Kinetic modeling of quality changes of tomato during storage

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Abstract: Quality deterioration in tomato along the supply chain due to postharvest losses has become a continual challenge in Middle East countries. The aim of this study is to determine the changes in tomato quality parameters during storage. Fresh tomatoes were purchased from the Central Market of Fruits and Vegetables and stored at 10℃ and 22℃ for 12 days to assess color, weight loss, firmness, and total soluble solids parameters. Statistical analysis, like R^2, X^2, *SE* and *RMSE*, and ANOVA were performed using SPSS software. Experimental results showed a high significant impact (p < 0.05) in tomato quality parameters such as color, firmness and weight loss stored at 22℃. Storage at 22℃ had a rapid alteration of redness or greenness (a*) and lightness (L*) parameters to the darker region. A slow increase on weight loss, redness (a*), color index (CI), tomato color index (COL) and total color differences (Δ*E*) was observed with less decrease on L* and firmness during the exposure to 10℃ storage. The appropriate model to demonstrate the color change was the first-order model. However, firmness was described by the zero-order model. Zero-order and first-order models used to describe quality changes during storage. Overall, tomato stored at 10℃ provided a desired result of firmness, weight loss and color change compared to tomato stored at 22℃.

Key words: color, firmness, kinetic model, quality, tomato

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1 Introduction

The quality characteristics of fresh tomato (*Lycopersicon esculentum* L.) is mostly determined by color, firmness, flavor (Sibomana et al. 2011), shape, size and nutritional values (Pinheiro et al. 2013). Tomato color is the initial external visual characteristic that determines the level of consumers' acceptance (Khairi et al. 2015). Significant color changes happen at different phases of tomato development starting from green color (chlorophyll) followed by orange color (β-carotene) and red color (lycopene) contents (Pinheiro et al. 2013; Rai et al. 2012). Lycopene is the most important carotenoid which is representing 98% of carotenoids and provides red color development and characteristics of tomato (Tadesse et al. 2015). Firmness is an essential quality-related characteristic in tomato which might be one of the final indexes that influence how buyers decide to select a given tomato in the market (Sirisomboon et al. 2012; Chen and Opara 2013). It can be controlled via pericarp tissue elasticity, cell wall tissue integrity and the activity of enzymes that are included in product softening during ripening process (Sibomana et al. 2011). Flavor is another quality attribute of fresh tomato that results frequently from a combination of acids and sugar for taste and volatile compounds for aroma (Messina et al. 2012).

As tomato is a climacteric vegetable, ripening could occur after harvesting which has been classified as a complex process of tomato development that is limited by ethylene (Karlova et al. 2011; Majidi et al. 2014). It is a result of physiological and biochemical changes, leading

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to a ripe phase which terminates in dramatic changes in firmness, color and flavor (Pinheiro et al. 2013). Tomato is extremely perishable and this allows for extensive losses of the produce during postharvest supply chain (SC) (Ayandiji et al. 2011) that is highly susceptible to spoilage (Mandal et al. 2018) which was highly increased with the advancement of storage duration (Rai et al. 2012). About 20% - 25% losses of tomato have been recorded in tropical countries from harvesting, storage, transportation and marketing (Mandal et al. 2018).

Temperature is a very significant factor that can affect the quality of stored tomato due to its direct effect on deterioration rate (Arah et al. 2015). Keeping tomato at low storage temperature can decrease the metabolic activities resulted in less damage and deterioration (Atanda et al. 2011). However, extreme increase of temperature of storage condition is responsible to increase respiration, transpiration (Mayani et al. 2016) and ethylene production. While high reduction of storage temperature (refrigerated storage) can cause chilling injuries, therefore, reducing fresh produce quality (Mandal et al. 2018; Gardas et al. 2018). Storage at high temperature is not achievable. Elevated storage temperature can increase the percentage of weight reduction and inhibit the processes of ripening process (Tadesse et al. 2015). Overall, high quality reduction was observed as storage temperature increased (Atanda et al. 2011). Ayomide et al. (2019) reviewed that storage at 10℃ was the most suitable storage temperature for delaying senescence and maintaining quality of fresh produce. While temperature below 10℃ resulted in chilling injury symptoms such as poor formation of color and decay. However, Ponce-Valadez et al. (2016) also found that storage at 12.5℃ can provide better sensory quality compared to storage at 10℃. Storage temperature effects the color development and uniformity of tomato. The most important limiting quality factor of tomato kept below 8℃ is color but over 13℃ firmness becomes the most significant limiting quality factor (Tadesse et al. 2015). Moreover, flavor development and sugar content of tomato is affected by temperature storage (Beckles 2012) and it is sensitive to a temperature below 12℃ (Zhang et al. 2016). Nutritional value and quality of any fresh produce like tomato may be affected by postharvest storage. Losses of some nutritional components in tomato like vitamin C increased when tomato was stored at higher temperature (25℃) compared to storage at low temperature (4℃) (Sablani et al. 2006).

The majority of changes and deterioration on physiological changes and other biochemical activities of tomato are largely dependent on storage temperature (Majidi et al. 2014). The loss in water content of tomato is highly affected by moisture content available in the surrounded ambient air which is also known as relative humidity. Relative humidity is another factor that can affect the quality of the stored tomato. The amount of water content in fresh tomato is between 70% - 95% (Ramaswamy 2014). During storage, water movement between stored tomato and its surroundings can occur (Atanda et al. 2011). This type of interactions resulted in dehydration which is known as transpiration leading to tomato quality losses like visual changes, weight loss, shriveling and texture changes (El-Ramady et al. 2015). High relative humidity can maintain quality appearance, nutrition, weight and flavor and decrease softening and wilting of stored tomato (Arah et al. 2015). High relative humidity is the best solution that could be applied to avoid transpiration process and water loss in tomato during storage (Ayomide et al. 2019).

