

Full Length Research Paper

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 F₁, 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 F₁ 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 Ncm² following a modified procedure of (Tigist et al., 2013). Fruit weight was measured using an electronic balance (Model AG64-100 manufactured by Wagetech 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 (Ncm²)

Significant differences (P≤0.05) among storage

Table 1. Fruit firmness (Ncm²) 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 16°C, 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% at 16°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.

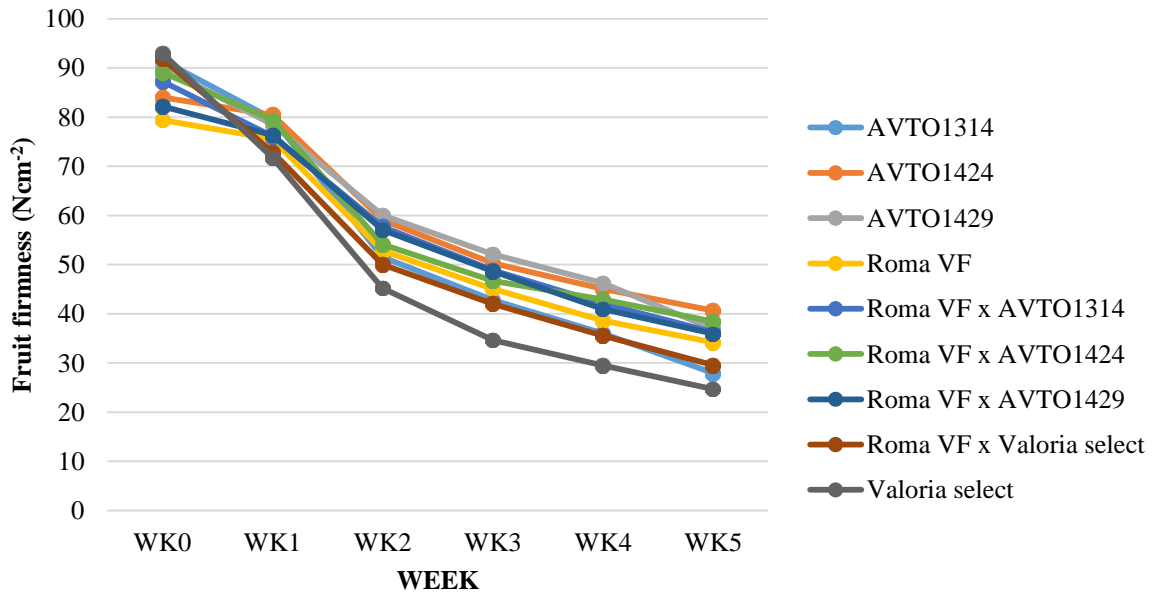


Figure 1. Fruit firmness (Ncm⁻²) in nine tomato lines at 4°C temperature level during five weeks storage duration. Source: Authors.

