EJED 2021 4(1):1–11
Ethiopian Journal of Environment and Development
http://www.du.edu.et/duj

RESPONSE OF TOMATO FRUIT PHYSICOCHEMICAL QUALITY AND SHELF LIFE TO MATURITY STAGE AND STORAGE DURATION

Dargie Tsegay Berhe

Dilla University, College of Agriculture and Natural Resource
Author's E-Mail: tsegadar@yahoo.com

Received: 30th June 2021 *Accepted: 13th September 2021*

DOI: **10.20372/ejed.v04i1.01**

Abstract
As a climacteric nature and fresh produce, tomato is highly perishable that needs smooth postharvest handling, technologies and treatment methods to maintain its quality and extend shelf life. The aim of the study was to explore the influence of different maturation stages and storage duration. The experiment was conducted in Dilla University from April to May 2021 which consisted of five maturation stages and five storage duration with three replications arranged in CRD factorial combination. Fifty fruits for each maturity stage were taken and packed inside boxes and stored in refrigeration at 12°C temperature and 95% relative humidity. Fruits were evaluated for firmness, pH value, total soluble solids, titratable acidity and shelf life. The interaction effects of maturation stage and storage period were highly significant in fruit firmness, titratable acidity, pH value and shelf life. The highest firmness was observed in fruits harvested at full green stage (0% coloration) during the initial storage period and declined when fruits get ripened and stored for prolonged period of time. Total soluble solids and pH value increased simultaneously with advancing maturation stage and storage duration. However, the content of titratable acidity increased up to half ripening stage and the second week, followed by a diminishing trend when fruits fully ripened and stored for prolonged time. Therefore, harvesting at the right maturation stage and proper postharvest handling of tomato fruits is vital to maintain physicochemical quality and extend storability potential with obvious commercial interest.

Keywords: Maturity stage, Postharvest handling, Quality, Tomato, Shelf life

1 Introduction

Tomato (*Solanum lycopersicum* L.) is one of the popular horticultural crops in Ethiopia (Yusufe *et al.*, 2017) and ranked first among all vegetables in terms of its nutritional contribution with high biological activity in the human diet (Suarez *et al.*, 2018). The issue of post-harvest losses is of high importance in the efforts to combat hunger, raise revenue and improve food security in the world's poorest countries like Ethiopia. One-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year (Gustavsson *et al.*, 2011) due to post-harvest losses. In Ethiopia the highest postharvest loss (45.3%) is recorded in tomato fruit (Kasso and Bekele, 2018).

Tomato as a climacteric fruit, its ripening process is a genetically programmed of events that terminates with senescence (Al-Dairi *et al.*, 2021; Tiwari *et al.*, 2020). Postharvest factors such as transpiration, fungal infection, acceleration of the ripening process and senescence could affect the quality parameters of tomato fruit. Preservation treatments (Alyousuf *et al.*, 2021; Chavan and Sakhale, 2020), postharvest handling technologies (Dyshlyuk *et al.*, 2020;

Aghadi *et al*., 2020; Changwal *et al*., 2021) and low temperature are the effective mechanisms to reduce ethylene production (Riudavets *et al*., 2016).

The main features of tomato such as rapid ripening rate and high perishability shortened the shelf life and rapid loss of qualities (Paul and Pandey, 2013; Opara *et al*., 2011). Ethylene hormone is considered as trigger of a wide range of physical, physiological and biochemical changes in tomato. The ripening process is accelerated by ethylene and this endogenous production of that hormone results in short postharvest life (Tiwari *et al*., 2020). The effect of the ripening stage on the postharvest quality of tomatoes can further be compounded by sub-optimal handling such as rough handling, poor sanitation and warm storage temperatures, which provide opportunities for huge losses (Al-Dairi *et al*., 2021; Abera *et al*., 2020; Chavan and Sakhale, 2020; Gatahi, 2020).

Tomato fruits are harvested at different ripening stages from mature green to red coloured depending on the market requirements (Njume *et al*., 2020) and consumer preferences (Tolasa *et al*., 2021). When fruits are harvested at early maturity stages, they may not have developed the ability to produce much flavour. On the other hand, if fully ripened fruits were harvested, they would have a very short postharvest life (Changwal *et al*., 2021).

Even though there are several research findings in tomato pre and postharvest handling and processing technologies, there is limited information on the influence of maturity stages and storage duration on retaining the postharvest physicochemical quality properties and extending shelf life. Therefore, the purpose of this study was to mitigate the huge postharvest loss between producer and consumer mainly aimed to evaluate the response of tomato fruit quality and shelf life, harvested at different maturity stages and cold stored for prolonged periods.

2 Materials and Methods

2.1 Experimental Site Description

The experiment was carried out from April to May 2021 at Dilla University, which is located at $6°25'25''$ N latitude and $38°16'45''$ E longitudes. Dilla has an altitude of 1434 meters above sea level and found in 361km south of Addis Ababa, the capital city of Ethiopia. The temperature and relative humidity of the storage refrigerator were 12°C and 95%, respectively.

