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Impacts of harvesting stages and pre-storage treatments on shelf life and quality of tomato (Solanum lycopersicum L.)

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Abstract: Post-harvest loss is the greatest impediment, which reduces tomato (Solanum lycopersicum L.) production in many developing countries, including Ethiopia. A research was carried out to evaluate the effect of harvesting stages and pre-storage treatments on fruit quality and shelf life of tomato, variety Roma VF. The experiment comprised three levels of harvesting stages (mature green, turning and light red) and eight levels of pre-storage treatments, viz., 500 ppm sodium hypochlorite (NaClO), 8% calcium chloride (CaCl₂), 50% cactus mucilage (CM), 500 ppm NaClO+8% CaCl₂, 500 ppm NaClO+50% CM, 8% CaCl₂ + 50% CM and 500 ppm NaClO+8% CaCl₂ + 50% CM. Treatments laid out in 3×8 factorial arrangements in a completely randomized design with three replications. Tomato fruits were stored for about 20 days at ambient temperatures, placed on fixed tables. Quality attributes and shelf life parameters were collected at four-day interval during 20 days of storage. The results showed that harvesting stages and pre-storage treatments indicated highly significant (p ≤ 0.01) impacts on quality and shelf life of tomato fruits. Fruits harvested at mature green stage and coated with 50% cactus mucilage significantly retained low percentage of decay (41.67%), highest marketable fruit (50%), low pH (4.25) and highest ascorbic acid (13.4 mg/100 g) during the storage.
period and it increased the shelf life the fruits by about 10 days as compared to the control. From the results of the study, harvesting tomatoes at mature green stages and coating them with 50% cactus mucilage can be recommended for increasing the shelf life and quality of the tomato fruits.

**Subjects: Agriculture & Environmental Sciences; Biochemistry; Food Chemistry**

**Keywords: Cactus mucilage; harvesting stage; pre-harvest treatments; quality; tomato shelf life**

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important, nutritious and widely grown vegetables in the world (Dragan et al., 2010). It is considered as an important cash-generating crop for smallholders and medium-scale commercial farmers providing employment opportunity in the production and processing industries in Ethiopia (Central Statistics Agency [CSA], 2016; Teka, 2013; Tola, 2014). Farmers are interested more in tomato production than other vegetables for its multiple harvests, high profitability and its potential to improve income and nutrition of household (Awas et al., 2010; Tola, 2014). Teka (2013) stated that high nutritional and economical values of tomato and its potential health benefits have drawn an increased interest in tomato-based products among consumers. Thus, the use of tomato in the modern human diet is so extensive that it is almost impossible to dissociate it from the menus of fast foods and pizza (Silva et al., 2008; Tan et al., 2013).

In Ethiopian more than 25 open-pollinated tomato varieties have been released, among them Melkaslasa, Melkashola, ‘Mar globe, Bishola, Feten, Eshet and Metadel released nationally and recommended by the Melkassa Agricultural Research Center for commercial production and small-scale farming systems in Ethiopia (Dessalegn, 2002). Roma VF, open-pollinated variety introduced and under production for the last 30 years in Ethiopia and considered as standard tomato variety. Many hybrid tomato varieties have been introduced by private seed companies to test for its suitability to Ethiopian conditions and more than 20 hybrids verified and they are under production. Among them Awassa, Awash River, Barnum, Briget 40, Eden, Galilea, Momtanz, Monica, Shanty, Tesha, Venise (Binalfew et al., 2016).

Even though tomato has numerous benefits, post-harvest loss is hampering its production and, as a result, many growers in developing countries have not become beneficiaries as anticipated (Arah et al., 2015). Azene et al. (2011) and Emana et al. (2017) claim that post-harvest losses could discourage farmers from venturing into production, thereby resulting in reduction in the quantity, quality and market value of produces. It is estimated that about 20 to 50% of harvested tomato is lost during harvesting, transportation, storage and before they reach consumers (Pila et al., 2010). The magnitude of tomato post-harvest losses in many African countries, like Ethiopia, is eventually very high and hard to estimate (Emana et al., 2017; Woldemichael & Demelash, 2014).

The main causes of crop post-harvest losses include inappropriate agronomic practices, mechanical damage, inappropriate harvesting stage, absence of pre-storage treatments, poor post-harvest handling practices, physiological deterioration, poor packaging and lack of appropriate storage facilities (Emana et al., 2017; Mujtaba & Masud, 2014). The greatest hurdle in post-harvest industry is physiological deterioration, a consequence of oxidation reaction, such as degradation, enzymatic browning, and oxidative rancidity and lack of appropriate pre-storage treatments that can minimize it (Eca et al., 2014).

Maturity at harvest can influence the postharvest fruit quality such as fruit taste, firmness and shelf-life which, in turn, can adversely affect tomato quality. The maturity stage of tomato fruit at harvest is an important determinant of many quality traits (Beckles, 2012). Tomato, being a climacteric fruit, can be harvested at different stages during maturity, like mature green, half ripen, or red ripen stage (Moneruzzaman et al., 2009). The physiological maturity stages in the
tomato fruit are described as mature green, breaker, turning, pink or light red, and red (Cantwell, 2010). Harvesting stage is one of the most important factors that affect the quality of fresh market and processed tomato (Teka, 2013). It determines post-harvest quality attributes of tomato fruit such as soluble solid, sugar, acidity, pH color and firmness etc. (Teka, 2013). It also governs the nutrient contents as well as storage life and final fruit quality of tomato fruit.

Inappropriate harvesting stage is the primary factor that causes great losses of tomato in many developing countries (Moneruzzaman et al., 2009). Tomato growers in most African countries harvest tomatoes when they are partially or fully ripened. Fully ripened tomatoes are susceptible to injuries during harvesting resulting in shorter shelf life. Fruits picked either too early or too late in their season are more susceptible to post-harvest physiological disorders, less storage durability, less sugar and total soluble solids content than fruits picked at the proper maturity (Cantwell, 2010; Moneruzzaman et al., 2008). Immature fruits are more subject to shriveling and mechanical damage, and are of inferior flavor quality (Genanew, 2013). Moneruzzaman et al. (2009) reported that tomato fruits harvested at immature green undergo serious losses due to their highly perishable nature. On the other hand, over-ripe fruits are likely to become soft and mealy with insipid flavor soon after harvest since they produce ethylene which can adversely affect the biochemical characteristics of the fruits (Hamdu et al., 2016). Besides, harvesting over-matured tomato fruits let them to be susceptible to mechanical injuries with a shorter shelf life (Arah et al., 2015). In spite of this fact, optimum harvesting stage of tomato fruit has not been determined in many developing countries (Moneruzzaman et al., 2009; Teka, 2013).

Increasing merely the productivity of crops has no more values than the customary production unless the post-harvest loss of produces is reduced (Wu & AARDO, 2010). Thus, minimizing post-harvest losses and quality deterioration of tomato fruits is the major goal that should be alleviated, especially in developing countries to ensure food security, economic growth and welfare of the society (Kasso & Bekele, 2016; Pila et al., 2010). Extending the shelf life of tomato fruits is of paramount importance for domestic and export markets. Profit could be maximized if increased production is accompanied by the holistic approach of integrated post-harvest handling practices applied to minimize the post-harvest losses and enhance the shelf life (Mujtaba & Masud, 2014).

Many techniques have been developed to minimize the postharvest losses and to extend the shelf life of tomato fruits. For instance, sodium hypochlorite (NaOCl) solution or chlorox has been used for surface disinfection in many fruits, including tomato fruits to reduce the incidence of fungal infection before any post-harvest treatment is applied (Arah et al., 2016; Genanew, 2013). It has also been found that calcium chloride (CaCl₂) delays ripening and senescence, reduces respiration, extends shelf life, maintains firmness, and reduces physiological disorders of many fruits and vegetables, including tomato fruits (Arah et al., 2016). Moreover, Olivas et al. (2008) and Romanazzi et al. (2016) indicated that use of edible coatings, such as cactus mucilage, which is an environment-friendly and safe to human health, is an alternative pre-storage treatment.

Each technique can be advantageous for certain application but also has limitation. For this reason, Pinheiro et al. (2013) suggested the use of different pre-storage treatments in combination for additive or even synergetic antimicrobial effects, with very good results in maintaining nutritive properties of tomato too. However, the effectiveness of these pre-storage treatments alone or in combination with each other in maintaining quality and extending shelf life of tomato has not been evaluated and proved. Furthermore, the physiological and biochemical responses of tomato fruits of different physiological maturity stages have not been assessed in association with these pre-storage treatments. In view of this, determination of optimum harvesting stage and pre-storage treatments plays a key role in maintaining quality, longer marketability and long shelf life. Therefore, this study was carried out to evaluate the impacts of harvesting stages and pre-storage treatments of tomato fruits on the quality and shelf life of Roma VF variety.
2. Materials and methods

2.1. Description of the study area
Tomato was grown at Dire Dawa Tony Farm, Haramaya University research field, located at 9°6′N, 41°8′E and at an altitude of 1197 m above sea level in Eastern Ethiopia. The area enjoys a bi-modal type of rainfall that extends from March to May and July to September for the small and main rainy seasons, respectively. The aggregate average annual rainfall that the area gets from these two seasons is about 516 mm (Tesfu et al., 2017). The monthly mean maximum and minimum temperature of the area ranges from 35.0°C in June to 14.9°C in December, respectively (Tesfu et al., 2017).