Improving refrigeration storage condition of tomato is required to reinforce the quality and shelf life of the product. Controlling fresh produce means controlling physical and chemical changes during storage. All of this can be done by studying the reaction of interest quantitatively. Kinetic parameters that describe such type of changes are required (Pinheiro et al. 2013). Different studies on modeling the changes of quality parameters of stored tomato and other fresh produce were found. Van Dijk et al. (2006) developed two models where the first one depends on the basic laws of chemical kinetics which describes moisture loss and firmness reduction of tomato in time at constant condition. The other model was related to least squares regression analysis which links the obtained firmness data to near infrared spectral data.

Pinheiro et al. (2013) also found that fractional conversion model was used to describe the experimental data on firmness, color parameters (a* and hue) and weight loss. Schouten et al. (2010) used kinetic and batch models to describe the behavior of firmness over time and to describe firmness variation within slices batches, respectively. Furthermore, transpiration rate model was also developed by Pereira et al. (2018). The model helps to understand the development of water loss included in table grapes with RH, temperature, and time. Therefore, the present study was done to assess the effect of storage condition on tomato quality parameters namely weight loss, firmness, total soluble solid (TSS) and color. Additionally, it aimed to study the effect of storage temperature on the quality kinetics parameters of tomato.

2 Materials and methods

2.1 Experiment design

Tomatoes (*Roma variety*) (Approx. 32 kg) were directly purchased from AL-Mawalih Fruit and Vegetable Market (23°35'28.1"N latitudes and 58°13'28.3"E longitudes) and transported to Postharvest Laboratory, College of Agriculture and Marine Sciences at Sultan Qaboos University (23°35'25.1"N latitudes and 58°10'07.9"E longitudes), Sultanate of Oman during Autumn 2018 (November). Tomatoes with uniform size, color, surface conditions and with no bruises or any infection sign were chosen to undergo some quality assessments after 0, 2, ..., 12 days. Surface excess moisture and soil was removed by cleaning and drying the samples.

This experiment was conducted at ambient condition (22℃ with 65% - 67% RH) and control storage condition (10℃ with 82% - 85% RH). Each of these groups was divided into seven subgroups. Five replicates were included in each of these seven subgroups. Each of these replicates was subjected to all quality parameters. The number count of tomato was also recorded to estimate the number of losses. Temperature and RH were taken into consideration using temperature meter (Model: TES 13604, TES Electrical Corp., Taiwan).

2.1.1 Tomato weight loss %

Tomatoes for each subgroup were weighed by using electric weight balance (Model: GX.4000, Japan). The percentage of tomato weight loss per subgroup was calculated by the following equation (Baninaiem et al. 2016):

$$\text{Weight loss (\%)} = \frac{Initial\ weight\ of\ tomato - final\ weight\ of\ tomato}{Initial\ weight\ of\ tomato} \times 10 \qquad (1)$$

2.1.2 Tomato color change

A colorimeter was used to measure color parameters of tomato sample (Model: TES 135A, TES Electrical Corp., Taiwan) that expresses the colors values as L* (Darkness or Lightness), a* (Reddish or Greenish), b* (Yellowish or Blueness) at each time respectively (Pathare et al. 2013). The values of L*, a* and b* were used to calculate total color difference (ΔE*) (Equation 2), chroma (Equation 3), hue angle (Equation 4), (Chayjan and Alaei 2016), color index (CI), and tomato color index (COL) (Equation 5 and Equation 6), respectively (Pathare et al. 2013) to describe color changes (Bal et al. 2011) during 12 days in different storage conditions

$$\Delta \mathrm{E} *= \sqrt{\Delta a *^2 + \Delta b *^2 + \Delta L *^2} \qquad (2)$$

$$\text{Chroma} = \sqrt{a *^2 + b *^2} \qquad (3)$$

$$\text{Hue}° = \tan \wedge -1 \left(\frac{b*}{a*}\right) \qquad (4)$$

$$\text{CI} = a^*/b^* \qquad (5)$$

$$\text{COL} = (2000 \times a^*)/(L^* \times Chroma) \qquad (6)$$

2.1.3 Tomato firmness

Firmness of tomato was estimated by standard procedure of OECD (2018) at two days interval of the experiment using hand penetrometer (Model: FT 327, EFFEGI, Italy).

2.1.4 Tomato Total Soluble Solids (TSS)

TSS was determined in tomato with the help of hand-held refractometer calibrated in ° Brix at 20℃ by following the procedure described by Gharezi et al. (2012).

2.2 Kinetic model

In order to ascertain weight loss, color, and firmness changes of tomato as a function of storage time, an equation of a fractional conversion kinetic model was reported (Pinheiro et al. 2013) and several equations for the application of this model were disclosed. Basically, the rate associated with the change with the quality factor

(C) can be expressed by the following model (Chayjan and Alaei 2016; Bal et al. 2011):

$$\frac{dC}{dt} = -kC^n \quad (7)$$

where k is kinetic rate constant at temperature T, C is the quality factor at time t and n is the reaction order. The time dependence relationship for majority of foods appears to be explained by zero-order model (Equation 8), or first-order model (Equation 9) kinetic models (Bal et al. 2011):

$$C = C_0 \pm kt \quad (8)$$

$$C = C_0 \times \exp(\pm kt) \quad (9)$$

where C_0 is the initial observed quality parameter, C is the quality parameter at specific time during storage, ± demonstrates the formation and deterioration of any quality parameter (Pinheiro et al. 2013).

2.3 Statistical analysis

All statistical analysis were performed using SPSS 20.0 (International Business Machine Crop., USA) software. The influence of experimental variables (storage conditions and time) on tomato quality parameters were studied using the analysis of variance (ANOVA) in general linear mode where the average values were investigated at 5% level of significance ($p < 0.05$). Regression analysis such as reduced chi-square (X^2) (Equation 10), coefficient of determination (R^2) (Equation 11), root mean square error (*RMSE*) (Equation 12) and standard error (*SE*) (Equation 13) were performed as a primary standard to select the best fit of the tested kinetic model to the experimental data. The model that adequately fits the quality parameters of tomato is determined by the highest R^2 and the lowest X^2, *RMSE* and *SE*. The following equations were used for parameters estimations (Bal et al. 2011) :

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(MR_{pre} - MR_{exp,i})^2} \quad (10)$$

$$x^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N-n} \quad (11)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2} \quad (12)$$

where $MR_{pre,i}$ and $MR_{exp,i}$ are the i^{th} predicted and experimental quality parameters value and MR_{pre} is the average predicted quality parameters values, n is the constant model numbers and N is observation numbers.

$$SE = \frac{S}{\sqrt{n}} \quad (13)$$

where S is the standard deviation and n is sample size.

