Maturity Stage and Post-Harvest Treatments on Quality and Shelf Life of Tomatoes

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Abstract

Background: Tomato (Lycopersicon esculentum Mill) is a climacteric fruit widely cultivated for its high nutritional value and diverse culinary applications. However, its perishable nature and short shelf life contribute to significant postharvest losses, which are exacerbated by inadequate harvesting practices, improper ripening conditions, and poor storage facilities. Optimizing maturity stages and postharvest treatments is crucial for minimizing losses and maintaining tomato quality during marketing and storage. Methods: A laboratory experiment was conducted to assess the effects of maturity stages and postharvest treatments on the quality and shelf life of tomatoes. A randomized complete block design (RCBD) was used with two factors: maturity stages (M1: mature green, M2: half ripe, M3: full ripe) and storage conditions (T1: uncovered, T2: polythene covering, T3: $CaCl_2$ + polythene covering), resulting in nine treatment combinations. Parameters such as physiological weight loss, total soluble solids (TSS), acidity, pH, vitamin-C content, and shelf life were analyzed over seven-day intervals. Statistical analyses were performed using the MSTAT-C package, with treatment differences evaluated by the LSD test at a 5% probability level. Results: Physiological weight loss was highest (19.29%) in fully ripe tomatoes under uncovered conditions and lowest (8.40%) in mature green tomatoes treated with $CaCl_2$ and polythene covering. TSS content increased with ripening, peaking at 6.17 in fully ripe, uncovered tomatoes. Acidity decreased with ripening, from 0.46 in mature green to 0.40 in fully ripe tomatoes, while pH values showed an opposite trend. Vitamin-C content was highest (9.51 mg/100g) in half-ripe tomatoes under polythene covering but decreased during storage. The longest shelf life (26.33 days) was achieved with mature green tomatoes treated with $CaCl_2$ and polythene covering, compared to the shortest (13.83 days) in fully ripe, uncovered tomatoes. Conclusion: For optimal tomato quality and extended shelf life, mature green tomatoes treated with $CaCl_2$ and polythene covering are recommended for long-distance marketing, while fully ripe tomatoes are preferable for immediate fresh consumption. This approach can reduce postharvest losses and preserve essential nutrients during storage and transportation.

Keywords: Tomato ripening, shelf life, maturity stages, post-harvest treatments, quality preservation

Significance | Understanding optimal maturity stages and post-harvest treatments reduces spoilage, extends shelf life, and preserves quality of tomatoes for marketing.

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Introduction

Tomato (*Lycopersicon esculentum Mill.*) is a globally significant vegetable crop cultivated extensively for its fleshy fruits. Belonging to the Solanaceae family, tomatoes are climacteric fruits, experiencing a respiratory peak during the ripening process, which makes them highly perishable with a typical shelf life of 2–3 weeks. They are an integral part of global cuisines, consumed fresh in

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salads or processed into products such as sauces, ketchups, purees, and soups (Hobson & Davies, 1971; Kalloo, 1991). The nutritional profile of tomatoes includes an abundance of vitamins A and C, as well as minerals such as calcium, phosphorus, and iron, making them a dependable source of nutrients (Islam, 1996). In Bangladesh, tomatoes contribute over 7% of the total vitamin C intake from vegetables (BBS, 2005). Additionally, they are rich in total sugars (2.5–4.5%), starch (0.6–1.2%), and bioactive compounds like lycopene, which is a potent antioxidant with cancer-preventive properties (Bhutani & Kallo, 1983).

The postharvest quality of tomatoes is determined by factors such as firmness, color uniformity, and absence of mechanical injuries or bruises. However, tomatoes are prone to significant postharvest losses due to factors such as decay, mechanical damage, and inadequate handling or storage conditions (Shetty et al., 1989; Risse et al., 1985). It is estimated that 30–40% of harvested tomatoes in developing countries are lost due to spoilage, exacerbated by a lack of proper harvesting techniques, storage facilities, and market access (Akamine, 1970). Beyond physical losses, spoilage also leads to the degradation of essential nutrients, vitamins, and minerals.