The experiment was carried out at Haramaya University main campus, Horticulture Laboratory at ambient temperatures (20–25°C) and relative humidity of 70–90% from 11 October to 5 November 2017. During this period, the storage environment was cool naturally due to seasonal change and considered as winter season to the area. The laboratory area size is wide enough to store the fruits. The laboratory building was constructed from bricks and big glass widow which allowed good aeration into the storage room. The research laboratory is located 9°24′N latitude and 42°01′E longitude at 510 km from Addis Ababa in eastern part of Ethiopia.

2.2. Treatments and experimental design
The experiment comprised two factors: factor-A (maturity stages) and factor-B (pre-storage treatments). Factor-A consisted of three levels, while factor-B comprised eight levels. The levels of factor-A were: mature green (M1), turning (M3) and light red (M5), whereas the levels of factor-B included control (only water washed), surface sterilizing the samples with 500 ppm (5%) sodium hypochlorite (NaClO) solution, dipping the samples in 8% calcium chloride (CaCl₂) solution, coating the samples with 50% (w/v) cactus mucilage (CM), 500 ppm NaClO + 8% CaCl₂, 500 ppm NaClO + 50% CM, 8% CaCl₂ + 50% CM and 500 ppm NaClO + 8% CaCl₂ + 50% CM. The treatments were laid out in 3 × 8 factorial arrangements in a completely randomized design (CRD) with three replications. The treatment combinations and its description is presented in Table 1.

2.3. Cultivation practices of tomato
Roma VF, which is considered as standard tomato variety, having determinate growth habit and globular fruit shape and matures 95 to 100 days (Degefa et al., 2012). It is the most widely used tomato variety in the country. Seedlings were raised on nursery bed having 10 m length and 1 m width at Dire Dawa, Tony farm. The seed beds were prepared and leveled well before sowing the seeds. Furrows were prepared at a distance of 10 cm across the length of the bed, the seeds were sown, and the nursery beds were mulched with straw (EARO, 2004). The beds were watered every day until the seeds germinated fully and twice a week afterwards. Seedlings were transplanted in to the experimental field when seedlings attained 2–3 true leaf stages. The field was ploughed to fine tilth and leveled well before transplanting the seedlings. The field was laid out and seedlings were transplanted on the prepared field in the first week of July 2017. Triple super phosphate as source of phosphorus fertilizer at the rate of 92 kg P₂O₅ ha⁻¹ and nitrogen at the rate of 46 kg ha⁻¹ was applied uniformly to all plots. All agronomic practices such as; weeding, cultivation, supplementary irrigation was applied during the growing season as per the recommendations given to produce the crop. Staking was done to hold the foliage and the fruit off the ground, to allow uniform spray coverage and to make harvesting easier.

2.4. Harvesting, sample collection and preparation
Harvesting was performed manually with care to minimize mechanical injury to fruits by excluding mottled, bruised, diseased, punctured and damaged fruits. The harvested tomato fruits were sorted into three classes: mature green, turning and light red based on their physiological maturity stages and external color by using standard USDA color chart (United States Department of Agriculture (USDA), 1991). Approximately, 80 kg of tomato fruits was collected for each three harvesting stages from which twenty-four samples each containing forty-eight tomato fruits were
Table 1. Treatments and its description on the impacts of harvesting stages and pre-storage treatments on shelf life and quality of tomato

| Treatment Code | Treatment (Trt)                                      | Treatment description                                      |
|----------------|------------------------------------------------------|------------------------------------------------------------|
| T1             | M1+ control (H₂O)                                   | Mature green + only water                                   |
| T2             | M1 + 5% NaClO                                        | Mature green + sodium hypochlorite                          |
| T3             | M1 + 8% CaCl₂                                        | Mature green + calcium chloride                             |
| T4             | M1 + 50% CM                                          | Mature green + cactus mucilage                             |
| T5             | M1 + 5% NaClO + 8% CaCl₂                            | Mature green + sodium hypochlorite + calcium chloride       |
| T6             | M1 + 5% NaClO +50% CM                               | Mature green + sodium hypochlorite + cactus mucilage       |
| T7             | M1 + 8% CaCl₂ + 50% CM                              | Mature green + cactus mucilage                             |
| T8             | M1 + 5% NaClO + 8% CaCl₂ + 50% CM                    | Mature green + sodium hypochlorite + calcium chloride + cactus mucilage |
| T9             | M3 + control (H₂O)                                   | Turing + only water                                         |
| T10            | M3 + 5% NaClO                                        | Turing + sodium hypochlorite                               |
| T11            | M3 + 8% CaCl₂                                        | Turing + calcium chloride                                  |
| T12            | M3 + 50% CM                                          | Turing + cactus mucilage                                   |
| T13            | M3 + 5% NaClO + 8% CaCl₂                             | Turing + sodium hypochlorite + calcium chloride            |
| T14            | M3 + 5% NaClO +50% CM                                | Turing + sodium hypochlorite + cactus mucilage             |
| T15            | M3 + 8% CaCl₂ + 50% CM                               | Turing + calcium chloride + cactus mucilage                |
| T16            | M3 + 5% NaClO + 8% CaCl₂ + 50% CM                    | Turing + sodium hypochlorite + calcium chloride + cactus mucilage |
| T17            | M5 + control (H₂O)                                   | Light red + only water                                     |
| T18            | M5 + 5% NaClO                                        | Light red + sodium hypochlorite                            |
| T19            | M5 + 8% CaCl₂                                        | Light red + calcium chloride                               |
| T20            | M5 + 50% CM                                          | Light red + cactus mucilage                                |
| T21            | M5 + 5% NaClO + 8% CaCl₂                             | Light red + sodium hypochlorite + calcium chloride         |
| T22            | M5 + 5% NaClO +50% CM                                | Light red + sodium hypochlorite + cactus mucilage          |
| T23            | M5 + 8% CaCl₂ + 50% CM                               | Light red + calcium chloride + cactus mucilage             |
| T24            | M5 + 5% NaClO + 8% CaCl₂ + 50% CM                    | Light red + sodium hypochlorite + calcium chloride + cactus mucilage |

taken using simple random sampling method. Totally, seventy-two samples of tomato fruits were prepared for the experiment.

The twenty-four samples of tomato fruits prepared for each three harvesting stages were dipped/treated in the respective pre-storage treatments and air-dried. The treated tomato fruits in each replication were divided into two sub-samples, destructive and non-destructive, each containing twenty-four fruits and placed separately on tables aside to each other within each replication in the laboratory. Bamboo sticks were used to set the samples apart from each other. Data were collected at four-day interval on 0, 4, 8, 12, 16 and 20 days after storage. Data related with physical characteristics of tomato fruits, such percentage of decay and marketability, were recorded from non-destructive sub-sample. But, data related with destructive analysis, such as firmness, pH and
total soluble solids, were collected from destructive sub-samples by taking two fruits randomly on each sampling day. During storage in the laboratory, the air temperatures was ranged from 20 to 25°C with 70 to 90% relative humidity.

2.5. Preparation of chemical solutions and cactus mucilage
The concentration of the pre-storage treatments used in this experiment and their dipping time were set based on the previous findings and recommendations (Oluwaseun et al., 2014b; Pila et al., 2010; Pinheiro et al., 2013; Seyoum et al., 2012). Accordingly, 500 ppm concentration and 10 minutes fruit dipping time was used for NaClO as it was prescribed by Mujtaba and Masud (2014). Similarly, 8% concentration and 10 minutes dipping time were used for CaCl₂ according to the recommendation given by Genanew (2013). This solution was prepared by dissolving 100 grams of solid CaCl₂ in 1 L sterile distilled water. The cactus mucilage was prepared according to method prescribed by Oluwaseun et al. (2014a). First cactus leaves were peeled and cubed. Then, the samples were homogenized in sterile-distilled water. Since cactus mucilage has not been used as pre-storage treatment for tomato so far, 50% (w/v) concentration and 30 seconds dipping time, which was recommended for papaya by Oluwaseun et al. (2014b), was used for tomato in this experiment.

2.6. Physical and subjective quality analyses

2.6.1. Percentage of physiological loss in weight (PLW)
was determined according to the method described by Moneruzzaman et al. (2008). The 24 tomato fruits within each non-destructive sub-sample were weighed periodically at four-day interval using digital balance. The differential weight loss was calculated for each interval day and was converted into percentage as

\[
PLW(\%) = \left(\frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}}\right) \times 100
\]

where; initial weight was the weight taken before imposing treatment and final weight was the weight of fruits recorded on each sampling days.

