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Shelf-life and post-harvest quality of tomato (*Lycopersicon esculentum* Mill.) varieties to different packaging materials at Mersa, North Wollo, Ethiopia

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Key words: Packaging materials, quality, shelf life, tomato varieties.

Abstract: Tomato *(Lycopersicon esculentum Mill.)* has a short shelf life at ambient conditions and is a highly perishable crop. Extreme post-harvest losses occur as a result of the wrong packaging materials. However, by employing the right packing materials, tomato varietals can have longer shelf lives. Globally rising fresh tomato demand has forced the development of essential mechanisms, including packaging materials, to improve shelf life. The current study was initiated to evaluate the quality and shelf-life of tomato varieties in response to packaging materials at Mersa, North Wollo, Ethiopia, during 2021 cropping season. Three replications of a completely randomized design were used to test three tomato varieties (Roma VF, Oval red and Woyno) and seven packing materials [closed carton (CC), open carton (OC), closed wooden box (CWB), open wooden box (OWB), perforated polyethylene bag (PPB), non-perforated polyethylene bag (NPPB) and control (C)] at room temperature (20-22°C). According to the findings, there is a significant (P<0.05) interaction effect between packaging materials and varieties on a number of parameters, including physiological weight loss, decay percentage, disease incidence, total soluble solids (TSS), tomato fruit PH, juice color score, overall acceptability, marketability percentage, and shelf life. Non-perforated polyethylene plastic experienced the highest physiological weight losses of 79.88% and 79.63% after 18 days of storage. Roma VF variety showed the greatest weight loss. In addition, PPB showed the lowest decay percentage (20%) and maximum marketability (20%) during the 18th day of storage. At the end of storage, NPPB with Roma VF and Woyno varieties had a substantially (100%) larger decay loss of tomato fruits. NPPB has been linked to the highest disease incidence (20%). Roma VF and Oval red recorded the highest pH tomato fruit's color and overall acceptability score on PPB. It can, thus, be concluded that packaging of tomato fruits in PPB can extend shelf-life with better-quality of the produce. However, to develop plausible recommendation, the study should be repeated in multi-location with more packaging methods and varieties over seasons.

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All relevant data are within the paper and its Supporting Information files.

Authors contributions:
The authors (Dr. Seid Hussen and Dr. Biruk Masrie) developed the idea and initiation, edit the draft the proposal, and write the manuscript. The co-author (Solomon Worku) conducted the research, did data collection and analysis.

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The authors declare no competing interests.

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1. Introduction

The tomato (*Lycopersicon esculentum* Mill.) crop, which was domesticated in Mexico, is the most commonly grown vegetable crop in the world. From the equator to Chile, the western coastal plain of South America is where it originated (Mapes and Basurto, 2016). It ranks first on the list of canned vegetables and is the most extensively consumed vegetable crop, followed by the potato and sweet potato (Yesdhanulla and Aparna, 2018). The cultivated tomato was first used in Ethiopian agriculture between 1935 and 1940. It is one of the most important crops grown by smallholder farmers in Ethiopia. Tomatoes are essentially a perennial plant, even though they are farmed as an annual crop. They are regarded as a delicate warm-season crop that is prone to cold (Abdu, 2016).

Tomatoes have a relatively short shelf life due to several postharvest physiological, physical, and chemical changes that occur during storage (Haile and Safawo, 2018). Various methods and strategies are being evaluated to minimize postharvest losses and enhance their storage life. Because they are a climacteric and perishable fruit, tomatoes have a very short shelf life, under normal circumstances (Caroline *et al.*, 2015; Ayomide *et al.*, 2019). Fruit rot, inappropriate handling and storage techniques, and external injury received during harvest are the main causes of post-harvest losses. A tomato fruit's fresh weight is 90% water, and the size of the fruit is influenced by the water supply to the plant. Fruit with this much water content is perishable. The majority of fruits and vegetables suffer from water loss during storage, which is impacted by temperature (>55°F) and relative humidity (<80%) conditions (Bonazzi and Dumoulin, 2011).

Despite the growth of Ethiopia's horticultural sector, there is still a lack of funds to address post-harvest loss and crop quality issues (Kasso and Bekele, 2018). Post-harvest losses of horticulture crops in Ethiopia were observed to range from 15% to 70% (Urge *et al.*, 2014). Post-harvest loss of horticulture products in Ethiopia was attributed to a number of factors, including transportation, a lack of proper storage facilities, and unsuitable packaging materials (Hagos, 2014; Kasso and Bekele, 2018). Losses during and after harvest are a significant source of food loss because they have a direct impact on people's livelihoods and the whole economy, which is important for food security, nutrition, and lowering poverty.