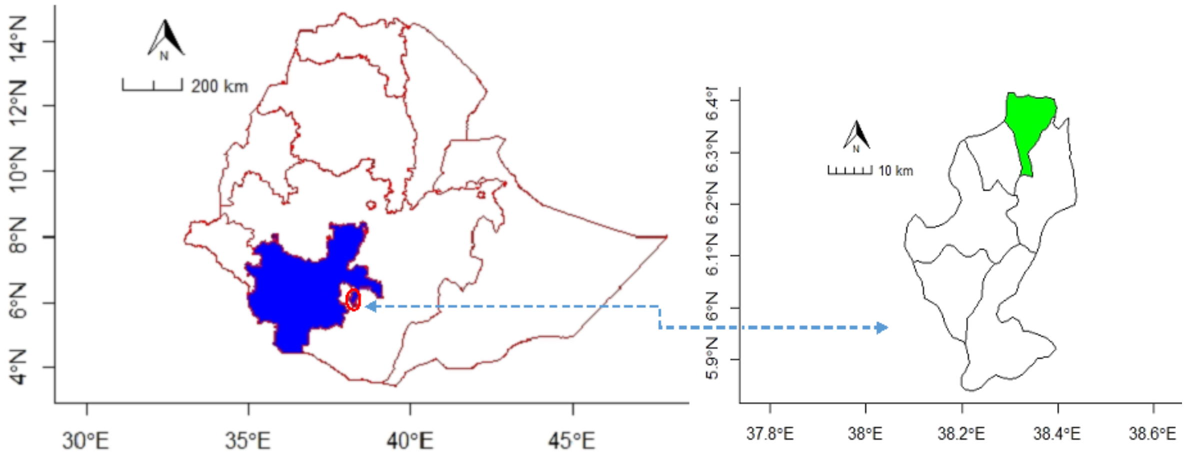

Figure 1. Research site (*Blue color: SNNPRS; Green color: Dilla Zuria wereda*)

2.2 Experimental Design and Treatments

The treatments were comprised of tomato fruit (plum variety) harvested at five maturity stages (0, 25, 50, 75, 100% colourations) and stored for four weeks (0, 1, 2, 3 and 4 weeks) under cold storage at $12°C$ temperature and 95% relative humidity. The treatments were combined in complete randomized design (CRD) factorial experiment, resulting in a total of 25 treatment combinations with three replications and 75 total observations (5*5*3). Each treatment consisted of fifteen fruits per replication packed in card board boxes for storage.

2.3 Experimental Procedures

Fruits of tomato were harvested from greenhouse in different maturity stages determined in the field by fruit colouration guide plus days from anthesis. The fruits were harvested manually with care to minimize mechanical injuries or damage at 0% colouration (full green), 25% colouration, 50% colouration (half ripened), 75% colouration, and 100% colouration (completely ripened). After harvest, tomato fruits were immediately transported using plastic crates and held at $12°C$ temperature and 95% relative humidity. Fruits with bruises, sign of infection or those different from the group were discarded from the samples. The fruits were also washed with tape water, surface dried with soft cloth and subdivided, sorted, weighed and stored in three refrigerators as technical replication. All fruits were packed using a card board box for all treatments separately.

2.4 Data Collection Procedures

Samples of tomato fruits were randomly taken from each treatment for physicochemical quality assessments. First, data were measured at the initial stage of storage period and subsequent records were taken each week. Fruit quality data were collected for firmness, total soluble solids, titratable acidity, pH value and determined the storability potential of tomato fruits.

2.4.1. Fruit Firmness

Fruit firmness was measured using texture analyzer according to Xie *et al.* (2009). The firmness measurement was carried out using a cylindrical stainless-steel probe of $2mm$ in diameter. The speed of the probe was set at $1mm.s^{-1}$. Puncture tests were carried out on rectangular fruit pieces taken from the two opposite equatorial sides of the same fruit. Three tomato fruits were analyzed per replication and results were expressed in Newton per pod.

2.4.2. Total Soluble Solids (TSS)

Juice of tomato fruits was extracted from three fruits in a blender as described by Cherono *et al.* (2018). The homogenized sample was filtered using funnel with filter paper in a beaker. The filtrate was taken for TSS determination using digital refractometer in ^{o}Brix by placing a few drops of clear tomato juice on the prism surface. Between samples, the prism of the refractometer was cleaned thoroughly, rinsed with distilled water and dried using soft tissue paper.

2.4.3. Titratable Acidity (TA)

$10ml$ juice of tomato fruit was extracted from three fruit samples, $90ml$ of distilled water was added and then homogenized in a blender. The homogenized sample was filtered by funnel with filter paper in a beaker. The titratable acidity of tomato was measured by titration instrument using $NaOH$ (0.1N) as a standardized titration solution (Teka, 2013). The $NaOH$ was slowly titrated into the juice-water solution. When the point of neutrality or the end point of titration was reached at pH of 8.2, the amount of $NaOH$ used on the burette read off and recorded to calculate the TA using the following formula.

$$TA(g) = \frac{(Titre * 0.1N\,NaOH * 0.67)}{1000} * 100$$

2.4.4. pH Value

$10ml$ juice of tomato was extracted from three fruits and $90ml$ distilled water was added and homogenized in a blender as described by Cherono *et al.* (2018). The homogenized sample was filtered using funnel with filter paper in a beaker and the *pH* value of the filtrate was measured using *pH* meter with the application of the electrode directly in to the blended pulp. The electrode was removed and rinsed in distilled water to make it ready for the next sample test.