3 Results and discussions

3.1 Temperature and relative humidity

This study demonstrated significant changes occur in tomato samples stored at ambient condition (22℃ with 65% - 67% RH), where color, surfaces conditions and quality parameters changed compared to storage at control condition (10℃ with 82% - 85% RH) which is considered to be an efficient condition to maintain tomatoes for long time (Tigist et al. 2013). The study also reported similar observation, where storing under low temperature is an effective method to maintain the quality of fruits and vegetables due to its ability to reduce transpiration, respiration rate and ethylene production.

3.2 Total number of tomatoes

It was observed that about 22% (Approx. 10) tomatoes stored at ambient condition were disposed due to non-uniformity on surface conditions, color alterations, and shrinking which made them useless for further analysis. However, there was no visible symptoms of injuries and the quantity was the same as tomatoes at control condition during the whole days of experiment.

3.3 Quality losses assessment

3.3.1 Tomato weight loss (%)

The effect of both storage conditions on tomatoes weight loss is presented in Figure 1. Storage days and temperature shows a significant ($p < 0.05$) influence on tomato weight loss. The total weight loss of tomato stored at 22℃ was 16.6% compared to 3.18% weight losses in tomato stored at 10℃ during storage period.

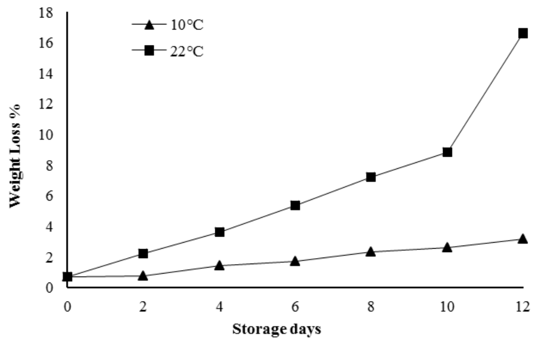

Figure 1 Weight loss of tomato during 12 days of storage at 10℃ and 22℃

The main reason for high weight loss in fresh stored tomato at ambient condition can be attributed to dehydration of tomato during storage (Fagundes et al. 2015), transpiration and respiration rate (Abiso et al. 2015; Gharezi et al. 2012). Furthermore, ambient temperature condition can increase the differences in the vapor pressure between tomato and its surrounded environment which is the main factor that can induce rapid transfer of moisture from tomato to the surrounded air (Tadesse et al. 2015). At ambient storage condition, low relative humidity reduces the amount of water in the fresh produce resulted in weight reduction (Ayomide et al. 2019). The results are in agreement with earlier study of (Park et al. 2018), who also found that weight loss of fresh tomato stored at 20℃ was higher (7.18%) than tomato kept at 12℃ (3.32%) and 8℃ (1.91%) for 20 days storage period. Similar findings were reported by Abiso et al. (2015) and Pinheiro et al. (2013) on the stored tomato.

Zero-order and first-order models were used to represent tomato weight loss (Table 1). It showed that tomato weight loss stored at 10℃ could be sufficiently characterized by zero-order model (R^2 = 0.9761), whereas the kinetic changes of weight loss stored at 22℃ fitted well with first order model (R^2 = 0.9372).

Table 1 The statistical values of zero-order and first-order models of tomato quality parameters at two different storage conditions

Parameters	Storage condition	Zero Order Model					First Order Model				
		k (day^{-1})	R^2	*Std. error*	X^2	*RMSE*	*k (day^{-1})*	R^2	*Std. error*	X^2	*RMSE*
Weight loss	10℃	0.2166	0.9761	0.1604	0.1554	0.1355	0.1357	0.9466	0.1525	0.4249	0.1289
	22℃	1.1498	0.8761	2.0374	1.0682	1.7219	0.2263	0.9372	0.2834	2.2743	0.2395
L*	10℃	-0.1436	0.5052	0.6727	0.1735	0.5686	-0.0112	0.5066	0.05243	0.0053	0.0443
	22℃	-0.7691	0.9346	0.9626	0.6054	0.8136	-0.0886	0.9792	0.9626	0.0090	0.0516
a*	10℃	0.5589	0.9432	0.6493	0.1645	0.5487	0.1978	0.9687	0.1299	0.9777	0.3064
	22℃	1.0983	0.9246	1.4846	121.876	1.2547	0.1347	0.8387	0.2470	1.1898	0.4330
b*	10℃	0.1250	0.3720	1.4035	0.2564	1.4230	0.0042	0.3734	0.0255	0.0008	0.0215
	22℃	-0.7426	0.4641	3.7761	15.058	11.1754	-0.0155	0.4540	0.0804	0.0084	0.0679
Chroma	10℃	0.1320	0.3991	1.4210	0.1843	1.2000	0.0045	0.3999	0.0258	0.0008	0.0218
	22℃	-0.6094	0.3645	3.8082	1.5345	3.2180	-0.0125	0.3550	0.0798	0.0126	0.0846
Hue°	10℃	0.1810	0.4726	0.8428	21.0234	0.7645	0.0312	0.3430	0.1808	0.7029	0.1438
	22℃	0.1906	0.0782	3.0963	13.0626	2.6168	-0.0549	0.5701	0.1994	2.1187	0.7823
CI index	10℃	0.0098	0.9274	0.1297	0.0317	0.0110	0.2281	0.9554	0.2060	5.0430	1.8942
	22℃	0.0248	0.9390	0.0299	1.9718	0.0252	0.1444	0.8375	0.2660	2.9927	1.0948
COL	10℃	1.5932	0.9295	2.0763	6.50902	1.7540	0.2227	0.9830	0.1224	0.1890	0.1082
	22℃	9.2905	0.9905	4.2756	0.75757	3.6135	0.2292	0.8915	0.3345	2.2915	0.8505
ΔE	10℃	0.5284	0.7298	1.5217	38.4635	3.8280	0.0441	0.9330	0.0494	1.5663	0.5905
	22℃	1.5734	0.8023	3.6969	7.7253	3.1240	0.0772	0.7158	0.2036	2.2950	0.8574
Firmness	10℃	0.1321	0.9706	0.1088	0.0220	0.1171	0.0308	0.9574	0.0306	0.0031	3.24824E-07
	22℃	-0.2146	0.9794	0.1475	0.0657	0.1246	-0.101	0.9498	0.1098	0.1161	0.0928

