sciendo

Journal of Horticultural Research 2022, vol. 30(1): 51–60
DOI: 10.2478/johr-2022-0005

© The Author(s) 2022. This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/).

SHELF-LIFE PREDICTION OF CITRUS LEMON USING A MULTIVARIATE ACCELERATED SHELF-LIFE TESTING (MASLT) APPROACH

Rokhani HASBULLAH*, Egy R. ISMAIL
Bogor Agricultural University, Indonesia

Received: February 2022; Accepted: May 2022

ABSTRACT

The shelf life of agricultural products is characterized by several quality parameters simultaneously. Estimating the shelf life using the multivariate accelerated shelf-life testing (MASLT) approach is expected to provide a more accurate shelf-life prediction. This research aims to examine the effect of temperature storage on lemon fruit quality and predict their shelf life with the MASLT approach. A total of 21 lemons for each treatment (storage temperatures) were washed and stored at 25, 35, and 45 °C. Changes in the quality of lemons were observed every day for 7 days, including moisture content, weight loss, firmness, total soluble solids, and color. Principal component analysis (PCA) was used to simplify many experimental lemon quality parameters to form a new coordinate system with maximum variance through linear transformation to form a new coordinate system with maximum variance. The results showed that 91.3% of the variance of all observational data could be explained by the first principal component (PC_1). Multivariate kinetics of quality parameter changes following a zero-order reaction. The plot of ln k_m against 1/T shows a multivariate activation energy value (E_a) of 62.99 kJ·mol^{-1} with a pre-exponential factor (k_0) of 3.87 × 10^{10} PC_1 score per day. The reaction acceleration factor (Q_{10}) based on storage temperatures of 35 °C and 45 °C is 2.17. The results of the predicted shelf life at cold temperatures (10 °C) and room temperature (25 °C) were 60.0 days and 18.8 days, respectively.

Key words: Arrhenius, lemon, MASLT, principal component analysis, shelf life

INTRODUCTION

Lemon (*Citrus limon*) originates from Asia. Various parts of this plant are used, including fruit peel, flowers, and leaves. The total soluble solids (TSS) of citrus fruit make up about 10–20% of the fresh weight (Kassim et al. 2020), and the citric acid content of lemon juice is about 5–6%, providing a sour taste. The citric acid from lemons is often used as an ingredient in cosmetics due to the ability to repair damaged skin and stimulate its regeneration (Sarwono 2007). In Indonesia, there is quite a big difference between exporting and importing lemons. In 2020, the volume of imports was 11 614.0 tons, whereas the export of lemons was only 131.3 tons (Erkan & Dogan 2019; Statistics Indonesia 2020a). The high import shows that the domestic supply of lemons is insufficient, which opens up opportunities for the development of the production and processing of lemons in Indonesia.

Indonesia has not set quality standards for lemons sold to consumers. Membership in the Organisation for Economic Co-operation and Development (OECD) results in compliance with the standard established by this organization.

*Corresponding author
e-mail: rokhani@apps.ipb.ac.id

The quality and shelf life of lemons are influenced by various physiological and biochemical changes that occur during the growth, development, and maturation of the fruit (Statistics Indonesia 2020b). The maturity level of citrus fruits at harvest is one of the essential factors affecting quality parameters, such as skin color, total antioxidant capacity, concentration of organic acids, and shelf life. Lemon is a non-climacteric fruit (Mukhim et al. 2015). In sweet citrus fruit, a gradual decrease in ascorbic acid, titrated acids and an increase in TSS occurred along with the ripening process (Ladaniya 2010). The results of the study by Al-Rousan et al. (2012) showed an increase in the percentage of juice, TSS, sugar–acid ratio, and pH value in Navel oranges in line with the extension of the harvest period (Al-Rousan et al. 2012).

Providing high-quality lemons requires producers to store the fruit in appropriate temperature and humidity conditions (Martínez-Hernández et al. 2018; Chowdhury et al. 2020). One part of a high-quality strategy is to study the shelf life of lemons. However, a full shelf-life test requires a high number of fruits over a long time. In order to facilitate this problem, tests are carried out under conditions able to shorten the shelf life, namely in nonoptimal conditions of product storage.

The accelerated shelf-life testing (ASLT) method is generally carried out using the Arrhenius equation. Here, Arrhenius and Q_{10} models can be used to predict the shelf life of lemons. The assumption used in this model is that increasing the storage temperature strengthens the reactions related to the deterioration of the fruit quality.

Estimation of shelf life using the ASLT method involves only one quality parameter. In fact, food quality is determined by many quality parameters, so the general use of ASLT can result in significant differences between the quality parameters used. A new approach to determine food shelf life by simultaneous considering many parameters of called multivariate accelerated shelf-life testing (MASLT) was proposed by Pedro and Ferreira (2006).

MASLT is based on principal component analysis (PCA), which aims to find a new set of axes in the multivariate space that better describes the structure of the data. The principal component analysis is constructed by linear combinations of the original variables (Pedro & Ferreira 2006). The lemon quality parameters include TSS, moisture content, firmness, weight loss, and color. Therefore, lemons' shelf life can be estimated based on many quality parameters simultaneously with the MASLT approach to produce a more precise estimate of shelf life. This study aims to (1) examine the effect of temperature storage on the quality of lemons and (2) predict the shelf life of lemons with the MASLT approach.