2.4.5. Shelf Life

The shelf life of tomato fruits was evaluated by counting the number of days required to attain the last stage, but up to the stage when fruits remained still acceptable for marketing as described by Pila *et al.* (2010). It was decided based on the appearance and spoilage of fruits. When 50 percent of fruits showed symptoms of shrinkage or spoilage due to pathogens and chilling injury, that lot of fruits was considered to have reached end of shelf life.

2.5 Statistical Analysis

The experiment was subjected to two-way analysis of variance in complete randomized design and data were analysed using R program (version 4.1.4, 2021). Analysis of variance was performed to determine the effect of independent variables (maturity stage and storage duration) on the dependent variables (TSS, TA, *pH* value, firmness and shelf life) at a 5% significance level ($P < 0.05$). To determine the significant differences between treatment means, fisher's range test was applied. Correlation analysis was also computed to see the relationship between the principal components.

3 Results and Discussion

3.1 Fruit Firmness

The interaction effect of maturity stage and storage duration on tomato fruit firmness shown high significance ($P < 0.001$). The highest firmness (82.89 *N*) was observed in fruits harvested at 0% maturation stage (full green) during the initial storage period, followed by fruits harvested at 0% maturation stage stored for one week (74.14 *N*) and 25% maturation stage at the initial storage period (73.74 *N*). On the other hand, the minimum values of tomato fruit firmness were recorded at 100% maturation stage (fully ripened) during the fourth (16.49 *N*) and third (22.46 *N*) weeks, respectively (Figure 2).

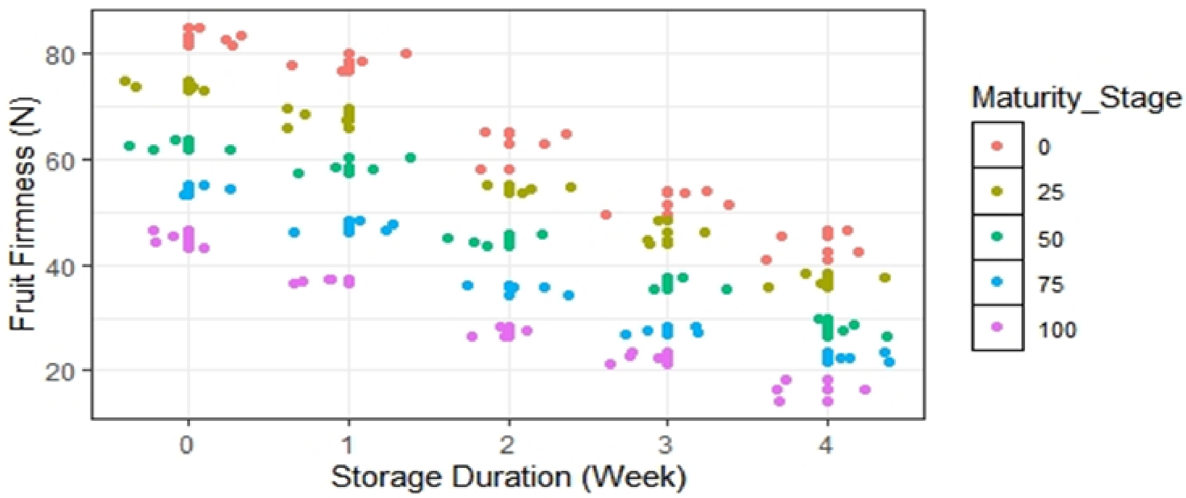

Figure 2. Response of tomato fruit firmness to maturity stage and storage duration

Fruit firmness was in an increment trend with declining maturity stages and storage duration (Figure 2). Fruits harvested at the full green stage were firmer by 46.31% than fruits harvested at complete ripened stage. The finding of this study is incoherence with several research results (Tolasa *et al.*, 2021) who stated that fruit firmness is deteriorated with increasing ripening stages. The apparent decline in fruit firmness with increased maturity stage might be due to cell wall softening directly influencing the levels of fruit firmness. It is also in agreement with the result of Pila *et al.* (2010) who reported that decrease in texture is due to the activity of softening enzymes such as pectin methyl esterase (Chuni *et al.*, 2010). This could also be due to the presence of hemicelluloses and pectin substances that lead to disruption and loosening of the cell walls (Paul and Pandey, 2013).

Tomato fruit firmness reduced throughout the storage periods. The highest value of fruit firmness was reported at the initial storage time and the lowest value during the fourth week. This result is in agreement with several research findings (Tolasa *et al.*, 2021; Chavan and Sakhale, 2020; Moneruzzaman *et al.*, 2008). The decline in firmness of tomato fruits during increase storage periods could be due to high respiration rate, weight loss and enzymatic changes (Cantwell *et al.*, 2009). It was indicated that the high-water content of fruits might have provided high turgidity and resulted in high fruit firmness at the initial storage period (Tolasa *et al.*, 2021). Tomato fruit firmness had very strong negative correlation ($r = -0.97^{***}$) with total soluble solids and pH value ($r = -0.95^{***}$) while positive correlation ($r = 0.56^{**}$) with titratable acidity (Figure 3).