2.6.2. Percentage of fruit decay (PFD)
PFD was determined by counting the number of tomato fruits rotten and shriveled periodically and expressed in percentage as employed by Tsegay et al. (2013):

\[
PFD(\%) = \left(\frac{\text{No. of decayed fruits}}{\text{Total No. of fruits}}\right) \times 100
\]

2.6.3. Marketable tomato fruit (MTF)
MTF was subjectively assessed based on the method by periodically counting the number tomato fruits, which were firm, free from disease and good in appearance was and expressed in percentage as described by Melkamu et al. (2009), using the following:

\[
MTF(\%) = \left(\frac{\text{No. of marketable tomato fruits}}{\text{Total No. of tomato fruits}}\right) \times 100
\]

2.6.4. Shelf life of fruits
Shelf life of fruits was determined by counting the number of days required to attain the last stage of ripening, but up to the stage when fruits remained still acceptable for marketing as described by Moneruzzaman et al. (2009). It was decided based on the appearance and spoilage of fruits. Note: When 50% of fruits within a sample showed symptoms of shrinkage or spoilage, the sample was considered to have reached end of shelf life.
2.6.5. Fruit firmness
Fruit firmness was measured with automatic digital penetrometer (Model P734) according to method described by Seyoum et al. (2003). Here two tomato fruits were randomly taken from each destructive sub-sample and put on the top of penetrometer table in the center position using centering guide. By using scroll down button, the needle of the penetrometer was scrolled down until it reached the fruit surface. The low voltage illuminator on the table of penetrometer was switched on and the magnifying lens, which was attached to the table of the penetrometer, was used to check whether the penetrometer needle touched the surface of tomato fruit or not. A constant force or load of 50 g was applied for two seconds to puncture tomato fruits. Then the start button was clicked and automatically the needle penetrated in the fruit and the depth of penetration in millimeter was recorded for the two fruits separately and the average of the two was taken as the penetration depth for the samples.

2.7. Chemical analyses
The two tomato fruits, which were punctured during determination of firmness, were taken and sliced. An aliquot of clear juice was prepared using a juice extractor (Type 6001x, USA) and used for all chemical analyses.

2.7.1. The pH value of tomato juice
pH was measured following the procedures described by Association of Official Analytical Chemists (AOAC) (2007) using a Metrohm 691 pH meter.

2.7.2. Total soluble solids (TSS in °Brix)
TSS was determined based on the methods described by Tsegay et al. (2013). A digital hand refractometer (Model: RFM-860, Japan) with lower range (0 to 32 °Brix) and resolutions of 0.2 °Brix was used to determine it by placing a few drops of clear juice on the prism of the refractometer.

2.7.3. Titratable acidity (TA) of tomato pulp
was determined according to the method described by Moneruzzaman et al. (2009). Ten milliliters of tomato pulp was taken from the prepared juice and diluted to 30 mL with sterile-distilled water. The diluted juice was filtered through cheesecloth and 10 mL of the filtrated tomato juice was poured into a conical flask. Then, two drops of 1% phenolphthalein indicator was added and the flask was shaken vigorously. A 50 mL burette was filled with 0.1 N NaOH solution and the solution was titrated into the conical the flask while keeping the flask shaking till a permanent pink color appeared. The volume of NaOH solution used for a titration was recorded and percent titratable acidity was calculated using the following formula (Moneruzzaman et al., 2009):

\[
TA (\%) = \frac{(T \times N \times V \times E)}{(V_2 \times W \times 1000)} \times 100
\]

where: T: Titre, N: normality of NaOH, V1: volume made up, E: milliequivalent wt. of acid, i.e. citric acid in tomato = 0.06404, V2: volume of extract, WS: weight of sample.

2.7.4. Total soluble solids to acid ratio (TSS:AR)
was calculated by dividing the value of total soluble solid (°Brix) to the value of percentage of titratable acidity by employing the method described by Caron et al. (2013).

2.7.5. Ascorbic acid (AA)
was determined according to method described by Pila et al. (2010) using 2,6-dichlorophenol-indophenol visual titration method. An aliquot of 10 mL tomato juice was diluted to 30 mL with 3% metaphosphoric acid and filtered through cheese cloth. From the filtrate, 10 mL of aliquot was titrated with the standard dye to pink end point, which persisted in for about 15 seconds. Thus the ascorbic acid was expressed as:
\[ AA \ (mg \ 100g^{-1}) = \frac{(TxDxV2)}{(V1xWS)} \times 100 \]

where: \( T \): titre, \( D \): dye factor, \( V2 \): volume made up, \( V1 \): volume of aliquot taken for titration and \( WS \): weight of sample taken.

### 2.8. Statistical analysis

The collected data on different parameters were statistically analyzed using the General Linear Model (GLM) of GenStat 16th edition (GenStat, 2016). When ANOVA showed significant differences, mean separation was carried out using Duncan’s Multiple Range Test (DMRT) to compare differences between treatment means at \( p \leq 0.05 \).

### 3. Results and discussion

#### 3.1. Physiological loss in fruit weight (%)

Impacts of harvesting stages and pre-storage treatments on percentage of physiological loss in fruit weight (PLW) of tomato were assessed during storage and depicted (Figure 1). Analysis of variance (ANOVA) revealed that physiological maturity stage, pre-storage treatments and their combinations had highly significant \( (p \leq 0.01) \) effect on percentage of physiological loss on tomato fruit weight. The percentage of physiological weight loss increased progressively with increase in storage duration and with advancement of physiological maturity stages. The minimum and maximum PLW were recorded in tomato fruit samples, which were harvested at light red and mature green stages, respectively, of pre-storage treatments. Similar findings were also reported by Davila-Avina et al. (2011) and Okalie and Sanni (2012). The high percentage of physiological weight losses in mature green tomato fruits are due to high rate of dehydration that generally happens in tender tissues (Moneruzzaman et al., 2008).

However, there was a significant difference in the magnitude of PLW among treatments. The maximum weight loss (62.47%) was recorded in T1 (M1+ water) at 20\textsuperscript{th} days of storage. In a similar manner, the treatments T9 (M3+ water) and T17 (M5+ water) also resulted in high PLW (57.53 and 53.97%, respectively). This phenomenon might be due to the uncontrolled ripening, sudden increase in ethylene production, higher respiration and transpiration rates (Sammi & Masud, 2008).
2007). On the other hand, the lowest physiological weight loss (12.77%) was recorded in the treatment T20 (M5 + 50% CM). Treatment T12 (M3 + 50% CM) and T4 (M1 + 50% CM) also resulted in low PLW (16.33 and 21.37%, respectively) compared to other treatments. On 20th days after storage (DAS), treatment T4 reduced the PLW (21.37%) by three-fold as compared to the treatment T1 with PLW value of 62.47%. This current result is in agreement with the finding of Zegbe et al. (2015) who reported reduction in PLW in guava fruits coated with cactus mucilage. The reduction in PLW in tomato fruits coated with cactus mucilage could be due to its effect as a semipermeable barrier against oxygen, carbon dioxide and moisture, thereby reducing respiration and water loss and counteracting the dehydration and shrinkage of tomato fruits (Petriccione et al., 2015).

Tomato fruits dipped in 8% CaCl₂ and coated with 50% CM (T23, T15 and T7) also slightly reduced the PLW during the storage as compared to other treatments. This indicated the significant role of CaCl₂ as ethylene absorbent to reduce respiration rate (Mujtaba & Masud, 2014). The present result revealed that cactus mucilage alone or in combination with CaCl₂ could be used to minimize PLW, which was directly related the loss of saleable tomatoes.

### 3.2. Fruit decay (%)

There was no visible sign of decay in all tomato fruits until fourth day after storage (Figure 2). However, from the 4th DAS onwards, percentage of fruits decayed (PFD) rapidly increased with progression of storage duration and advancement of maturity stages (highest in light red and lowest in mature green fruit stages). The present findings are in conformity with reports of Ciccarese et al. (2013) and Tsegay et al. (2013) who reported that PFD in fruits harvested at completely ripened stage and stored for longer period was always higher than in fruits harvested at intermediate stages and stored for less storage time. Bayoumi (2008) and Moneruzzaman et al. (2008) also concluded that the higher PFD in late harvesting stage of fruits was due to higher rate of respiration, more skin permeability for water loss and higher susceptibility to infection by decay microorganisms than in early harvested tomato fruits.

The two-way interaction effect of harvesting stages and pre-storage treatments of tomato fruits on PFD was highly significant (p ≤ 0.01). Throughout the entire storage period, the maximum PFD...
(at fourth day from 34.72% at 20th day 97.22%) occurred in the treatment T17 (M5+ water). The treatments T21 (M5 + 5% NaClO + 8% CaCl2) and T18 (M5 + 5% NaClO) also showed high PFD (97.22 and 95.83%), respectively as compared to other tomato fruit treatments. On the contrary, the minimum PFD (41.67% at 20th day) was recorded in the treatment T4 (M1+ CM), followed by T12 (M3+ CM) and T7 (M1+ CaCl2 + CM), with PFD of 54.17 and 62.50%, respectively.