MATERIALS AND METHODS

Materials

The materials used in this study were lemon 'Cai Kahuripan' produced in Lembang District, West Java Province, Indonesia. Fruits were harvested at the physiological light green mature stage, having an average weight of 132.7 g. The lemons were washed and dried with a cloth, then stored in an Eyela Environmental Chamber at 95% relative humidity with temperatures of 25, 35, and 45 °C. Changes in the quality of lemons were observed every day for 7 days, including TSS, moisture content, firmness, weight loss, and lemon color. Observations at 45 °C were stopped when the sample got a hedonic score of less than 2.5. The tools used were: ATAGO PAL-α Digital Refractometer to measure TSS, rheometer for fruit firmness, chromameter for fruit color, oven for moisture content, vernier calipers for fruit diameter, desiccator, juicer, analytical balance, and environmental chambers.

Physical properties measurement

Weight

Changes in lemon weight were observed to determine the daily weight loss of lemons, which was calculated using Eq. (1).

$$WL = [(m_o - m_t)/m_o] \times 100\% \quad (1),$$

where WL is weight loss (%), m_o is the initial weight (g), and m_t is the weight at time t (g).

Moisture content

Lemon moisture content analysis was carried out using the oven method. The lemon slices were weighed and then dried in an oven for 24 hours at a temperature of 105 °C, and then the results of the drying were weighed. The moisture content of the sample was calculated using Eq. (2).

$$MC_{wb} = [(m_1 - m_2)/m_1] \times 100\% \quad (2),$$

where MC_{wb} is the moisture content of the wet base sample (%), m_1 is the weight of the initial sample before drying (g), and m_2 is the weight of the final sample after drying (g).

Firmness

The firmness of lemons was measured in the radial direction using a rheometer. The resulting data is presented in the form of the maximum forces that the lemon fruit can receive until the rheometer test rod can penetrate the lemon peel.

Total soluble solids

The TSS value is indicated in °Brix in the range 0–85°. The lemons were squeezed to get the extract that was dropped onto a refractometer prism, and the TSS value was recorded (Gardjito & Wardana 2003).

Peel color

Lemon colors were analyzed using a chromameter to measure the color coordinates (L*, a*, and b*). Based on these coordinates, two parameters are calculated to represent the information, namely the hue angle (h*) and the total color difference (∆E*). The equation of the hue angle and the total color difference are shown in the Eq. (3) and Eq. (4).

$$h = \tan^{-1}(b^*_{t,T}/a^*_{t,T}) \quad (3),$$

$$\Delta E^* = \sqrt{(L^*_{t,T} - L^*_{0,T})^2 + (a^*_{t,T} - a^*_{0,T})^2 + (b^*_{t,T} - b^*_{0,T})^2} \quad (4),$$

where $L^*_{t,T}$, $a^*_{t,T}$, and $b^*_{t,T}$ correspond to the sample observed at time t and temperature T, while $L^*_{0,T}$, $a^*_{0,T}$, and $b^*_{0,T}$ are the observed sample at t = 0 at the same temperature of T (Pedro & Ferreira 2006).

Organoleptic test

Lemons were evaluated by 30 untrained panelists to observe changes in quality, including color, firmness, skin texture, and appearance of lemons during storage at 45 °C. The test scale used values from 1 – dislike very much, 2 – dislike, 3 – neutral, 4 – like, to 5 – very much like. The lemon sample was considered to have been rejected if the panelists had given a score not higher than 2.5.

Multivariate accelerated shelf-life testing approach

MASLT is based on compressing the space spanned by the original variables through PCA and then using the score as a property for further shelf-life assessment. Since PCA can be considered a least-squares procedure, the multivariate parameters can be interpreted as the loading average of the kinetic parameters obtained from the original properties. The main assumption of MASLT is that degradation reactions are the primary source of variation in the dataset as the samples initially have the same composition and the storage conditions are well controlled. Therefore, PCA should be driven by time-related phenomena (Pedro & Ferreira 2006).

Estimation of shelf life with the MASLT approach is carried out in several stages. First, the MASLT uses the PC scores generated by the PCA model to describe the kinetics of the degradation reaction. Next, the PC score was used to model the Arrhenius equation, explaining the relationship between temperature and the rate constant of degradation. In the end, the information obtained allows the calculation of the storage time (Chaudhry et al. 2018).

Statistical data analysis

Principal component analysis

Data on quality change obtained from observations during fruit storage at temperatures of 25, 35, and 45 °C were analyzed based on zero-order reaction kinetics (Eq. 5). The data were then analyzed using PCA using statistical software OriginPro 2021b to obtain the PC score. The PC values were then plotted against time for each temperature following the Arrhenius model.

$$A_t = A_0 + k_m \cdot t \quad (5),$$

where A_t – quality at time t, A_0 – initial quality, k_m – kinetic constant, and t – time (days).

