Shelf-Life Estimation of Muntok White Pepper (*Piper nigrum* Linn.) Hard Candy using Q_{10} Method

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Date received: August 14, 2023
Revision accepted: May 30, 2025

Abstract

Candy is a product that all people like. One of the ingredients that can be used to make candy is white pepper from Bangka Island, called Muntok White Pepper. This white pepper contains the highest piperine content in the world, which is 6-7% (w/w). Muntok white pepper hard candy can add to the diversification of spice-based food products. Therefore, information related to shelf-life is crucial to ensure product safety. This study aimed to determine the shelf-life of Muntok white pepper hard candy products using the Q_{10} *method. Products packaged in metalized plastic were tested for shelf-life at three different storage temperatures (25, 35, and 45 °C) for 28 days. The study used five observation times (0, 7, 14, 21, and 28 days) with test parameters of moisture content and sensory quality (color, aroma, taste, and texture). The results showed that temperature and storage time differences affected the moisture content of Muntok white pepper hard candy (*$p < 0.05$*). The results of the shelf-life test show that the texture parameter of Muntok white pepper hard candy deteriorates faster, with a k value of 0.5323 at 25 °C. The results of the estimated shelf-life obtained show that this Muntok white pepper hard candy has a shelf-life of 40 days when stored at room temperature (25 °C).*

Keywords*:* accelerated shelf-life testing (ASLT), confectionery, functional food, kinetics, quality

1. Introduction

Pepper is one of Indonesia's leading commodity spices. Indonesia became the second-largest pepper exporter in the world after Vietnam in 2019 (Food and Agriculture Organization [FAO], 2020). The Bangka Belitung Island Province is Indonesia’s largest pepper-producing province, which contributes to providing pepper supply (Astuti and Bahtera, 2019). Two commonly traded pepper types are white and black (Mahdi and Suprehatin, 2021). Black pepper is obtained from the fruit of pepper without peeling the skin, while the skin is peeled for white pepper.

Indonesian white pepper produced in Bangka Belitung Province is known as Muntok. Although white pepper has good potential and many benefits, the use of white pepper as a processed product is still limited. In addition, fluctuating pepper prices caused most farmers to leave pepper farming and decreased pepper export activities (Astuti and Bahtera, 2019). Thus, product diversification of pepper is needed to optimize its utilization. Pepper candy is a product made from pepper. The Muntok white pepper hard candy formulation has been carried out by Hutami *et al.* (2021). The research showed that the panelists liked the white pepper candy, with an overall hedonic test parameter score of 6.65 (towards like). Muntok white pepper hard candy had a golden yellow color, a slightly spicy taste, a hard texture, and no peppery smell.

Determining product shelf-life is crucial to providing food quality and food safety for consumers. Shelf-life is usually indicated on a food label by either a best-before date or a use-by date as a reflection of the time products retain quality and remain safe for consumption. In Indonesia, the shelf-life of products must be stated per the Indonesian Food and Drug Control Agency (IFDCA) Regulation Number 31 of 2018 concerning Processed Food Labeling (IFDCA, 2018). Therefore, the shelf-life estimation of Muntok white pepper hard candy must be done. The shelf-life of a product is influenced by storage temperature and duration (Yang *et al.*, 2024). The shelf-life of candy can reach one year if it is processed correctly and properly (Koswara, 2009). The most common method used to estimate shelf-life is the Accelerated Shelf-life Testing (ASLT) method. The ASLT method estimates shelf-life by accelerating quality changes in critical parameters.

One of the ASLT methods for estimating shelf-life is the Q_{10} method using the Arrhenius model. This model determines changes in oxidation reaction rate or decline in food quality product rate as an impact of specific storage temperature (Syarief and Halid, 1993). Renumarn and Choosuk (2020) successfully tested the shelf-life of chewy santol candies using the Q_{10} method. The Q_{10} method quickly predicts food products' shelf-life at various storage temperatures (Oceanic *et al.*, 2017). The Q_{10} method is used to estimate the shelf-life of a product through the chemical reaction rate alteration in response to every 10-degree rise in temperature (Xiao *et al.*, 2022). Estimating shelf-life using the Q_{10} method uses Ea (activation energy) value.

