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Shelf-life Estimation of Dried Chili in Vacuum Packaging

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ABSTRACT

This research aimed to build a model for estimating the shelf life of dried chilies in vacuum packaging stored at any storage temperature. The shelf-life estimation of dried red chilies was carried out based on the change rate of dried chilies quality parameters using the ASLT (Accelerated Shelf-Life Testing) method with the Arrhenius approach. The shelf-life estimation using the ASLT method was carried out by conditioning the storage room, which could accelerate the degradation reaction, stored at temperatures above room temperature. Prior to storage, red chilies were dried until their moisture content reaches 10%. Then it was packaged in vacuum packaging made of PE (polyethylene) plastic and stored at 35°C. During the storage period, the observation was conducted on some quality parameters, namely moisture content, color, and vitamin C content. The same experiments were also carried out at 40°C, 45°C, and 50°C to obtain different rate constant values. The shelf-life estimation results from the Arrhenius equation model were selected based on the critical parameter, in this study the critical parameter was the decrease of vitamin C content. The shelf life of dried red chilies that were packed in vacuum stored at room temperature (25°C) could maintain its quality up to 365 days.

1. INTRODUCTION

Fresh agricultural products such as fruit and vegetables are susceptible to damage due to physical, chemical, microbiological and physiological influences. In general, the quality of fresh agricultural products will decrease during post-harvest handling, causing their shelf life to be relatively short. Red chili (*Capsicum annuum* L.) is a commodity with high economic value, but its quality is easily degraded when fresh. The price of red chilies always fluctuates due to unstable supply. During the main harvest season, the supply of fresh red chilies increases so the price tends to fall. However, when the supply of fresh red chilies is limited and the harvest is over, the price of red chilies increases significantly. Fresh chilies will wither due to the high rate of transpiration. If stored at room temperature without treatment, the weight of the chilies will decrease and the chilies will only last for 2 to 3 days (Sulistyaningrum & Darudriyo, 2018). High water content is one of the causes of damage and short shelf life of chilies (Ramdani *et al.*, 2018).

Appropriate post-harvest handling technology is needed to maintain the economic value of red chilies, one of which is by drying. Drying can extend the shelf life of agricultural products and can maintain product quality for a certain time. Drying aims to remove a certain amount of water from the product through the evaporation process. Good quality dried red chilies generally have a water content of 8-15%. According to SNI 01-3389-1994 (BSN, 20xx) the maximum water content for dry food products is 15%. High water content in dry products can cause the product to damage easily (BPTP, 2015). Mechanical dryers are one of the methods of choice for drying food. The advantage of using this drying method is that the drying process is more stable and the drying temperature can be adjusted to achieve optimal results. Meanwhile, the drawback of using drying is that it can change the properties of the product, such as changing the texture and color of the product if the drying temperature is too high (Parfiyanti *et al*., 2016). According to Murti (2017), drying curly red chilies with a drying temperature of 50 °C is the most optimal for maintaining their quality, where the vitamin C content remains high and the chilies are bright red.

Even though the water content has been reduced a lot, dried red chilies must be packaged in appropriate packaging to prevent changes in quality during storage. Vacuum packaging can protect products from exposure to oxygen and contamination by insects or microorganisms (Mastini *et al*., 2015). Vacuum packaging during storage is effective in reducing the increase in water content, because in vacuum storage the air in the packaging has been removed resulting in a vacuum condition which can inhibit the penetration of water into the material from the environment (Pandit & Permatananda, 2022). The choice of packaging materials and packaging techniques that are suitable for dry agricultural products is one of the factors that influences the shelf life of the product. One of the packaging materials for dried chilies is PE (polyethylene) plastic. Mulyawan *et al*. (2019) stated that PE plastic has strong characteristics, can withstand oil and fat, is difficult for gas and liquids to penetrate, and does not cause chemical reactions in products. PE plastic can reduce the concentration of oxygen gas and increase the concentration of carbon dioxide gas (Ansar *et al*., 2021). In this way, oxygen and water vapor which can speed up the damage process through chemical reactions are difficult to penetrate into the packaging so that the product can last longer with good quality.