Reaction kinetics model

The natural logarithm value of the multivariate kinetic constant ($\ln k_m$) at temperatures of 25, 35, and 45 °C is plotted against one per absolute temperature (1/T) following the Eq. (6).

$$\ln k_m = \ln k_o + [(E_a/R) \times (1/T)] \quad (6),$$

where k_m – multivariate kinetic constant (PC score per day), k_o – pre-exponential factor (PC score per day), E_a – multivariate activation energy ($J \cdot mol^{-1}$), T – temperature (K), R – gas constant (8.314 $J \cdot mol^{-1}$).

Based on the Eq. (6), the value of Q_{10} based on two values of k_m at temperature of 35 °C and 45 °C using Eq. (7) can be determined.

$$Q_{10} = \frac{k_{m(45\,°C)}}{k_{m(35\,°C)}} \quad (7).$$

Shelf-life analysis

The shelf life of lemons at various temperatures is estimated by Eq. (8) based on a storage temperature of 45 °C.

$$t_{s.T} = t_{s.45}\, Q_{10}^{[(45\text{-}T)/10]} \quad (8),$$

where t – storage time (days), $t_{s.45}$ – shelf life at base temperature 45 °C (days) $t_{s.T}$ – shelf life at estimated temperature (days).

RESULTS

Quality change kinetics during storage

All the reduced quality parameters that resulted in damage to the fruit were dependent on temperature and time of storage. In our experiment, parameters such as weight loss, moisture content, firmness, TSS content, and skin color were controlled.

Weight loss

The research data showed a continual increase in weight loss with time and temperature (Fig. 1A). The greatest weight loss on day 5 occurred at a storage temperature of 45 °C (18.80%), followed by a storage temperature of 35 °C (10.03%) and 25 °C (6.19%).

Moisture content

The research data showed a continual decrease in the moisture content of lemons with time and temperature (Fig. 1B). Storage of lemons at higher temperatures resulted in a greater reduction in moisture content. The moisture contents of lemons on day 5 at temperatures of 25, 35, and 45 °C were 91.47, 91.15, and 90.14%, respectively.

Firmness

The research data showed a decrease in the firmness of lemons, almost proportional to time and temperature (Fig. 2A). Firmness loss was caused by an increase in respiration rate. The highest firmness value of lemon fruit was on day 0 (6.58 kgf). The lowest firmness on day 5 occurred at a storage temperature of 45 °C (2.35 kgf), followed by a storage temperature of 35 °C (4.78 kgf), and a temperature of 25 °C (5.38 kgf).

Total soluble solids

The determination of TSS, reflecting the total mineral elements dissolved, showed an increase in TSS of lemons after being stored for 5 days (45 °C) and 7 days (25 and 35 °C) (Fig. 2B). TSS of lemons at the beginning was 5.02 °Brix, which is different from the results of the study of Dong et al. (2019), with the lowest TSS of lemons being 6.09 °Brix. This difference can occur due to different agricultural practices, assoil nutrient content, harvest time, environment, and other factors (Summo et al. 2018).

Color

Color was measured based on the CIELAB scale of three coordinate values, namely L*, a*, and b*. The L* coordinate represents luminosity with a range of black (L* = 0) and white (L* = 100). The a* coordinate has a negative value for a green color and a positive value for a reddish color. The b* coordinate has a positive value for the yellowish color and a negative value for the bluish color (Sant'Anna et al. 2013). The parameters used to analyze the color coordinates are the hue angle (h*) and the total color difference (ΔE*), which are shown in Figures 2C and 2D.

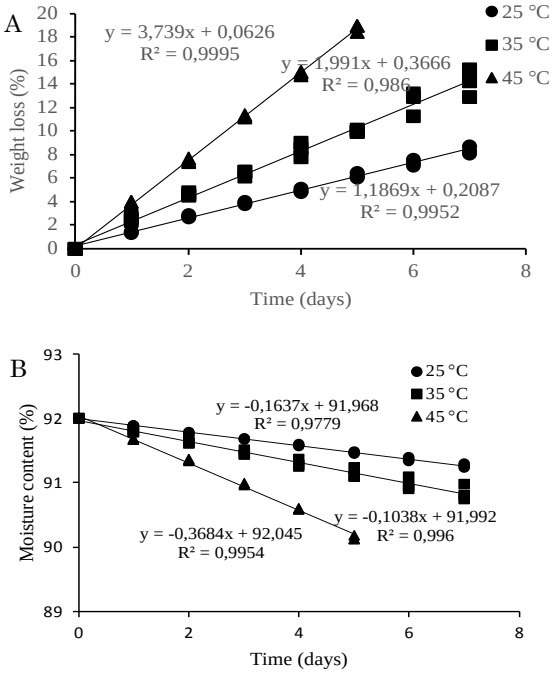


Figure 1. Changes in weight loss of lemons during storage (A) and changes in moisture content (B)