Packaging has emerged as a crucial intervention to extend the storage life of fresh produce, including tomatoes. Proper packaging inhibits physiological deterioration, reduces weight loss, and creates modified gas atmospheres around the produce, which slows respiratory activity (Hobson, 1982; Shetty et al., 1989; Risse et al., 1985). Studies have shown that wrapping tomatoes in polyethylene film significantly reduces weight loss and delays ripening, thereby preserving firmness (Hobson, 1982). Treatments such as calcium chloride ($CaCl_2$) applications further enhance postharvest quality by delaying ripening, reducing respiration, and preventing physiological disorders (Sharma et al., 1996).

The physiological weight loss of tomatoes is primarily attributed to dehydration due to transpiration and respiration. Transpiration results from water vapor pressure differences between the atmosphere and the fruit surface, while respiration involves the loss of carbon as carbon dioxide during metabolic processes (Moneruzzaman et al., 2009; Mallik et al., 1996; Bhowmik & Pan, 1992). Ripening-induced biochemical changes, such as the conversion of starch to simple sugars, contribute to increased total soluble solids (TSS) in tomatoes, enhancing their flavor and sweetness (Moneruzzaman et al., 2008b; Helyes et al., 2006).

Similarly, ripening affects the acidity and vitamin C content of tomatoes. Acidity tends to decrease as malic and citric acids are metabolized during ripening, while vitamin C levels initially increase and subsequently decline during storage due to oxidation (Bhattacharya, 2004; Mathooko & Nabawancuka, 2003). The shelf life of tomatoes depends on maturity at harvest and storage conditions. Mature green tomatoes exhibit the longest shelf life, while fully ripe tomatoes are more perishable (Wills & Tirmazi, 1982). Calcium applications have been particularly effective in extending shelf life by strengthening cell walls and delaying senescence (Sharma et al., 1996).

This study aims to evaluate the effects of different maturity stages and postharvest treatments on the quality, nutrient retention, and shelf life of tomatoes. Specifically, the research investigates how maturity stages (mature green, half-ripe, and fully ripe) and storage conditions (uncovered, polyethylene-covered, and $CaCl_2$-treated polyethylene-covered) influence key parameters such as physiological weight loss, TSS, acidity, pH, vitamin C content, and shelf life. The findings provide practical insights for optimizing tomato handling and storage to minimize postharvest losses and improve marketability.

2. Materials and Methods

2.1 Materials and Methods

The present investigation was conducted in the laboratory of the Department of Crop Science and Technology, University of Rajshahi, Bangladesh, during February to March 2016. Freshly harvested tomatoes (500 g) of the variety *ACI Super* were used for the study. The tomatoes were collected from the experimental field of the department.

2.2 Experimental Design

The experiment was conducted using a two-factor Randomized Complete Block Design (RCBD) with three replications. The first factor was maturity stages, which included three levels: mature green (M1), half ripe (M2), and full ripe (M3). The second factor was storage conditions, also categorized into three levels: uncovered (T1), covered with polythene (T2), and treated with calcium chloride ($CaCl_2$) along with polythene covering (T3). This design resulted in nine treatment combinations, representing all possible interactions between the three maturity stages and three storage conditions.

2.3 Parameters Studied

To evaluate the impact of maturity stages and postharvest treatments, several parameters were assessed at seven-day intervals during the storage period. Physiological Loss in Weight (PLW) was calculated as a percentage using the formula:

$$\text{PLW } (\%) = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \times 100$$

Total Soluble Solids (TSS) were measured using a digital refractometer (Atago, Japan) and expressed in °Brix, following the methodologies of Moneruzzaman et al. (2008b) and Helyes et al. (2006). Acidity was determined through titration with 0.1 N NaOH using phenolphthalein as an indicator, as outlined by Aneesh et al. (2007). The pH of tomato juice was measured with a pH meter (Orion Star A211, Thermo Scientific). Vitamin-C content was quantified using the 2,6-dichlorophenol-indophenol titration method described by Mathooko and Nabawancuka (2003) and De Castro et al. (2006). Lastly, the shelf life of the tomatoes was defined as the number of days they remained marketable without visible spoilage, assessed through visual inspection.