Prior to marketing, transit, and storage, horticultural crops experience the worst post-harvest loss and quality deterioration. Common horticultural goods' post-harvest loss was attributed primarily to inadequate packaging, poor transportation, inadequate storage, and unfavorable market conditions (Seid *et al.*, 2013). Various studies have explored the magnitude of vegetable postharvest losses, production limitations, and agronomic practices. However, there is a dearth of data on the impact of storage conditions and packing materials on tomato fruit shelf life. Furthermore, the knowledge of different packaging materials and storage methods used by small-holder farmers and customers in Mersa and neighboring districts of Northeastern Ethiopia where the current research was conducted is scarce, despite few experiences across various regions of the country. Tomato growers, distributors and consumers can benefit from choosing the best possible packaging material to preserve tomato quality during harvest and extend shelf life. The objective of this study is to examine the impact of various packaging materials on the postharvest quality and shelf-life of tomato varieties at Mersa, North Wollo, Ethiopia.

2. Materials and Methods

Description of the study area

The current experiment was conducted at Mersa College of Agriculture, Woldia University, North Wollo, Ethiopia. The area is geographically locate at 390° 38' E and 11°35'N with an altitude of 1600 m asl in the semi-arid tropical belt of north-eastern Ethiopia. It is 491 km away from Addis Ababa to the northeast and 30km away from Woldia town to the south. It receives an average annual rain fall ranging from 750 to 1000 mm with a bimodal pattern, short rainy season from February to April and long rainy season from July to September. The average annual temperature is about 28.5°C. The soil texture is clay loam and classified as vertisol. The pH of the soil is slightly acidic to slightly alkaline.

Treatments and experimental design

There were seven packaging materials available; namely open carton (OC), closed carton (CC), perforated polyethylene bag (PPB), non-perforated polyethylene bag (NPPB), open wooden box (OWB), closed wooden box (CWB), and control (without packaging) (C); along with three varieties of tomato;

Woyno, Oval red, and Roma VF. The experiment comprised of 21 treatments with three replications arranged in completely randomized design (CRD). The three tomato varieties were produced independently in a field. Half a Kg of tomato fruits for each replication was used for the experiment. In accordance with specifications of the design, each treatment was assigned randomly to the experimental units within a replication.

Description of experimental materials

Varieties. Three tomato varieties (Roma VF, Woyno and Oval red) were used in the experiment. Seeds of all varieties were obtained from Sirinka Agricultural Research Center located at 20 kms to the north of the experimental site. Their descriptions are indicated in Table 1. Tomato fruits of each variety at the time of harvesting are as shown in the figure below (Fig. 1).

Fig. 1 - Tomato varieties used in the experiment (A=Roma VF, B=Oval red, C=Woyno).

Packaging materials. The treatment consisted of seven different packaging materials (open carton, closed carton, open wooden box, closed wooden box, perforated polyethylene bag, non-perforated polyethylene bag and ambient (without packaging) as control.

Closed carton (CC). A carton made from paperboard with the size of 42 cm length25 cm height and 35 cm width was used. The carton was closed after putting the fruits inside the carton.

Open carton (OC): A carton made from paperboard with the size of 42 cm length, 25 cm height and 35 cm width was used. Fruits were placed inside the carton and were left open.

Closed wooden box (CWB). A wooden box made from wood with the size 40 cm length, 30 cm height and 30 cm width was used. The box was closed after putting the fruits inside it.

Open wooden box (OWB). A wooden box made from wood with the size 40 cm length, 30 cm height and 30 cm width was used. Fruits were placed inside the wooden box and were left open.

Perforated polyethylene bag (PPB). A Perforated polyethylene bag made from plastic with 0.4mm thickness of white polyethylene bag and it was having 25% hole designed for the experimentation purpose, were obtained from market. Fruits were placed in perforated polyethylene bag.

Non-perforated polyethylene bag (NPPB). A non-Perforated polyethylene bag made from plastic with 0.4 mm thickness of white polyethylene bag designed for the experimentation purpose, were obtained from market. Fruits were placed in non-perforated polyethylene bag.

Control (without packaging) (C). Fruits were placed on open table at room temperature in laboratory without any packaging**,** were designed for the experimentation purpose.

Experimental management

Seeds were sown in rows of 15 cm spacing on well prepared raised nursery beds having the size of 1 m x 1 m (for each variety) at Mersa Habru Agricultural and Rural Development Office fruit nursery site. Seeds were covered lightly with fine soil and with

Table 1 - Description of tomato varieties used for the experiment

Description	Types of Varieties		
	Roma VF	Woyno	Oval red
Year of release	1977	2006	2007
Altitude (masl)	700-1900	800-2000	800-2000
Growth habit	Determinate	Determinate	Determinate
Fruit shape	Globular	Oblong	Oval
Utilization	Fresh	Fresh	Fresh
Maturity (days)	95-100	100-120	100-110
Yield Research field	400	45	42
Yield Farmer`s field	120-140	13-17	14-18

two-three cm thick grass mulch. Transplanting of seedlings to experimental field was done when seedlings attain the height of about 13-15 cm and at 3-4 true leave stage. All management activities were given as needed till harvesting. Fruits were harvested at breaker stage. Fruits were selectively harvested to maintain uniform color, sizes and fruits without any defects. The selectively harvested fruits were cleaned to remove the dust. Then the fruits were allowed to dry for half an hour by spreading on newspaper over the floor. Initial weight was taken from each variety and packed in the aforementioned packaging materials. Half kilogram tomato fruits per treatment were packed in each packaging materials at room temperature (20-22°C) (Fig. 2).