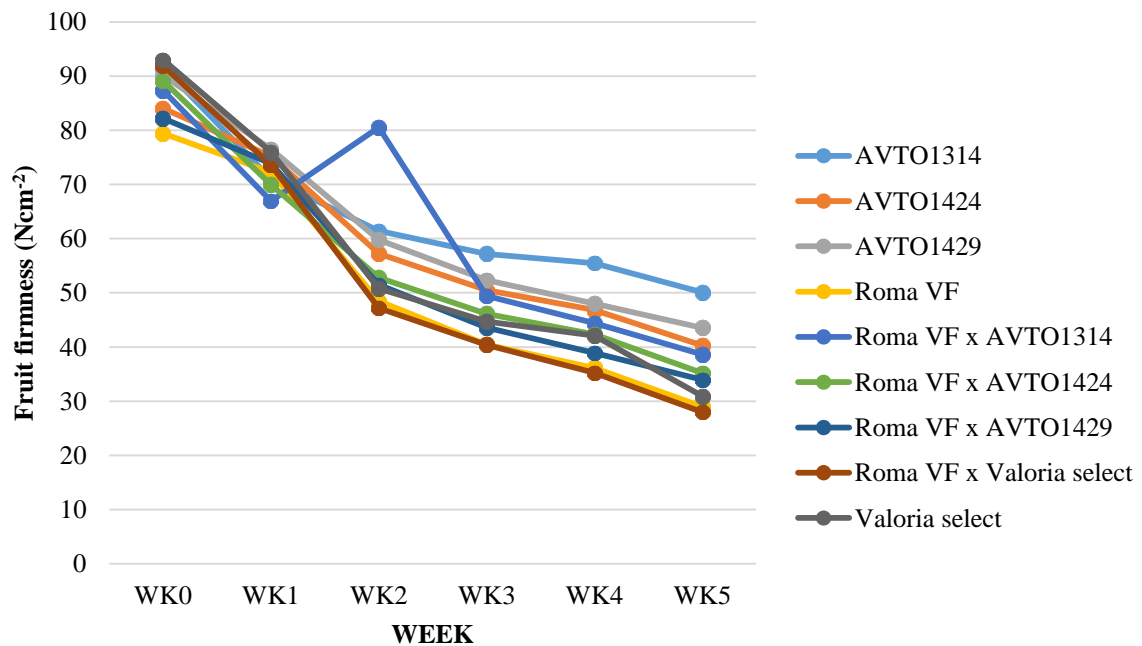


Figure 2. Fruit firmness (Ncm⁻²) in nine tomato lines at 16°C temperature level during five weeks storage duration. Source: Authors:

Fruit weight (g)

Significant differences ($P \leq 0.05$) 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

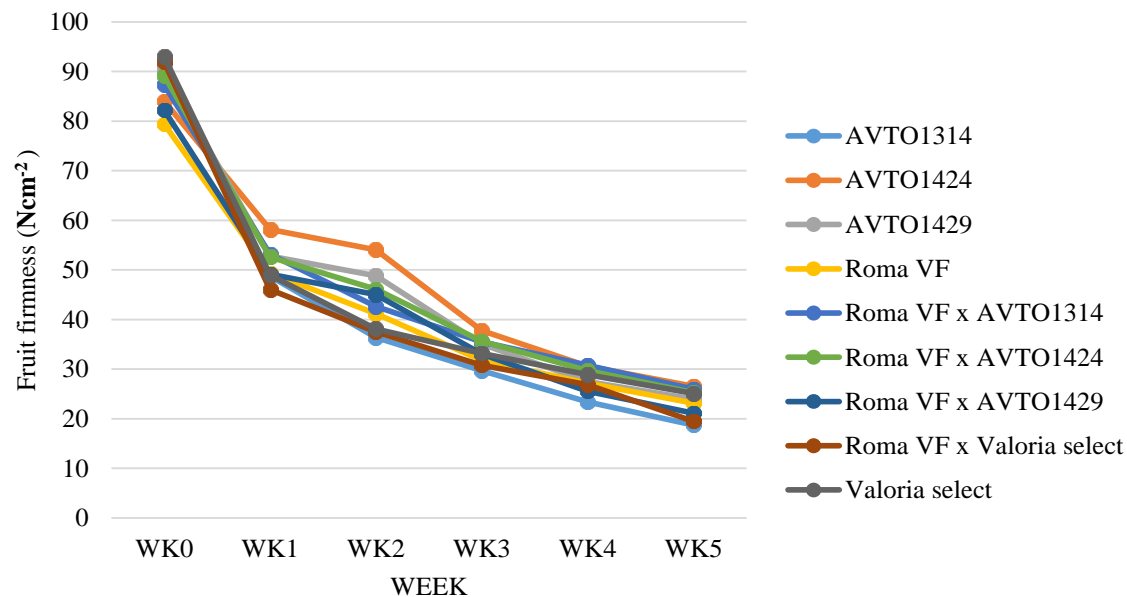


Figure 3. Fruit firmness (Ncm⁻²) in nine tomato lines at 25°C temperature level during five weeks storage duration.
Source: Authors

