



Comparative storage conditions on the post-harvest losses and quality of tomato (*Solanum lycopersicum* L.) fruits

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Abstract

Tomato (*Solanum lycopersicum* L.) is a member of the Solanaceae family, and its fruit is perishable with low shelf life due to postharvest losses, which depend on the variety, management and storage practices. Temperature also influences post-harvest life of tomato and rate of biological processes including ripening, softening, flavour, aroma, and weight loss. The optimum temperature influencing good quality of tomato fruit, enhancing shelf life and minimizing post-harvest losses is inadequately determined. Therefore, the objective of this study was to determine the effect of optimal storage temperature on quality and marketability parameters of tomato fruits. The experiment was carried out in the laboratory of post-harvest at Sokoine University Agriculture using Completely Randomized Design (CRD) arrangement of treatments replicated three times. The experiment had two treatments which include tomato fruits stored at Ambient ($26\pm 1^\circ\text{C}$) and Cool Bolt ($16\pm 1^\circ\text{C}$). The result showed that the highest weight loss (7.71%) was for Ambient ($26\pm 1^\circ\text{C}$), while the least loss (3.01%) was recorded for tomato fruits stored in Cool Bolt ($16\pm 1^\circ\text{C}$). Tomato fruits showed significant increase in hue, chlorophyll degradation and weight and firmness loss. The rate of reduction in hue angle of fruits stored at ambient ($26\pm 1^\circ\text{C}$) was low compared to that of the fruits stored at Cool Bolt ($16\pm 1^\circ\text{C}$). The shelf life of the fruits significantly increased ($p < 0.001$) with decreasing storage temperature. Cold storage (Cold Bot) further, was able to maintain marketability value by 98.9% compared to 60.1% of ambient storage. However, it has shown no influence on Titratable Acid (TA) and Total Soluble Solids/Titratable Acid (TSS/TA) ratio. Therefore, Cold Bolt ($16\pm 1^\circ\text{C}$) storage has greater influence in maintenance of physiochemical quality parameters of tomato fruits. The study concludes that Cool Bot treatment was able to preserve tomato color for longer periods, than ambient storage.

Key words: *Ambient condition; cold bolt; shelf life; storage; tomato*

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Introduction

Tomato (*Solanum lycopersicum* L.) belongs to the family Solanaceae. It is one of the most popular vegetables highly produced in the world due to its fruit quality and nutritional content (Thole *et al.*, 2021; Ofori *et al.*, 2022). The crop has great economic values with profitable returns (Mohan *et al.*, 2023) and an excellent source of minerals, vitamins and bioactive compounds in human diet (Ofori *et al.*, 2022). The daily intake per person is 70-90 g equivalent to the recommendation of 25.55 - 32.85 kg per year per adult person (Viskelis *et al.*, 2015) for a better well-being.

World tomato production in 2020 was about 186.82 million tons of fresh fruit from an estimated 5.05 million ha with an average yield of 37 tons ha⁻¹ (FAOSTAT, 2022). The current production of tomato is worth USD 90 billion (Bhandari *et al.*, 2021). The data from the Statistical Agency of the Food and Agriculture Organization of the United Nations (FAOSTAT) show that there has been an increase in tomato production in the world. However, Wongnaa *et al.* (2023), showed that the global supply chains of tomato are limited by postharvest losses ranging from 10% to 40% of harvested tomato fruits. In Africa, especially sub-Saharan Africa the production of tomato is high but its marketability is constrained by poor post-harvest management practices (Magala *et al.*, 2024).

In Tanzania, tomato serves as a source of income for producers but its production is noted less profitable due to post harvest losses which lower returns to growers, processors and traders (Mutungi *et al.*, 2012; Arah *et al.*, 2015). In the country, poor post-harvest management practice is estimated to cause a loss of 50% of fresh tomatoes before reaching consumers (Rutta, 2022). There are physical, physiological, and hygienic conditions which cause damage and affect color, texture, flavor and nutritional value of the tomato (Arah *et al.*, 2015). Generally post-harvest losses of tomato are caused by limited access to cold storage facilities which cause rapid spoilage of freshly

harvested tomatoes (Rutta, 2022). Therefore, Coolbot was suggested to best address the challenges in terms of perishability of horticultural crops like tomato in some areas in the world, which is still under infant in the country (Majubwa *et al.*, 2022). This technology once well reported could facilitate producers on the matter.

Other factors such as crop immaturity, inadequate quality control, incidence and severity of pests damage, physical damage, exposure to improper temperatures, and delays time from harvest and consumption also hinder post-harvest handling (Prusky, 2011). The moderate deterioration of eggplant shelf-life underscored by (Majubwa *et al.*, 2022) cannot be generalized to tomato because very low temperature has been observed to have detrimental effects to quality and shelf-life of many African fruits including tomato. Fruit firmness are intrinsic and extrinsic factors that have greatest influence on the tomato marketability probability (Díaz-Pérez *et al.*, 2018). The storage and maturation recommendations for tomato fruits are well known, but injury and damages occur during packaging impairs biological and respiration processes, and lower ethylene production which in turn lead to deterioration of tomatoes (Stathers *et al.*, 2018). Keeping tomatoes fresh and sealed through thermal and refrigerated packaging may extend the shelf life of the produce (Mohan *et al.*, 2023), but the optimal storage temperature and quality of storage facilities that do not interrupt quality and shelf life of tomato are contentiously debated. The current study was conducted to establish the effect of storage temperature on the quality losses and shelf life of tomato fruits in order to reduce post-harvest losses.