These results are in agreement with the investigations of Oluwaseun et al. (2014a) who reported the reduction of microbial mesophilic population loads on mangoes coated with cactus mucilage. The reduction in PFD in tomato fruits coated with cactus mucilage is probably due to its antimicrobial effect and physical barrier against the entry of decay microorganisms (González-Aguilar et al., 2010; Olivas et al., 2008; Oluwaseun et al., 2014b; Seyoum et al., 2012). Moreover, cactus mucilage has the ability to dispense itself on the surface of the tomato fruits. This mucilage can reduce respiration rate and ethylene production, which, in turn, reduces water loss and shrinkage of the fruits. Inversely, the higher PFD in the control treatments at each harvesting stage was probably due to post-harvest microbial, uncontrolled ripening, higher respiration and transpiration rates (Sammi & Masud, 2007).

Even though the antimicrobial effect of sodium hypochlorite (Chlorox) was reported by many researchers (Arah et al., 2016; Pila et al., 2010), it could not reduce respiration rate and water loss. As a result, the percentage of fruit decay due to shrinkage became high in tomato fruits sterilized with 500 ppm NaClO alone and in combination with 8% CaCl2 at each harvesting stages. However, the combination of 500 ppm NaClO with 50% CM at each harvesting stage, slightly reduced shrinkage and PFD in tomato fruits probably due to cactus mucilage has dispensed itself on the surface of the fruits and reduced the loss of water.

3.3. Marketable fruits (%)
The interaction effect of harvesting stages and pre-storage treatments on percentage of marketable tomato fruits (MTF) are presented hereunder (Figure 3). On the initial day, the whole tomato fruits harvested at green mature, turning and light red stages were 100% marketable. However, from the 4th DAS onwards, percentage of marketable tomato fruits rapidly decreased with progression storage duration and advancement of physiological maturity stages. The decrease in MTF
during the prolonged storage duration could be due to the influence of high respiration rate, fruit senescence, enzymatic degradation of fruit cell wall and decay (Ciccarese et al., 2013; Tsegay et al., 2013).

The two-way interaction effect of harvesting stages and pre-storage treatments on percentage of marketable tomato fruits was highly significant ($p \leq 0.01$). The least 2.77% of marketable tomato fruits was recorded in tomato fruits harvested at light red stage and water washed T17 (M5+ Control) and T21 (M5+ NaClO+CaCl$_2$) and T18 (M5+ NaClO) also resulted in low (4.17%) marketable fruits as compared to other treatments. This is probably due to sodium hypochlorite dipping left a taint on the surface of some tomato samples (Melkamu et al., 2009). On the contrary, the highest (50%) marketable fruits was recorded in T4 (M1 + 50% CM), followed by T12 (M2+ CM) and T7 (M1+ CaCl$_2$ + CM) 37.5 and 33.33%, respectively, at the end of storage time. On 20$^{th}$ DAS, the percentage of MTF harvested at mature green and coated with CM (T4 = 50%) is about 55% higher than the MTF harvested at light red stage and washed with water (T17 = 2.78%). The increase in percentage of MTF coated with cactus mucilage directly correlated with its ability to reduce percentage of decay of tomato fruits by acting as a physical barrier when applied on the surface of fruits for the entry of microorganisms (Oluwaseun et al., 2014a) and its potential in minimizing weight loss (Zegbe et al., 2015).

Although physiological processes, such as ethylene production and respiration, are generally higher in green-matured fruits than in turning and red matured fruits (Wu & AARDO, 2010), tomato fruits harvested at green maturity stage and coated with cactus mucilage showed high marketability and retained better chemical quality than samples harvested at turning and light red maturity stages. Thus this present study revealed that application of CM is convenient in increasing the percentage of MTF.

### 3.4. Firmness (mm/50 g force applied)

The texture of fruits and vegetables is often interpreted in their firmness, crispness, juiciness, and toughness (attributed to the fibrousness of plant tissue), where firm or crispy tissues are generally desired in fresh and minimally processed produces. Texture is an important quality indicator for eating and cooking, and a factor in withstanding shipping stresses (Lin & Zhao, 2007). Impact of harvesting stage and pre-storage treatments on firmness of tomato fruits during storage was depicted hereunder (Table 2). The analysis of variance (ANOVA) revealed that the main effects of harvesting stages and their interaction effects with pre-storage treatments were highly significant ($p \leq 0.01$) on the first day and from the 4$^{th}$ DAS onwards, respectively. The firmness of tomato fruits progressively decreased with increase in storage time. This result is consistent with findings of Lahay et al. (2013) who reported a reduction in firmness of fruits during prolonged storage periods. The decrease in firmness during prolonged period could be due to the influence of high respiration rate, fruit senescence and enzymatic degradation of fruits’ cell wall (Cantwell et al., 2009; Ciccarese et al., 2013).

In addition, the highest firmness (lowest value in depth per 50 g applied) occurred in mature green tomato fruits, while the lowest firmness occurred in light red tomato fruits throughout the entire storage duration. Previously, Teka (2013) found that tomato firmness considerably decreased with fruit physiological maturity stages. The decrease in fruit firmness with advance in maturity stage might be related to the degradation of polysaccharides (Teka, 2013) and cell wall softening due to the activity of softening enzymes, such as pectin methylesterase (Rao et al., 2011). The current research results indicated that the minimum firmness occurred in tomato fruits harvested at light red stage and in water-washed treatment (T17) throughout the entire storage duration. On the contrary, the highest firmness was recorded in tomato fruits harvested at mature green and dipped in CaCl$_2$ (T3) solution. A similar finding by Genanew (2013) indicated the retention of fruit firmness in tomato fruits dipped in calcium chloride.
Table 2. The interaction impacts of harvesting stages and pre-storage treatments on firmness of tomato fruits during storage (depth in mm per 50 g force applied) in 2017

| Trt. Code | Treatment (Trt) | 1<sup>st</sup> day | 4<sup>th</sup> day | 8<sup>th</sup> day | 12<sup>th</sup> day | 16<sup>th</sup> day | 20<sup>th</sup> day |
|-----------|-----------------|-------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| T1        | M1+ Control (H₂O) | 4.69<sup>a</sup> | 5.65<sup>b</sup> | 6.37<sup>f</sup> | 6.62<sup>g</sup> | 6.80<sup>def</sup> | 6.95<sup>de</sup> |
| T2        | M1+ NaClO        | 4.69<sup>a</sup> | 5.56<sup>d</sup> | 6.02<sup>d</sup> | 6.29<sup>def</sup> | 6.59<sup>de</sup> | 6.93<sup>de</sup> |
| T3        | M1+ CaCl₂        | 4.69<sup>a</sup> | 4.75<sup>a</sup> | 5.39<sup>a</sup> | 5.62<sup>ab</sup> | 6.19<sup>a</sup>  | 6.44<sup>a</sup>  |
| T4        | M1+ CM           | 4.69<sup>a</sup> | 4.96<sup>ab</sup> | 5.76<sup>bc</sup> | 6.01<sup>bc</sup> | 6.23<sup>a</sup>  | 6.74<sup>bc</sup> |
| T5        | M1+ NaClO+CaCl₂  | 4.69<sup>a</sup> | 5.42<sup>ac</sup> | 5.88<sup>c</sup> | 6.33<sup>cd</sup> | 6.64<sup>bcd</sup> | 6.85<sup>cd</sup> |
| T6        | M1+ NaClO+CM     | 4.69<sup>a</sup> | 5.31<sup>d</sup> | 5.85<sup>c</sup> | 6.14<sup>cd</sup> | 6.53<sup>b</sup>  | 6.86<sup>cd</sup> |
| T7        | M1+ CaCl₂+CM     | 4.69<sup>a</sup> | 4.86<sup>bc</sup> | 5.64<sup>b</sup> | 5.89<sup>b</sup>  | 6.26<sup>a</sup>  | 6.69<sup>b</sup>  |
| T8        | M1+ NaClO+CaCl₂ + CM | 4.69<sup>a</sup> | 5.03<sup>c</sup> | 5.82<sup>c</sup> | 6.13<sup>cd</sup> | 6.32<sup>a</sup>  | 6.72<sup>b</sup>  |
| T9        | M3+ Control (H₂O) | 5.42<sup>b</sup> | 6.43<sup>kn</sup> | 6.71<sup>jk</sup> | 6.99<sup>h</sup>  | 7.16<sup>ij</sup> | 7.33<sup>km</sup> |
| T10       | M3+ NaClO        | 5.42<sup>b</sup> | 6.31<sup>hl</sup> | 6.53<sup>p</sup>  | 6.72<sup>ij</sup> | 6.91<sup>km</sup> | 7.18<sup>km</sup> |
| T11       | M3+ CaCl₂        | 5.42<sup>b</sup> | 5.73<sup>g</sup>  | 6.02<sup>d</sup>  | 6.17<sup>cde</sup> | 6.25<sup>a</sup>  | 6.53<sup>g</sup>  |
| T12       | M3+ CM           | 5.42<sup>b</sup> | 5.98<sup>i</sup>  | 6.23<sup>e</sup>  | 6.29<sup>de</sup> | 6.61<sup>k</sup>  | 6.86<sup>cd</sup> |
| T13       | M3+ NaClO+CaCl₂  | 5.42<sup>b</sup> | 6.19<sup>s</sup>  | 6.47<sup>bd</sup> | 6.59<sup>g</sup>  | 6.80<sup>def</sup> | 7.14<sup>g</sup>  |
| T14       | M3+ NaClO+CM     | 5.42<sup>b</sup> | 6.13<sup>h</sup>  | 6.39<sup>f</sup>  | 6.44<sup>g</sup>  | 6.73<sup>cde</sup> | 7.07<sup>e</sup>  |
| T15       | M3+ CaCl₂+CM     | 5.42<sup>b</sup> | 5.92<sup>n</sup>  | 6.17<sup>e</sup>  | 6.30<sup>def</sup> | 6.58<sup>bc</sup> | 6.76<sup>bc</sup> |
| T16       | M3+ NaClO+CaCl₂ + CM | 5.42<sup>b</sup> | 6.05<sup>kl</sup> | 6.35<sup>f</sup>  | 6.38<sup>de</sup> | 6.59<sup>bc</sup> | 6.90<sup>bc</sup> |
| T17       | M5+ Control (H₂O) | 6.31<sup>c</sup> | 6.80<sup>h</sup>  | 6.94<sup>g</sup>  | 7.19<sup>h</sup>  | 7.36<sup>b</sup>  | 7.46<sup>ij</sup> |
| T18       | M5+ NaClO        | 6.31<sup>c</sup> | 6.73<sup>h</sup>  | 6.89<sup>g</sup>  | 7.13<sup>h</sup>  | 7.20<sup>j</sup>  | 7.37<sup>h</sup>  |
| T19       | M5+ CaCl₂        | 6.31<sup>c</sup> | 6.30<sup>ab</sup> | 6.36<sup>f</sup>  | 6.60<sup>g</sup>  | 6.70<sup>bc</sup> | 6.92<sup>d</sup>  |
| T20       | M5+ CM           | 6.31<sup>c</sup> | 6.40<sup>kn</sup> | 6.65<sup>n</sup>  | 6.76<sup>ij</sup> | 6.97<sup>np</sup> | 6.97<sup>dp</sup> |
| T21       | M5+ NaClO+CaCl₂  | 6.31<sup>c</sup> | 6.50<sup>ik</sup> | 6.86<sup>ij</sup> | 7.01<sup>h</sup>  | 7.08<sup>ij</sup> | 7.30<sup>ij</sup> |
| T22       | M5+ NaClO+CM     | 6.31<sup>c</sup> | 6.44<sup>kn</sup> | 6.72<sup>f</sup>  | 6.91<sup>f</sup>  | 7.09<sup>f</sup>  | 7.31<sup>f</sup>  |