Fig. 2 - Experimental arrangement at room temperature (20-22°C).

Data collection

Physiological weight loss, pH of tomato fruit juice, decay percentage, color score**,** disease incidence (%), overall acceptability and percentage marketability were collected during the experimental period from the total population at 3 days interval (0, 3, 6, 9, 12, 15 and 18 days).

The physiological weight loss was taken at 3 days interval starting from date of packaging and determined using the methods described by (Workneh *et al.*, 2012). It was determined using sensitive balance (type JD2000-2). The following formula was used to calculate weight loss.

$$\text{Physiological weight loss (\%)} = \frac{\text{Initial weight - final weight}}{\text{Initial weight)}} \times 100$$

The juice content (%) was determined by crashing randomly selected fruits then extracting using juice extractor and calculate juice content as follows:

$$\text{Juice content (\%)} = \frac{\text{Total weight of juice-beaker weight}}{\text{Total weight of fruit}} \times 100$$

pH of tomato fruit juice. Randomly selected fruits from each packaging was extracted using juice extractor and measure with pH meter (Harvard digital pH meter, Model H198103, made from Italy).

Disease incidence (%). The fruits were observed visually for rotting and microbial infection and calculated according to the formula given below (Khruengsai *et al.*, 1991).

$$\text{Disease incidence (\%)} = \frac{\text{Number of infected fruits}}{\text{Total number of fruits}} \times 100$$

Percentage of marketability. The marketable quality of fruits was subjectively assessed by procedure of Workneh *et al.* (2012) with a slight modification. These descriptive quality attributes were determined subjectively by observing the level of visible mold growth, decay, shriveling, smoothness and shininess of fruits with (15 respondents). A 1-5 rating, with1 = unusable, 2 = usable, 3 = fair, 4 = good, 5 = excellent was used to evaluate the fruit quality. Fruits receiving a rating of 3 and above were considered as marketable. The numbers of marketable fruits was used as a measure to calculate the percentage of marketable fruits during storage. After subjectively assessing the product, it was calculated using the following formula.

$$\text{Marketability \%} = \frac{\text{No. of marketable tomato fruit}}{\text{Total no. of sampled tomato fruit}} \times 100$$

Shelf life. The shelf life was calculated by counting the days required to attain the last stage of ripening, but up to the stage when fruit remained still acceptable for marketing (Rao *et al.*, 2011).

Decay or rotting (%). Decay or rotting was determined by the visual observation. Development of spots on the fruit's skin and softening and rotting of fruits were also being recorded.

Color and overall acceptability score. Color was measured by comparing with the color chart described by Dadzie and Orchard (1997). It was determined by counting (15 respondents) the number of respondents from 0 to 5 scoring. A 1-5 rating with 0 = poor, 2 = fair, 3 = good, and 4 = very good and 5 = excellent and finally the mean data will be analyzed. On the same way, overall acceptability was assessed by the above selected respondents and the result was taken by the 1-5 rating similar with marketability. The predominant colors which were used for evaluation are Green, 2=Breaker, 3=Turning, 4=Pink, 5= Light Red, 6= Red and 7 = Deep Red.

Total soluble solids (TSS). The TSS was determined following the procedures described by (Waskar *et al.*, 1999). An aliquot of juice was extracted using a juice extractor. A hand refract meter (WAY-2s Abb'e, 0-20 Brixo) was used to determine TSS the refractor meter was washed with distilled water. The refractometer was standardized against distilled water (0 percent TSS) and measure TSS.

Data analysis

The data obtained was statistically analyzed for analysis of variance (ANOVA) using General Linear Model (GLM) using SAS 9.13 version (SAS, 2002).The mean separation was made based on Least Significant Difference (LSD) at 5% level of significance.

3. Results and Discussion

Physiological weight loss

Tomato fruits experience great physiological weight loss if stored under normal conditions without any treatment and safe storage environment (Iqbal *et al.*, 2022). Physiological weight loss of tomato fruits was significantly influenced by the main effect of packaging materials (P<0.001), varieties (P<0.01) and interaction effect (P<0.01) of packaging materials and varieties at 18th days of storage. The result showed that, the highest physiological weight loss (79.88%) was recorded from control (without packaging) followed by Open carton (74.70%) from variety Roma VF (Table 2). The lowest Physiological weight loss (32.72%,) was recorded from variety Oval red with perforated plastic package, which was lower than the weight loss of tomato fruits subjected to all other packaging materials.