Materials and methods

Plant material

Tomato fruits of the variety "ASILLA" were harvested at mature pinky stage (breaker) from farmers field located in Mlali, Morogoro region,

Tanzania in June, 2020. The fruits were harvested at maturity stage and harvesting selection criteria was guided using the biological color chart of USDA (1991). Disease-free fruits with uniform shape, size and weight but without any physical injuries or defects were selected. The samples were taken to the Horticulture Post harvest Laboratory of the Department of Crop Science and Horticulture at Sokoine University of Agriculture for physicochemical and quality analysis.

Experimental design

The experimental design was Completely Randomized Design (CRD) with eight treatment levels including two temperature levels and six storage period levels. The design has three replications and each replication was assigned 30 tomato fruits placed in each plastic crate at ambient (26±1°) and Cool Bolt (16±1°) conditions. For Ambient and Cool bolt storage treatments, initial relative humidity content was 60–65% and 80–90 %, respectively. From each of three replications located in each treatment, three tomato fruit samples were taken randomly for quality analysis every three days starting from the day of harvest. Also, ten fruits from each replication were marked randomly (1-10) for weight loss and color changes analysis for each three days without replacing it. Data was collected for an interval of three days from 0 to 15th day after harvesting (15 days storage period). On each sampling day, three fruits per experimental unit were randomly taken from each replication for quality analysis.

Data collection

During the experiment the fruit firmness, color, pH, total soluble were recorded.

Fruit firmness

A destructive deformation test was used to evaluate fruit firmness by loading the tomatoes in a material testing machine (Testometric m350-10CT, England). For firmness measurement, the fruit sample was placed between two flat surfaces

and the compressive force (N) required for 2mm deformation of the fruit was recorded.

Colour (Hue°)

The colour parameter (Hue°) was determined using the colour chart described by (Dadzie and Orchard, 1997) cited by Haile and Safawo (2018). The colour was determined by scoring after comparing tomato fruits samples from each replication with the marked hue values as indicated in the chart.

pH

The tomato pH value was measured in triplicate using the procedure described by (Tigist *et al.*, 2013).

Total Soluble Solids (TSS)

The total soluble solid (TSS) was determined by refractometer (Model Misco®) which was standardized against distilled water (0°Brix TSS) following the procedures described by (Melkamu *et al.*, 2008).

Titrateable Acid (TA)

The titrateable acidity of tomato was measured by the methods described by (Melkamu *et al.*, 2008). Sugar-acid ratio was calculated by dividing total soluble solid to titrateable acidity of the given sample under analysis (Mohammed *et al.*, 1999). Then, the Titrateable Acid was calculated by using equation 1:

$$\text{Percentage (\%)} \text{ of acid} = \frac{\text{mL NaOH} \times \text{N (NaOH)} \times 0.064 \times 100}{\text{mL Juice or g Juice}} \dots\dots\dots (1)$$

Where 1 mL of 0.1 NaOH is equivalent to 0.0064g citric acid.

Total soluble solids to titratable acidity ratio (Ripening Index)

The ripening was determined by TSS to TA ratio of tomato slurry which was calculated, using equation 2 (Moneruzzaman *et al.*, 2009):

$$\frac{\text{TSS/TA}}{\text{Fruit}} \dots\dots\dots (2) \quad \text{\% TA of the fruit}$$

Physiological weight loss (%)

Tomato fruits were weighed to obtain initial weight before being placed in each storage condition. The loss in weight was recorded at 3 days interval until 15 days which served as the final. The physiological weight loss was determined using the equation 3 described by Workneh *et al.* (2011).

$$\frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100\% \dots(3)\dots$$

Shelf life

The shelf life of tomato was subjectively assessed by procedures of Mohammed *et al.* (1999).

Marketability

The marketability attribute was determined subjectively by observing visible shriveling, smoothness, Mold growth, decay and shininess.

Data analysis

Data collected was subjected to the analysis of variance (ANOVA) using GenStat V.16 statistical package (VSN International). The means for Cool Bot and ambient storage conditions were compared using the Least Significant Difference (LSD) at $p=0.05$, while means for storage

duration was compared using the Turkey’s Honest Significance Difference (HSD) Test at $p=0.05$. Using the following statistical model for a two-factor completely randomized design;

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ij}$$

Where Y_{ij} is the observed response in the ij th factors; μ is the overall (grand) mean; α_i and β_j are the main effects of the factors storage levels and storage periods (durations), respectively; $(\alpha\beta)_{ij}$ is the interaction between the factors; ϵ_{ij} is the random error

Results

Effects of storage conditions on physical qualities of tomato fruits

The results on the effect of storage conditions on physical quality of tomato fruits are shown in Table 1. The results show that there was a significant ($p<0.001$, $LSD = 2.14$) difference among storage conditions in color change. Cold storage (Cool bot) had the lowest color change/hue value (48.2) compared to ambient storage (57.1). Lowest physiological weight loss was significantly ($p<0.001$, $LSD = 1.096$) recorded on tomato fruits stored in Cool bot (3%) opposed to (7.17%) at ambient storage. Furthermore, the results showed that both firmness (puncture) and compression of tomato fruits under both storage conditions were significantly ($p<0.001$, $LSD = 0.01$) different.