2.4 Statistical Analysis

Data collected from the experiment were analyzed statistically using the MSTAT-C software package. Analysis of variance (ANOVA) was conducted to assess the significance of the effects of treatments. Treatment means were compared using the Least Significant Difference (LSD) test at a 5% level of probability.

2.5 Postharvest Treatments

2.5.1 Polythene Wrapping:

Tomatoes in T2 and T3 treatments were wrapped in polyethylene film to create a modified atmosphere, reducing respiration and transpiration rates (Hobson, 1982; Shetty et al., 1989).

***2.5.2 Calcium Chloride ($CaCl_2$) Treatment*:**

For T3, tomatoes were dipped in a 2% $CaCl_2$ solution for 5 minutes, air-dried, and then wrapped in polythene. Calcium treatment was applied to strengthen cell walls and delay senescence (Sharma et al., 1996).

2.5.3 Observation Period

Measurements for all parameters were taken at intervals of 7, 14, and 21 days.

3. Results and Discussion

3.1 Physiological Loss in Weight (PLW)

The maturity stages of tomatoes significantly influenced weight loss during storage (Table 1). The highest weight loss (19.29%) occurred in tomatoes at the full ripe stage, while the lowest weight loss (9.80%) was observed in tomatoes at the green mature stage. Storage conditions also played a crucial role in determining weight loss. Tomatoes stored uncovered experienced the highest weight loss (17.25%), whereas those treated with calcium chloride ($CaCl_2$) and covered with polythene exhibited the lowest weight loss (12.48%). The combined effect of maturity stages and storage conditions on weight loss was also statistically significant (Table 2). The maximum weight loss (22.89%) occurred in full ripe tomatoes stored uncovered, while the minimum weight loss (8.40%) was found in green mature tomatoes treated with $CaCl_2$ and covered with polythene.

The observed increase in weight loss during storage is attributed to dehydration, which commonly affects the tender tissues of tomatoes. This finding aligns with the report by Moneruzzaman et al. (2009), who noted a similar trend.

Additionally, weight loss tends to increase progressively over time, regardless of the maturity stage, as observed by Mallik et al. (1996). The primary causes of weight loss in fresh tomatoes are transpiration and respiration. Transpiration involves the loss of water due to a vapor pressure gradient between the atmosphere and the fruit's surface. Respiration contributes to weight reduction by releasing carbon dioxide; for every molecule of carbon dioxide produced, a carbon atom is lost from the fruit (Bhowmik & Pan, 1992).

3.2 Total Soluble Solids (TSS)

Maturity stages significantly affected the total soluble solids (TSS) content of tomatoes (Table 1). The highest TSS value (5.90 °Brix) was recorded in tomatoes at the full ripe stage, while the lowest value (4.65 °Brix) was found in green mature tomatoes. Storage conditions also had a notable impact on TSS. Tomatoes stored uncovered exhibited the highest TSS value (5.54 °Brix), while those treated with $CaCl_2$ and covered with polythene had the lowest TSS value (5.26 °Brix). Polythene-covered storage yielded an intermediate TSS value of 5.36 °Brix.