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

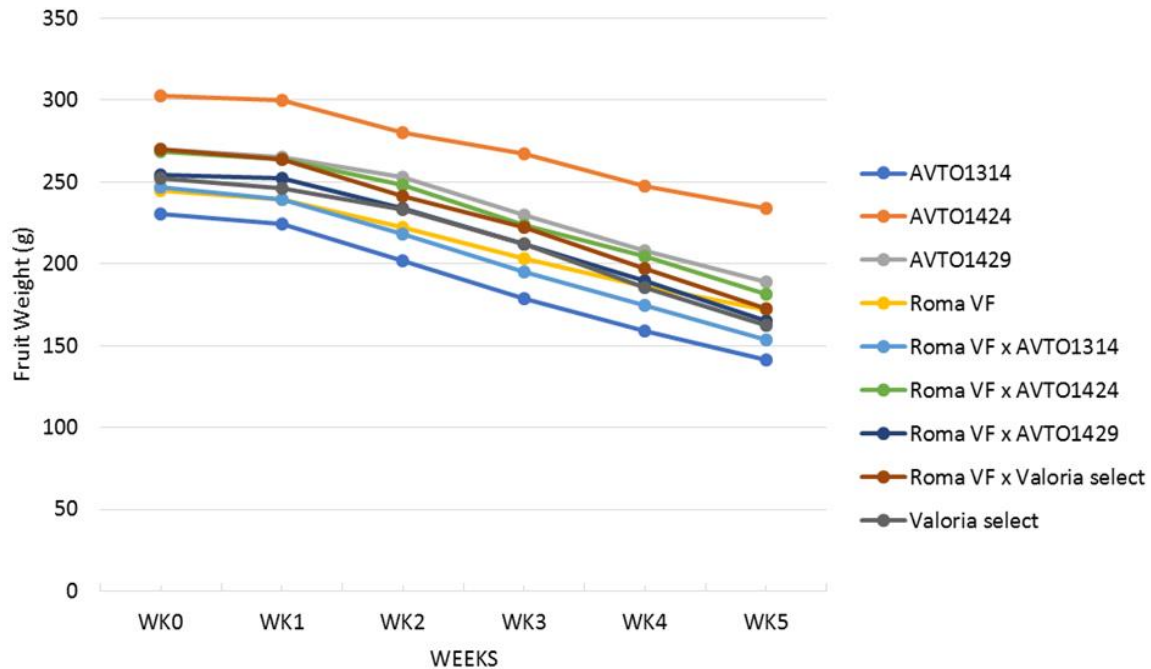


Figure 4. Fruit weight (g) in nine tomato lines at 4°C temperature level during five weeks storage duration. Source: Authors

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)