Storage factors such as temperature, humidity and sunlight can affect the shelf life of the product, if these factors are not taken into account the shelf life of the product will be reduced (Hariyadi, 2019). The shelf life of food products is very important information for consumers when consuming the product. This relates to the safety and quality assurance of products when received by consumers. Dried red chilies are stored by conditioning the storage room above room temperature and shelf life can be estimated using the ASLT (Accelerated Shelf Life Testing) method using the Arrhenius equation. Determining shelf life using the ASLT method is carried out by accelerating the quality degradation reaction which is used as a critical parameter (Haryati *et al*., 2015). This can be done in modified storage conditions, with storage at extreme temperatures and humidity. The advantage of the ASLT method is that it produces high accuracy with a relatively short testing time (Mulyono *et al*., 2018). Therefore, the aim of research regarding critical quality parameters and the rate of decline of these parameters is to determine the shelf life of dried red chilies in vacuum packaging and to find out how long dried red chilies can be stored at any storage temperature using the ASLT method combined with the Arrhenius equation.

2. MATERIALS AND METHODS

The curly red chili variety TM-999 with a harvest age of 85 DAP (days after planting) was used as material for the research. Fresh red chilies were obtained from farmers in Ciburayut Village, Cigombong District, Bogor Regency, West Java. Other materials included PE plastic used as packaging material; chemicals such as 1% starch indicator, 0.01N iodine, 0.01N sodium thiosulfate, and 0.01N sulfuric acid. Equipment included a rack type mechanical dryer, desiccator, eyela KCL 2000, chromameter, vacuum sealer, labels, filter paper, aluminum cup, petri dish, digital scale, dropper pipette, beaker, graduated cylinder, Erlenmeyer flask, test tube, and burette.

2.1. Research Implementation

Initial research was carried out by drying red chilies. Fresh red chilies obtained from farmers are sorted and cleaned from dirt attached to the outer layer. Fresh red chilies are then dried using a rack type dryer at a temperature of 50±5 °C for 18-20 hours to obtain a moisture content of around 10%. After that, the dried red chilies are placed in a desiccator for 30 minutes to reduce the temperature. Dried red chilies at normal temperature were then stored in vacuum using PE plastic with a size of 17cm × 25cm and a thickness of 80 microns. Each package is filled with 50 grams of dried red chilies. Then each package containing the sample was stored in Eyela KCL 2000 at four storage temperatures, namely 35, 40, 45, and 50 °C with 80% humidity. Throughout the storage time the samples were observed on three quality parameters. Water content, vitamin C and color are the quality parameters of dried red chilies that are observed during storage. Observations were made five times with two repetitions during the storage period, so that the total packaging required for the four dry red chili storage temperatures was 40 packages. The observation time for each storage temperature varies according to the estimated time span for damage to occur which can be seen in Figure 1.

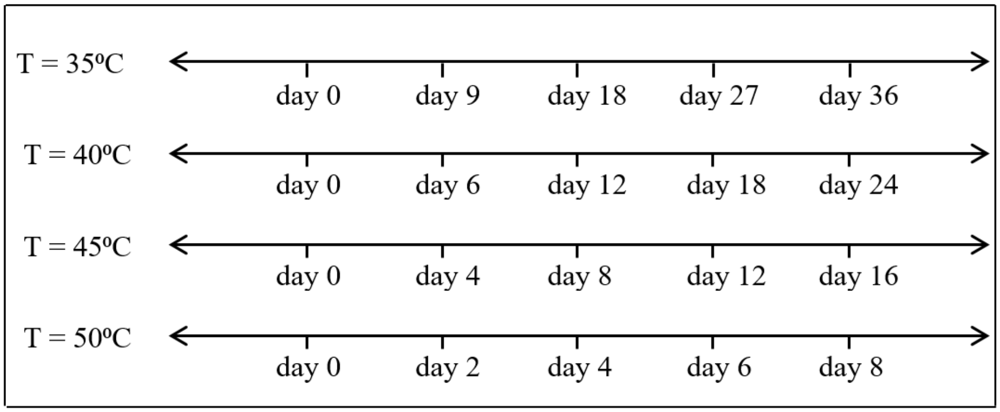

Figure 1. Observation period during storage of red chillies

2.2. Quality Analysis

2.2.1. Water content

Water content measurements were carried out by evaporating water from the sample at a high temperature for several hours until the free water was completely evaporated (AOAC, 2005).