Also, the results showed significant ($p<0.001$) difference among storage periods (durations) in color change (Hue), Weight loss, compression and puncture. For all parameters, 0 day showed highest value (64.67, 0, 0.25 and 0.25 for color change, weight loss, compression and puncture, respectively) while 15 days had the lowest among all.

Table 1*Effects of Storage Condition and Duration on Physical/External Qualities of Tomato Fruits*

Treatments	Hue	Weight loss (%)	Compression (kg)	Firmness (Puncture) (kg)
Factor A: Storage condition				
Cool bot 16 ± 1°C	48.2a	3.01a	0.2a	0.1a
Ambient 26 ± 1°C	57.1b	7.17b	0.2b	0.1b
<i>Grand Mean</i>	52.7	5.09	0.2	0.1
<i>SE±</i>	0.76	0.394	0	0
<i>CV%</i>	10.6	94.7	14.6	15.5
<i>L.S.D (0.05)</i>	2.14	1.096	0.01	0.01
<i>F.pr.</i>	<0.001	<0.001	0.028	<0.001
Factor B: Storage period (days)				
0	64.67d	-	0.25b	0.25c
3	59.89cd	3.395a	0.1717a	0.1147b
6	55.33c	4.264a	0.1772a	0.0892a
9	49.56b	5.058ab	0.1622a	0.0813a
12	45.22ab	5.792ab	0.1617a	0.0844a
15	41.33a	6.948b	0.1778a	0.0847a
<i>Grand Mean</i>	52.7	5.09	0.2	0.1
<i>SE±</i>	1.32	0.623	0.01	0
<i>CV%</i>	10.6	94.7	14.6	15.5
<i>L.S.D (0.05)</i>	3.7	1.734	0.02	0.01
<i>F.pr.</i>	<0.001	<0.001	<0.001	<0.001

SE± = Standard error of means, CV% = Coefficient of variation, L.S.D = Least significance difference. Means bearing same letter(s) within a column are not significantly ($p>0.05$) different according to Turkey's Honesty Significance test at $p = 0.05$ significance level.

Interaction effect of storage condition and duration on tomato fruits physical/external qualities

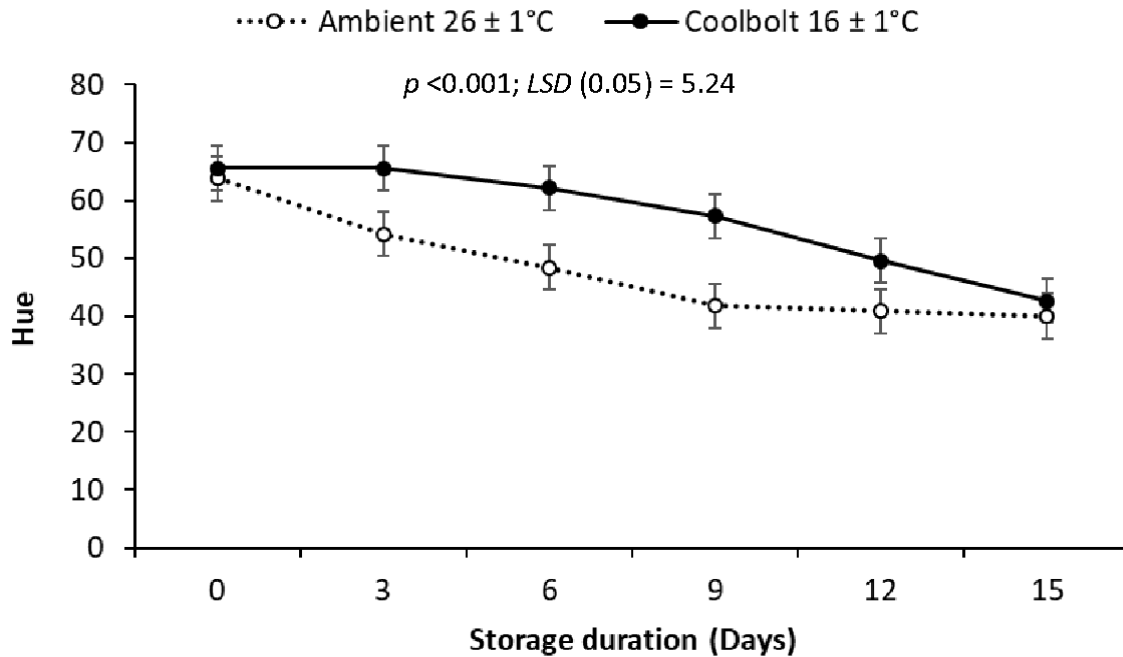
Color

The decrease of greenness and increase of redness in tomato fruits was associated with increase in hue value (degree of redness). Significant ($p=0.05$)

difference in hue value of tomato fruits was found between storage conditions (Fig. 1). After 15 days of storage, tomato fruits were relatively red, whereby low hue value (42.7) was recorded for tomato fruits under cold storage (Cool bot), but tomatoes under ambient storage had hue value (40.0). There were no significant changes in color of tomato fruits stored in cold storage (Cool bot) during the first three days.