The parameters used in determining the shelf-life of Muntok white pepper hard candy products are moisture content and sensory quality. High temperatures will denature or damage protein molecules. As a result, the protein's ability to bind water is reduced; high temperatures also weaken the binding power of sucrose and glucose to water. Therefore, it can increase free moisture content, which can affect the increased moisture content of candy (Syarief and Halid, 1993). Moisture content in hard candy will affect the texture profile. The moisture content is essential to confectionery products' quality and shelf-life. Oceanic *et al.* (2017), states that color degradation occurs faster with the length of storage time and increases storage temperature because of the Maillard reaction due to storage at high temperatures. In addition, consumer acceptance of the product is essential in determining the quality of Muntok white pepper hard candy. Therefore, Muntok white pepper hard candy shelf-life estimation using Q_{10} method was carried out using moisture content and sensory parameters.

2. Methodology

2.1 Materials and Tools

The materials used were sucrose (*Rose Brand®, PT Adi Karya Gemilang, Indonesia*), water, *Muntok* white pepper powder (*Lada Kita®, Bumdesma Mitra Lada Bersatu, Indonesia*), glucose syrup (*Guangzhou Shuangolao Company LTD, China*), and metalized plastic (5 × 3 size with WVTR 0.8872 gram/m^2 day).

The tools used were digital scales, stove, pan, basin, stirrer, candy mold, thermometer, incubator (*Memmert® 854 Schwabach W-Germany*), hand sealer, analytical balance, and distillation apparatus.

2.2 Research Methods

2.2.1 Production of Muntok White Pepper Hard Candy (Hutami *et al.*, 2021)

Sucrose and glucose were weighed in a 50:50 ratio. Sucrose was then added to water and stirred at 90 °C for 3 minutes. Then, glucose was added and stirred for 5-7 minutes at 110°C. The stirring process was continued until the mixture reached 150°C. The candy mixture was cooled for 10 seconds, then 1% white pepper was added and stirred. The mixture was cooled down to room temperature at 27 °C.

The characteristics of the Muntok white pepper hard candy used in this study, as previously developed and reported by Hutami *et al.* (2021), are shown in Table 1.

Table 1. Chemical contents, antioxidant activity, microbiology content, and nutritional value of the Muntok white pepper hard candy (Hutami *et al.,* 2021)

Composition	Content	Nutritional value (kcal)*
Moisture (% wb)	3.46	-
Protein (%)	1.43	0.17
Fat (%)	12	3.24
Ash (%)	0.89	-
Total carbohydrate (%)	82.22	9.86
Reducing sugar (%)	11.31	1.36
Saccharose (%)	62.93	7.55
Antioxidant activity IC_{50} (mg/L)	141,208.03	-
Total plate count (colonies/g)	8×10^1	-

**The numbers indicate the nutritional values contained in each piece of candy (3 g)*

2.2.2 Determination of the shelf-life of Muntok White Pepper Hard Candy (Modified from Renumarn and Choosuk, 2020)

The shelf-life of Muntok white pepper hard candy was estimated using the Q_{10} method based on the moisture content and sensory parameters. The candy products were stored at 25 °C, 35 °C, and 45 °C for 28 days. A temperature of 25 °C is the ambient temperature. Under this temperature, we can determine the condition of the candy in its ambient state (Jafari *et al.,* 2017). Meanwhile, 35 °C and 45 °C were selected to accelerate product deterioration at temperatures above ambient conditions (Sulaiman *et al.,* 2024). The number of samples analysed was 45, comprising 15 samples from each experimental temperature (25 °C, 35 °C, and 45 °C). Three samples from each storage temperature were taken consistently on days 0, 7, 14, 21, and 28 to analyse their moisture content. It represents three replications for each storage temperature for every 7 days of storage. The observation was conducted for 28 days, as hard candy products possess low moisture content, making them relatively stable against quality deterioration. Furthermore, the elevated storage temperatures used were sufficient to accelerate degradation within the 28 days, enabling the results to represent storage durations equivalent to several months or even years at ambient temperature. This experiment is in line with the study by Renumarn and Choosuk (2020), who conducted a shelf-life observation of candy over 30 days at storage temperatures of 25 °C, 35 °C, and 45 °C. Each sample was weighted 3 g and then packed in metalized plastic packaging, 4.5 cm x 2.5 cm. The result data was analysed to estimate the shelf-life obtained.