2.2.2. Vitamin C

The vitamin C content was tested using the iodimetry method (direct titration using 0.01N iodine solution) (Ernest et al., 2017).

2.2.3. Color

The color of dried red chilies was measured tusing a chromameter. The displayed values expressed the L^* (lightness), a^* (red-green chroma), and b^* (yellow-blue chroma). The L^* values ranged from 0 (black) to 100 (white); positive a^* value is red and negative is green; and positive b^* value is yellow and negative is blue. The color change of dried red chilies was expressed by a decrease in the a^* value (Nielsen, 2017).

2.3. Shelf Life Estimation

The ASLT method combined with the Arrhenius equation is one way to determine the shelf life of food products by estimating it based on changes in product quality that have the highest rate (Hariyadi, 2019). The highest damage reaction rate was observed during storage of the three quality parameters to determine the critical parameters. In determining the shelf life of dried red chilies in vacuum packaging using the Arrhenius equation, first is looking for the reaction orders at various storage temperatures which are expressed in order zero and order one. The reaction order model was developed from the following equation (Haryanto *et al*., 2020):

$$\text{Reaction rate} = -\frac{d[A]}{dt} = k[A] \quad (1)$$

After integration it become:

$$ln\, A_t = ln\, A_o - k\, t \tag{2}$$

where A_t is the final product quality value, A_o is the initial product quality value, k is a rate constant of quality degradation reaction, and t is storage time (days).

Zero and first order equations were solved using linear regression equations expressed in equations (3) and (4). Zeroth order is the graph of the relationship between the values k and t and first order is the graph of the relationship between $ln\, k$ and t.

$$A_t = A_o - k\, t \qquad \text{(zeroth order)} \tag{3}$$

$$ln\, A_t = ln\, A_o - k\, t \qquad \text{(first order)} \tag{2}$$

From this equation, the slope value can be obtained which is the reaction rate constant (k) for decreasing product quality. The reaction order with the largest R^2 value was selected for the Arrhenius equation. The Arrhenius equation was created by plotting $ln\, k$ and $1/T$ expressed in K unit, so that the intercept and slope values were obtained (equation 5).

$$ln\, k = ln\, k_o - (E_a/RT) \tag{5}$$

Next, the results of the reaction order equation for each quality parameter were included in the model (equation 6)

$$k = k_o \times e^{-(E_a/RT)} \tag{6}$$

where k is reaction rate constant for quality degradation as a function of temperature, k_o is frequency factor constant, E_a is the activation energy, R is the ideal gas constant (8.315 J/mol K), and T is storage temperature (K).

Determining the shelf life of dried red chilies stored in vacuum packaging was carried out by looking for the reaction rate decreasing as a function of temperature (k) from the three quality parameters. Critical parameters were selected based on those with the largest value of the quality degradation reaction rate. The critical limit or a product was classified as not suitable for consumption was determined based on the SNI quality requirements. If there are no standard requirements for product quality, the damage (poor) quality was determined from 50% of the initial quality of the product before storage (Supariatna *et al*., 2018). Equations (7) and (8) were used to estimate shelf life for dry red chilies using vacuum packaging.

$$t_s = (A_o - A_t)/k \qquad \text{(zeroth order)} \tag{7}$$

$$t_s = (ln\, A_o - ln\, A_t)/k \qquad \text{(first order)} \tag{8}$$

where t_s is shelf life (day), A_o is the quality value of initial product, A_t is the quality value of final product, and k is the quality decreasing rate constant as a function of temperature.

