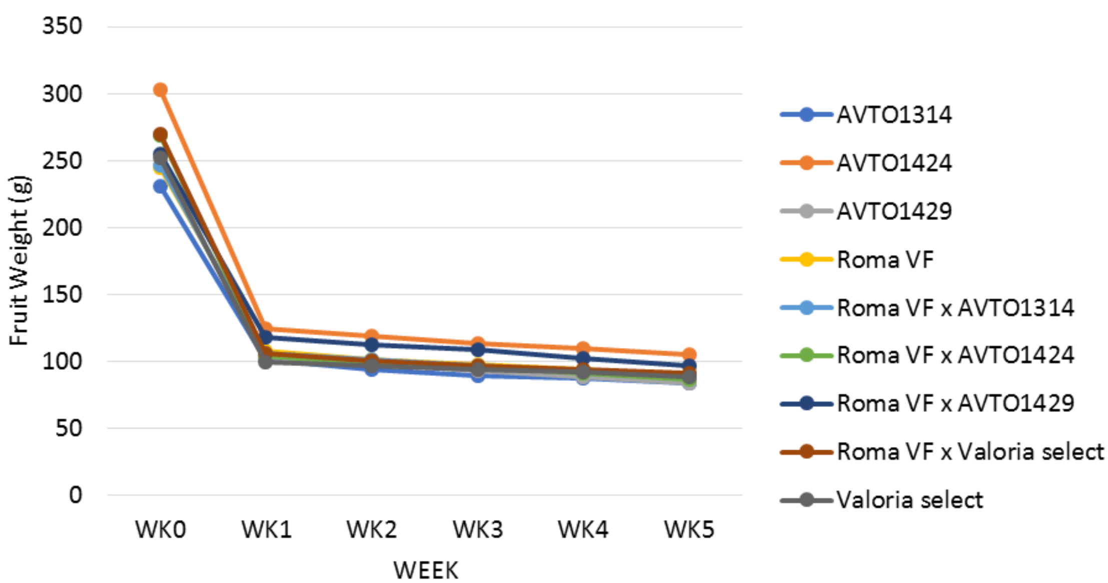

Figure 6. Fruit weight (g) in nine tomato lines at 25°C temperature level during five weeks storage duration.
Source: Authors

corroborates the findings upon reporting a decrease in fruit firmness, fruit mass, colour and total acidity with time during storage. In quality assessment, fruit firmness immensely influences the fresh market demand of consumers (Tigist et al., 2013). There is diversity in preference of fruit firmness, for instance, soft tomato fruits are highly preferred for processing unlike for fresh market (Tadesse et al., 2012). However, to factor in the transportation delays, firm tomato fruits are highly preferred to further accommodate potential mechanical damages on transit and increase post-harvest shelf life for fresh market (Kader, 2002). Similarly, Cherono and Workneh (2018) revealed fruit bruising and mechanical damages that accelerates ripening rate and decreased quality and loss of marketable value upon transporting from rural farms to markets in sub-Saharan Africa.

In this study, least fruit weight loss of 33.10% was obtained at 4°C storage temperature over the five weeks (Figure 4). Heavy fruit weights upon storage at 4°C were shown by Javanmardi and Kubota (2006). Furthermore, at high storage temperatures, there was significant loss in weight of tomato fruits that were partly associated to increased physiological and metabolic processes. Low storage temperatures besides having establishing least fruit weight loss, they were further shown lower respiratory and transpiration processes (Mwendwa et al., 2016; Tigist et al., 2013). Owing to the subjectiveness of fruit qualities such as shrinkage, wrinkles and lack of shiny surface, it lowers its fresh market demand from consumers. However, these perceived fruit qualities are inevitable when under poor storage conditions, especially the firmness and weight loss (Tadesse et al., 2012). To consider appropriate fruit shelf life, fruit qualities are key indicators for either fresh market or processing (Nelson and Alirio, 2012). For example, Workneh et al. (2012) revealed that the period of storage for a fruit without losing its marketability demand are majorly influenced by the prevailing storage temperatures.

The weight loss of the fruits stored at 4ºC for five weeks was minimum among the conditions. In addition, the firmness of the fruits after five weeks was the similar level with that stored at 16ºC, probably showing no statistical significance between the two conditions. The two indexes of the shelf life, firmness and weight, were not correlated, for example, firmness was reduced more severely in the fruits stored at 25ºC for five weeks than that at 16ºC but weight of the fruits of the two conditions was similar or slightly lower in the fruits stored at 16ºC. This is probably because weight loss is exclusively attributed to water loss while decrease in fruit firmness may be attributed to a summation of many appearance defects some of which may result from excessive loss of water (Machado et al., 2018).

Conclusion

The fruit weight and firmness decreased from the first to the fifth week of storage. The lowest loss in fruit firmness was recorded in fruits stored at 16°C (58.19%) while the highest loss (73.34%) was recorded at 25°C. The lowest loss in fruit weight was recorded in fruits stored at 4°C (33.10%) while the highest loss (68.17%) was recorded at 16°C. Average weight loss of <38.76% was recorded in tomato lines throughout the storage period at 4°C. From the data, the best storage condition is the temperature 4ºC. The two indexes of the shelf life, firmness and weight, were not correlated, for example, firmness was reduced more severely in the fruits stored at 25ºC for five weeks than that at 16ºC but weight of the fruits of the two conditions was similar or slightly lower in the fruits stored at 16ºC. Tomato lines AVTO1424 and Roma VF had the lowest loss in fruit firmness and weight at 4ºC while lines AVTO1314, Roma VF x AVTO1314 and AVTO1429 had the lowest loss in fruit firmness and weight at 16ºC. This implies that the lines have longer shelf-life of more than five weeks.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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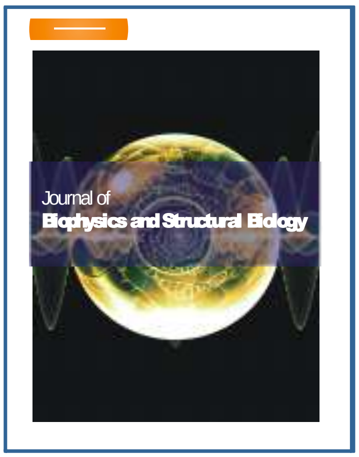

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