Figure 1

Interaction Effects of Storage Condition and Duration on Tomato Fruits Color



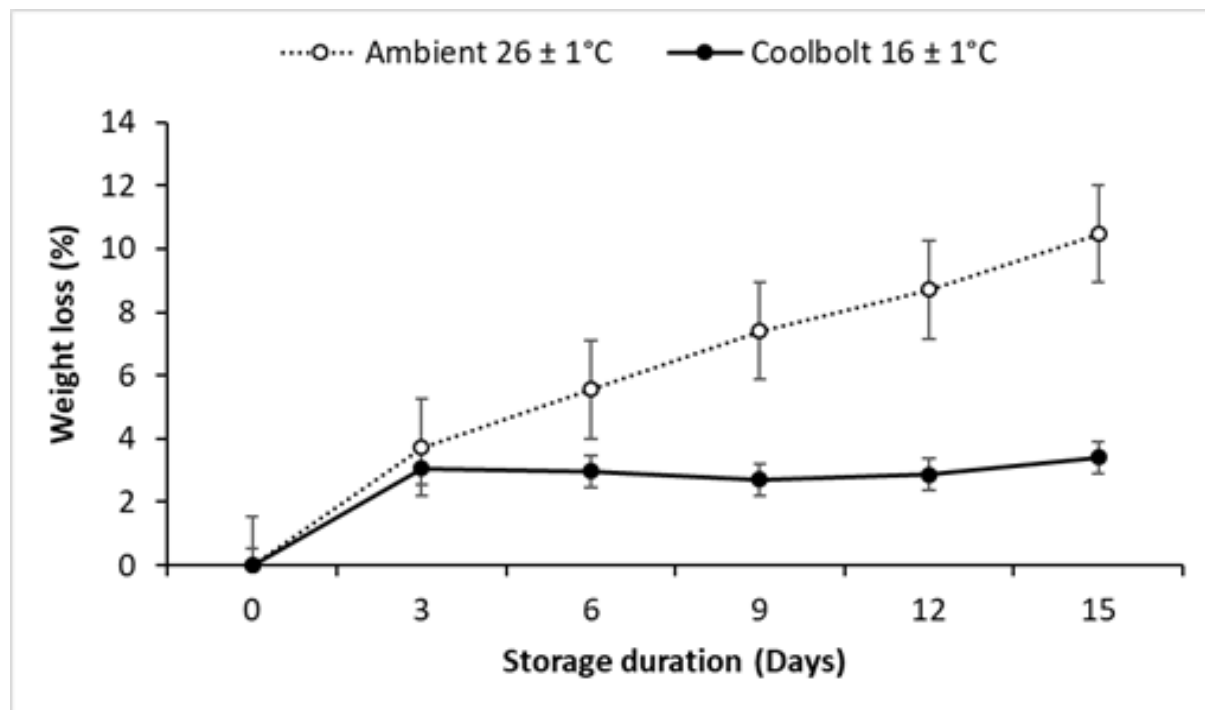
Weight loss

The results show that there were significant interactions ($p=0.05$) effect between storage condition and duration with respect to weight loss. Cool bot storage significantly reduced ($p<0.001$) weight loss in the tomato fruits over the 15 days

storage period (Fig. 2). At the end of 15th day, tomato fruits stored at cold storage (Cool bot) had lost 3.4% of their initial weight, while those in the ambient had lost 10.4% of their initial weight. Also, for the first three days of storage, high change in weight for both storage conditions was observed.

Figure 2

Interaction Effects of Storage Condition and Duration on Tomato Fruits Weight Loss



Firmness

The results on firmness both on compression and puncture showed no significant ($p=0.05$), for all 15 days of storage (Table 2).

Table 2*Interaction Effects of Storage Condition and Duration Compression and Puncture of Tomato Fruits*

Storage duration (Days)	COMPRESSION (kg)		PUNCTURE (kg)	
	Ambien t	Cool bolt 16 ± 1°C	Ambien t	Cool bolt 16 ± 1°C
0	0.25b	0.25b	0.25d	0.25d
3	0.1761a	0.1672a	0.11bc	0.1194c
6	0.17a	0.1844a	0.0733a	0.105bc
9	0.1433a	0.1811a	0.076a	0.0867ab
12	0.155a	0.1683a	0.0822ab	0.0867ab
15	0.1717a	0.1839a	0.0733a	0.0961abc
<i>Grand Mean</i>	<i>0.2</i>		<i>0.1</i>	
<i>SE±</i>	<i>0.01</i>		<i>0.01</i>	
<i>CV%</i>	<i>14.6</i>		<i>15.5</i>	
<i>L.S.D (0.05)</i>	<i>0.03</i>		<i>0.02</i>	
<i>F.pr</i>	<i>0.174</i>		<i>0.101</i>	

SE± = Standard error of means, CV% = Coefficient of variation, L.S.D = Least significance difference. Means bearing the same letter(s) within a column are not significantly ($p>0.05$) different according to Turkey's Honesty Significance test at $p = 0.05$ significance level.