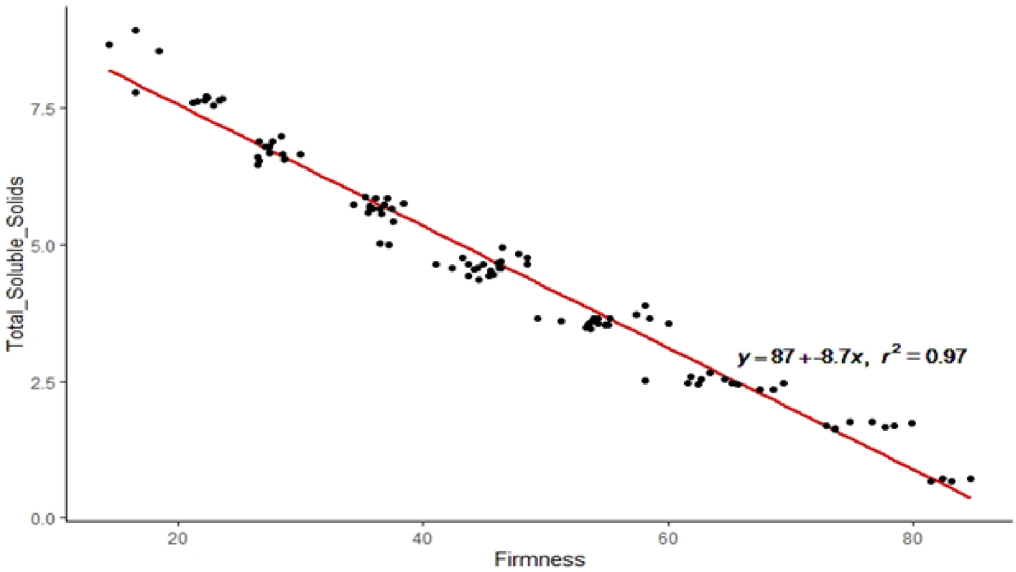

Figure 3. Correlation between firmness and total soluble solids of tomato fruit

3.2 Total Soluble Solids (^{o}Brix)

The main effect of maturity stage and storage period in tomato total soluble solid shown highly significant difference ($P < 0.001$); while the interaction effect was non-significant ($P > 0.05$). The data presented in figure 4 vividly depicts that TSS of tomato was influenced by maturity stage and storage duration. TSS content increased with advancing in maturity stages. The mean TSS of tomato fruit harvested at 0, 25, 50, 75 and 100% maturation stages were 2.60, 3.60, 4.65, 5.62 and 6.59 ^{o}Brix, respectively. The maximum TSS value recorded at fully ripened stage was higher by 39.45% compared to fruits harvested at full green stages.

The TSS content in this study is in alignment with several research findings (Tolasa *et al.*, 2021) who reported an increasing trend in TSS content as the maturity stages increased. The increment in TSS might be due to disassociation of some molecules and structural enzymes to soluble compounds, which directly influence the levels of total soluble solids (Dyshlyuk *et al.*, 2020; Chuni *et al.*, 2010). The increase in TSS during successive stages of maturation could also be due to the degradation of polysaccharides to simple sugars thereby causing a rise in the level of TSS (Tolasa *et al.*, 2021; Moneruzzaman *et al.*, 2008; Zapata *et al.*, 2008).

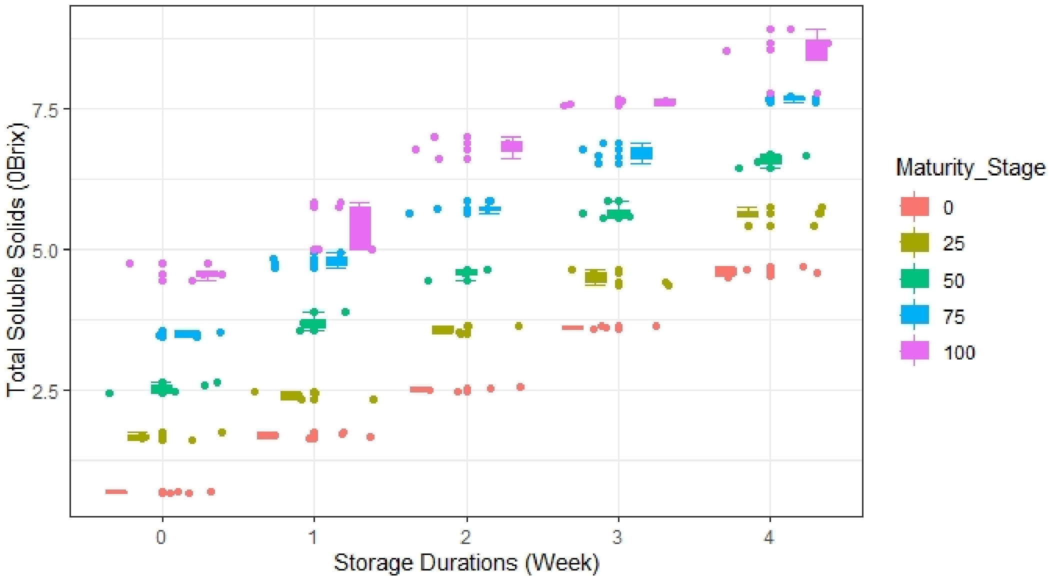

Figure 4. Response of tomato fruit total soluble solid to maturity stage and storage duration

Like maturity stages, TSS of tomato fruits was also influenced by storage duration. TSS content increased alongside storage duration. This result is in line with reports of Al-Dairi *et al.*, 2021, Tolasa *et al.*, 2021, Pila *et al.*, 2010; Cantwell *et al.*, 2009) who found that an increase in total soluble solids during prolonged storage periods. The increment in the TSS content for stored fruits was probably due to increasing of respiration and metabolic activity. In this regard Pila *et al.* (2010) found that higher respiration also increases the synthesis and use of metabolites resulting in higher TSS due to the higher change from carbohydrates to sugars. It could also be due to fruit senescence, degradation and high weight loss (Cantwell *et al.*, 2009) and the hydrolytic changes in starch concentration (Gyanendra, 2012) during storage which may lead to higher concentration of sugars in fruits.