In the current investigation, the highest weight loss observed in tomato fruits at the control treatment may be due to the higher respiration rate exercised. The result is supported by the findings of Sinha *et al.* (2019), in which maximum weight loss was recorded from control, without packaging materials. In addition, another group of researchers also report-

Table 2 - Interaction effects of packaging materials and varieties on physiological weight loss and decay percentage (at 9, 12, 15 and 18 days) of tomato at Mersa during 2021 cropping season

Variety	Packaging materials	Physiological weight loss				Decay percentage			
		9	12	15	18	9	12	15	18
Woyno	OC	29.73 c	41.37 d	59.99 d	68.89 d	20.00 c	40.00 d	80.00 c	20.00 a
	CC	23.59 e	31.51 g	49.06 f	58.02 f	0.00 c	0.00 d	46.67 c	80.00 c
	OWB	26.77 d	36.38 e	51.83 e	60.10 e	20.00 a	20.00 c	60.00 a	80.00 c
	CWB	25.04 e	34.64 f	48.73 g	56.59 g	0.00 c	20.00 c	40.00 d	80.00 c
	PPB	13.19 g	19.69 h	27.75 h	32.72 h	0.00 c	0.00 d	20.00 e	60.00 d
	NPPB	2.83 h	40.09 d	58.14 d	67.14 d	0.00 c	0.00 d	60.00 a	100.00 a
	C	40.96 a	56.03 a	68.55 a	79.47 a	0.00 c	0.00 d	60.00 a	100.00 a
Oval red	OC	31.89 b	41.94 d	61.45 d	71.27 d	20.00 a	40.00 a	60.00 a	80.00 c
	CC	24.24 e	32.95 g	47.70 g	55.33 g	0.00 c	20.00 c	46.67 c	100.00 a
	OWB	30.75 c	40.45 d	58.63 d	68.01 d	0.00 c	20.00 c	40.00 d	80.00 c
	CWB	23.10 e	31.17 g	45.02 g	52.21 g	20.00 a	20.00 c	40.00 d	80.00 c
	PPB	15.86 f	21.56 h	31.23 h	36.23 h	0.00 c	0.00 d	20.00 e	60.00 d
	NPPB	2.34 h	40.09 d	58.14 d	67.44 d	20.00 a	20.00 c	33.33 d	86.67 c
	C	42.33 a	57.57 a	68.65 a	79.63 a	0.00 c	26.67 b	53.33 b	80.00 c
Roma VF	OC	32.78 b	44.44 b	64.40 b	74.70 b	0.00 c	20.00 c	60.00 a	93.33 b
	CC	24.50 e	33.32 g	48.54 g	56.29 g	20.00 a	40.00 a	60.00 a	93.33 b
	OWB	31.55 c	42.90 c	62.21 c	72.15 c	0.00 c	40.00 a	60.00 a	86.67 c
	CWB	23.74 e	31.99 g	46.34 g	53.76 g	0.00 c	20.00 c	60.00 a	86.67 c
	PPB	16.88 f	21.87 h	31.71 h	36.78 h	0.00 c	0.00 d	20.00 e	60.00 d
	NPPB	2.62 h	40.34 d	58.49 d	67.64 d	0.00 c	20.00 c	60.00 a	93.33 b
	C	42.65 a	58.00 a	68.86 a	79.88 a	6.67 b	20.00 c	60.00 a	100.00 a
LSD (0.05)		2.03	2.31	3.99	4.39	4.15	4.152	10.99	10.17
Significant level		4.40 **	7.01 **	15.87 **	22.83 **	320.65 ***	276.19 ***	250.79 ***	143.92 ***
CV (%)		5.21	3.77	4.52	4.28	5.21	3.77	4.52	4.28

* significant at P≤0.05; ** highly significant at P≤0.01; *** very highly significant at P≤0.001; means with the same letter (s) within a column are not significantly different at 5% level of significance.

ed that the highest weight loss was recorded for tomato stored in ambient atmosphere without packaging (control) (Sualeh *et al.*, 2016). The highest weight loss from control and open carton may be due to faster metabolism at higher temperature, increased cell wall degradation and higher membrane permeability leading to exposure of cell water for easy evaporation (Yao *et al.*, 2020).The lowest physiological weight loss might be due to the fact that, polyethylene plastic protects the fruits from adverse conditions by avoiding mechanical damage, reducing moisture loss, providing beneficial modified atmosphere and preventing pilferage (Sinha *et al.*, 2019). Similarly, Hailu *et al.* (2014) reported that weight loss of fruits in polyethylene bags was far low than from unpackaged fruits. Lower weight loss of packaged fruits could be due to slow rate of transpiration and prevention of excessive moisture loss.