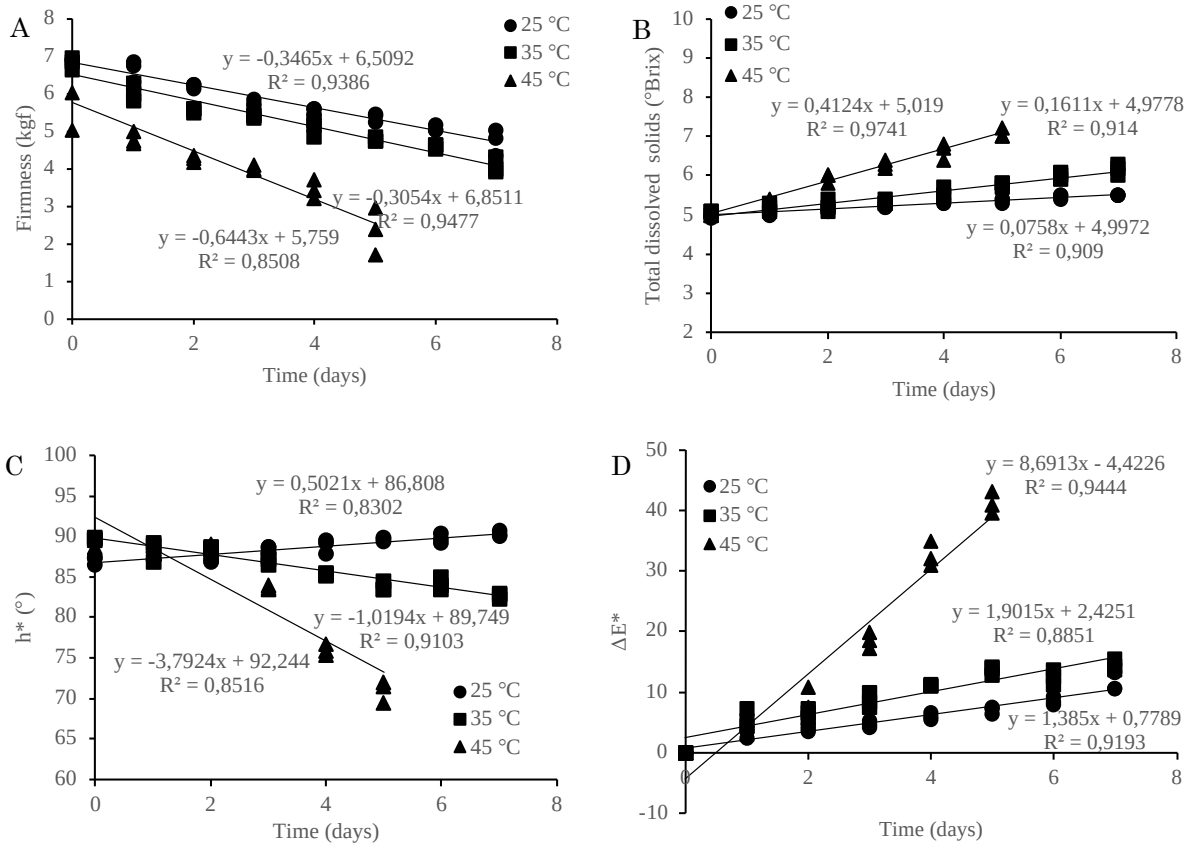


Figure 2. Change in the firmness (A), changes in the total dissolved solid (B), changes in the hue angle (h*) (C), and total change in color difference (ΔE*) of lemon samples during storage at temperatures of 25, 35, and 45 °C (D)

The hue angle (h*) for storage temperatures of 35 and 45 °C decreased, while there was a deviation at a storage temperature of 25 °C, which increased. The hue angle of lemons on day 0 was 88.5° and on day 5 at temperatures of 25, 35, and 45 °C, 89.60°, 83.81°, and 70.88°, respectively. Similar results were also found in the study of Sun et al. (2019) that there was a decrease in the hue angle (h*) of lemons with increasing storage time (Sun et al. 2019).

Hue angles of 0° or 360° represent red, angles 90°, 180°, and 270° represent yellow, green, and blue, respectively (Pathare et al. 2013). A hue angle closer to a 90° angle indicates that the color of the lemon is closer to yellow, whereas a direction closer to a 45° angle reflects an orange color. The hue angle data showed that the storage temperatures of 35 and 45 °C resulted in a color change that led to an orange color, while at a storage temperature of 25 °C, it led to a yellow color. The deviation that occurs to the storage temperature of 25 °C can be caused by the chromameter, which has decreased accuracy due to the age of the tool.

Organoleptic test

The liking or hedonic test is based on panelists' personal evaluation of likes or dislikes and their levels (Sofiah & Achyar 2008). In this study, the hedonic test was carried out only for fruits stored at a temperature of 45 °C. This was done as an information base for estimating the shelf life of lemons. This test is stopped if the score is less than 2.5. Table 1 shows that samples of lemons at a storage temperature of 45 °C began to be slightly disliked by the panelists from day 3, with an average score of 2.76. Rejection of lemon fruit samples from all panelists occurred on day 4 with an average score of less than 2.5. The hedonic test parameter that experienced rejection earlier was the firmness parameter.