2.3 Research Parameters

2.3.1 Moisture Content (AOAC, 2005)

Moisture content was tested using a distillation method. The sample was weighed at 5-10 g and put into a boiling flask, previously prepared in the oven. The 60-100 mL of toluene reagent was added to the flask. The mixture was heated on an electric heater while refluxing slowly at a low temperature for 45 minutes. The reflux continued with high heating for 1 to 1.5 hours. After the water has been distilled, the volume of water accommodated in the distillate reservoir was determined by reading the meniscus in the flask. The moisture content was calculated using Equation 1:

$$Moisture\ content\ (\%) = \frac{Distillate\ volume}{Sample\ Weight}\ x\ 100\% \tag{1}$$

The moisture content test was replicated 3 times.

2.3.2 Sensory Quality Testing

The sensory evaluation of this research was conducted using a hedonic rating test according to Setyaningsih *et al.* (2010) and Shahbaz *et al.* (2025). The sensory evaluation was carried out using 30 untrained panelists. The panelists were male and female students of the Food Technology and Nutrition Department of Universitas Djuanda, aged between 18 and 20 years, and familiar with candy products. Five sensory evaluation sessions for the candy were conducted on days 0, 7, 14, 21, and 28. In each session, each panelist received one piece of candy from each storage temperature treatment, with each piece weighing 3 grams. Samples were prepared by removing them from their primary packaging, placing them in serving containers, and labeling them with identification codes before testing. The testing was conducted using an unstructured 10 cm line scale ranging from 0 to 10. An unstructured scale is recommended as untrained panelists were used, which may produce a complex response distribution (Ledahudec *et al.,* 1992). The evaluated sensory parameters were color, aroma, taste, and texture. All parameter scales ranged from dislike extremely (0) to like extremely (10).

2.3.3 Shelf-life Calculation

2.3.3.1 Determination of Reaction Order

The shelf-life calculation was conducted according to Asiah *et al.* (2018). The reaction order was determined by plotting the average value of the moisture content test and the average score of quality parameters during storage into the equation. The reaction order was obtained by making a regression equation for order 0 with Equation 2 and order 1 with Equation 3:

$$Qt = Qo - kt \tag{2}$$

$$lnQt = lnQo - kt \tag{3}$$

Note: Qo = initial quality value of storage; Qt = quality value at storage time t; k = reaction rate constant/degradation at temperature T; t = storage time (days). The larger reaction order determines shelf-life by looking at the more considerable R^2 *value.*

2.3.3.2 Determination of activation energy

The activation energy can be obtained from each quality parameter's slope value (reaction rate) multiplied by the ideal gas constant (R), 1.986 cal/(mol·K).

2.3.3.3 Determination of Quality Decline Constant

After determining the reaction order, the next step is calculating the reaction constant by plotting the value of ln k with 1/T using the Arrhenius equation. The equation provides ln k and Ea/R values, which can then be used to determine the value of k at different temperatures using the Arrhenius equation (Equation 4).

$$\ln k \ = \ln k0 \ - (\frac{Ea}{R})(\frac{1}{T}) \quad (4)$$

*Where k is reaction rate constant; k_o = constant (frequency factor); Ea = activation energy (kal/mol); T = absolute temperature (K); R = gas constant (*1.986 cal/ (mol·K)*).*

2.3.3.4 Determination of Reaction Order

Prediction of shelf-life using the empirical approach of the Arrhenius equation assumes that the product has experienced a significant decrease in quality, which can be felt by consumers when the product has reached the quality value at storage time t (Qt) (Asiah *et al.*, 2018). Estimating product shelf-life at storage temperature treatment can be calculated by Equation 5 if the reaction follows reaction order 0 or Equation 6 if the response follows reaction order 1.

$$ts \ = \ Qo \ - \ Qt \ / \ k \quad (5)$$

$$ts \ = \ lnQo \ - \ lnQt \ / \ k \quad (6)$$

Note: Q_0 = initial quality value of storage; Q_t = quality value at storage time t/final quality limit; k = reaction rate constant/degradation at temperature T; ts = shelf-life temperature T.