Effects of storage condition on internal qualities of tomato fruits

The results Table 3 show that there was no significant difference among storage conditions with respect to pH ($p>0.05$), TA and TSS to TA ratio. However, TSS differed significantly ($p=0.05$) among storage conditions whereby cool bolt 16 ± 1°C had the highest TSS (3.9).

Table 3*Effects of Storage Condition and Duration on Internal Qualities of Tomato Fruits*

Treatments	pH	TSS (%Brix)	TA (%)	TSS/TA
Factor A: Storage condition				
Ambient 26 ± 1°C	4.7a	3.8a	0.2a	23.7a
Cool bolt 16 ± 1°C	4.8a	3.9b	0.2a	22.7a
<i>Grand Mean</i>	4.8	3.8	0.2	23.2
<i>SE±</i>	0.02	0.03	0.02	1.17
<i>CV%</i>	2.4	6.7	55.8	37.2
<i>L.S.D (0.05)</i>	0.04	0.1	0.04	3.3
<i>F.pr.</i>	0.064	0.002	0.197	0.526
Factor B: Storage period (days)				
0	4.693b	4.3d	0.1707a	28.12b
3	4.76bc	3.989c	0.2347a	21.39ab
6	4.582a	3.878bc	0.1707a	26.35b
9	4.811c	3.722b	0.1707a	24.94ab
12	4.866c	3.456a	0.2347a	17.47a
15	4.816c	3.739b	0.2347a	20.95ab
<i>Grand Mean</i>	4.8	3.8	0.2	23.2
<i>SE±</i>	0.03	0.06	0.02	2.03
<i>CV%</i>	2.4	6.7	55.8	37.2
<i>L.S.D (0.05)</i>	0.07	0.17	0.08	5.71
<i>F.pr</i>	<0.001	<0.001	0.169	0.004

SE± = Standard error of means, CV% = Coefficient of variation, L.S.D = Least significance difference. Means bearing same letter(s) within a column are not significantly ($p > 0.05$) different according to Turkey's Honesty Significance test at $p = 0.05$ significance level.

Interaction effect of storage condition and other parameters of tomato fruits

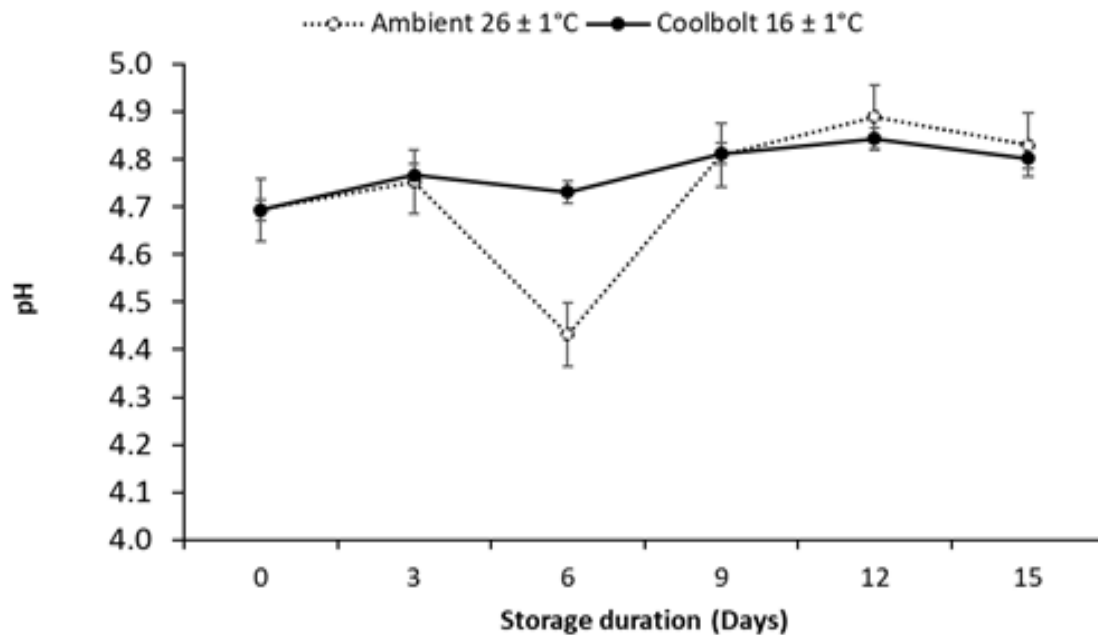
pH

The result shows that there was significant ($p \leq 0.05$) interaction effect of storage conditions on pH of tomato fruits during 15th days of storage. The results show that for the first three days of storage duration there was significant increase in pH of tomato fruits in both storage conditions, but

during the third to six days of storage this trend suddenly decreased from 4.75 to 4.7 and 4.4 for Cold storage and Ambient storage, respectively (Figure 3). Then rapid increase in pH value was recorded in tomato fruits stored at ambient storage from six to 15th day of storage duration. Further, from 9 to 15th day of storage duration the increase in pH value of tomato fruits stored at ambient storage was higher than that of Cold storage.