3. RESULTS AND DISCUSSION

3.1. Water content

The water content at the end of storage at 35, 40, 45, and 50 °C with 80% humidity respectively was 13.96%; 12.60%; 12.09%; and 12.65%. The results of this research show that the water content of dried red chilies has not reached the critical point. Dried red chilies are said to have been damaged or reached a critical point if the water content is 15% in accordance with SNI 01-3389-1994 for dry product quality requirements. This can be caused because dried red chilies are stored in vacuum packaging. Vacuum packaging can maintain the water content of dried red chilies, so they do not easily absorb high humidity in the storage room. Pandit & Permatananda (2022), stated that the air in the packaging during vacuum storage is removed so that the packaging becomes a vacuum and can inhibit the absorption of water by materials from the environment. The graph of the increase in water content according to zero and first order during storage is given in Figure 2.

From the zero and first order graphs, the quality reduction equation for each storage temperature is obtained which is summarized in Table 1. The average value of R2 at zero order is 0.9310 while at first order it is 0.9220. The kinetic

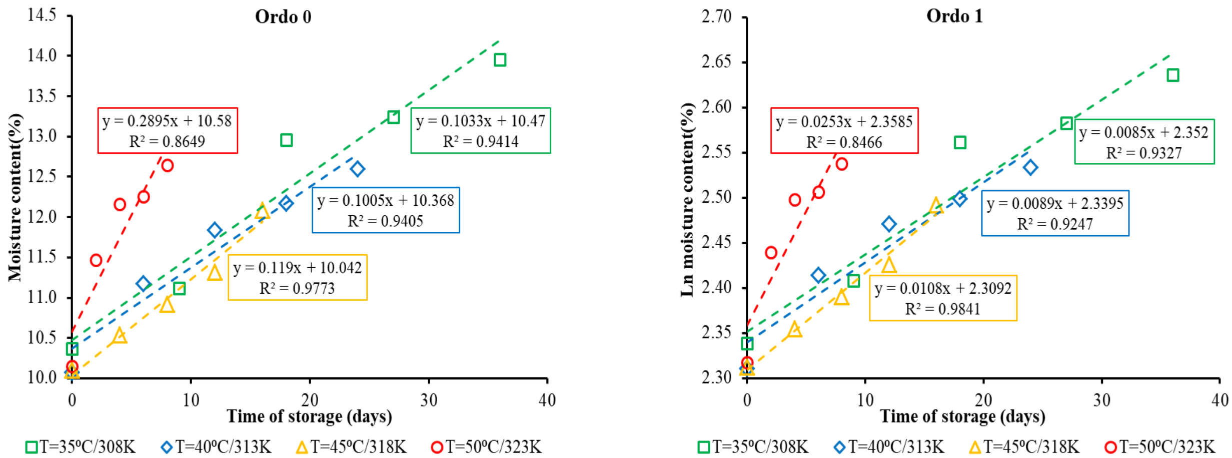

Figure 2. Moisture content increment of dry red chilies during storage using vacuum packaging

model or reaction order is selected based on the regression equation with the largest coefficient of determination (R^2). The higher the R^2 determination value, the more accurate the data used (Arif *et al*., 2014). An increase in zero-order water content has a greater R^2 value, so the constant resulting from the zero-order equation was chosen to be used in the Arrhenius equation shown in Figure 3. Anggraini *et al*. (2019) obtained the results of the zero-order equation for the water content quality parameters for estimation of the shelf life of brown sugar jam with the same graphic trend but different constant values. The constant value is greatly influenced by the characteristics of the product. In reaction kinetics, the decline in the quality of food ingredients at zeroth order is the rate of damage that occurs constantly or linearly, while first order is for the rate of damage that occurs non-constantly or exponentially (Sabarisman *et al*., 2017).