Decay percentage

Packaging materials vary in their tendency to reduce decay percentage of tomato fruits (Olveira-Bouzas *et al.*, 2021). Decay percentage was significantly influenced by packaging materials (P<0.001), tomato varieties (P<0.05) and their interactions (P<0.001). The highest decay percentage (100 %) was obtained from both Roma VF and Woyno without packaging. It was followed by non-perforated polyethylene plastic and closed carton. However, the lowest decay percentage (20 %) was recorded from variety Woyno with open carton followed by Oval red (60%) with perforated plastic (Table 2). It is clearly identified that decay percentage increased with the storage time for all storage methods and ripening stages. This result is line with the work of (Moneruzzaman *et al.*, 2009). Tomatoes at light red stage showed rapid deterioration. Total deterioration of the fruit was recorded from closed carton with variety Oval red, non-perforated polyethylene plastic with variety of Woyno, and Control both from variety Roma VF and Woyno on the 18th days of storage period.

Disease incident percentage

Disease incident was significantly influenced by packaging materials (P<0.001), tomato varieties (P<0.001) and their interactions (P<0.001). Maximum disease incident (100%) was recorded from both variety Woyno and Oval red using non-perforated polyethylene plastic, followed by the same packaging materials from Roma VF variety (93.33%).

Disease incidence was found only in fruits with non-perforated polyethylene plastic and closed carton packaging materials (Table 3). This could be due to inadequate air flow in non-perforated plastic and the accumulation of water from fruit respiration, which creates an environment conducive to fungi growth. After 12 days, the variety Woyno under closed cartons also started disease incidence while Roma VF in non-perforated polyethylene plastic increased by 20 % while all other packaging materials showed no incidence of disease. This result is in line with the findings of (Bautista-Baños *et al.*, 2008). The highest disease occurrence may be due to the increasing of moisture content in the storage of both closed carton and non-perforated polyethylene plastic packages. The water accumulation inside the packaging is high because of limited movement and exchange of air which can result in the occurrence of fungal disease.

Color

Color was significantly influenced by packaging materials (P<0.001) and their interactions (P<0.05). During the storage period, there was a general change of tomato fruit colour from breaker to deep red. The highest color change was observed in control followed by open carton and wooden box. Variation of skin color was due to variety and packaging material. In comparison of tomato fruit variety color change from the breaker to deep red, Roma VF variety showed highest loss of greenness, while it was lowest in Woyno (Table 3). This result is in line with the work of Tigist *et al.* (2013), who reported that variety Roma VF showed faster rate of loss of greenness while it was slower for Melkasalsa that during normal ripening of tomato fruit, tissue colour changes from green through orange to red, which coincides with ethylene biosynthesis and a climacteric rise in respiration. The color acceptability of control fruits is shorter as compared to other packaging materials (between 3 to 18 days of their storage), that is, in the range of very good to excellent especially perforated plastic packed tomato fruits. This change was due to the action of treatments on the fruits as polyethylene packaging (perforated) helps the color retention as described by (Ashenafi and Tura, 2018).

pH of tomato fruit juice

A significant variation in pH of tomato fruit juice was observed due to the main effect of packaging materials (P<0.001), varieties (P<0.01) and their interactions (P<0.001). The control had the highest pH value (4.23) in all varieties of tomato fruit fol-

Table 3 - Interaction effects of packaging materials and varieties on disease incidence percentage and color (at 9, 12, 15 and 18 days) of tomato at Mersa during 2021 cropping season