3.3 Titratable Acidity (%)

There was a highly significant ($P < 0.001$) difference in the interaction effects of maturity stage and storage duration on titratable acidity (TA) of tomato fruits (Figure 5). The maximum (1.51%) and minimum (0.27%) TA values of tomato fruit were observed at 50% maturation stage stored for one week and 100% maturation stage at the fourth week of storage time, respectively. TA values increased from full green to 50% maturation stages followed by a gradual declining when fruits ripening to the completely coloured stage throughout all storage duration. This result is in line with Al-Dairi *et al.* (2021), Zapata *et al.* (2008), Moneruzzaman *et al.* (2008) and Cantwell *et al.* (2009) who reported that TA increased with increasing in storage time; and the highest TA values were found in fruits harvested at maturation stage than green fruits. In addition, Tolasa *et al*. (2021) stated that tomato fruit titratable acidity decreased with advancing in maturity stages, and the maximum acidity was found in half-matured tomato and declined in fully ripened fruits. The reduction in titratable acidity during storage might be due to the fruits undergoing the ripening process which diminished its malic acid and favoured the formation of sugars (Moneruzzaman *et al*., 2008).

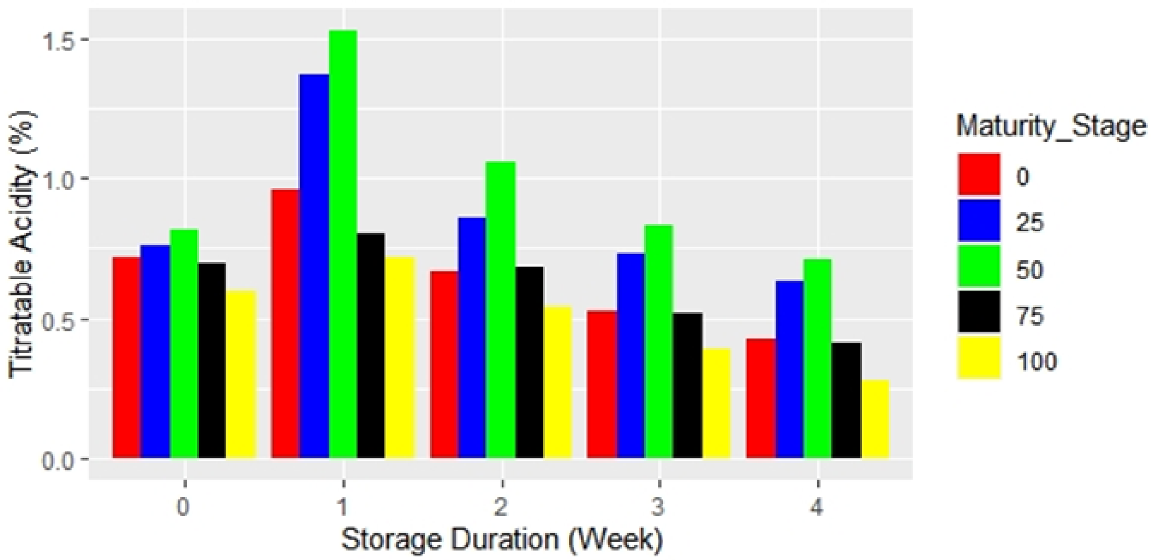

Figure 5. Response of tomato titratable acidity to maturity stage and storage duration

Regarding to the storage duration, there was an increment in titratable acidity until the first week followed by a decreasing trend with increasing storage period. This finding agrees with reports of Tolasa *et al*. (2021) and Anthon *et al*. (2011) who observed that titratable acidity of fruits increased to some extent and then decreased with prolonged storage periods. As confirmed by Anthon and Barrett (2012), this could be due to higher rate of respiration and fruit senescence during increasing storage period that might have utilized titratable acids as a substrate for catabolic process. This is in line with the work of Chavan and Sakhale (2020) who stated that the decrease in TA value during prolonged storage period is due to the rise in respiration rate that might necessitate using more organic acids in the respiration process. In accordance with the reports of Dyshlyuk *et al*. (2020), fruits might utilize the acids during the storage so that the acid in the fruits during prolonged storage periods decreases. This fact has been further substantiated by Tolasa *et al*. (2021) who observed that the change in titratable acidity during prolonged storage was mainly due to the metabolic activities of living tissues which takes place depletion of organic acids.

3.4 *pH* Value

The interaction effect of maturity stage and storage duration on *pH* value of tomato fruits shown highly significant ($P < 0.001$) difference (Table 1). The *pH* of tomato fruits progressively increased with increasing in storage duration. The highest (7.34) and lowest (2.87) *pH* values of tomato fruit were observed at 100% maturation stage stored for four weeks and 0% maturation stage at the initial storage period, respectively. *pH* values increased from full green to full maturation stages throughout all storage duration.