Table 1. Equation for water content of red chilies based on zeroth and first order for four different temperatures

Temperature (°C)	Zeroth Order		First Order	
	Equation	R^2	Equation	R^2
35	$A_{t_t} = 10.470 + 0.1033t$	0.9414	$ln\ A_{t_t} = 2.3520+0.0085t$	0.9327
40	$A_{t_t} = 10.368 + 0.1005t$	0.9405	$ln\ A_{t_t} = 2.3395+0.0089t$	0.9247
45	$A_{t_t} = 10.042 + 0.1190t$	0.9773	$ln\ A_{t_t} = 2.3092+0.0108t$	0.9841
50	$A_{t_t} = 10.580 + 0.2895t$	0.8649	$ln\ A_{t_t} = 2.3585+0.0253t$	0.8466

Note : A_{t_t} = water content of red chilies as a function of storage time t (day)

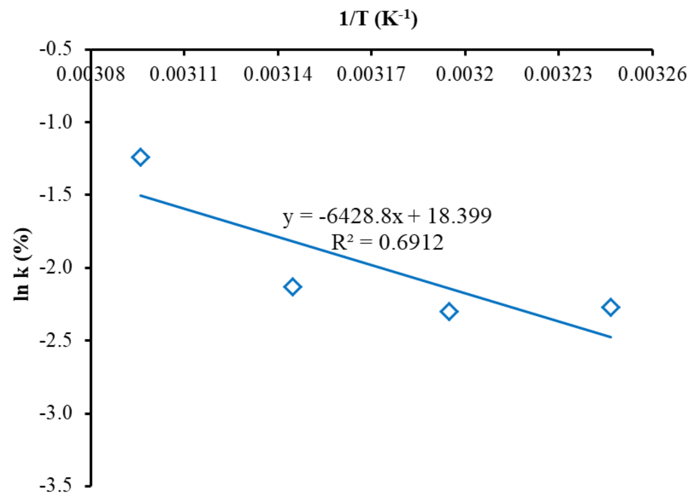

Figure 3. Arrhenius equation plot based on first order function for water content of red chilies

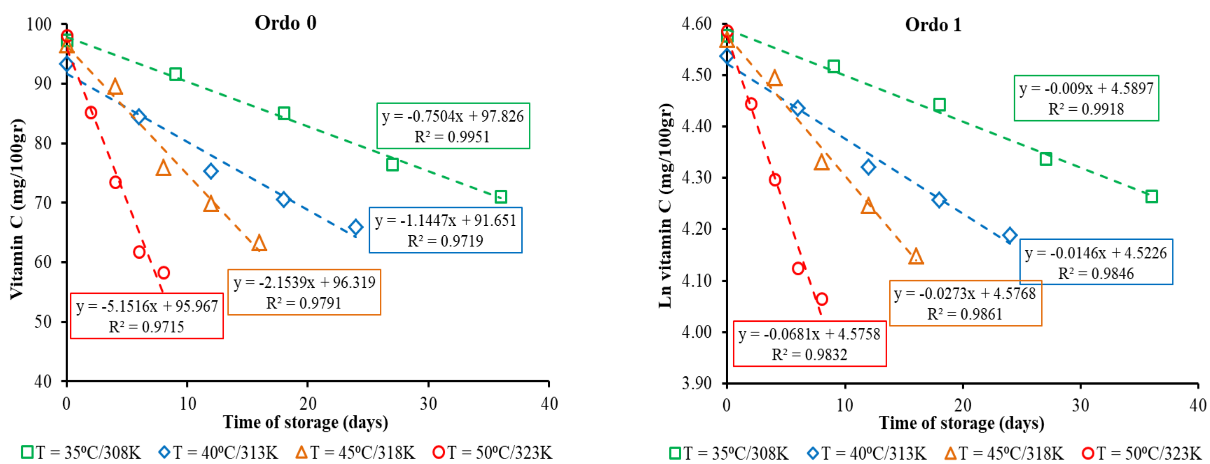

Figure 4. Declining of vitamin C of dry red chilies during storage using vacuum packaging

Table 2. Equation for vitamin C of red chilies based on zeroth and first order for four different temperatures