(Continued)
Table 2. (Continued)

| Trt. Code | Treatment (Trt) | Days After Storage (DAS) |   |   |   |   |
|-----------|-----------------|-------------------------|---|---|---|---|
|           |                 | 1<sup>st</sup> day      | 4<sup>th</sup> day   | 8<sup>th</sup> day | 12<sup>th</sup> day | 16<sup>th</sup> day | 20<sup>th</sup> day |
| T23       | M5+ CaCl<sub>2</sub> + CM | 6.31<sup>c</sup>       | 6.40<sup>**</sup> | 6.60<sup>**</sup> | 6.77<sup>**</sup> | 6.88<sup>**</sup> | 6.95<sup>**</sup> |
| T24       | M5+ NaClO+CaCl<sub>2</sub> + CM | 6.31<sup>c</sup>       | 6.39<sup>**</sup> | 6.69<sup>**</sup> | 6.86<sup>**</sup> | 7.00<sup>**</sup> | 7.20<sup>**</sup> |

Significance: HS**: highly significant (p ≤ 0.01); M1: mature green; M3: half ripen (turning); M5: light red stage; CM: Cactus mucilage, SE: Standard error; CV (%): Percentage of coefficient of variance; HS: Harvesting stages.

Means with the same letters in a column are not significantly different at 1% level of significance according to DMRT.
The retention in firmness of tomato fruit samples, which were treated with calcium chloride, was due probably to the fact that calcium plays an important role in maintaining the cell wall integrity by increasing the amount of endogenous calcium available to bind with de-esterified pectic residues (Husain et al., 2012). Likewise, CM with CaCl₂ also significantly maintained the firmness of tomato fruits throughout the storage period. This present result is in agreement with the findings of Oluwaseun et al. (2014b) who observed retention of flesh firmness of papaya fruit achieved by Opuntia cactus mucilage coatings.

3.5. pH of tomato juice
Effect of harvesting stage and pre-storage treatments on pH of tomato fruit pulp is illustrated hereunder (Table 3). The analysis of variance revealed that the main effects of harvesting stages and their interaction effects with pre-storage treatments were highly significant (p ≤ 0.01). The pH value of tomato pulp progressively increased with increase in storage time. The current result agrees with the findings of Melkamu et al. (2009) who reported an increase in the pH value of tomato fruits 3.8 at harvest to 5.0 at the full ripe stage during storage period. Moreover, the pH values of tomato fruits varied significantly among different fruit maturity stages. The minimum 4.25 and maximum 4.65 pH values were recorded in mature green and light red tomato fruit samples, respectively at 20 days of storage. Similar results were reported by Borji and Jafarpour (2012) who reported that the pH of tomato fruit increased with increase in maturity stages from mature green to full ripe stages. The increase in pH values with increase the pronged storage duration and with ripening stages was probably due to the degradation or respiration of organic acids into sugars (Mujtaba & Masud, 2014).

The present research results indicated that the minimum (4.25 pH) value was recorded in tomato fruits harvested at mature green and coated with cactus mucilage (T4). Likewise, the treatment T7 (M1+ CaCl₂ + CM) and T3 (M1+ CaCl₂) also resulted in low pH (4.29 and 4.33), respectively. On the contrary, the maximum 4.65 pH value was recorded in tomato fruits harvested at light red stage and water washed T17 (M5+ Control). Similarly, the treatments T18 (M5+ NaClO) and T9 (M3+ Control) also resulted in high pH (4.60 and 4.56, respectively) at 20 days of storage period. Anthon et al. (2011) suggested that pH value of fresh tomato fruit, which ranged from 4.25 to 4.4 is optimum and desirable to ensure food safety. Teka (2013) further stated that tomato fruits, which have pH values higher than 4.4 are not suitable for processing since the pulp is susceptible to thermophilic pathogens. This shows that pH values as low as possible (up to the point that it does not adversely affect taste) are desirable for industrial use.

From the present result, cactus mucilage significantly maintained the pH of tomato fruit to optimum level even during the late storage duration as compared to the other treatments. A similar result was obtained by Oluwaseun et al. (2014b) who reported low pH value maintained in papaya fruit coated with cactus mucilage due to the semi-permeable mucilage film formed on the surface of the fruit, which might modify the internal atmosphere, i.e., endogenous CO₂ and O₂ concentrations of the fruit, thus retarding ripening. Moreover, the pre-storage application of calcium chloride alone or in combination with cactus mucilage also reduced the pH value of tomato and this result is consistent with the findings of Mujtaba and Masud (2014) who reported the pre-storage application of CaCl₂ reduced the pH of tomato fruits during their storage.

3.6. Total soluble solids (°Brix)
Effect of harvesting stages and pre-storage treatments on total soluble solids (TSS) of tomato pulp during storage tabulated hereunder (Figure 4). The variance of analysis revealed that the main effects of harvesting stages showed significant (p ≤ 0.05) effect on TSS on the first day before pre-storage treatments were applied. However, from the 4th DAS and onwards, the interaction effects of harvesting stages with pre-storage treatments were highly significant (p ≤ 0.01). There was an increase in the TSS value of tomato pulp progressively during the first 12 days after storage and sharply dropped thereafter. In addition, the TSS of tomato fruit pulp progressively increased with increase in harvesting stages; the highest 5.97 TSS (°Brix) occurred in light red and water washed
Table 3. The interaction impacts of harvesting stages and pre-storage treatments on pH values of tomato fruits during 20 days storage period