Variety	Packaging materials	Disease incidence				Color			
		9	12	15	18	9	12	15	18
Woyno	OC	0.00 c	0.00 d	0.00 d	0.00 e	5.33 c	6.00 a	7.00 a	7.00 a
	CC	0.00 c	6.67 c	20.00 b	20.00 c	5.00 c	6.00 a	7.00 a	7.00 a
	OWB	0.00 c	0.00 d	0.00 d	0.00 e	5.00 c	6.00 a	7.00 a	7.00 a
	CWB	0.00 c	0.00 d	0.00 d	0.00 e	5.00 c	6.00 a	7.00 a	7.00 a
	PPB	0.00 c	0.00 d	0.00 d	0.00 e	5.00 c	5.67 a	6.67 b	7.00 a
	NPPB	0.00 c	20.00 b	40.00 a	100.00 a	4.00 d	5.00 b	6.00 c	6.67 b
	C	0.00 c	0.00 d	0.00 d	0.00 e	5.00 c	5.67 a	7.00 a	7.00 a
Oval red	OC	0.00 c	0.00 d	0.00 d	0.00 e	5.00 c	6.00 a	7.00 a	7.00 a
	CC	0.00 c	0.00 d	0.00 d	20.00 c	5.00 c	6.00 a	7.00 a	7.00 a
	OWB	0.00 c	0.00 d	0.00 d	0.00 e	5.00 c	6.00 a	7.00 a	7.00 a
	CWB	0.00 c	0.00 d	0.00 d	0.00 e	5.00 c	6.00 a	7.00 a	7.00 a
	PPB	0.00 c	0.00 d	0.00 d	0.00 e	5.00 c	5.67 a	6.67 b	7.00 a
	NPPB	20.00 a	20.00 b	40.00 a	100.00 a	4.33 d		6.00 c	6.67 b
	C	0.00 c	0.00 d	0.00 d	0.00 e	5.33 c	6.00 a	7.00 a	7.00 a
Roma VF	OC	32.78 b	44.44 b	64.40 b	74.70 b	5.00 c	6.00 a	7.00 a	7.00 a
	CC	0.00 c	0.00 d	6.67 c	6.66 d	5.00 c	6.00 a	7.00 a	7.00 a
	OWB	0.00 c	0.00 d	0.00 d	0.00 e	5.33 c	6.00 a	7.00 a	7.00 a
	CWB	0.00 c	0.00 d	0.00 d	0.00 e	5.67 b	6.00 a	7.00 a	7.00 a
	PPB	0.00 c	0.00 d	0.00 d	0.00 e	5.00 c	6.00 a	7.00 a	7.00 a
	NPPB	20.00 a	40.00 a	40.00 a	93.33 b	4.00 d	5.00 b	5.00 d	6.00 c
	C	0.00 c	0.00 d	0.00 d	0.00 e	6.00 a	6.00 a	7.00 a	7.00 a
LSD (0.05)		0.43	0.42	2.08	4.16	0.46	0.36	0.29	0.29
Significant level		57.49 ***	66.67 ***	44.4 ***	27.51 ***	0.20 **	0.17 **	0.17 ***	0.06 *
CV (%)		12.96	6.11	18.04	15.60	5.52	3.73	2.66	2.60

* significant at P≤0.05; ** highly significant at P≤0.01; *** very highly significant at P≤0.001; means with the same letter(s) within a column are not significantly different at 5% level of significance.

lowed by Open wooden box in varieties Roma VF (4.18) and Oval red (4.15).Whereas lowest pH value were obtained in packaged fruits treated with closed carton from Woyno variety (3.1) (Table 4).

The result showed that pH values ranging from 3.10-4.23 from all variety and packaging materials after 12 days of storage period. Generally, the pH of fruits increases as fruits undergo ripening. This might be due to citric acid in tomato juice, with pH of fruit normally between 4.0 and 4.5 (Anyasi *et al.*, 2016). The higher pH of fruits under ambient storage condition could be associated with the utilization of acids for catabolism of sugar at faster rate. High storage temperature leads to faster respiration rate. The lower pH values of packaged fruits could be explained by the relatively reduced respiration rate in the package can inhibit loss of organic acids.

Fruit juice content

Fruit juice content and functional properties of tomato and other vegetables is likely to be affected by the type of storage condition and packaging materials (Alenazi *et al*., 2020). In the current experiment, a significant variation in fruit juice content was observed due to the main effect of packaging materials (P<0.001) and varieties (P<0.01). PPB had highest fruit juice content (93.70%) on Oval red tomato fruit varieties and followed by both OC and control (92.37%) under variety Roma VF. Whereas, the lowest juice content was recorded from OWB (85.26) and CWB (85.44) packaging materials on Woyno variety followed by NPPB (88.26%) on Oval red variety (Table 4). Similar findings were reported by (Gebeyehu, 2018). The variation of juice content may be due to differences in packaging materials which can affect the firmness and metabolic processes. The variation in juice content of tomato fruit among varieties might be due to their genetic differences.

Total soluble solids (°Brix)

Total soluble solid (TSS) is one of the quality parameters in fruits and vegetables (Mesa *et al*., 2022). In the present research, TSS was significantly influenced by packaging materials (P<0.001), varieties (P<0.001) and interaction effect of packaging methods and varieties (P<0.01). During the 12 day of storage period the TSS was range from 3.65 to 5.11°Brix (Table 4). The result showed that, the highest TSS (5.11) was recorded from variety Roma VF under the control followed by Oval red variety. The lowest TSS (3.65) was recorded from variety Woyno using non-perforated polyethylene plastic (Table 4). The result agrees with the work of Sualeh *et al.* (2016).