Temperature (°C)	Zeroth Order		First Order	
	Equation	R^2	Equation	R^2
35	$A_{t_t} = 97.826 – 0.7504t$	0.9951	$ln\ A_{t_t} = 4.5897 – 0.0090t$	0.9918
40	$A_{t_t} = 91.651 – 1.1447t$	0.9719	$ln\ A_{t_t} = 4.5226 – 0.0146t$	0.9846
45	$A_{t_t} = 96.319 – 2.1539t$	0.9791	$ln\ A_{t_t} = 4.5768 – 0.0273t$	0.9861
50	$A_{t_t} = 95.967 – 5.1516t$	0.9715	$ln\ A_{t_t} = 4.5758 – 0.0681t$	0.9832

Note : A_{t_t} = vitamin C of red chilies as a function of storage time t (day)

3.2. Vitamin C

Chili is a horticultural product that contains quite high levels of vitamin C. Vitamin C can play a role in the body in increasing the absorption of iron and calcium, as well as as an antioxidant that can protect cells from causing cancer (Ernest *et al*., 2017). The vitamin C content of dried red chilies in vacuum packaging decreased during storage. During one day of storage there was a decrease of 0.728 mg/100g during storage at a temperature of 35 °C, 1.143 mg/100g at a temperature of 40 °C, 2.075 mg/100g at a temperature of 45 °C, and 4.979 mg/100g at a temperature of 50 °C. From these results it can be concluded that the higher the storage temperature, the more quickly the vitamin C contained in dried red chilies will decrease. According to Safaryani *et al*. (2017), the concentration of ascorbic acid (another term for vitamin C) can easily change, because ascorbic acid is very sensitive to high temperatures. According to Yuda & Suena (2016), high temperature storage will accelerate the degradation of ascorbic acid, because at high temperatures the enzyme activity that plays a role in breaking down ascorbic acid will occur more quickly. Zero order and first order graphs for vitamin C reduction are shown in Figure 4.

Table 2 displays zero and first order equations with an average R^2 of zeroth order of 0.9794 and first order of 0.9864. The largest R^2 value in reducing vitamin C is in first order, so the constant from the first order equation is used for the Arrhenius equation (Figure 5).

3.3. Color (a^*)

Based on the change in the red chroma color, dried chilies experience a daily decrease in the color a^* value of 0.214 at a storage temperature of 35 °C, a decrease of 0.452 at a storage temperature of 40 °C, a decrease of 1.184 at a storage temperature of 45 °C, and a significant decrease of 2.598 at a storage temperature of 50 °C. It can be seen that at a storage temperature of 50 °C there is a very rapid decrease in the a^* value, when compared to other storage

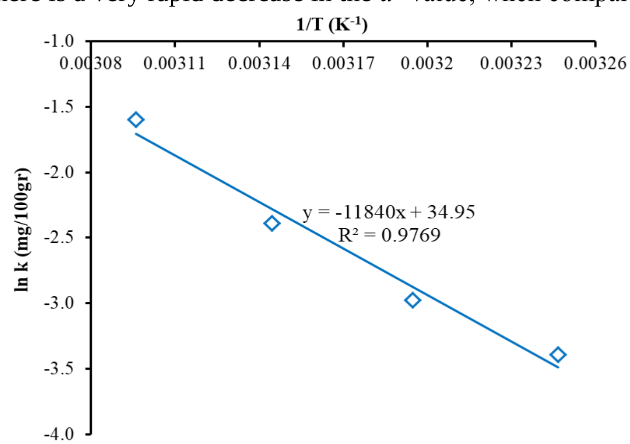

Figure 5. Arrhenius equation plot based on first order function for vitamin C of red chilies

temperatures. During storage, the higher the temperature and the longer the dry red chili is stored, the faster the color will change to become darker. The red color in chilies is produced from the carotenoid content. Carotenoid compounds are very sensitive to high temperatures, which causes the red color of chilies to quickly change to dark (Parfiyanti *et al*., 2016). Storage duration also affects the red pigment in chilies, over time the carotenoid compounds contained in chilies continue to decrease (Teoriman *et al*., 2022). The change in red color of chilies during storage is given in Figure 6 for zeroth order and first order.