Table 1. Interaction effect of maturity stage and storage duration on tomato pH-value (mean ± sd)

Maturity Stage (%)	Storage Duration (Weeks) 0	1	2	3	4	Mean
0	2.87 ± 0.05^{r}	3.36 ± 0.02^{p}	3.89 ± 0.08^{n}	4.17 ± 0.11^{kl}	4.49 ± 0.05^{j}	3.74 ± 0.06
25	3.16 ± 0.05^{q}	3.76 ± 0.08^{o}	4.24 ± 0.05^{k}	4.48 ± 0.12^{j}	5.02 ± 0.10^{h}	4.13 ± 0.08
50	3.70 ± 0.02^{o}	4.08 ± 0.06^{lm}	4.81 ± 0.05^{i}	5.07 ± 0.06^{h}	5.55 ± 0.08^{f}	4.64 ± 0.05
75	4.03 ± 0.06^{m}	4.48 ± 0.12^{j}	5.18 ± 0.05^{g}	5.57 ± 0.05^{f}	6.31 ± 0.14^{c}	5.11 ± 0.08
100	4.59 ± 0.12^{j}	5.86 ± 0.09^{e}	6.20 ± 0.11^{d}	6.86 ± 0.08^{b}	7.34 ± 0.06^{a}	6.17 ± 0.09
Mean	3.67 ± 0.06	4.30 ± 0.07	4.86 ± 0.07	5.23 ± 0.08	05.74 ± 0.09	
P-Value		***				
LSD		0.11				
CV (%)		1.69				

This finding is in agreement with Tolasa *et al.* (2021) who reported that pH content increased with advancing in ripening stages of tomato fruit. The rise in pH value during increasing fruit ripening stage was probably due to the decline of titratable acidity. This is in line with Anthon *et al.* (2011) who reported that the increase in pH value was paralleled by a decrease in titratable acidity, due to loss of respiratory citric acid. In contrast, Fawole and Opara (2013) reported that there was no significant difference in pH values during maturity stages of tomato fruits.

The highest pH value of tomato fruit was observed on the fourth week while the lowest pH value was recorded in the initial storage time. This result is in line Tolasa *et al.* (2021) who reported that days of storage induced to increase pH of fruit juice. It was also confirmed by Al-Dairi *et al.* (2021) who found that there is an increment in pH value of tomato fruit during advancing in storage duration. The increase in the pH of stored fruits might be due to decreasing in acidity of the fruit and metabolic activity. Tomato pH value had a very strong positive correlation ($r = 0.90^{***}$) with total soluble solids (Figure 6).

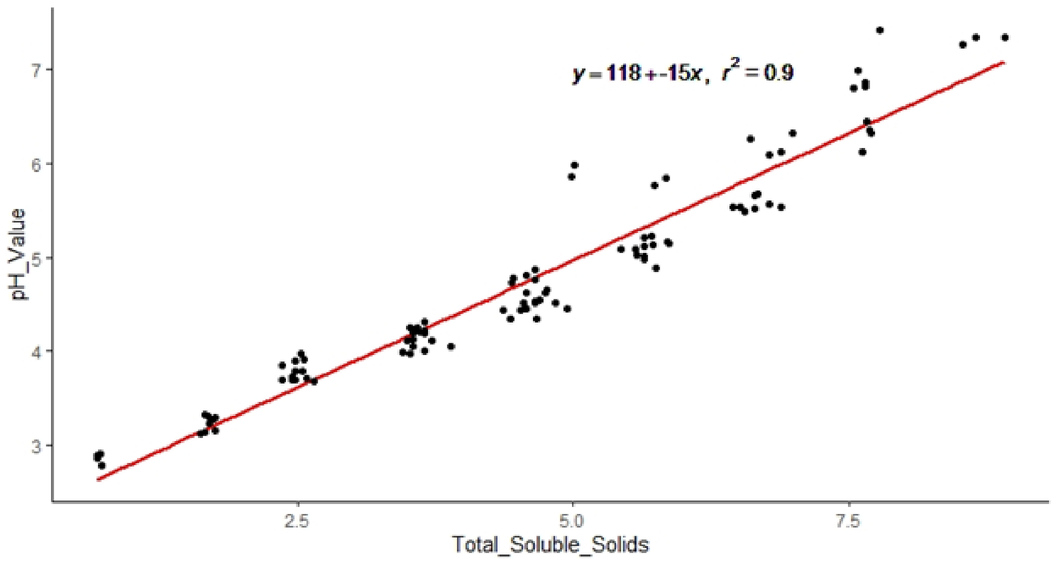

Figure 6. Correlation between pH value and total soluble solids of tomato fruits

3.5 Shelf Life

The interaction effects of maturity stage and storage duration on shelf life of tomato fruits shown highly significant difference ($P < 0.001$) (Table 2). The maximum shelf life was recorded at 50% maturation stage (30.65 days) followed by 25% maturation stage (27.62 days) stored for four weeks while the minimum shelf life was observed at full green stages during the initial storage period (12.27 days) and week one (14.46 days). At the initial storage periods, fruits harvested at 0% and 100% coloration stages end their shelf life due to rotting, wilting, chilling injury and development of spots on the fruit skin.