3.3.2 Tomato color change

Storage time and temperature showed a significant impact ($p < 0.05$) on L* value of tomato. Figure 2 shows that L* value decreased from 14.13± to 11.76 and 4.96± at 10°C and 22℃ during storage days respectively. Significant reduction was revealed in L* value of tomato stored at 22℃. This can reflect the increase of tomato darkening that attributed to carotenoids synthesis (Pinheiro et al. 2013; Saad et al. 2016). However, there was no effect ($p > 0.05$) of storage at 10℃ on L* value of tomato for 12 days storage **(**Figure 2**)**. The effect of storage at ambient temperature found in the current agreed with findings of Messina et al. (2012) after storing tomato for 21 days at 19℃.

Storage at both conditions for 12 days had a significant effect on a* value of fresh tomato ($p < 0.05$) and it reaches its maximum alteration by day 12 as it is shown in Figure 3. It increased from -2.19 to 5.68 and 12.22 at control and ambient respectively. The main reason of a* value alteration from green color (-) to red color (+) specifically at 22℃ is due to the degradation of chlorophyll, pigments synthesis during ripening (Tigist et al. 2013; Kim et al. 2019) and biosynthesis of ethylene (Hatami et al. 2013) which permit red color development (Weingerl and Unuk 2015). This scenario was also reported in tomato stored for seven and 14 days (Messina et al. 2012) and at 20℃ in mature tomato during 20 days (Park et al. 2018). Munhuewyi (2012) also demonstrated that storage at ambient temperature can afford an ideal condition for tomato to ripe leading to increase of the red values (a*) compared to low storage condition. Zou et al. (2018) revealed high rapid of red color development in cherry tomatoes stored at 25℃ compared to 10℃ and 4℃ after 28 days storage period.

The study showed no significant differences ($p > 0.05$) on b* value of fresh tomato during storage for 12 days at 10℃ and 22℃ (Figure 4). The results also showed no significant changes ($p > 0.05$) in chroma (Figure 5) and hue (Figure 6) of tomatoes at control and ambient conditions. Hue increased on day two at both storage temperatures. It was fluctuated on tomato stored at 10℃ for 12 days storage. While, it decreased slowly from 87.27° and reached 77.72° on day two and 12, respectively at 22℃. This could be related to the fact explained by Messina et al. (2012) that yellow-pale colour reaches its maximum concentration before complete ripening, where β-carotene and lycopene achieve their peak.

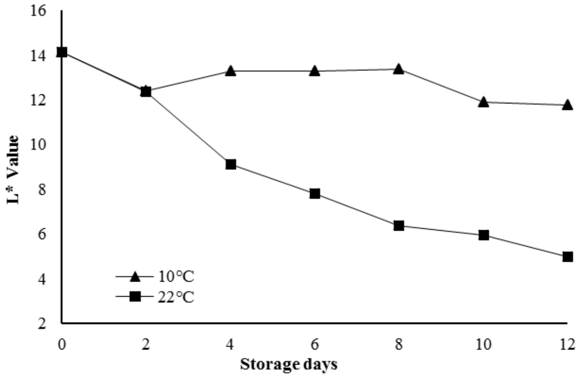

Figure 2 L* value of tomato during 12 days of storage at 10℃ and 22℃

Color index (CI) is frequently used for tomato color development (Kim et al. 2019). Storage time and temperature shows a significant ($p < 0.05$) effect on colour index CI (Figure 7) on tomato stored at 10℃ and 22℃. The dramatic increase in tomato CI was mostly observed in tomato stored at 22℃ with 0.26 in the last day of storage after it was -0.04 on day zero that attributed to the rapid increased of red color (a*) (Saad et al. 2016). In contrast, storage at 10℃ showed an increase of CI from -0.04 on day zero and reached 0.09 ± 0.01 on day 12. In this study, COL showed similar trend of increase as CI for 12 days storage (Figure 8).