Table 1. Average ± standard deviation hedonic score of lemon fruit at storage temperature of 45 °C

Time (days)	Average score			
	Color	Firmness	Texture	Appearance
0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
1	4.3 ± 0.6	4.0 ± 0.9	4.2 ± 0.8	4.2 ± 0.6
2	3.9 ± 1.1	3.3 ± 0.7	3.3 ± 1.0	3.9 ± 0.9
3	2.9 ± 0.8	2.6 ± 0.7	2.7 ± 1.0	2.8 ± 0.9
4	2.5 ± 1.0	1.7 ± 0.4	2.4 ± 1.0	2.4 ± 1.0
5	1.8 ± 0.4	1.0 ± 0.0	1.1 ± 0.3	1.1 ± 0.3

Principal component analysis and principal component relationship with time

Average data from repeated measurements of each quality parameter (weight loss, firmness, TSS, moisture content, and color) at different storage temperatures (25, 35, and 45 °C) were analyzed by PCA to produce a PC that can represent several of the observed quality parameters. The PCA results show that the first principal component (PC_1) can explain 91.29% of the total variance of all observational data, while PC_2, PC_3, PC_4, PC_5, and PC_6 are 5.44%, 1.56%, 0.97%, 0.70%, and 0.04% respectively, so the total is 100%.

Mariana (2013) explains that to determine the number of PCs used, it can be based on the cumulative proportion of the diversity of the original data described by the n main components of at least 80% (Mariana 2013). Therefore, the PC dataset against the time used is only PC_1 because it is considered sufficient to represent the entire observational data. PC_1 data at storage temperatures of 25, 35, and 45 °C plotted against time is shown in Figure 3.

The plot of PC_1 scores against time shows a high correlation between the reaction order described in the Arrhenius equation, which is zero order, with a coefficient of determination for temperature data of 25, 35, and 45 °C of 0.9895, 0.9834, and 0.9860, respectively. PC_1 is not plotted following order one or order two because it produces a low correlation to that order.

Multivariate modeling and estimating shelf life

The order for the reaction used depends on the degree of closeness of the data to the Arrhenius equation of order zero, one, two, and so on. The linear regression equation of the PC_1 score of time (Table 2) is analogous to the zero-order Arrhenius equation, namely $A_t = A_0 - k_m \cdot t$. Based on this equation, the slope of the linear regression equation above states the multivariate kinetic constant (k_m), which is constant for each storage temperature.

Furthermore, the value of k_m is plotted following the Arrhenius equation related to temperature, namely $\ln k_m = \ln k_0 + (E_a/R)(1/T)$. The y-axis represents $\ln k_m$, and the x-axis represents 1/T with temperature in Kelvin units. Based on this equation, the slope of the curve is expressed as the value of E_a/R, where R is the gas constant ($R = 8.314\ J \cdot mol^{-1}$), while the intersection of the curve with the y-axis is the value of $\ln k_0$. The Arrhenius equation obtained is then used to obtain the k_m value at the desired storage temperature (25, 35, and 45 °C). The k_m constant, Arrhenius equation, and activation energy are presented in Table 2.

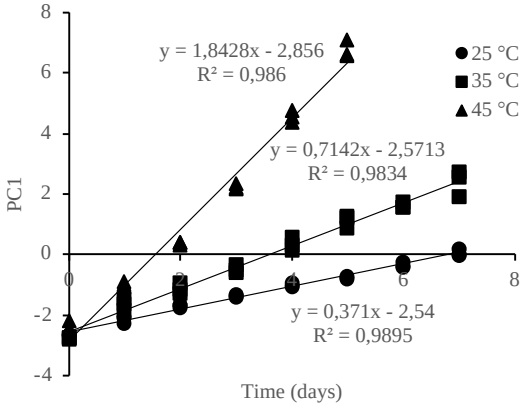


Figure 3. Multivariate kinetics of the *PC1* score of lemon samples during storage at temperatures of 25, 35, and 45 °C

Table 2. Parameters of zero-order reaction kinetics of *PC1* score as a function of storage of lemons at temperatures of 25, 35, and 45 °C

Temperature	k_m[a]	Linear regression	k_o	E_a
(°C)	(PC_1 per score day)	Equation[b]	(PC_1 per score day)	(kJ·mol^{-1})
25	0.3710			
35	0.7142	$\ln k_m = 24.379 - 7576.9\ (1/T)$	2.17	62.99
45	1.8428			

[a] k_m states the multivariate kinetic constants based on the linear regression equation
[b] this equation is generated from linear regression on the ln k_m vs. 1/T curve

Activation energy is the minimum amount of energy required for the reaction to proceed. The magnitude of the activation energy can describe the magnitude of the effect of temperature on the reaction. The magnitude of the activation energy shows a significant change in the value of ln k_m with only a few degrees of change in storage temperature. The values of activation energy were classified into three groups, namely small (6.37–62.76 kJ·mol^{-1}), medium (62.76–125.52 kJ·mol^{-1}), and high (209.20 –418.4 kJ·mol^{-1}) (Arpah 2007). Based on Table 2, the activation energy obtained is 62.99 kJ·mol^{-1}, which is classified as moderate activation, indicating that the change rate of quality parameters is relatively moderate.