2.3.3.5 Determination of the Value of the Reaction Acceleration Factor (Q_{10})

Finding the value of the acceleration factor for the degradation reaction (Q_{10}) can help estimate product shelf-life at various distribution temperatures. For example, the value of Q_{10} explains that increasing the temperature by 10 °C will double the rate of chemical reaction (Equation 7).

$$Q10 = eEa(T2 - T1)/RT1T2 \quad (7)$$

Note: Q_{10} = acceleration factor; Ea = activation energy (kal/mol); T_2 = absolute temperature 2 (K); T_1 = absolute temperature 1 (K); R = constant gas 1.986 cal/ (mol·K)).

After the value of the quality degradation factor (Q_{10}) is obtained, it can be estimated that the expiration time at various storage temperatures is formulated as follows (Equation 8).

$$ts\ (T2) = \frac{ts\ (T1)}{Q10^{\frac{T2-T1}{10}}} \qquad (8)$$

Note: Q_{10} = acceleration factor of quality decline; $ts_{(T1)}$ = expiration time at base temperature (months); $ts_{(T2)}$ = expiration time at estimated temperature (months).

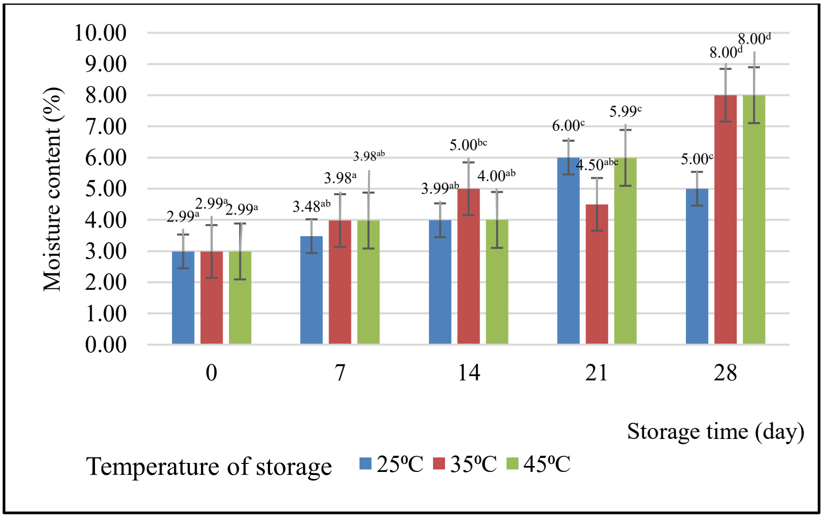
2.4 Data Analysis

The analysis used to process the results of the moisture content test is the Analysis of Variance test (ANOVA). If the p-value < 0.05, the treatment had a significant effect and continued with Tukey's HSD post-hoc test at a 95% confidence interval (significance level = 0.05).

3. Results and Discussion

3.1 Changes in Moisture Content of Muntok White Pepper Hard Candy during Storage

Changes in moisture content parameters were obtained by testing the distillation method's moisture content every 7 days for 28 days at three different storage temperatures. The following is the average value of the moisture content parameter test results for 28 days of storage (Figure 1).



Note: different letter notations indicate significant differences at the 5% level

Figure 1. Moisture content of Muntok white pepper hard candy during 28 days of storage in 25 ºC, 35 ºC, and 45 ºC

The concentration value increases at higher temperatures and longer storage times. For example, the average moisture content in the sample at day 0 was 2.99% and significantly increased at day 28 to 7.33%. Then the average moisture content during storage at 25 °C was 4.49%, followed by the average moisture content at 35 °C and 45 °C, namely 4.89% and 4.49%. Renumarn and Choosuk (2020) also reported this related study, which stated that the moisture content increased with the temperature and storage time in chewy santol (Kraton-Yee) candies samples. Luthfiyanti *et al.* (2020) also reported that the Ciplukan leaf extract candy experienced a 2.67 times increase in moisture content after being stored for 12 days at 28 °C. Furthermore, Pratama *et al.* (2021) observed that the moisture content of ginger jelly candy increased 1.13 times after being stored for 28 days at room temperature.