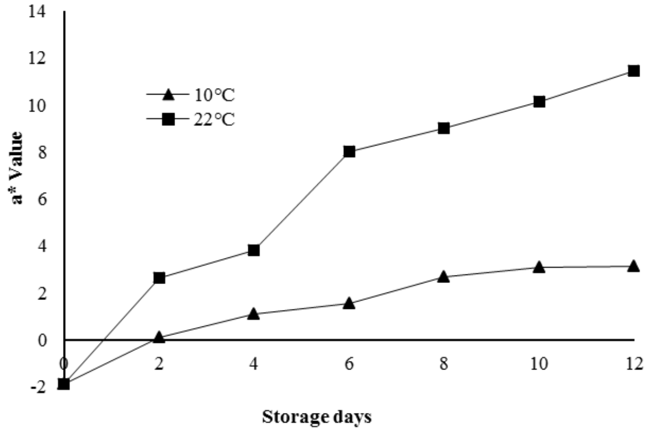

Figure 3 a* value of tomato during 12 days of storage at 10℃ and 22℃

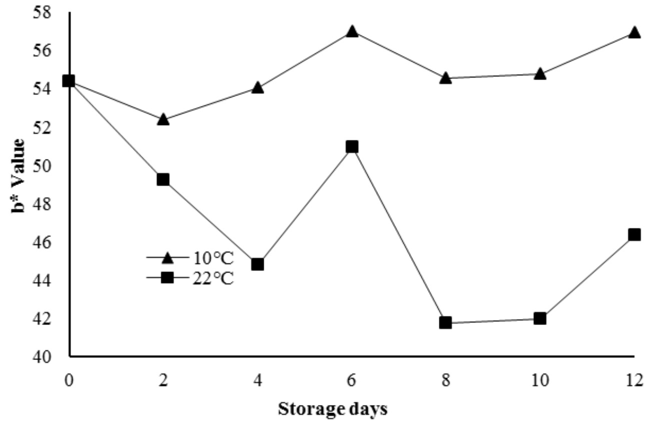

Figure 4 b* value of tomato during 12 days of storage at 10℃ and 22℃

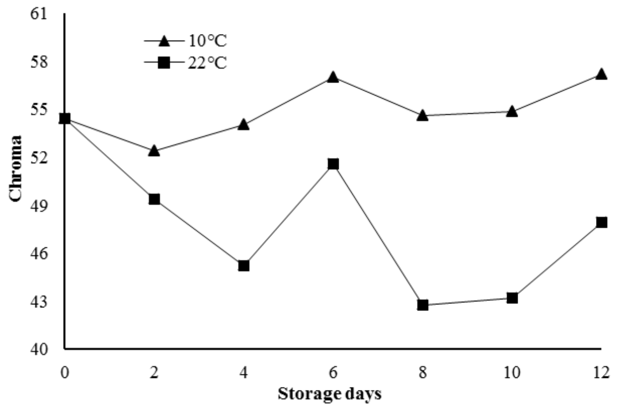

Figure 5 Chroma value of tomato during 12 days of storage at 10℃ and 22℃

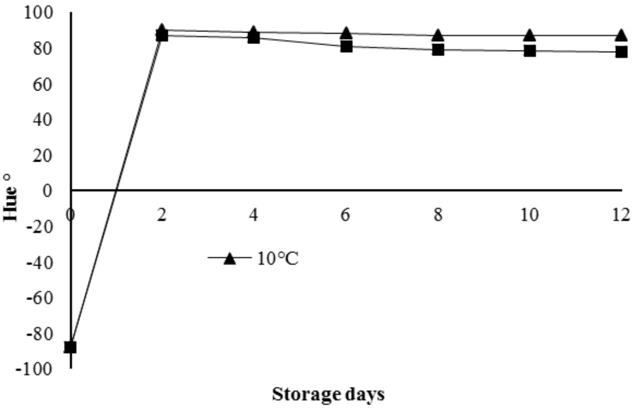

Figure 6 Hue° value of tomato during 12 days of storage at 10℃ and 22℃

According to Tadesse et al. (2015), both colour indices increment could be as an indication of dark red colour development due to the accumulation of lycopene that linked with internal membrane system. In their study, high red color development was observed in tomato stored at 30℃ and 20℃ compared to storage at 4℃.

As a whole, total color change ΔE of tomato stored at both storage conditions was significantly increased ($p < 0.05$) (Figure 9). However, total colour difference (ΔE) of stored tomato at 22℃ was higher than that of tomato stored at 10℃. Total color differences in tomato increased by 58% at 22℃ compared to 30% at 10℃ for 12 days storage period.

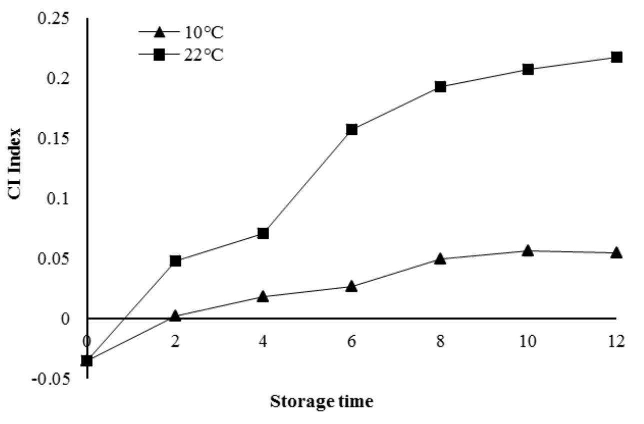

Figure 7 CI index value of tomato during 12 days of storage at 10℃ and 22℃

The statistical results of colour changes and colour indices were performed for kinetic and mathematical modelling. Zero-order and first-order model kinetic parameters are presented in Table 1. The results revealed that both zero-order and first-order kinetic models for colour parameters (L*, a* and b*) and colour indices (CI, COL and ΔE) can be described for stored tomato.