The storage temperature strongly influences the size of the multivariate kinetic constant (k_m) of lemons. The results of the model showed a strong correlation between the temperature of storage and the constant rate of the quality decrease. The higher the temperature in storage, the higher the rate constant for the decline in fruit quality. From the results of the study, it can be seen that the temperature of 25 °C for lemon storage is better than the temperatures of 35 and 45 °C.

The reaction acceleration factor (Q_{10}) value was determined based on the value of k_m at the storage temperature treatment of 35 and 45 °C using the shelf-life analysis equation. The value of Q_{10} (Eq. 7) for the zero-order reaction equation was 2.17. Furthermore, this Q_{10} value can be used to estimate the shelf life at various storage temperatures, with the shelf life based on a storage temperature of 45 °C is 4 days. The results of the estimated shelf life at various storage temperatures based on Eq. (8) are shown in Figure 4.

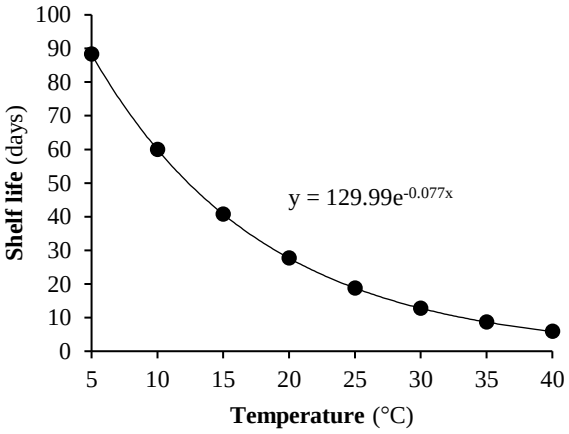


Figure 4. The relationship between storage temperature and shelf life of lemons ($y = 129.99e^{-0.077x}$)

DISCUSSION

The effect of temperature storage on the quality of lemons

The weight loss of lemons refers to water. Loss of water also causes a decrease in appearance quality due to wilting and shrinkage of the texture to become soft, mushy, and decrease nutritional value. Our result is in line with the study on mango fruit, where weight loss increased faster at higher temperatures (Kusumiyati et al. 2018). The fast transpiration rate was directly proportional to the speed of fruit loss in weight of Bali salak (Pudja 2009).

A decrease in moisture content is related to the transpiration rate of lemons. Postharvest storage of fruits and vegetables at lower temperatures can reduce transpiration and extend shelf life. According to Díaz-Pérez (2019), the transpiration rate in lemon can be reduced by about 30% by waxing the fruit's skin.

Softening reflects a decomposition of the fruit. The more decomposed polysaccharides make the fruit softer, and the breakdown of cell wall compounds, which were initially in the form of insoluble protopectin, turned into soluble pectin. This sequence occurs in the respiration process during fruit ripening (Purwadi et al. 2007). The relatively dense cell wall changes into more loose, affecting the attractive forces inside the fruit. The reshuffle that causes the weakening of the cell walls reduces the attractive forces between cells (Ilmi et al. 2015).

The TSS of lemons on day 5 at 25, 35, and 45 °C were 5.37, 5.77, and 7.07 °Brix, respectively. Higher storage temperatures can increase the respiration rate of lemons (Artés-Hernández et al. 2007). An increase in respiration rate has implications for an increase in the TSS of lemons. This is in line with Khathir et al. (2019) that the increase in TSS results from of the formation of sugar in the respiration process that breaks down complex carbohydrates. The increase in TSS is connected with the length of storage. The results reported by Kayesh et al. (2018) showed an increase in the TSS of lemons with increasing storage time due to an increase in the respiration rate of lemons. In immature fruit, many carbohydrates are stored in the form of starch, and during the process leading to maturity, the content will turn into sugar (Putri et al. 2015).

The total color difference (ΔE*) of lemons on the 5th day at temperatures of 25, 35, and 45 °C was 7.09, 13.62, and 41.25, respectively. This parameter indicates the distance between two points of spatial coordinates of L*, a*, and b*. Besides being easy to measure, color is an important parameter to monitor quality during shelf life because of the linear relationship between them (Kathir et al. 2019).

The total color difference can be classified analytically as very distinct ($\Delta E^* > 3$), distinct ($1 < \Delta E^* < 3$), and small difference ($\Delta E^* < 1.5$) (Adekunte et al. 2010). Based on this classification, the total color differences of lemons at all storage temperatures were classified as very distinct ($\Delta E^* > 3$), starting from the first day of storage.

Color is the first organoleptic attribute seen by consumers in buying or consuming a product (Apandi et al. 2016). The texture is a feature of a material construction as a result of a combination of several physical properties, including size, shape, amount, and elements of the formation of materials that can be felt by the senses of touch and taste (Midayanto & Yuwono 2014).

Shelf life of lemons

Physical and chemical changes are closely related to the decrease in fruit quality during storage. Data on changes in lemon quality parameters were obtained from the three representative samples of each storage temperature, then plotted against time. The plot results show changes in quality concerning storage time for temperatures of 25, 35, and 45 °C. The quality degradation rate constant is the value of the rate of decline in a material leading to damage in the storage process. So the higher the value of the constant rate of decline in quality, the faster the damage will occur. This means that the damage to the fruit of storage affects the shelf life of the fruit (Khatir et al. 2019).