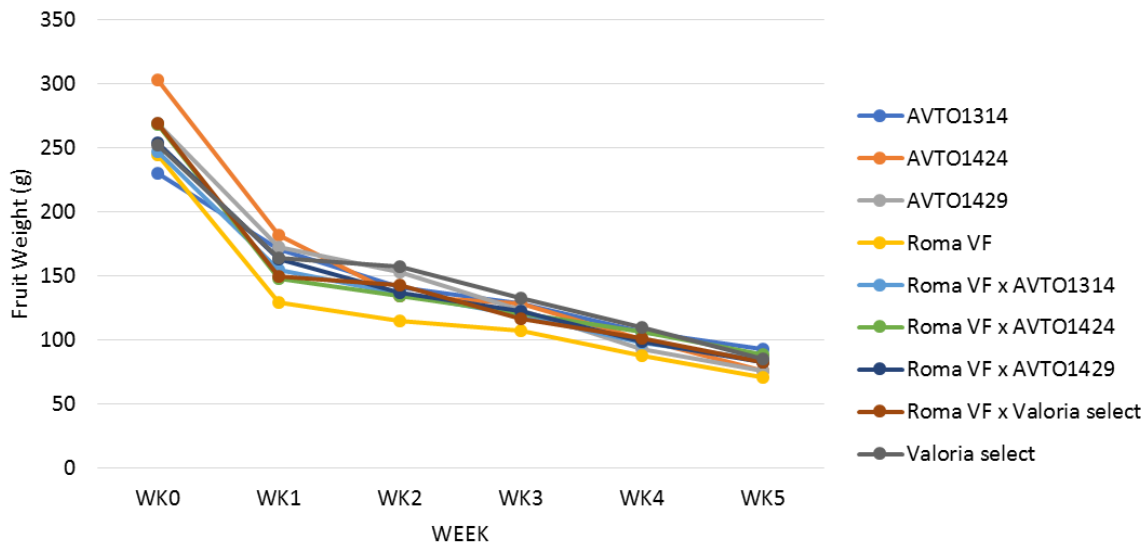


Figure 5. Fruit weight (g) in nine tomato lines at 16°C temperature level during five weeks storage duration. Source: Authors

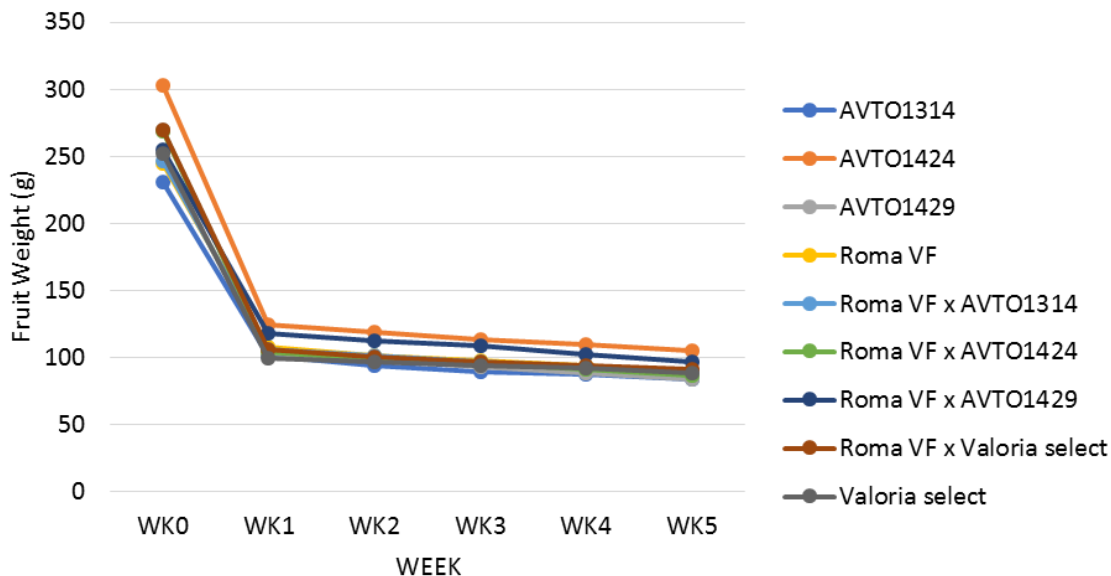


Figure 6. Fruit weight (g) in nine tomato lines at 25°C temperature level during five weeks storage duration. Source: Authors

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 4°C 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 16°C, 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 25°C for five weeks than that at 16°C but weight of the fruits of the two conditions was similar or slightly lower in the fruits stored at 16°C. 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 4°C. 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 25°C for five weeks than that at 16°C but weight of the fruits of the two conditions was similar or slightly lower in the fruits stored at 16°C. Tomato lines AVTO1424 and Roma VF had the lowest loss in fruit firmness and weight at 4°C while lines AVTO1314, Roma VF x AVTO1314 and AVTO1429 had the lowest loss in fruit firmness and weight at 16°C. 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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