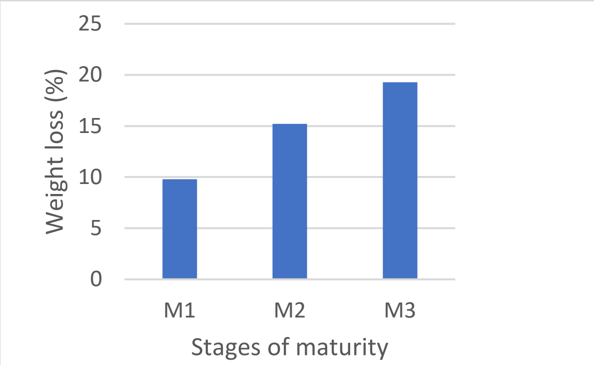
The interaction between maturity stages and storage conditions revealed statistically significant differences in TSS content (Table 2). The highest TSS value (6.17 °Brix) was observed in full ripe tomatoes stored uncovered, while the lowest TSS value (4.60 °Brix) occurred in green mature tomatoes treated with $CaCl_2$ and covered with polythene. Other combinations, such as green mature tomatoes stored uncovered (4.62 °Brix) and green mature tomatoes with polythene covering (4.73 °Brix), also exhibited relatively low TSS values.

TSS content increased progressively during the ripening process across all maturity stages, consistent with the findings of Moneruzzaman et al. (2008b) and Helyes et al. (2006). Tsudat et al. (1999) reported that TSS content tends to rise during the ripening and storage period due to the conversion of starch into sugars. This degradation of polysaccharides into simple sugars results in a noticeable increase in TSS (Naik et al., 1993). The current study's results also corroborate the findings of Shehla and Masud (2007) and Abdullah et al. (2004), who noted an increase in TSS in tomatoes stored under various packaging conditions.

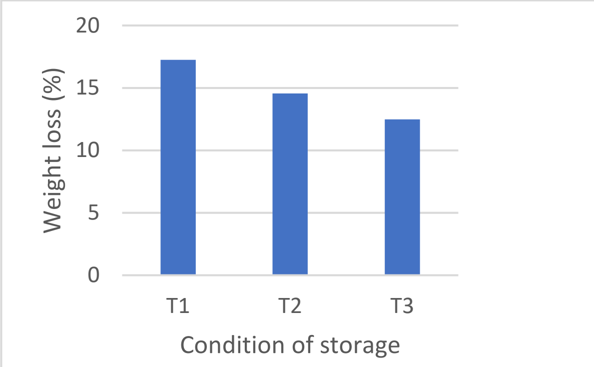
The increase in TSS during ripening is largely due to enzymatic activities that break down complex carbohydrates into simpler sugars, enhancing the fruit's sweetness. Additionally, packaging materials can influence the rate of biochemical changes, contributing to variations in TSS content. These findings provide valuable insights into optimizing storage conditions to preserve the quality of tomatoes.

3.3Acidity

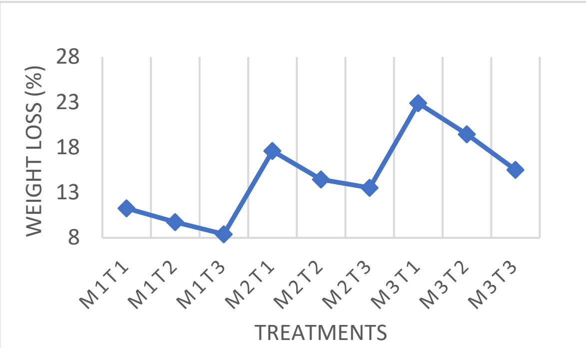
Significant variations in acidity were observed across different maturity stages of tomatoes (Table 1). The highest acidity (0.46) was recorded in tomatoes at the green mature stage, while the lowest acidity (0.40) was found in full ripe tomatoes. Storage conditions also had a significant influence on acidity. Tomatoes stored uncovered exhibited the highest acidity (0.44), whereas tomatoes covered with polythene or treated with $CaCl_2$ and polythene showed the lowest acidity (0.42). These findings align with previous studies by Aneesh et al. (2007) and Shehla and Masud (2007), which



a) Effect of stage of maturity on weight loss (%) of tomato



b) Effect of condition of storage on weight loss (%) of tomato



c) Combined effect on weight loss (%) of tomato

Figure 1. Effect of maturity stage and storage conditions on weight loss (%) of tomato (a) Effect of maturity stage, (b) Effect of storage conditions (c) The combined effect[Where M_1-Mature green, M_2-Half ripe, M_3-Full ripe; T_1-Uncovered condition T_2-Covering with polythene and T_3-Treated with $CaCl_2$+ polythene covering]