| Trt. Code | Treatment (Trt) | 1<sup>st</sup> day | 4<sup>th</sup> day | 8<sup>th</sup> day | 12<sup>th</sup> day | 16<sup>th</sup> day | 20<sup>th</sup> day |
|-----------|-----------------|--------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| T1        | M1+ Control (H₂O) | 3.117<sup>a</sup> | 3.233<sup>a</sup> | 4.153<sup>l</sup> | 4.193<sup>j</sup> | 4.303<sup>j</sup> | 4.450<sup>i</sup> |
| T2        | M1+ NaClO       | 3.117<sup>a</sup> | 3.220<sup>b</sup> | 4.080<sup>j</sup> | 4.160<sup>j</sup> | 4.290<sup>k</sup> | 4.430<sup>k</sup> |
| T3        | M1+ CaCl₂       | 3.117<sup>a</sup> | 3.150<sup>c</sup> | 4.000<sup>c</sup> | 4.100<sup>c</sup> | 4.207<sup>c</sup> | 4.330<sup>c</sup> |
| T4        | M1+ CM          | 3.117<sup>a</sup> | 3.133<sup>c</sup> | 3.893<sup>a</sup> | 4.053<sup>d</sup> | 4.150<sup>a</sup> | 4.250<sup>g</sup> |
| T5        | M1+ NaClO+CaCl₂ | 3.117<sup>a</sup> | 3.210<sup>d</sup> | 4.060<sup>j</sup> | 4.160<sup>f</sup> | 4.260<sup>j</sup> | 4.390<sup>j</sup> |
| T6        | M1+ NaClO+CM    | 3.117<sup>a</sup> | 3.200<sup>c</sup> | 4.020<sup>a</sup> | 4.120<sup>d</sup> | 4.250<sup>f</sup> | 4.350<sup>i</sup> |
| T7        | M1+ CaCl₂+CM    | 3.117<sup>a</sup> | 3.140<sup>c</sup> | 3.953<sup>b</sup> | 4.090<sup>d</sup> | 4.180<sup>b</sup> | 4.290<sup>j</sup> |
| T8        | M1+ NaClO+CaCl₂ + CM | 3.117<sup>a</sup> | 3.153<sup>d</sup> | 4.010<sup>d</sup> | 4.110<sup>d</sup> | 4.223<sup>d</sup> | 4.340<sup>g</sup> |
| T9        | M3+ Control (H₂O) | 3.133<sup>c</sup> | 3.323<sup>m</sup> | 4.253<sup>q</sup> | 4.353<sup>i</sup> | 4.447<sup>r</sup> | 4.560<sup>n</sup> |
| T10       | M3+ NaClO       | 3.133<sup>c</sup> | 3.280<sup>i</sup> | 4.210<sup>c</sup> | 4.323<sup>j</sup> | 4.410<sup>p</sup> | 4.520<sup>c</sup> |
| T11       | M3+ CaCl₂       | 3.133<sup>c</sup> | 3.170<sup>c</sup> | 4.070<sup>n</sup> | 4.200<sup>c</sup> | 4.323<sup>k</sup> | 4.390<sup>c</sup> |
| T12       | M3+ CM          | 3.133<sup>c</sup> | 3.150<sup>c</sup> | 3.947<sup>b</sup> | 4.160<sup>j</sup> | 4.233<sup>g</sup> | 4.320<sup>c</sup> |
| T13       | M3+ NaClO+CaCl₂ | 3.133<sup>c</sup> | 3.260<sup>b</sup> | 4.200<sup>n</sup> | 4.287<sup>g</sup> | 4.380<sup>c</sup> | 4.480<sup>c</sup> |
| T14       | M3+ NaClO+CM    | 3.133<sup>c</sup> | 3.243<sup>j</sup> | 4.147<sup>i</sup> | 4.267<sup>m</sup> | 4.370<sup>n</sup> | 4.460<sup>n</sup> |
| T15       | M3+ CaCl₂+CM    | 3.133<sup>c</sup> | 3.157<sup>c</sup> | 4.040<sup>f</sup> | 4.177<sup>j</sup> | 4.260<sup>f</sup> | 4.370<sup>n</sup> |
| T16       | M3+ NaClO+CaCl₂ + CM | 3.133<sup>c</sup> | 3.190<sup>c</sup> | 4.110<sup>j</sup> | 4.210<sup>j</sup> | 4.340<sup>j</sup> | 4.427<sup>k</sup> |
| T17       | M5+ Control (H₂O) | 3.193<sup>c</sup> | 3.397<sup>r</sup> | 4.313<sup>r</sup> | 4.387<sup>s</sup> | 4.457<sup>s</sup> | 4.653<sup>r</sup> |
| T18       | M5+ NaClO       | 3.193<sup>c</sup> | 3.383<sup>n</sup> | 4.257<sup>q</sup> | 4.363<sup>j</sup> | 4.427<sup>q</sup> | 4.603<sup>n</sup> |
| T19       | M5+ CaCl₂       | 3.193<sup>c</sup> | 3.240<sup>i</sup> | 4.130<sup>k</sup> | 4.260<sup>n</sup> | 4.337<sup>i</sup> | 4.420<sup>j</sup> |
| T20       | M5+ CM          | 3.193<sup>c</sup> | 3.210<sup<f</sup> | 4.087<sup>n</sup> | 4.223<sup>k</sup> | 4.273<sup>h</sup> | 4.360<sup>j</sup> |
| T21       | M5+ NaClO+CaCl₂ | 3.193<sup>c</sup> | 3.320<sup>m</sup> | 4.230<sup>p</sup> | 4.330<sup>n</sup> | 4.390<sup>j</sup> | 4.560<sup>n</sup> |
| T22       | M5+ NaClO+CM    | 3.193<sup>c</sup> | 3.273<sup>i</sup> | 4.177<sup>m</sup> | 4.303<sup>n</sup> | 4.383<sup>s</sup> | 4.480<sup>n</sup> |

(Continued)
| Trt. Code | Treatment (Trt) | Days after Storage (DAS) |
|-----------|-----------------|--------------------------|
|           |                 | 1<sup>st</sup> day | 4<sup>th</sup> day | 8<sup>th</sup> day | 12<sup>th</sup> day | 16<sup>th</sup> day | 20<sup>th</sup> day |
| T23       | M5+ CaCl<sub>2</sub>+ CM | 3.193<sup>c</sup> | 3.227<sup>j</sup> | 4.117<sup>j</sup> | 4.250<sup>i</sup> | 4.297<sup>g</sup> | 4.390<sup>i</sup> |
| T24       | M5+ NaClO+CaCl<sub>2</sub>+ CM | 3.193<sup>c</sup> | 3.260<sup>k</sup> | 4.150<sup>l</sup> | 4.283<sup>n</sup> | 4.350<sup>m</sup> | 4.450<sup>l</sup> |
| Significance |                  | HS**                    | **                       | **                       | **                       | **                       | **                       |
| SE (±)    |                  | 0.05                    | 0.02                     | 0.03                     | 0.03                     | 0.02                     | 0.02                     |
| CV (%)    |                  | 2.5                     | 0.9                      | 1.1                      | 1.0                      | 0.8                      | 0.8                      |

Means with the same letters in a column are not significantly different at 1% level of significance according to DMRT; **: highly significant (p ≤ 0.01); M1: mature green; M3: half ripen (turning); M5: light red stage; CM: Cactus mucilage, SE: Standard error; CV (%): Percentage of coefficient of variance; HS: Harvesting stages.
treatment T17 (M5+ Control), whereas the lowest 4.93 TSS (°Brix) value was recorded in tomato fruits harvested at mature green stage, T4 (M1+ CM) at final storage time. Many studies have also shown that the total soluble solids increased during ripening as a result of degradation of polysaccharides to simple sugars (Kamol et al., 2014; Majidi et al., 2011; Okalie & Sanni, 2012).

A similar finding was recorded by Petriccione et al. (2015) who reported low increase in TSS values for strawberry fruit coated with chitosan; and this finding might reflect changes in the internal atmosphere of the fruit, with a reduction in the O₂ level and/or an increase in the CO₂ level, which reduced the respiration rates and metabolic activities, such as the conversion of sugars into CO₂ and H₂O. Moreover, the pre-storage application of calcium chloride alone or in combination with cactus mucilage (T3 and T7) also reduced the TSS value of tomato and this result is consistent with the findings of Pila et al. (2010) who reported that the pre-storage application of calcium chloride on tomato fruits reduced the TSS value of the fruits during their storage probably due to slowing down of respiration and metabolic activity hence retardant the ripening process.

### 3.7. Titratable acidity (%)

Impacts of harvesting stages and pre-storage treatments on total titratable acidity (TA) of tomato fruit pulp during storage is depicted in tabular form below (Figure 5). The analysis of variance revealed that the main effects of harvesting stages showed significant (p ≤ 0.05) effect on TA on the first day before pre-storage treatments were applied. However, from the 4th DAS onwards, the interaction effects of harvesting stages with pre-storage treatments were highly significant (p ≤ 0.01). There was a decreasing trend in the TA values of tomato pulp progressively with increase in storage time. In addition, the TA of tomato fruit pulp progressively decreased with increase in the harvesting stages, i.e. the highest 0.62% in mature green stage tomato and the lowest 0.19% in tomato fruits harvested at light red stages. The reduction of titratable acidity with prolonged storage duration and with advancement of maturity stages as fruit ripens is due to the metabolic activities of living tissues that take place and further oxidation of organic acids to sugar (Genanew, 2013). Bhattarai and Gautam (2006) also stated that the fruit itself might utilize the acids so that the acid in the fruits storage periods decreases.

The result of the present study indicated that all the treatments and their interactions caused highly significant (p ≤ 0.01) differences in the percentage of titratable acidity of tomato fruits from
Figure 5. The interaction impacts of harvesting stages and pre-storage treatments on TA (%) of tomatoes during storage in 2017.