Table 2. Interaction effect of harvesting stage and storage duration on mean shelf life (days)

Maturity Stage	Storage Duration (Weeks)					Mean
(%)	0	1	2	3	4	
0	12.27^k	14.46^j	15.26^i	16.76^h	18.51^g	15.45
25	18.41^g	22.98^e	24.34^d	25.63^c	27.62^b	23.80
50	21.15^f	24.35^d	25.85^c	27.41^b	30.65^a	25.88
75	16.52^h	18.87^g	22.65^e	24.43^d	25.65^c	21.62
100	15.26^i	16.73^h	17.17^h	21.24^f	23.56^e	18.79
Mean	16.72	19.48	21.05	23.09	25.20	
P-Value			***			
LSD			0.69			
CV (%)			11.27			

The results are in line with the findings of several researchers (Changwal *et al*., 2021; Tolasa *et al*., 2021; Pila *et al*., 2010), who reported that tomato fruits harvested at half ripened stage had a better shelf life than the unripe and full red tomato fruits. This could be due to the high weight loss percentage and respiration rate of completely ripened fruits and lack of a well-developed fruit cuticular wax layer at full green stage which in turn might have resulted in lower shelf life. Moreover, the increasing trend in overall shelf life of fruits during prolonged storage period might be due to the presence of refrigeration storage equipment. This reality is supported by Chavan and Sakhale (2020) who found that refrigeration is used to reduce spoilage and extend the shelf life of fresh fruit and vegetables by slowing down the metabolism and reducing fruit deterioration.

4 Conclusion

In the investigation of the effect of maturity stages (0, 25, 50, 75 and 100% fruit colouration) and storage duration (0, 1, 2, 3 and 4 weeks) on fruit firmness, total soluble solids, titratable acidity, *pH* value and shelf life of tomato fruits, there was a significant difference in the main or interaction effects. The interaction effect of maturity stage and storage duration was highly significant ($P < 0.001$) in titratable acidity, *pH* value, fruit firmness and shelf life. The main effects of maturity stage and storage duration on total soluble solids shown highly significant difference ($P < 0.001$). TSS and *pH* value increased while fruit firmness and the storability potential of tomato fruits declined with advancing maturity stages. Fruits harvested at 50% and 25% colouration stages had the highest titratable acidity and shelf life across all storage duration which could be used for long distance marketing.

Conflict of Interest

The author declares that there is no conflict of interest.

References

Aghadi C.N., Balana B.B. and Ogunniyi A.I. (2020). Postharvest losses and the impact of reusable plastic container technology on profitability: Evidence from tomato traders in Nigeria. *Strategy support program*, working paper 65.

Al-Dairi M., Pathare P.B. and Al-Yahyai R (2021). Chemical and nutritional quality changes of tomato during postharvest transportation and storage. *Journal of the Saudi Society of Agricultural Sciences*, 20(**4**): 52-89.

Alyousuf A., Hamid D. and Desher M. (2021). Effect of Silicic Acid Formulation (Silicon 0.8%) on Two Major Insect Pests of Tomato under Greenhouse Conditions. *Silicon*, https://doi.org/10.1007/s12633-021-01091-7.

Anthon E. and Barrett M. (2012). Pectin Methylesterase activity and other factors affecting pH and titratable acidity in processing tomatoes. *Journal of Food chemistry*, 132: Pp. 915-920.

Anthon E., Lestrange M. and Barrett M. (2011). Changes in *pH*, acids, sugars and other quality parameters during extended vine holding of ripe processing tomatoes. *Journal of the Science of Food and Agriculture*, 93: 98-109.

Cantwell M., X. Nie and G. Hong. (2009). Impact of storage conditions on grape tomato quality. 6^{th} *ISHS Post-harvest Symposium*. University of California, Davis. 8p.

Changwal C., Shukla T., Hussain Z., Singh N., Kar A., Singh V.P., Abdin M.Z. and Arora A. (2021). Regulation of Postharvest Tomato Fruit Ripening by Endogenous Salicylic Acid. *Front. Plant Sci*. 12: 663943. https://doi.org/10.3389/fpls.2021.663943.

Chavan R.F. and Sakhale B.K. (2020). Studies on the effect of exogenous application of salicylic acid on post-harvest quality and shelf life of tomato fruit Cv. Abhinav. Food Research, 4(**5**): 1444-1450. https://doi.org/10.26656/fr.2017.4(5).131.

Cherono K., Sibomana, M., Workneh, T.S. (2018). Effect of infield handling conditions and time to pre-cooling on the shelf-life and quality of tomatoes. *Brazilian J. Food Technol.*, 21:1-12.

Chuni S.H., Awang Y. and Mohamed T.M (2010). Cell Wall Enzymes Activities and Quality of Calcium Treated Fresh-cut Red Flesh Dragon Fruit (Hylocereus polyrhizus). *Int. J. Agric. Biol.*, 12: 713-718.

Dyshlyuk L., Babich O., ProsekovA., Ivanova S., Pavsky V. and Chaplygina T. (2020). The effect of postharvest ultraviolet irradiation on the content of antioxidant compounds and the activity of antioxidant enzymes in tomato. *Heliyon* 6: e03288, https://doi.org/10.1016/j.heliyon.2020.e03288.