Decreasing the value of a^* according to the zeroth and first order functions shown in Table 3 produces four equations with the average value of R^2 for zero order being 0.9592 and for first order being 0.9628. The largest R^2 value is from first order, so the constant from the first order equation is used for the Arrhenius equation (Figure 7).

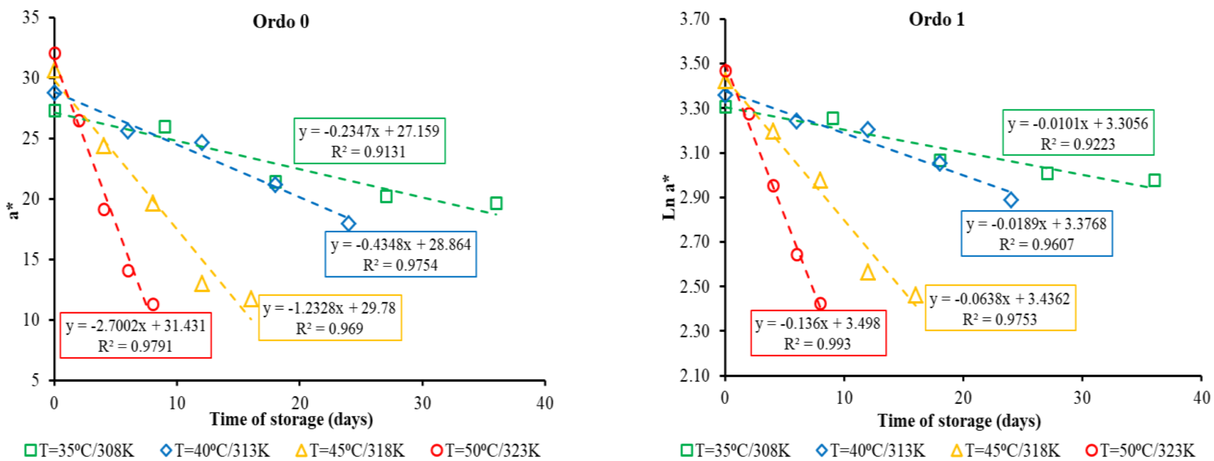

Figure 4. Decreasing of color value a^* of dry red chilies during storage using vacuum packaging

Table 3. Equation for color value a^* of red chilies based on zeroth and first order for four different temperatures

Temperature (°C)	Zeroth Order		First Order	
	Equation	R^2	Equation	R^2
35	$A_{t_s} = 27.159 - 0.2347t$	0.9131	$ln\ A_{t_s} = 3.3056 – 0.0101t$	0.9223
40	$A_{t_s} = 28.864 - 0.4348t$	0.9754	$ln\ A_{t_s} = 3.3768 – 0.0189t$	0.9607
45	$A_{t_s} = 29.780 - 1.2328t$	0.9690	$ln\ A_{t_s} = 3.4362 – 0.0638t$	0.9753
50	$A_{t_s} = 31.431 - 2.7002t$	0.9791	$ln\ A_{t_s} = 3.4980 – 0.1360t$	0.9930

Note : A_{t_s} = color value a^* of red chilies as a function of storage time t (day)

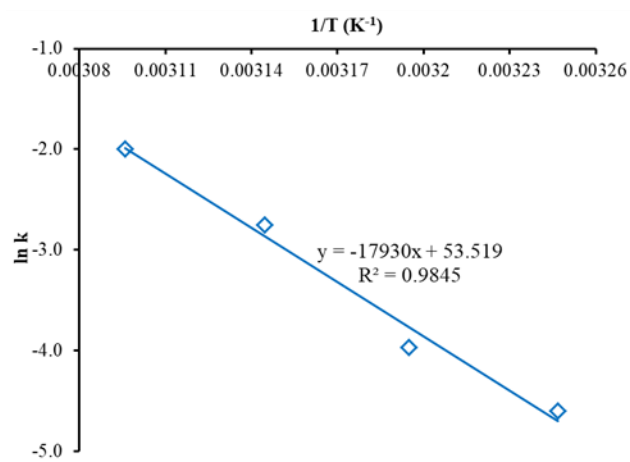

Figure 5. Arrhenius equation plot based on first order function for color a^* of red chilies