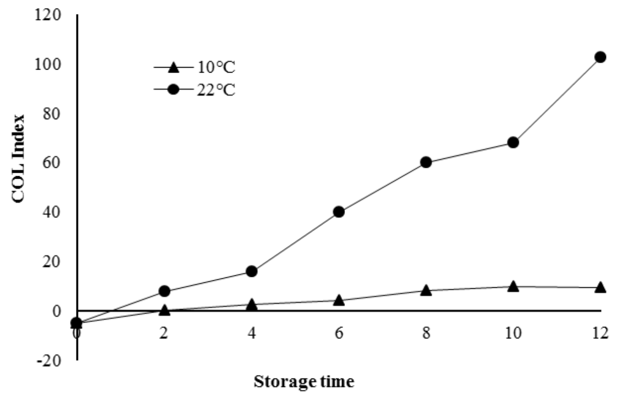

Figure 8 COL index value of tomato during 12 days of storage at 10℃ and 22℃

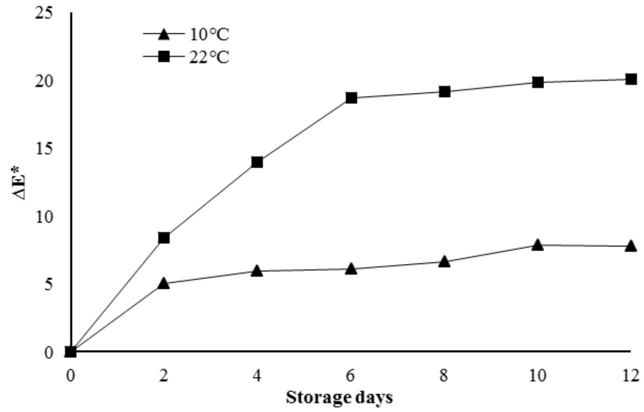

Figure 9 ΔE value of tomato during 12 days of storage at 10℃ and 22℃

Tomato colour changes indicated that L* value at both storage conditions could be described by first-order model with high values of R^2 and lower values of *SE*, X^2 and *RMSE* (Table 1). However, the kinetics of a* value at 10℃ could be adequately described by first-order model (R^2 = 0.9687), whereas a* value at 22℃ was almost fitted with zero-order model (R^2 = 0.9246) (Table 1). Based on first-order kinetic model, the kinetic rate constant for L* increased from -0.0112 at 10℃ to -0.0886 at 22℃. Therefore, increasing the degradation of chlorophyll and synthesis of lycopene (red color) for 12 days storage period.

The modelling studies revealed that the values determined for (CI, COL and ΔE) at 10℃ could be sufficiently explained by first-order model (R^2 = 0.9554, 0.983 and 0.933 respectively). On the other hand, these indices followed zero-order kinetic model at 22℃ (R^2 = 0.939, 0.9905 and 0.8023 respectively) shown in Table 1.

3.3.3 Tomato firmness

The study found that there was a significant effect of both storage conditions ($p < 0.05$) on firmness of fresh tomato for 12 days. Firmness of stored tomato is progressively declined at 22℃, however slight increased at 10℃ (Figure10). For example, it was degraded from 3.54 to 1.14 at ambient condition and increased from 3.54 to 5.06 for 12 days.

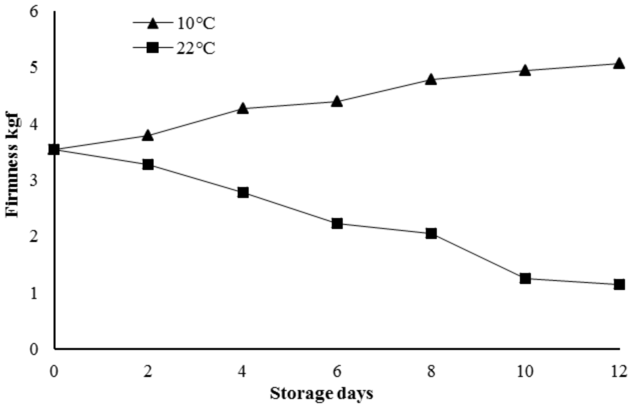

Figure 10 Firmness value of tomato during 12 days of storage at 10℃ and 22℃

Similar findings were also obtained by Tigist et al. (2013), where storage at temperature near to 22℃ decreased tomato firmness during storage resulted from moisture content loss (Abiso et al. 2015) and activation of enzymes which can degrade the cell wall of tomato (Hatami et al. 2013; Jung and Park 2012). According to Rugkong et al. (2010), enhanced mealiness and softening of tomato is linked with the increase on Pectin-Methylesterase (PME) activity. Pinheiro et al. (2013) also obtained that the changes_occurring in firmness are associated with enzymes activity like PME and Poly-Galacturonase (PG). Degradation of pectin is done by those two enzymes which occur in two stages. It starts as pectin is de-methylated via PME resulted in the formation of methanol and low level of both polygalacturonic acid pectin methylation. Second, pectin is depolymerized via PG that result in short chains of de-methylated pectin and then make firmness changes (in term of softening).

The experimental data of stored tomato firmness at 10℃ and 22℃ conditions was described by zero-order kinetic model which was evaluated by coefficient of determination (R^2= 0.9706 and 0.9794) respectively. The kinetic rate constant for tomato firmness was high at 10℃ and low at 22℃ with 0.1321 and -0.0155 day $^{-1}$ respectively.

3.3.4 Tomato Total Soluble Solids (TSS)

The study showed that there is no significant effect ($p > 0.05$) of storage condition and time on total soluble solid (TSS) contents of fresh tomato at both storage conditions (Figure 11) which was ranging from 4.04 to 4.50 °Brix at both storage conditions. Similar scenario of non-significance observed for 16 days at 4℃, 20℃ and 30℃ (Tadesse et al. 2015). However, Gharezi et al. (2012) and Islam et al. (2012) showed a gradual increase on tomato TSS at ambient condition as ripening process increase. Furthermore, Tigist et al. (2013) reported a significant effect of ambient room condition on tomato total soluble solids (TSS) content during 32 days. Due to the non-significance relationship between storage temperature and duration and tomato TSS, model was not possible to be applied.

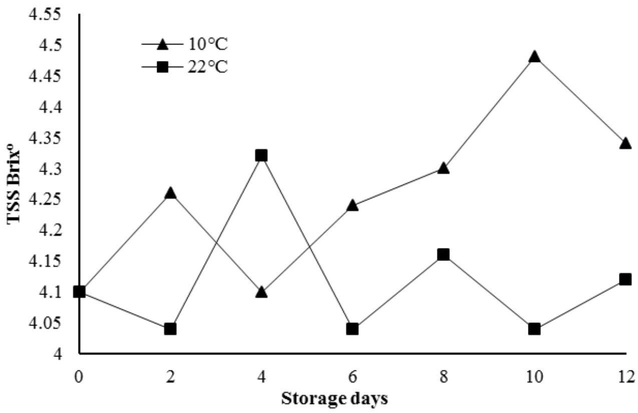

Figure 11 TSS value of tomato during 12 days of storage at 10℃ and 22℃

4 Conclusions

The two different storage conditions (10℃ and 20℃) of tomato influenced their weight loss, color and firmness. Tomato stored at 10℃ showed delayed changes in term of firmness, color and weight loss which provides desired quality characteristics after 12 days storage. Huge changes and damages occur in tomato quality attributes on tomato stored at 22℃ which made it unusable for further analysis. Stored tomato weight loss, firmness and color were well fitted by zero and first order kinetic models. Tomato weight loss stored at 10℃ could be characterized by zero order model and well fitted with first order model at 22℃. The first order kinetic model was used to describe the kinetic of L* value of tomato stored at both conditions. a*, COL, CI and ΔE were adequately fitted with first order kinetic model at 10℃ and sufficiently described by zero order model at 22℃. The findings also indicated that the kinetics changes on tomato firmness could be explained with zero order model. Generally, storage temperature needs to be considered carefully to provide high quality postharvest tomato without any loss.