Figure 3

Interaction Effects of Storage Condition and Duration on Tomato Fruits pH



Total soluble sugar

The results Table 4 show that, there was a significant ($p=0.05$, L.S.D =0.17) interaction effect of storage condition and duration in total soluble sugar of tomato fruits. At the initial day of storage duration, the highest TSS value of 4.3% was recorded for both storage conditions; this value decreased as days of storage increased to the value of 3.7% during the 15th day of storage duration for both storage conditions.

Titrateable acids

The results show that there is no significant ($p \leq 0.05$) interaction between storage condition and storage duration in titrateable acid of tomato fruits (Table 4). The TA column on results in Table 4 bears the same letters. This means that there is no significant effect of storage conditions (Cool bot

and ambient) and duration on Titrateable acid of tomato fruits. Besides, the result in the same Table shows that there was no change in TA of tomatoes fruits which was recorded during 3th, 12th and 15th days of storage, where the TA value of 0.2347% was found to remain constant. Furthermore, the TA value remained constant during the 6th and 9th days of storage from the value (0.1707%) recorded at the initial day of storage.

Total soluble solids to titrateable acidity ratio

The results show that there was no significant ($p \leq 0.05$) interaction effect of storage condition and duration on TSS/TA (Repining Index). It was observed that there was no significant interaction effect of storage temperature and duration on total soluble solids Table 4, whereby TSS; TA column bears the same letters with very slight change in TSS and TA ratio from initial day of storage to final day of storage.

Table 4*Interaction Effects of Storage Condition and Duration on Internal Qualities of Tomato Fruits*

Storage duration (Days)	TSS (%Brix)		TA (%)		TSS: TA	
	Ambient 26 ± 1°C	Cool bolt 16 ± 1°C	Ambient 26 ± 1°C	Cool bolt 16 ± 1°C	Ambient 26 ± 1°C	Cool bolt 16 ± 1°C
0	4.3d	4.3d	0.1707a	0.1707a	28.13a	28.12a
3	4.067cd	3.911bcd	0.256a	0.2133a	21.73a	21.05a
6	3.811bc	3.944bcd	0.1422a	0.2133a	28.08a	24.61a
9	3.578ab	3.867bc	0.1707a	0.1707a	23.74a	26.14a
12	3.233a	3.678bc	0.1991a	0.2702a	18.32a	16.62a
15	3.678bc	3.678bc	0.1991a	0.2702a	22.4a	19.5a
<i>Grand Mean</i>	3.8		0.2		23.2	
<i>SE±</i>	0.09		0.04		2.88	
<i>CV%</i>	6.7		55.8		37.2	
<i>L.S.D (0.05)</i>	0.24		0.11		8.08	
<i>F.pr</i>	0.038		0.521		0.925	

SE± = Standard error of means, CV% = Coefficient of variation, L.S.D = Least significance difference. Means bearing same letter(s) within a variable are not significantly ($p > 0.05$) different according to Turkey's Honesty Significance test at $p = 0.05$ significance level

Effects of storage condition on percentage

Marketability/shelf life of tomatoes fruits

The results show that a percentage of marketability of tomato fruit was significantly ($p < 0.001$, L.S. D= 2.14) affected by the storage condition (Cool bot and Ambient). Lowest percentage loss of marketable fruits was recorded from Cold storage condition (85.7%) and the highest percentage loss

of marketability was recorded from ambient storage condition (98.9%) during 15th of storage duration (Table 5). For storage period, the percentage marketability of tomato fruits decreased by 2.22%, 4.45%, 7.22%, to 9.44% at a three-day interval from 3th day of storage to 15th day of storage duration.

Table 5*Effects of Storage Condition and Duration on Tomato Fruits Shelf Life/Marketability*

Treatments	Marketability (%)
Factor A: Storage condition	
Cool bolt 16 ± 1°C	85.7a
Ambient 26 ± 1°C	98.9b
<i>Grand Mean</i>	92.3
<i>SE±</i>	0.73
<i>CV%</i>	3.4
<i>L.S.D (0.05)</i>	2.14
<i>F pr.</i>	<0.001
Factor B: Storage period (days)	