Table 4 - Interaction effects of packaging materials and varieties on Juice content, PH and TSS of tomato at Mersa during 2021 cropping season

Variety	Packaging materials	Storage period (days)		
		Juice content	pH	TSS
Woyno	OC	89.30 d	4.01 f	4.65 f
	CC	88.39 e	3.10 h	4.53 g
	OWB	85.44 e	4.05 f	4.59 g
	CWB	85.26 e	3.98 f	4.40 h
	PPB	90.29 d	4.12 e	4.08 i
	NPPB	88.96 d	3.75 g	3.65 j
	C	92.03 c	4.23 a	4.87 c
Oval red	OC	91.65 c	4.04 f	4.36 i
	CC	90.83 d	4.02 f	4.45 j
	OWB	90.51 d	4.15 d	4.27 i
	CWB	91.69 c	3.98 f	4.38 i
	PPB	93.70 a	4.12 e	4.01 j
	NPPB	88.26 e	4.06 f	4.02 j
	C	92.37 b	4.23 b	5.01 b
Roma VF	OC	92.37 b	4.02 f	4.69 e
	CC	91.46 d	4.04 f	4.36 i
	OWB	91.91 c	4.18 c	4.57 g
	CWB	91.31 d	3.93 f	4.41 h
	PPB	92.03 c	4.13 e	4.52 g
	NPPB	91.92 c	3.26 h	4.02 j
	C	92.04 c	4.23 a	5.11 a
LSD (0.05)		3.21	0.16	0.37
Significant level		7.13 *	0.07 ***	0.14 **
CV (%)		2.07	2.48	4.68

* significant at P≤0.05; ** highly significant at P≤0.01; *** very highly significant at P≤0.001; means with the same letter(s) within a column are not significantly different at 5% level of significance.

The variation in TSS might be due to advancement of fruit ripening, packaging materials and variety of tomato fruit. Total soluble solids (°Brix) of control and treated tomato fruits showed that they increased as the ripening proceeds. The lowest TSS value of non-perforated polyethylene plastic may be due to slowing down of respiration and metabolic activity. Whereas the highest TSS in the control may be due to high respiration and metabolic activity rise ripening process as result increasing TSS. In this regard, the view of Kumar *et al.* (2022) is noteworthy that the slower respiration also slows down the synthesis and use of metabolites resulting in lower TSS due to the slower change from carbohydrates to sugars which result in retardation of the ripening process.

The changes in TSS content that occur during ripening are correlated with the hydrolytic shifts in starch concentration after harvest. Using sugars as a respiration substrate, the TSS content of fruits could decrease with time storage due to increased temperature and biosynthesis processes or polysaccharide degradation at maturity (Azene *et al.*, 2014).

Overall acceptability (score)

Overall acceptability was significantly influenced by packaging materials (P<0.001), tomato varieties (P<0.01) and their interactions (P<0.001). The present study revealed that under Woyno variety, non-perforated polyethylene plastic and control fruits showed, lower overall acceptability as compared to other packaging materials and varieties at 18 days of storage period (Table 5). At the later stage of ripening (18 days), Non Perforated polyethylene plastic and control fruits showed a lower overall acceptability scores (0-3). Oval red and Roma VF varieties of tomato fruits under perforated plastic showed better overall acceptability followed by both carton packed and wooden box packaging (Table 5).

The results led to a conclusion that the main reason behind this improvement was due to the prevention of fruit from decay organism and the fruit will have stored reserve which is protected from adverse

Table 5 - Interaction effects of packaging materials and varieties on overall acceptability and marketability percentage (at 9, 12, 15 and 18 days) at Mersa during 2021 cropping season

Variety	Packaging materials	Overall acceptability				Marketability percentage			
		9	12	15	18	9	12	15	18
Woyno	OC	4.00 d	3.00 d	1.00 c	0.00 c	80.00 d	60.00 c	20.00 c	0.00 c
	CC	4.00 d	3.00 d	1.00 c	0.00 c	80.00 d	60.00 c	20.00 c	0.00 c
	OWB	3.00 f	4.00 b	1.00 c	0.00 c	60.00 f	60.00 c	20.00 c	0.00 c
	CWB	4.00 d	4.00 b	1.00 c	0.00 c	80.00 d	60.00 c	20.00 c	0.00 c
	PPB	5.00 a	4.00 b	2.00 b	1.00 a	100.00 a	80.00 a	40.00 a	20.00 a
	NPPB	3.00 f	2.00 f	0.00 e	0.00 c	40.00 g	20.00 f	0.00 d	0.00 c
	C	4.00 d	2.00 f	1.00 c	0.00 c	60.00 f	40.00 e	20.00 c	0.00 c
Oval red	OC	4.00 d	3.00 d	1.00 c	0.00 c	80.00 d	60.00 c	20.00 c	6.67 b
	CC	4.00 d	3.00 d	2.00 b	0.00 c	80.00 d	60.00 c	20.00 c	0.00 c
	OWB	4.00 d	2.33 e	1.00 c	1.00 a	80.00 d	53.33 d	20.00 c	0.00 c
	CWB	4.00 d	3.00 d	2.00 b	0.00 c	73.33 e	60.00 c	20.00 c	0.00 c
	PPB	5.00 a	4.00 b	3.00 a	1.00 a	93.33 b	80.00 a	26.66 b	0.00 c
	NPPB	3.00 f	1.67 f	0.00 e	0.00 c	60.00 f	20.00 f	0.00 d	0.00 c
	C	4.00 d	3.00 d	1.00 c	0.00 c	73.33 e	66.67 b	20.00 c	0.00 c
Roma VF	OC	4.00 d	3.00 d	2.00 b	1.00 a	80.00 d	60.00 c	20.00 c	0.00 c
	CC	3.67 e	3.00 d	1.00 c	0.00 c	73.33 e	40.00 e	20.00 c	0.00 c
	OWB	3.67 e	3.33 d	1.00 c	0.00 c	73.33 e	40.00 e	20.00 c	0.00 c
	CWB	4.33 c	3.67 c	0.67 d	0.00 c	86.67 c	60.00 c	20.00 c	0.00 c
	PPB	4.67 b	4.33 a	3.00 a	0.67 b	93.33 b	80.00 a	40.00 a	20.00 a
	NPPB	3.00 f	2.00 f	1.00 c	0.00 c	60.00 f	20.00 f	20.00 c	0.00 c
	C	3.33 f	2.00 f	1.00 c	0.00 c	66.67 f	40.00 e	0.00 d	0.00 c
LSD (0.05)		0.46	0.59	0.21	0.21	11.74	5.87	4.15	4.15
Significant level		0.22 **	0.61 ***	0.71 ***	0.33 ***	144.97 **	170.37 ***	222.22 ***	69.84 ***
CV (%)		6.83	11.63	9.92	56.69	8.80	6.59	13.68	79.37