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References

Abiso, E., N. Satheesh, and A. Hailu. 2015. Effect of storage methods and ripening stages on postharvest quality of tomato (*Lycopersicom Esculentum* Mill) cv. Chali. Annals. *Annals. Food Science and Technology*, 6(1): 127-137.

Arah, I. K., E. Kumah, E. Anku, and H. Amaglo. 2015. An overview of post-harvest losses in tomato production in Africa: causes and possible prevention strategies. *Journal of Biology, Agriculture and Healthcare*, 5(16): 78-88.

Atanda, S., P. Pessu, S. Agoda, I. Isong, and I. Ikotun. 2011. The concepts and problems of post–harvest food losses in perishable crops. *African Journal of Food Science*, 5(11): 603-613.

Ayandiji, A., O. Adeniyi, and D. Omidiji. 2011. Determinant post harvest losses among tomato farmers in Imeko-Afon local Government area of Ogun State, Nigeria. *Global Journal of Science Frontier Research*, 11(5): 23-27.

Ayomide, O., O. Ajayi, and A. Ajayi. 2019. Advances in the development of a tomato postharvest storage system: towards eradicating postharvest losses. *In Journal of Physics: Conference Series*, 1378, 022064.

Bal, L. M., A. Kar, S. Satya, and S. N. Naik. 2011. Kinetics of colour change of bamboo shoot slices during microwave drying. *International Journal of Food Science and Technology*, 46(4): 827-833.

Baninaiem, E., A. Mirzaaliandastjerdi, S. Rastegar, and K. Abbaszade. 2016. Effect of pre-and postharvest salicylic acid treatment on quality characteristics of tomato during cold storage. *Advances in Horticultural Sciences*, 30(3): 183-192.

Beckles, D. M. 2012. Factors affecting the postharvest soluble solids and sugar content of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biology and Technol*ogy, 63(1): 129-140.

Chayjan, R. A., and B. Alaei. 2016. New model for colour kinetics of plum under infrared vacuum condition and microwave drying. Acta *Scientiarum Polonorum Technologia Alimentaria*, 15(2): 131-144.

Chen, L., and U. L. Opara. 2013. Texture measurement approaches in fresh and processed foods—A review. *Food Research International*, 51(2): 823-835.

El-Ramady, H., E. Domokos-Szabolcsy, N. Abdalla, H. Taha, and M. Fári. 2015. (Postharvest management of fruits and vegetables storage) In *Sustainable Agriculture Reviews*, eds. E. Lichtfouse, vol. 15, 65-152. Cham, Switzerland：Springer International.

Fagundes, C., K. Moraes, M. B. Pérez-Gago, L. Palou, M. Maraschin, and A. Monteiro. 2015. Effect of active modified atmosphere and cold storage on the postharvest quality of cherry tomatoes. *Postharvest Biology and Technology*, 109: 73-81.

Gardas, B. B., R. D. Raut, and B. Narkhede. 2018. Evaluating critical causal factors for post-harvest losses (PHL) in the fruit and vegetables supply chain in India using the DEMATEL approach. *Journal of cleaner production*, 199: 47-61.

Gharezi, M., N. Joshi, and E. Sadeghian. 2012. Effect of postharvest treatment on stored cherry tomatoes. *Journal of Nutrition & Food Sciences*, 2(8): 1-10.

Hatami, M., S. Kalantari, and M. Delshad. 2013. Responses of different maturity stages of tomato fruit to different storage conditions. *Acta Horticulturae*, 1012: 857-864

Islam, M., T. Morimoto, and K. Hatou. 2012. Storage behavior of tomato inside a zero energy cool chamber. *Agricultural Engineering International: CIGR Journal*, 14(4): 209-217.

Jung, H. M., and J. G. Park. 2012. Effects of vibration stress on the quality of packaged apples during simulated transport. *Journal of Biosystems Engineering*, 37(1): 44-50.

Karlova, R., F. M. Rosin, J. Busscher-Lange, V. Parapunova, P. T. Do, A. R. Fernie, P. D. Fraser, C. Baxter, G. C. Angenent, and R. A. de Maagd. 2011. Transcriptome and metabolite profiling show that APETALA2a is a major regulator of tomato fruit ripening. *The Plant Cell*, 23(3): 923-941.

Khairi, A., M. Falah, A. Suyantohadi, N. Takahashi, and H. Nishina. 2015. Effect of storage temperatures on color of tomato fruit (*Solanum lycopersicum* Mill.) cultivated under moderate water stress treatment. *Agriculture and*

Agricultural Science Procedia, 3: 178-183.

Kim, D. S., D. U. Lee, J. H. Choi, S. Kim, and J. H. Lim. 2019. Prediction of carotenoid content in tomato fruit using a fluorescence screening method. *Postharvest Biology and Technology,* 156: 110917.

Majidi, H., S. Minaei, M. Almassi, and Y. Mostofi. 2014. Tomato quality in controlled atmosphere storage, modified atmosphere packaging and cold storage. *Journal of Food Science and Technology,* 51(9): 2155-2161.

Mandal, D., C. Lalhmingchawii, T. K. Hazarika, and A. C. Shukla. 2018. Effect of chitosan, wax and particle film coating on shelf life and quality of tomato cv. Samrudhi at ambient storage. *Research Journal of Agricultural Sciences*, 9: 111-116.