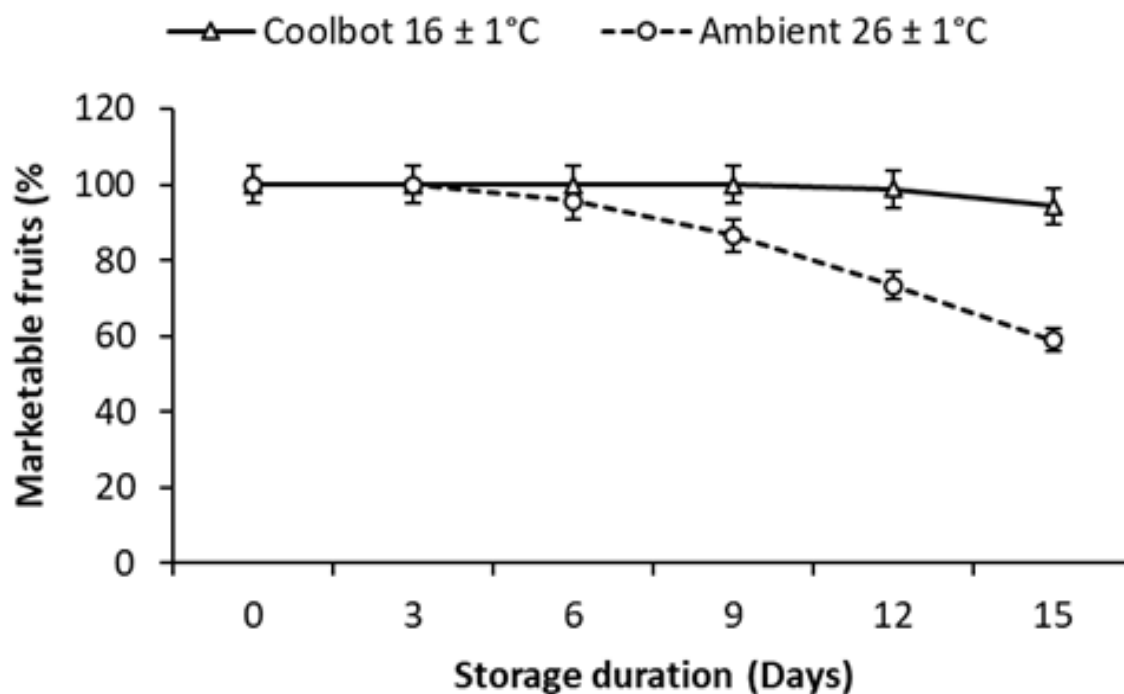
Interaction effect of storage condition and duration on tomatoes fruits shelf life/marketability

The results show that there were significant interactions ($p \leq 0.05$) between storage conditions and durations to marketability percentage of tomato fruits. Cool bolt storage significantly

reduced marketability percentage of the tomato fruits over the 15 days storage period (Figure 4) by 5.56% while Ambient storage reduced marketability percentage by 41.11%. Also, for the first three days of storage, constant marketability percentage value 100% was observed for both Cold and Ambient storage conditions.

Figure 4

Interaction Effects of Storage Condition and Duration on Tomato Fruits Shelf Life/Marketability



Discussion

Effects of storage condition and duration on physical/external qualities of tomato fruits

Color change

The results show that there was a significant difference among storage conditions in color change. The differences between storage conditions might be due to the ripening and respiration rates in ambient storage which were

higher than those in cold storage (Cool bolt) storage. Color changes are described by the hydroxylation of carotenoids and synthesis of xanthophylls. The decline of chlorophyll content might be due to increased chlorophyllase activity and increased oxidation processes. The gradual decrease in greenish color of harvested tomato and increase of redness of tomato fruits is associated with increase in hue value. Similar trends have also been reported by Kudachikar *et al.* (2011) in banana

plantain where the color of banana fruits was highly affected by the storage treatment, and that Cool bolt treatment gave better results than Ambient storage.

Physiological weight loss

Higher physiological weight loss on tomato fruits stored in Cool Bot dispatches the weight of physiological weight loss of tomato fruit stored in ambient conditions over the 15th day period. This implies that Cool Bot maintains the water content, lowering the physiological respiration and removal of water from the fruit surface. Tolesa and Workneh (2017) reported that tomato fruits stored inside zero energy evaporative cooling chambers resulted in only 2.6% PWL, compared to ambient storage 5.4%. This implies that storage under Cool Bot storage conditions over 15th days provide good conditions to keep the PWL below the threshold level of 10% that minimizes physiological weight loss.

Firmness

The firmness (puncture) values observed for stored tomato fruits was due to favorable storage conditions, however compression of tomato fruits under both storage conditions was not noted as significant. The results mean that Cold storage (Cool Bot) maintained fruit firmness (puncture) better than the ambient storage. Tomatoes in Cool bolt treatment kept an acceptable level of firmness (puncture) up to the 15th day of storage duration because Cool bolt cold chamber prevents decline of tomato firmness. Decreasing storage temperature slows the metabolic activities of fresh stored tomato including its firmness. Softening of tomato and kiwi fruit tissues during storage is caused by enzymatic breakdown of pectin (Van Dijk and Tijssens, 2000). Further, Scalzo *et al.* (2005) and Vanoli *et al.* (2009), reported the lower rate of firmness loss in apple fruits during the storage period in Cold storage compared to Ambient storage. As opposed to Cold storage, an Ambient condition may also speed-up ripening and gradual softening of tomato fruits that weaken its shelf life.