Gatahi D.M. (2020). Challenges and Opportunities in Tomato Production Chain and Sustainable Standards. *International Journal of Horticultural Science and Technology*, 7(**3**): 235-262, https://doi.org/10.22059/ijhst.2020.300818.361.

Gezai Abera, Ali M. Ibrahim, Sirawdink Fikreyesus Forsido and Chala G. Kuyu (2021). Assessment on post-harvest losses of tomato (*Lycopersicon esculentem* Mill.) in selected districts of East Shewa Zone of Ethiopia using a commodity system analysis methodology. *Heliyon*, 6: e03749.

Gustavsson J., Cederberg C., Sonesson U., Otterdijk R.V. and Meybeck A. (2011). Global Food Losses and Food Waste: Extent, Causes and Prevention. Food and Agriculture Organization of the United Nations, Rome.

Gyanendra K.R., K. Rajesh A.K. Singh P.K. Rai R. Mathura and A.K. Chaturvedi. (2012). Changes in antioxidant and phytochemical properties of tomato (*Lycopersicon esculentum* Mill.) under ambient condition. *Pakistan Journal of Biotechnology*, 44(**2**): 667-670.

Kasso M., and Bekele A. (2018). Post-harvest loss and quality deterioration of horticultural crops in Dire Dawa Region, *Ethiopia. J. Saudi Soc. Agric. Sci.* 17(**1**): 88-96.

Moneruzzaman K.M., A.B. Hossain W. Sani and M. Saifuddin. (2008). Effect of stages of maturity and ripening conditions on the physical characteristics of tomato. *American Journal of Biochemical and Biotechnology*, 4(**4**): 329-335.

Njume C.A., Ngosong C., Krah C.Y. and Mardjan S. (2020). Tomato food value chain: managing postharvest losses in Cameroon. *Earth and Environmental Science*, 542: 012021, https://doi:10.1088/1755-1315/542/1/012021.

Opara, U. L., Al-Ani, R., & Al-Rahbi, N. M. (2011). Effect of fruit ripening stage on physico-chemical properties, nutritional composition and antioxidant components of tomato (*Lycopersicum esculentum*) cultivars. *Food and Bioprocess Technology*, 5, 3236-3243.

Paul V. and Pandey R. (2013). Delaying tomato fruit ripening by 1-methylcyclopropene (1-MCP) for better postharvest management: Current status and prospects in India. *Indian Journal of Plant Physiology*, 18(**3**):195–207, https://doi.org/10.1007/s40502-013-0039-6.

Pila N., Gol B. and Rao R., (2010). Effect of Postharvest Treatments on Physicochemical Characteristics and Shelf Life of Tomato (*Lycopersicon esculentum* Mill.) Fruits during Storage. *American-Eurasian Journal of Agriculture and Environmental Science*, 9(**5**): 470-479.

Riudavets J., Alonso M., Gabarra R., Arnó J., Jaques J. and Palou L. (2016). The effects of postharvest carbon dioxide and a cold storage treatment on Tuta absoluta mortality and tomato fruit quality. *Postharvest Biology and Technology*, 120: 213-221.

Suarez M.H., Rodriguez E.M. and Romero C.D. (2018). Chemical composition of tomato (*Lycopersicum esculentum*) from tenerife, the Canary Islands. *University of La laguna, Avda. Food Chem*. 106: 1046-1056.

Teka T.A. (2013). Analysis of the effect of maturity stage on the postharvest biochemical quality characteristics of tomato (*Lycopersicon esculentum* Mill.) fruit. *Intl. Res. J. Pharmaceut. Appl. Sci.*, 3(**5**): 180-186.

Tiwari I., Shah K.K., Tripathi S., Modi B., Shrestha J., Pandey H.P., Bhattarai B.P. and Rajbhandari B.P. (2020). Post-harvest practices and loss assessment in tomato (*Solanum lycopersicum* L.) in Kathmandu, Nepal. *Journal of Agriculture and Natural Resources*, 3(**2**): 335-352, https://doi.org/10.3126/janr.v3i2.32545335.

Tolasa M., Gedamu F. & Woldetsadik K. (2021). Impacts of harvesting stages and pre-storage treatments on shelf life and quality of tomato (*Solanum lycopersicum* L.). *Cogent Food & Agriculture*, 7: 1863620 https://doi.org/10.1080/23311932.2020.1863620.

Xie B.X., Gu Z.Y., Wang S., Zhuang H.W., Zeng J.X., and Zeng J.Q. (2009). Effect of 1-MCP on texture properties of fresh fruit in storage shelf period of Zizyphus jujuba 'Zhongqiusucui. *ISHS Acta Horticulturae*, 840: 499-504.

Yusufe M., Mohammed A. and Satheesh N. (2017. Effect of duration and drying temperature on characteristics of dried tomato (*Lycopersicon esculentum* L.) cochoro variety. Acta Universitatis Cibiniensis. *Series E: Food Technol*. 21(**1**): 41-50.

Zapata P.J., Guillen F., Martinez-Romero D., Castillo S., Valero D. and Serrano M. (2008). Use of alginate or zein as edible coatings to delay postharvest ripening process and to maintain tomato quality. *Journal of the Science of Food and Agriculture*, 88: 1287-1293.