Table 1. Single effect of maturity stage and storage condition on total soluble solids (TSS), acidity, pH, vitamin-C and shelf life of tomato

Treatments	**Total Soluble Solids (TSS)**	**Acidity**	**pH**	**Vitamin-C**	**Shelf Life**
Maturity stages					
M_1	4.65c	0.46a	5.68a	5.50c	23.11a
M_2	5.61b	0.42b	5.20b	9.51a	19.11b
M_3	5.90a	0.40c	4.52c	7.48b	16.50c
Level of significance at 1%	**	**	**	**	**
LSD 1%	0.13	0.01	0.11	0.09	1.03
Storage condition					
T_1	5.54a	0.44a	5.22a	7.50	17.44c
T_2	5.36b	0.42b	5.12b	7.54	19.22b
T_3	5.26b	0.42b	5.07c	7.46	22.06a
Significance at 1% level	**	**	**	NS	**
LSD at 1%	0.13	0.01	0.11	--	1.03

NS=Non significant

**=Significant at 1% level of probability, *=Significant at 5% level of probability

Where M_1-Mature green, M_2-Half ripe, M_3-Full ripe

T_1-Uncovered condition T_2-Covering with polythene and T_3-Treated with $CaCl_2$+ polythene covering

Table 2. Combined effect of maturity stage and storage condition on weight loss (%), total soluble solids (TSS), acidity, pH, vitamin-C and shelf life of tomato

Treatments combination	Total Soluble Solids (TSS)	Acidity	pH	Vitamin-C	Shelf Life
M_1T_1	4.73d	0.47	5.82	5.49d	20.67c
M_1T_2	4.62d	0.46	5.65	5.51d	22.33b
M_1T_3	4.60d	0.45	5.56	5.52d	26.33a
M_2T_1	5.71b	0.43	5.29	9.54a	17.83de
M_2T_2	5.67b	0.42	5.18	9.64a	18.33d
M_2T_3	5.45c	0.42	5.14	9.36b	21.17bc
M_3T_1	6.17a	0.42	4.54	7.48c	13.83f
M_3T_2	5.80b	0.40	4.52	7.47c	17.00e
M_3T_3	5.74b	0.39	4.49	7.50c	18.67d
Level of significance	*	NS	NS	**	*
LSD at 1%	--	--	--	0.16	--
LSD at 5%	0.17	--	--	--	1.31

NS=Non significant

**=Significant at 1% level of probability, *=Significant at 5% level of probability

Where M1-Mature green, M2-Half ripe, M3-Full ripe

T1-Uncovered condition T2-Covering with polythene and T3-Treated with CaCl2+ polythene covering reported that titratable acidity decreases during ripening and storage.

Bhattacharya (2004) explained that acidity serves as an indicator of fruit maturity, decreasing as ripening progresses. This reduction is attributed to the disappearance of organic acids such as malic acid, followed by citric acid, during ripening. The catabolism of citrate plays a crucial role in this process. Mattoo et al. (1975) and Salunkhe and Desai (1984) noted that sugar content in tomatoes increases during ripening, which correlates with decreased acidity. Furthermore, the appearance of a yellow hue during ripening also contributes to the reduction in acidity.

3.4pH

The pH levels of tomatoes varied significantly depending on their maturity stage (Table 1). The highest pH value (5.68) was observed in tomatoes at the green mature stage, while the lowest pH (4.52) was recorded in full ripe tomatoes. Storage conditions also influenced pH significantly. Uncovered tomatoes exhibited the highest pH (5.22), whereas tomatoes treated with $CaCl_2$ and covered with polythene showed the lowest pH (5.07). However, the combined effects of maturity stages and storage conditions on pH were not statistically significant (Table 2).

As ripening advanced, pH levels increased, a finding consistent with earlier studies. The gradual rise in pH during ripening reflects the breakdown of organic acids, which are replaced by increased sugar concentrations.