It can be seen from Figure 4 that an increase in the storage temperature will exponentially shorten the shelf life of lemons. The shelf life of lemons stored at cold temperature (10 °C) and room temperature (25 °C) is 60.0 days and 18.8 days, respectively. Sun et al. (2019) reported that lemons harvested at the yellow stage and then stored at cold temperatures (10 °C) have a shelf life of 30 days and those harvested and stored at the green stage up to 90 days (Purwadi et al. 2007). Khathir et al. (2019) explained that lower temperatures could extend shelf life because they can slow down the process of respiration and product transpiration. This research also showed the decrease in moisture content would be slower at lower storage temperatures reflecting the lower transpiration rate of lemons.

CONCLUSIONS

There was a strong correlation between the storage temperature and the rate of the quality decrease. The higher the temperature in storage, the higher the rate of the decline in fruit quality. During storage, lemon fruit quality parameters decreased in firmness, moisture content, and hue angle (h*) with a higher rate of decrease with increasing storage temperature. Weight loss, TSS content, and total color difference (ΔE*) increased with increasing storage temperature.

The PCA produces PC_1 (first principal component) of 91.29% variance in all observational data. The PC_1 plot of each treatment of storage temperature against time shows a zero-order reaction relationship of the Arrhenius equation.

The ln k_m plot against 1/T shows a multivariate activation energy value (E_a) of 62.99 kJ·mol^{-1} with a pre-exponential factor (k_0) of 3.87×10^{10} PC_1 per day score. The reaction acceleration factor (Q_{10}) based on storage temperatures of 35 and 45 °C is 2.17. This information gives a possibility to use MASLT to predict the shelf life of lemon fruit.

REFERENCES

Adekunte A.O., Tiwari B.K., Cullen P.J., Scannell A.G.M., O'Donnell C.P. 2010. Effect of sonication on colour, ascorbic acid and yeast inactivation in tomato juice. Food Chemistry 122(3): 500–507. DOI: 10.1016/j.foodchem.2010.01.026.

Al-Rousan W.M.M., Ajo R.Y., Angor M.M., Osaili T., Bani-Hani N.M. 2012. Impact of different irrigation levels and harvesting periods on the quantity and quality of Navel oranges (*Citrus sinensis*) and fruit juice. Journal of Food, Agriculture and Environment 10(2): 115–119.

Apandi I., Restuhadi F., Yusmarini 2016. Consumers preference mapping analysis for the sensory attribute of soyghurt product within the student Agricultural Faculty of University of Riau. Jom 3(1); 16 p.

Arpah M. 2007. Determination of food expiration. Department of Food Science and Technology, Faculty of Agricultural Technology, IPB University.

Artés-Hernández F., Rivera-Cabrera F., Kader A.A. 2007. Quality retention and potential shelf-life of fresh-cut lemons as affected by cut type and temperature. Postharvest Biology and Technology 43: 245–254. DOI: 10.1016/j.postharvbio.2006.09.009.

Chaudhry M.M.A., Amodio M.L., Babellahi F., de Chiara M.L.V, Rubio J.M.A., Colelli G. 2018. Hyperspectral imaging and multivariate accelerated shelf life testing (MASLT) approach for determining shelf life of rocket leaves. Journal of Food Engineering 238: 122–133. DOI: 10.1016/j.jfoodeng.2018.06.017.

Chowdhury M.G.F., Khan M.H.H., Miaruddin M., Rahman M.M. 2020. Postharvest quality and shelf life of lemon as affected by storage temperature and relative humidity. Journal of Agricultural Engineering IEB 43/AE(1):1–7.

Díaz-Pérez J.C. 2019. Transpiration. In: Yahia E.M. (Ed.), Postharvest Physiology and Biochemistry of Fruits and Vegetables. Woodhead Publishing, pp. 157–173. DOI: 10.1016/b978-0-12-813278-4.00008-7.

Dong X., Hu Y., Li Y., Zhou Z. 2019. The maturity degree, phenolic compounds and antioxidant activity of Eureka lemon [*Citrus limon* (L.) Burm. f.]: A negative correlation between total phenolic content, antioxidant capacity and soluble solid content. Scientia Horticulturae 243: 281–289. DOI: 10.1016/j.scienta.2018.08.036.

Erkan M., Dogan A. 2019. Chapter 5. Harvesting of Horticultural Commodities. In: Yahia E.M. (Ed.), Postharvest Technology of Perishable Horticultural Commodities. Woodhead Publishing, pp. 129–159. DOI: 10.1016/b978-0-12-813276-0.00005-5.

Gardjito M., Wardana A.S. 2003. Hortikultura, Teknik Analisis Pasca Panen. Transmedia Mitra Printika, Yogyakarta, Indonesia. [in Indonesian]

Ilmi N.K., Poerwanto R., Sutrisno 2015. Hot water treatment and storage temperature control to maintain the quality mango fruit (*Mangifera indica* L.) cv. Gedong. Jurnal Hortikultura 25(1): 78–87. DOI: 10.21082/jhort.v25n1.2015.p78-87. [in Indonesian with English abstract]

Kassim A., Workneh T.S., Laing M.D. 2020. A review of the postharvest characteristics and pre-packaging treatments of citrus fruit. AIMS Agriculture and Food 5(3): 337–364. DOI: 10.3934/agrfood.2020.3.337.