* significant at P≤0.05; ** highly significant at P≤0.01; *** very highly significant at P≤0.001; means with the same letter(s) within a column are not significantly different at 5% level of significance.

condition (Yahaya and Mardiyya, 2019). From breaker to turning stage, the colour of fruits changed from poor to fair by showing not more than 30% of surface as not green in colour. When stage advances from pink to pink-red, the colour of all fruits was in the range of good to excellent. This result is in conformity with the work of (Priyankara *et al.*, 2017). Up to 9th days Roma VF tomato variety exhibited best color and consumer acceptability, followed by Oval red were as Woyno scores low consumer acceptability.

Marketability percentage

Marketability percentage was significantly influenced by packaging materials (P<0.001), tomato varieties (P<0.05) and their interactions (P<0.001). At 9th days of storage period the highest percentage marketability (100%) was obtained from Woyno tomato fruit varieties using perforated polyethylene plastic followed by the same packaging materials (93.33%) from both Roma VF and Oval red tomato fruit varieties (Table 5). The lowest marketability percentage was obtained from non-perforated polyethylene plastic (40%) of Woyno tomato fruit Variety followed by both Roma VF and Oval red (60%). When the storage period increase in storage period (18 days) tomato fruits packed only with perforated polyethylene plastic (20%) from both Roma VF and Woyno tomato fruit varieties followed by Oval red tomato fruit varieties using open carton packaging materials (6.67%).

The difference in marketability of tomato fruits was due to packaging materials, varieties of tomato fruits, and also percentage of decayed fruits and disease incidence obtained from non-perforated polyethylene bags. The present result is in line with the study of Haile and Safawo (2018) who reported that, packaging of climacteric fruits in low density polyethylene bags delay ripening and softening, and hence improves marketability. These beneficial effects can be explained by the modified atmosphere created inside the package as well as the reduction in water loss. Lower respiration and ethylene production rates, due to modification of atmospheric gases inside the package could be the possible reason to extend the storage life of fruits (Islam *et al.*, 2022).

4. Conclusions

Tomatoes are prone to careless handling and packaging throughout local manufacturing. As a result, there is a significant postharvest loss of tomato fruits at every stage, from harvest to consumption. The fruit must therefore be handled properly after harvest in order to improve its protection and shelf life. With this context in mind, the goal of this study was to evaluate the impact of packaging material on the quality and shelf life of tomato fruit varieties after harvest.

The physiological weight loss, percentage of decay, color score, general acceptability, TSS, pH, incidence of disease, variety, marketability, and shelf life of tomato fruits were all significantly influenced by packaging. Due to a faster respiration rate, the control had the greatest weight reduction. On perforated plastic, the weight reduction was accompanied by an accelerated water loss. Perforated plastic showed the highest marketability and degradation percentage. The Woyno variety under non perforated plastic had the highest illness incidence and the highest juice content (93.37%) of any type of plastic. Roma VF variety beneath perforated plastic had the highest TSS. When employing perforated plastic, followed by open cartons and hardwood boxes, the storage term for tomato fruit was significantly lengthened.

Under perforated plastic, the tomato variety with a longer shelf life was both Roma VF and Oval red. According to the findings of this study, tomato fruits packaged in low density polyethylene bags with perforations had a longer shelf life and better quality. However, a follow-up study in multiple locations and across seasons is necessary to substantiate this advice. There should be further research done using package types and materials that are not covered in this study.

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