Each other. The minimum 0.19% TA value was observed in tomato fruits harvested at light red and dipped in water treatment T17 (M5+ Control) followed by fruits samples harvested at light red and surface-sterilized by NaClO (T18), which was 0.24% TA. Tomato fruit samples, which were harvested at turning stage and dipped in water (M3+ Control) (T9) also increased to 0.28% TA value. On the contrary, the maximum 0.62% TA value was recorded in tomato fruits, which were harvested at mature green and coated with cactus mucilage (T4).

Titratable acidity (TA) estimates the organic acid contents of flesh fruits and it is one of the most important organoleptic quality factors for most fruits (Petriccione et al., 2015). Genanew (2013) suggested that extreme reduction in TA content as fruit ripens reduces the desirable quality of fruits and measures that minimize the rapid loss should be emphasized. From the present result, harvesting tomato fruits at mature green and coating them with cactus mucilage significantly minimized the rapid loss of titratable acidity in tomatoes throughout the storage duration.

A similar finding was reported by Petriccione et al. (2015) who observed low increase in TA values for strawberry fruit coated with chitosan, exhibit film-forming properties on fruit surface and used as protective barriers to reduce respiration and transpiration rates.

3.8. Total soluble solids to titratable acidity ratio
Statistical data analysis revealed that the main effects of harvesting stages showed highly significant (p ≤ 0.01) effect on total soluble solids to titratable acidity (TSS to TA) ratio on the first day before pre-storage treatments were applied. However, from the 4th DAS and onwards, the interaction effect of harvesting stages with pre-storage treatments were highly significant (p ≤ 0.01). Total soluble solids to titratable acidity ratio increased progressively with increase in storage time and with increase in ripening stages of tomato fruits (Table 4). On the first day, the lowest (5.04) and highest (6.42) TSS to TA ratio was observed in tomato fruits harvested at mature green and light red stages, respectively. The increase in TSS to TA ratio with prolonged storage duration and with increase in maturity stages as fruits ripen is due to the increase in sugar contents and reduction of acid contents of the fruits (Genanew, 2013; Sammi & Masud, 2007).

The current results of the present study indicated that all the treatments and their interactions caused highly significant (p ≤ 0.01) differences on the TSS to TA ratio of tomato fruit pulp. The
Table 4. The interaction impacts of harvesting stages and pre-storage treatments on TSS to TA ratio of tomatoes during storage in 2017

| Trt. Code | Treatment(Trt) | 1<sup>st</sup> day | 4<sup>th</sup> day | 8<sup>th</sup> day | 12<sup>th</sup> day | 16<sup>th</sup> day | 20<sup>th</sup> day |
|-----------|----------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| T1        | M1+ Control (H₂O) | 5.04<sup>a</sup> | 9.75<sup>m</sup> | 11.39<sup>b</sup> | 15.71<sup>h</sup> | 15.04<sup>h</sup> | 18.28<sup>l</sup> |
| T2        | M1+ NaClO       | 5.04<sup>a</sup> | 9.11<sup>j</sup> | 10.52<sup>j</sup> | 14.89<sup>j</sup> | 14.15<sup>j</sup> | 16.80<sup>j</sup> |
| T3        | M1+ CaCl₂       | 5.04<sup>a</sup> | 6.51<sup>cd</sup> | 7.16<sup>bcd</sup> | 9.10<sup>bc</sup> | 9.00<sup>p</sup> | 11.01<sup>c</sup> |
| T4        | M1+ CM          | 5.04<sup>a</sup> | 5.38<sup>a</sup> | 5.84<sup>a</sup> | 7.20<sup>a</sup> | 7.08<sup>a</sup> | 7.96<sup>a</sup> |
| T5        | M1+ NaClO+CaCl₂ | 5.04<sup>a</sup> | 7.86<sup>j</sup> | 9.81<sup>bc</sup> | 13.42<sup>j</sup> | 13.26<sup>j</sup> | 15.29<sup>j</sup> |
| T6        | M1+ NaClO+CM    | 5.04<sup>a</sup> | 7.11<sup>bc</sup> | 7.85<sup>cd</sup> | 12.22<sup>ef</sup> | 12.24<sup>e</sup> | 13.59<sup>ef</sup> |
| T7        | M1+ CaCl₂+CM    | 5.04<sup>a</sup> | 5.38<sup>ab</sup> | 6.44<sup>ab</sup> | 8.46<sup>bc</sup> | 8.46<sup>bc</sup> | 10.49<sup>c</sup> |
| T8        | M1+ NaClO+CaCl₂+CM | 5.04<sup>a</sup> | 6.76<sup>bcd</sup> | 7.64<sup>cd</sup> | 11.00<sup>de</sup> | 10.51<sup>c</sup> | 12.68<sup>d</sup> |
| T9        | M3+ Control (H₂O) | 5.69<sup>b</sup> | 11.18<sup>o</sup> | 15.65<sup>l</sup> | 19.31<sup>k</sup> | 18.89<sup>l</sup> | 21.23<sup>k</sup> |
| T10       | M3+ NaClO       | 5.69<sup>b</sup> | 10.20<sup>n</sup> | 13.79<sup>k</sup> | 16.14<sup>k</sup> | 17.35<sup>k</sup> | 18.60<sup>j</sup> |
| T11       | M3+ CaCl₂       | 5.69<sup>b</sup> | 6.91<sup>de</sup> | 7.99<sup>d</sup> | 11.13<sup>de</sup> | 11.63<sup>de</sup> | 13.69<sup>ef</sup> |
| T12       | M3+ CM          | 5.69<sup>b</sup> | 5.87<sup>abc</sup> | 7.06<sup>de</sup> | 8.41<sup>b</sup> | 8.57<sup>b</sup> | 9.67<sup>b</sup> |
| T13       | M3+ NaClO+CaCl₂ | 5.69<sup>b</sup> | 9.11<sup>j</sup> | 12.93<sup>j</sup> | 15.37<sup>h</sup> | 15.38<sup>j</sup> | 16.76<sup>j</sup> |
| T14       | M3+ NaClO+CM    | 5.69<sup>b</sup> | 7.54<sup>ab</sup> | 9.87<sup>bc</sup> | 13.55<sup>g</sup> | 13.47<sup>g</sup> | 16.18<sup>h</sup> |
| T15       | M3+ CaCl₂+CM    | 5.69<sup>b</sup> | 6.25<sup>c</sup> | 7.67<sup>cd</sup> | 10.12<sup>cd</sup> | 10.88<sup>cd</sup> | 12.68<sup>d</sup> |
| T16       | M3+ NaClO+CaCl₂+CM | 5.69<sup>b</sup> | 7.38<sup>de</sup> | 9.17<sup>ef</sup> | 11.61<sup>de</sup> | 12.24<sup>e</sup> | 15.09<sup>ef</sup> |
| T17       | M5+ Control (H₂O) | 6.42<sup>c</sup> | 13.49<sup>s</sup> | 20.23<sup>n</sup> | 24.78<sup>l</sup> | 21.91<sup>n</sup> | 31.40<sup>n</sup> |
| T18       | M5+ NaClO       | 6.42<sup>c</sup> | 11.79<sup>a</sup> | 17.95<sup>m</sup> | 20.53<sup>h</sup> | 20.13<sup>m</sup> | 24.44<sup>mn</sup> |
| T19       | M5+ CaCl₂       | 6.42<sup>c</sup> | 7.67<sup>j</sup> | 9.87<sup>bc</sup> | 12.50<sup>j</sup> | 13.34<sup>g</sup> | 14.36<sup>g</sup> |
| T20       | M5+ CM          | 6.42<sup>c</sup> | 6.65<sup>de</sup> | 8.81<sup>e</sup> | 10.75<sup>de</sup> | 11.63<sup>de</sup> | 13.25<sup>ef</sup> |
| T21       | M5+ NaClO+CaCl₂ | 6.42<sup>c</sup> | 10.83<sup>j</sup> | 14.23<sup>h</sup> | 17.78<sup>h</sup> | 17.75<sup>h</sup> | 20.00<sup>k</sup> |
| T22       | M5+ NaClO+CM    | 6.42<sup>c</sup> | 8.62<sup>k</sup> | 12.73<sup>j</sup> | 15.45<sup>n</sup> | 15.13<sup>g</sup> | 16.86<sup>g</sup> |
| T23       | M5+ CaCl₂+CM    | 6.42<sup>c</sup> | 7.13<sup>bj</sup> | 9.49<sup>ef</sup> | 11.81<sup>de</sup> | 12.45<sup>ef</sup> | 13.87<sup>ef</sup> |

(Continued)
Table 4. (Continued)

| Trt. Code | Treatment(Trt) | Days after storage (DAS) |
|-----------|----------------|-------------------------|
|           |                | 1<sup>st</sup> day | 4<sup>th</sup> day | 8<sup>th</sup> day | 12<sup>th</sup> day | 16<sup>th</sup> day | 20<sup>th</sup> day |
| T24       | M5+ NaClO+CaCl<sub>2</sub> + CM | 6.42<sup>c</sup> | 7.83<sup>j</sup> | 11.14<sup>hn</sup> | 13.48<sup>n</sup> | 14.15<sup>n</sup> | 16.57<sup>n</sup> |
| Significance |                | HS** | ** | ** | ** | ** | ** |
| SE (%)   |                | 0.10 | 0.12 | 0.35 | 0.79 | 0.43 | 0.34 |
| CV (%)   |                | 1.8  | 1.5  | 3.3  | 5.9  | 3.1  | 2.2  |