Table 4. Values of rate constant (k), determination coefficient (R^2), and activation energy (E_a) for each quality parameter of dried red chilies

No.	Quality parameter	k	R^2	E_a (J/mol)
1.	Kadar air	0.0597	0.6912	53455.47
2.	Vitamin C	0.0600	0.9751	110556.24
3.	Warna (a*)	0.0570	0.9845	149087.95

3.4. Shelf Life of Dried Red Chilies

Shelf life is a period of time for a product that is used between production and consumption. The storage time period indicates that the product is still acceptable and safe to consume. To calculate the shelf life of dried red chilies based on critical parameters. From the Arrhenius equation for each quality, the values of k, R^2, and E_a are obtained (Table 4). From this table it is found that the values of k, R^2, and E_a for the water content quality parameters are respectively 0.0597; 0.6912; and 53455.47 J/mol, while for vitamin C are 0.0600; 0.9751; and 110556.24 J/mol, and for color are 0.0570 ; 0.9845; and 149087.95 J/mol. The critical parameter used to estimate the shelf life of dried red chilies in vacuum packaging is the reduction in vitamin C content. This consideration is determined based on the largest k value, namely 0.0600, for the reduction in vitamin C content. The k value is the rate of quality degradation reaction, the greater the k value, the faster the product is damaged (Haryati et al., 2015). The E_a is the activation energy, the magnitude of the activation energy to reduce the quality of dried red chilies during storage.

Vitamin C is easily damaged because it is sensitive to extreme temperature changes, even in a short time the vitamin C content decreases by more than 50%. Asmawati *et al*. (2020) stated that high temperatures will speed up the enzymatic process in the product resulting in degradation of ascorbic acid. After vitamin C has been determined as a critical parameter, the next step is to look for the reaction rate of quality degradation as a function of temperature (k) during storage. The final storage limit means that the product cannot be accepted by consumers (Lestari *et al*., 2021). Equation (6) has been solved to get rate constant as the following:

$$k = 38.350 \times e^{(13296 \times T^{-1})} \tag{9}$$

Based on Equation (7) we can find the shelf life for dried red chilies using the Equation (8) to solve shelf life as the following:

$$t_s = ln(98.0883) - ln(49.0442)/k \tag{10}$$

From this equation, whatever the storage temperature, the shelf life can be estimated based on the reaction to the decline in product quality. The following is an estimate of shelf life from several storage temperatures for dried red chilies in vacuum packaging (Table 5). The results showed that the shelf life of dried red chilies based on the critical quality parameter of vitamin C, in vacuum packaging lasted 1720 days at a low temperature of 15 °C. Increasing storage temperature will result in the decreasing shelf life. Storage at 20 °C can last up to 782 days, and at 25 °C (room temperature) it can last up to 365 days. At the storage temperature of 30 °C, the shelf life of red chilies is 174 days.

Table 5. Estimation of shelf life of dried red chilies in vacuum packaging

Storage temperature (°C)	Shelf life (day)
15	1720
20	782
25	365
30	174

4. CONCLUSIONS AND SUGGESTIONS

Dried red chilies stored in vacuum packaging at high temperatures have a shorter shelf life compared to chilies stored at low temperatures, because high temperatures accelerate the reaction of product quality degradation. From the results of estimating the shelf life of vacuum packed dried red chilies using the ASLT method with the Arrhenius approach based on the critical quality parameter of vitamin C, stored at room temperature 25 °C the shelf life is 365 days, whereas if stored at a low temperature of 15 °C the shelf life is 1720 days.

For the next research, it is necessary to test the capsaicin content in chilies in order to determine the reaction to the decrease in the quality of spiciness in chilies during storage. In addition, real validation is needed in the field in the storage of dried red chilies stored in vacuum packaging.

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