Mayani, J. M., C. S. Desai, and P. S. Vagadia. 2016. Post-harvest management of horticultural crops. Delhi: Jaya Publishing House.

Messina, V., P. G. Domínguez, A. M. Sancho, N. Walsöe de Reca, F. Carrari, and G. Grigioni. 2012. Tomato quality during short-term storage assessed by colour and electronic nose. *International Journal of Electrochemistry*, 2012: 1-7.

Munhuewyi, K. 2012. Postharvest Losses and Changes in Quality of Vegetables from Retail to Consumer: A Case Study of Tomato, Cabbage and Carrot. M.S. thesis, Stellenbosch: Stellenbosch Univ.

OECD. 2018. Guidelines on objective tests to determine quality of fruit and vegetables, dry and dried produce [cited 13 of October 2018]. Available at: https://www.oecd.org/agriculture/fruit-vegetables/publications/47288602.pdf. Accessed Date: January 29, 2020.

Park, M. H., P. Sangwanangkul, and D. R. Baek. 2018. Changes in carotenoid and chlorophyll content of black tomatoes (*Lycopersicone sculentum* L.) during storage at various temperatures. *Saudi Journal of Biological Sciences,* 25(1): 57-65.

Pathare, P. B., U. L. Opara, and F. A. J. Al-Said. 2013. Colour Measurement and analysis in fresh and processed foods: a review. *Food and Bioprocess Technology,* 6(1): 36-60.

Pereira, E., R. G. B. Silva, W. A. Spagnol, and V. S. Junior. 2018. Water loss in table grapes: model development and validation under dynamic storage conditions. *Food Science and Technology,* 38(3): 473-479.

Pinheiro, J., C. Alegria, M. Abreu, E. M. Gonçalves, and C. L. Silva. 2013. Kinetics of changes in the physical quality parameters of fresh tomato fruits (*Solanum lycopersicum*, cv.'Zinac') during storage. *Journal of Food Engineering*, 114(3): 338-345.

Ponce-Valadez, M., H. B. Escalona-Buendía, J. M. Villa-Hernández, F. D. de León-Sánchez, F. Rivera-Cabrera, I. Alia-Tejacal, and L. J. Pérez-Flores. 2016. Effect of refrigerated storage (12.5 ℃) on tomato (*Solanum lycopersicum*) fruit flavor: a biochemical and sensory analysis. *Postharvest Biology and Technology*, 111: 6-14.

Rai, G. K., R. Kumar, A. Singh, P. Rai, M. Rai, A. Chaturvedi, and A. Rai. 2012. Changes in antioxidant and phytochemical properties of tomato (*Lycopersicon esculentum* mill.) under ambient condition. *Pakistan Journal of Botany*, 44(2): 667-670.

Ramaswamy, H. S. 2014. *Post-harvest Technologies of Fruits & Vegetables*. Lancaster: DEStech Publications, Inc.

Rugkong, A., J. K. Rose, S. J. Lee, J. J. Giovannoni, M. A. O'Neill, and C. B. Watkins. 2010. Cell wall metabolism in cold-stored tomato fruit. *Postharvest Biology and Techno*logy, 57(2): 106-113.

Saad, A. M., A. Ibrahim, and N. El-Bialee. 2016. Internal quality assessment of tomato fruits using image color analysis. *Agricultural Engineering International: CIGR Journal,* 18(1): 339-352.

Sablani, S., L. Opara, and K. Al-Balushi. 2006. Influence of bruising and storage temperature on vitamin C content of tomato fruit. *Journal of Food Agriculture and Environment*, 4(1): 54.

Schouten, R. E., A. Natalini, L. Tijskens, E. J. Woltering, and O. van Kooten. 2010. Modelling the firmness behaviour of cut tomatoes. *Postharvest Biology and Technology*, 57(1): 44-51.

Sibomana, C. I., A. M. Opiyo, and J. N. Aguyoh. 2011. Growth, yield and postharvest qualities of tomato (*Lycopersicon esculentum* M.) as influenced by soil moisture levels and packaging. M.S. thesis, Njoro :Egerton Univ.

Sirisomboon, P., M. Tanaka, and T. Kojima. 2012. Evaluation of tomato textural mechanical properties. *Journal of Food Engineering*, 111(4): 618-624.

Tadesse, T. N., A. M. Ibrahim, and W. G. Abtew. 2015. Degradation and formation of fruit color in tomato (*Solanum lycopersicum* L.) in response to storage temperature. *American Journal of Food Technology*, 10(4): 147-157.

Tigist, M., T. S. Workneh, and K. Woldetsadik. 2013. Effects of variety on the quality of tomato stored under ambient conditions. *Journal of Food Science and Technology*, 50(3): 477-486.

Van Dijk, C., C. Boeriu, F. Peter, T. Stolle-Smits, and L. Tijskens. 2006. The Firmness of Stored Tomatoes (cv. Tradiro). 1. Kinetic and near infrared models to describe firmness and moisture loss. *Journal of Food Engineering*, 77(3): 575-584.

Weingerl, V., and T. Unuk. 2015. Chemical and fruit skin colour markers for simple quality control of tomato fruits. *Croatian Journal of Food Science and Technology*, 7(2): 76-85.

Zhang, B., D. M. Tieman, C. Jiao, Y. Xu, K. Chen, Z. Fei, J. J. Giovannoni, and H. J. Klee. 2016. Chilling-induced tomato flavor loss is associated with altered volatile synthesis and transient changes in DNA methylation. *Proceedings of the*

National Academy of Science, 113(44): 12580-12585.

Zou, J., J. Chen, N. Tang, Y. Gao, M. Hong, W. Wei, H. Cao, W. Jian, N. Li, and W. Deng. 2018. Transcriptome analysis of aroma volatile metabolism change in tomato (*Solanum lycopersicum*) fruit under different storage temperatures and 1-MCP treatment. *Postharvest Biology and Technology*., 135: 57-67.