Means with the same letters in a column are not significantly different at 1% level of significance according to DMRT; **: highly significant (p ≤ 0.01); M1: mature green; M3: half ripe (turning); M5: light red stage; CM: Cactus mucilage, SE: Standard error; CV (%): Percentage of coefficient of variance; HS: Harvesting stages.
maximum TSS to TA ratio (31.4) was recorded in tomato fruit samples harvested at light red and water washed treatments (T17), followed by tomato fruit samples harvested at light red and surface sterilized by NaClO (T18), which was 24.44. Tomato fruit samples, which were harvested at turning stage and washed with water (T9), also increased the TSS to TA ratio (21.23) as compared to fruit samples harvested at mature green and dipped in water (T1). On contrary, the minimum TSS to TA ratio (7.96) was recorded in tomato fruit samples, which were harvested at mature green and coated with cactus mucilage treatment (T4). Tomato fruit samples, which were harvested at mature green and treated with the combination of calcium chloride and cactus mucilage (T7) also slightly, reduced the TSS to TA ratio of tomato fruit pulp.

Total soluble solids (TSS) to TA ratio estimates the sugars and organic acid contents of fleshy fruits and it is an important organoleptic quality factors for determining the taste and palatability of fruits (Sammi & Masud, 2007). Hamdu et al. (2016) suggested that the balance between sweetness and acidity should be at acceptable level to the human palate.

In the present study, a favorable balance between sweetness and acidity of tomatoes occurred in tomato fruit samples harvested at mature green and coated with cactus mucilage throughout the storage duration. A similar finding was reported by Martinez-Romero et al. (2006) who observed favorable balance between sweetness and acidity in sweet cherry fruit coated with Aloe vera for it controlled fruit present more pronounced ripening development. Petriccione et al. (2015) also observed a smaller increase in the TSS to TA ratio in strawberry fruit coated with chitosan during storage.

3.9. Ascorbic acid (mg 100 g⁻¹ sample)

The analysis of variance revealed that the main impacts of harvesting stages and their interactions with pre-storage treatments have highly significant (p ≤ 0.01) effects on ascorbic acid (AA) content of tomato fruits on the first day and from the 4th DAS onwards, respectively (Figure 6). There was a continuing rise in AA contents with prolonged storage duration and advanced physiological maturity stages, followed by slight decrease. At the initial, the lowest (8.63 mg 100 g⁻¹ sample) and highest (12.30 mg 100 g⁻¹ sample) AA were recorded in tomato fruits harvested at mature
green and half ripe (turning) stages, respectively. A similar finding was reported by Rahman (2006) and Moneruzzaman et al. (2009). The increase in AA contents in fruits is thought to be an indication that the fruit is still in the ripening stage, while a decrease indicated senescence of the fruit (Pila et al., 2010) due to enzymatic oxidation (Dragan et al., 2010).

Results of the two-way interaction indicated that the minimum AA content up to 8 days storage was recorded in tomato fruits harvested at mature green and washed with water (T1). From 12th DAS, however, the minimum AA shifted to tomato fruits harvested at light red stages and washed with water (T17) because tomato fruits harvested at mature green kept increasing in AA up to 16th DAS. On the contrary, the maximum (15.00 mg 100 g⁻¹ sample) AA content was recorded in tomato fruits harvested at half ripe (turning) stage and coated with cactus mucilage (T12) until 12th DAS, later and towards end of storage period, shifted to tomato fruits harvested at mature green stage and coated with cactus mucilage (T4). Mujtaba and Masud (2014) suggested that change in ascorbic acid contents in light red fruits should be maintained since the oxidized form of ascorbic acid is more prone to decomposition during storage, which leads to the loss of biological activity. In the present study, the loss of ascorbic acid was well retained in the treatments T12 (M2 + CM) and T4 (M1 + CM). A similar finding was reported by Oluwaseun et al. (2014b) who observed high vitamin C content in papaya fruit coated with Opuntia cactus mucilage. The reason for high vitamin C content in coated fruit can be attributed to slow ripening rate of treated fruit for coatings served as a protective layer (Adetunji et al., 2014; Ali et al., 2013, 2010).

Dipping tomato fruits in calcium chloride solution alone or in combination with cactus mucilage also significantly retained the loss of ascorbic acid during storage for it used to regulate oxidative process in cytosol (Hussain et al., 2012; Mujtaba & Masud, 2014). Therefore, this present study revealed that treating tomato fruits with CM alone or in combination with CaCl₂ is useful in retaining the loss of AA during storage.

3.10. Shelf life of tomato fruits (days)
Influence of harvesting stages and pre-storage treatments on shelf life of tomato fruits during the storage has been presented below (Figure 7). Analysis of variance of the data revealed that the interaction effects of harvesting stages and pre-storage treatments were highly significant (p ≤ 0.01). The minimum (6.83 days) shelf life was observed in the treatment T17 (tomato fruits
harvested at light red stage and water washed). Similarly, the treatments T24 (8 days), T18 (8.50 days) and T21 (8.67 days) also resulted in minimum shelf life of tomato fruits compared to the other treatments. On the other hand, the maximum (21.83 days) shelf life was recorded in treatment T4 (tomato fruits harvested at green maturity stage and coated with cactus mucilage). Likewise, treatments T12 (19.17 days) T7 (18.50 days) also resulted in better storage life of tomato fruits than other treatments. This investigation revealed that application of CM in combination with CaCl2 has slightly synergetic effect in maintaining the quality attributes of tomato fruits and extending the shelf life of tomato fruits as compared to other pre-storage treatments. The shelf life of tomato fruits harvested at mature green stage and coated with cactus mucilage (treatment T4) was extended by two weeks more than tomato harvested at light red stage and water washed (T17).

Melkamu et al. (2009) reported that mature green tomato fruits washed with water before storage can be stored for 16 days under ambient temperature condition. However, the present result revealed that the mature green tomato fruits coated with cactus mucilage can be stored for three weeks, i.e. five more days than which was reported earlier. Generally, the treatment T4 (M1 + CM) retained high ascorbic acid content, high titratable acidity and low pH and prolonged the shelf life of tomato fruits as compared to all other treatments. This research result is in agreement with the previous research done by Zegbe et al. (2015) who observed the overall high-quality attributes and prolonged shelf life of guava coated with cactus mucilage. Oluwaseun et al. (2014b) also observed increase in shelf life on papaya fruits coated with cactus mucilage. The increase in shelf life of tomato fruits coated with cactus mucilage could be due probably to the hydrophilic nature of cactus mucilage like polysaccharides, which create and serve as a barrier against water loss and gas exchange (Zegbe et al., 2015). Overall, the present study revealed that harvesting tomato fruits at mature green stage and treating them with cactus mucilage alone can significantly prolong the shelf life and maintain the physical and chemical qualities of tomato fruits. Furthermore, coating tomato fruits that are harvested at turning stage can also significantly extend the shelf life of the fruits.

4. Conclusion
The shelf life and quality of harvested tomato fruits are largely affected by harvesting stages and type of appropriate pre-storage treatments used. Physiological deterioration, a consequence of oxidation reaction and lack of appropriate and integrated post-harvest handling practices, is the greatest problem in post-harvest industry of tomato fruits. As a result, tomato fruit post-harvest losses are very high in developing countries, like Ethiopia. More than 50% of harvested tomato fruits are lost during the value chain before it reaches consumption or consumers. To minimize the tomato fruit quality and weight loss, designing appropriate harvesting stages and effective pre-storage treatments is of paramount importance.

The research results of the study showed that both harvesting stages and pre-storage treatments highly and significantly (p ≤ 0.01) affected the quality attributes and shelf life of the variety Roma VF tomato fruits during storage. Coating tomato fruits harvested at mature green stage with 50% cactus mucilage significantly reduced percentage of physiological loss in weight, percentage of decay, pH of tomato juice, titratable acidity and loss in ascorbic acid content of stored tomato fruits during the storage better than the other treatments.

Color properties of tomato fruit samples coated with cactus mucilage were not affected by the coating as compared to the other treatments at each harvesting stage. Marketability and appearance analysis showed that coated tomato fruit samples had high marketability even at the end of the 21-day holding or storage period. In overall conclusion, the coating of tomato fruits harvested at mature green stage integrated with cactus mucilage showed a tendency to prolong the tomato fruit shelf life, maintaining physical and chemical qualities. Hence, this current investigation on postharvest handling technology will greatly benefit small-scale retailers, wholesalers and processing industries to extend the shelf life without high losses in quality of tomato fruits for at least
three weeks. Further research is needed to fully exploit the potential of cactus mucilage as a coating material, particularly testing the concentration under cold room or controlled atmosphere tomato fruit storage conditions.

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