Kayesh E., Das S., Roni M.S., Rajib M.M.R., Islam M.M., Sultana H. 2018. Shelf life and quality of Sorboti lemon as affected by different chemicals and storage temperature. Archives of Agriculture and Environmental Science 3(3): 303–309. DOI: 10.26832/24566632.2018.0303014.

Khathir R., Sarmedi, Putra B.S., Agustina R. 2019. The prediction of tomato shelf life based on its total soluble solid by using Arrhenius and Q_{10} model. Rona Teknik Pertanian 12(1): 32–38. DOI: 10.17969/rtp.v12i1.12605. [in Indonesian with English abstract]

Kusumiyati, Farida, Sutari W., Hamdani J.S., Mubarok S. 2018. The effect of storage duration on total dissolved solids, firmness and weight loss of arumanis mango fruit. Jurnal Kultivasi 17(3): 766–771. [in Indonesian with English abstract]

Ladaniya M. 2010. Citrus Fruit: Biology, Technology and Evaluation. Academic Press, 576 p.

Mariana M. 2013. Analisis komponen utama. Jurnal Matematika dan Pembelajaran 2(2): 99–113. [in Indonesian]

Martínez-Hernández G.B., Gómez P.A., Orihuel-Iranzo B., Bretó J., Artés-Hernández F., Artés F. 2018. Innovative and sustainable postharvest treatments to control physiological disorders and decay in lemon fruit during long transport and commercialization. Acta Horticulturae 1194: 235–240. DOI: 10.17660/actahortic.2018.1194.35.

Midayanto D.N., Yuwono S.S. 2014. Determination of quality attribute of TofuTexture to be recommended as an additional requirement in Indonesian National Standard. Jurnal Pangan dan Agroindustri 2(4): 259–267. [in Indonesian with English abstract]

Mukhim C., Nath A., Deka B.C., Swer T.L. 2015. Changes in physico-chemical properties of Assam lemon (*Citrus limon* Burm.) at different stages of fruit growth and development. Bioscan 10(2): 535–537.

Pathare P.B., Opara U.L., Al-Said F.A.-J. 2013. Colour measurement and analysis in fresh and processed foods: A review. Food and Bioprocess Technology 6: 36–60. DOI: 10.1007/s11947-012-0867-9.

Pedro A.M.K., Ferreira M.M.C. 2006. Multivariate accelerated shelf-life testing: a novel approach for determining the shelf-life of foods. Journal of Chemometrics 20(1–2): 76–83. DOI: 10.1002/cem.995.

Pudja I.A. 2009. Respiration rate and weight loss of fresh salak Bali fruit on polyethylene plastic packaging during storage in modified atmosphere. Jurnal Agrotekno 15(1): 8–11. [in Indonesian with English abstract]

Purwadi A., Usada W., Isyuniarto 2007. Influence of ozonisation duration on the storage age of tomato fruit (*Lycopersicum esculentum* Mill). Prosiding PPI – PDIPTN, July 10. [in Indonesian with English abstract]

Putri T.K., Veronika D., Ismail A., Karuniawan A., Maxiselly Y., Irwan A.W., Sutari W. 2015. Utilization kind of local West Java bananas (banana and plantain) based figs and flour product. Jurnal Kultivasi 14(2): 63–70. [in Indonesian with English abstract]

Sant'Anna V., Gurak P.D., Marczak L.D.F., Tessaro I.C. 2013. Tracking bioactive compounds with colour changes in foods – A review. Dyes and Pigments 98: 601–608. DOI: 10.1016/j.dyepig.2013.04.011.

Sarwono B. 2007. Khasiat dan manfaat jeruk nipis, 6th ed. Agromedia Pustaka, Jakarta. [in Indonesian]

Sofiah B.D., Achyar T.S. 2008. Buku Ajar Kuliah Penilaian Indra. Universitas Padjadjaran, Jatinangor. [in Indonesian]

Statistic Indonesia 2020a. Buletin Statistik Perdagangan Luar Negeri Ekspor. Desember 2020. Badan Pusat Statistik. Jakarta. [in Indonesian]

Statistic Indonesia 2020b. Buletin Statistik Perdagangan Luar Negeri Impor. Desember 2020. Badan Pusat Statistik. Jakarta. [in Indonesian]

Summo C., Palasciano M., De Angelis D., Paradiso V.M., Caponio F., Pasqualone A. 2018. Evaluation of the chemical and nutritional characteristics of almonds (*Prunus dulcis* (Mill). D.A. Webb) as influenced by harvest time and cultivar. Journal of the Science of Food and Agriculture 98(15): 5647–5655. DOI: 10.1002/jsfa.9110.

Sun Y., Singh Z., Tokala V.Y., Heather B. 2019. Harvest maturity stage and cold storage period influence lemon fruit quality. Scientia Horticulturae 249: 322–328. DOI: 10.1016/j.scienta.2019.01.056.