Effects of storage condition and duration on internal qualities of tomato fruits

Total soluble sugars

The interaction effect of storage condition and duration on total soluble sugar TSS (%Brix) of tomato fruits was significantly significant. Total soluble sugars contribute to the flavor of fresh tomato fruits. Glucose and fructose; and acitrate, malate and glutamate contribute to sweetness and taste of tomato fruit. Poor total soluble sugar and acids content in tomato fruits have been associated with poor post-harvest storage of tomato (Guillén *et al.*, 2006; Zapata *et al.*, 2008). Majidi *et al.* (2014) noted that minimum changes in TSS values of tomato fruits in controlled atmosphere storage increased from 5.2% to 5.59% over 40 days. Initial rapid increase in TSS contents succeeded by its gradual decrease during the storage of cherry tomato fruits at ambient and cold storage conditions by Gharezi *et al.* (2012) is corroborated with results of this study.

Titrateable Acids

The result of titrateable acidity (TA) shows that there were no significant changes observed in storage conditions and for the duration of 15 days storage. The interaction between storage treatment and storage duration on tomato fruits was not significant because it is a genetically identical component of the variety especially on the internal quality improvements; other factors such as the harvesting stage can give a better significant effect on titrateable acid of tomato fruits. Lack of changes in acidity such as citric and malic acids during storage has also been noted to increase sour taste in tomato fruits by Cordenunsi *et al.*, 2003. Free amino acids may play the role of taste-enhancement (Bucheli *et al.*, 1999) with glutamic acid, the major free amino acid present in tomato fruits (Tiemann *et al.*, 2012).

Total soluble solids to titrateable acidity ratio (Ripening Index)

The study results show that there was no significant difference among storage conditions in TSS to TA ratio. However, TSS to TA ratio

determines the quality of freshness of a fruit. The TSS/TA is highly dependent on maturity stage, genetic and growth conditions (Melkamu *et al.*, 2008). Absence of significant interaction effect of storage condition and duration on total soluble solids is attributed by the packages and the intrinsic nature of tomato fruits. Ripening ratio in all treatments decreased with increased storage duration due to the slight increase in acidity. A decrease in total acidity during storage duration attributed to consumption of organic acids for energy production Cohen *et al.* (1990) as cited by (Chaudhary *et al.*, 2017). It is noted in the results of this study that storage temperature does not affect sugar content in tomato, but reduces its acidity. The ripening index is one of the most important factors influencing the taste, and determining the harvest time of the tomato fruits.

pH

The interaction effect of storage conditions on pH of tomato fruits during the 15th day of storage has a significant difference. The tomato juice contains citric acid which makes the pH of fruit range from 4.0 to 4.5. This range of pH is a desirable trait that prevents proliferation of microorganisms. The increase of pH value was recorded in tomato fruits stored in Ambient storage from 6th to 15th day of storage duration. Moreover, from 9th to 15th day of storage duration the increase in pH value of tomato fruits stored in Ambient storage was higher than that of Cold storage. This trend implies that there was enzymatic breakdown of pectin due to higher metabolic rate of tomato during storage period from both treatments as the ambient stored tomatoes decreases the firmness. The general trend of increase in pH values of tomato fruits tested as storage durations increase agrees with the findings of Mohammed *et al.* (1999) that even for processed tomato, pH follows a similar trend.

Effects of storage condition and duration on marketability/Shelf life

The percentage of marketable tomato fruits decreased during the storage period. However, at the beginning of the storage duration, the difference between the two treatments was

insignificant, but starting from day 6th, a significant difference was starting to be observed in both storage conditions. The cold storage (Cool bolt) significantly improved the marketability of tomato fruits. The result shows cold storage was able to maintain marketability value of tomato by 98.9% while ambient storage-maintained marketability value by 60.1% during 15th day of storage duration. This difference may be due to the difference in efficiency of storage conditions to influence change in physiological and physical conditions of tomato fruits. A similar result was observed by El-Khoreiby *et al.* (2011) who reported that cold storage during 1st day of storage had a significant influence on marketability of three peach fruit cultivars.

Conclusion

The cold storage postharvest technique had a significant effect on qualitative properties and shelf life of tomato fruits during 15th days of storage duration. Cold storage (Cold Bot) conditions at 16±1°C reduced physiological weight loss of tomato fruits by 7.17% compared to Ambient storage which was able to reduce it by 3.01%. The cold storage was able to maintain fruit firmness, fruit color, pH and total soluble solid contents compared to Ambient storage. The significant interactions of storage conditions and duration were also observed on tomato fruits' color, physiological weight loss, TSS, pH and shelf life with increased storage duration. Cool Bot treatment was able to preserve tomato color for longer periods, than ambient storage. Also, the rate of change of redness in Cool bolt storage was much slower than that of ambient storage during the 15th day of storage duration. Cold storage (Cold Bot) storage condition at 16±1°C is recommended for sustaining postharvest quality of tomato fruits. Nevertheless, further studies need to be conducted under different storage temperatures and longer periods of storage duration.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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