3.5Vitamin-C

Maturity stages significantly impacted the vitamin-C content of tomatoes (Table 1). The highest vitamin-C content (9.51 mg/100g) was found in half-ripe tomatoes, while the lowest content (5.50 mg/100g) was observed in green mature tomatoes. Storage conditions, however, had a non-significant effect on vitamin-C levels. Nevertheless, significant variations were noted in the combined effects of maturity stages and storage conditions on vitamin-C content (Table 2).

The highest vitamin-C content (9.64 mg/100g) was recorded in half-ripe tomatoes stored under polythene covering, followed closely by half-ripe tomatoes stored uncovered (9.54 mg/100g). Conversely, the lowest vitamin-C content (5.49 mg/100g) was found in green mature tomatoes stored uncovered. This trend aligns with findings from Mathooko and Nabawancuka (2003), Nei et al. (2005), De Castro et al. (2006), and Aneesh et al. (2007), who reported that vitamin-C levels increase during ripening.

Preserving ascorbic acid during storage is challenging due to its susceptibility to oxidation. Higher oxygen concentrations in the storage environment accelerate this process. Sinaga (1986) noted that vitamin-C content typically peaks at full ripening before gradually declining. This decline is attributed to ascorbic acid oxidation, as confirmed by Nazar et al. (1996), Eris et al. (1994), and Pal et al. (2002). These researchers observed a gradual decrease in vitamin-C content during storage and transport, reinforcing the findings of the current study.

3.6Shelf Life

The maturity stages of tomatoes had a significant impact on their shelf life (Table 1). The longest shelf life (23.11 days) was recorded for green mature tomatoes, while the shortest shelf life (16.50 days) was observed for full ripe tomatoes. Storage conditions also significantly affected shelf life. Tomatoes treated with $CaCl_2$ and covered with polythene exhibited the longest shelf life (22.06 days), whereas those stored uncovered had the shortest shelf life (17.44 days).

Significant variations were also noted in the combined effects of maturity stages and storage conditions on shelf life (Table 2). The longest shelf life (26.33 days) was recorded for green mature tomatoes treated with $CaCl_2$ and covered with polythene, while the shortest shelf life (13.83 days) was observed in full ripe tomatoes stored uncovered.

These findings align with the work of Wills and Tirmazi (1982), who reported that calcium plays a vital role in prolonging the shelf life of fruits. Calcium is a divalent cation that binds to the cell wall and plasma membrane, forming calcium pectates that strengthen cell walls. Calcium has gained significant attention for its ability to delay ripening and senescence, reduce respiration rates, and minimize physiological disorders (Sharma et al., 1996).

By reducing respiration rates and reinforcing cell wall structures, calcium treatment effectively extends the shelf life of tomatoes. These results emphasize the importance of appropriate storage conditions and treatments to maintain the quality and marketability of tomatoes during storage and transport.

4. Conclusion

In conclusion, the study demonstrated that tomato maturity stages and storage conditions significantly influenced key postharvest parameters, including weight loss, total soluble solids, acidity, pH, vitamin-C content, and shelf life. Green mature tomatoes treated with $CaCl_2$ and covered with polythene exhibited the lowest weight loss, longest shelf life, and optimal preservation of acidity and vitamin-C during storage. Full ripe tomatoes showed higher total soluble solids and reduced acidity, reflecting advanced ripening. These findings highlight the effectiveness of calcium treatment and appropriate storage methods in maintaining postharvest quality, ensuring extended shelf life, and enhancing the nutritional and market value of tomatoes.

Author contributions

M.M., M.K.A., and M.A.B.B. conceptualized and designed the study. S.F. conducted the literature review and contributed to data acquisition. J.R. and M.K.F. performed the data analysis and interpretation. M.J.A. and M.A. contributed to drafting the manuscript and revising it critically for intellectual content. All authors have read and approved the final manuscript.

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Competing financial interests

The authors have no conflict of interest.

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