The increase in moisture content is due to hard candy having hygroscopic properties that quickly absorb water from the environment. This is supported by Kurniawan *et al.* (2018), who stated that changes in moisture content can occur due to the absorption of water vapor from the air into the product during the storage period. The difference in humidity between the environment and the product can cause a difference in the partial pressure of water vapor to move from high to low pressure. The partial pressure or humidity of the water vapor from the environment is greater than that of the candy product in the packaging, causing the environmental moisture to move into the candy product (Utami *et al.,* 2014). The increase in storage temperature was directly proportional to the increase in the moisture content of the candy samples. It is related to the composition of the candies, which are primarily made up of sucrose. According to the phase diagram of the sucrose-water binary system (Hartel, 2001), higher storage temperatures can increase the water content in hard candies. It is due to the higher solubility of sucrose at elevated temperatures, which leads to an increase in the amount of dissolved water and a reduction in the amount of water bound within sucrose crystals.

3.2 Shelf-life Estimation

Estimation of the shelf-life of candy products was carried out using the Q_{10} method based on moisture content and sensory quality parameters. This decrease in quality was observed for 28 days of storage in an incubator at 25 °C, 35 °C, and 45 °C by testing the samples' moisture content and sensory deterioration every 7 days. Several stages are conducted to estimate the shelf-life of Muntok white pepper hard candy using the Q_{10} method.

3.2.1 Determination of Reaction Order

The reaction order was determined by plotting the average moisture content and sensory tests for color, aroma, taste, and texture parameters during storage (y-axis) and storage time (x-axis) at three different storage temperatures. The value of R^2 on the order of zero is obtained from the original data from the curve equation between the average value of the moisture content test and sensory test during storage (y-axis) and storage time (x-axis). In contrast, for the first order, it is obtained from the equation curve, ln the average value test for moisture content and ln sensory values (color, aroma, taste, and texture) during storage (y-axis) and ln storage time (x-axis).

The choice of reaction order is determined based on the most considerable R^2 value closest to 1. An R^2 value close to 1 indicates linear data and is considered accurate, while an R^2 value close to zero indicates non-linear data, which is considered inaccurate (Surahman *et al.,* 2020). Table 2 presents the results of the order 0 and order 1 equations with the resulting R^2 value. The result showed that the aroma, taste, and texture parameters follow reaction order 1, while the moisture content and color parameters follow reaction order 0.

Table 2. Equation and order of reaction parameters of moisture content, color, aroma, flavor, and texture in 25 ºC, 35 ºC, 45 ºC

Parameters	T°C	Regression Equation		R^2		Selected order for shelf-life calculation
		Order 0	Order 1	Order 0	Order 1	
Moisture Content	25	$y = -0.0455x + 0.332$	$y = -0.1931x - 1.0757$	0.9445	0.9276	0
	35	$y = -0.0446x + 0.3257$	$y = -0.2087x - 1.0726$	0.8856	0.8302	
	45	$y = -0.0502x + 0.3257$	$y = -0.2373x - 1.0726$	0.9492	0.9413	
Color	25	$y = -0.1673x + 7.2998$	$y = -0.024x + 1.9883$	0.8082	0.8087	0
	35	$y = -0.249x + 7.5466$	$y = -0.0361x + 2.0234$	0.8435	0.8315	
	45	$y = -0.5773x + 7.296$	$y = -0.0962x + 1.9975$	0.9223	0.9035	
Aroma	25	$y = -0.303x + 7.204$	$y = -0.0463x + 1.9771$	0.9305	0.9223	1
	35	$y = -0.3021x + 7.1454$	$y = -0.0462x + 1.9682$	0.9535	0.9566	
	45	$y = -0.37x + 6.918$	$y = -0.0583x + 1.9336$	0.8357	0.8594	
Flavor	25	$y = -0.038x + 6.402$	$y = -0.0064x + 1.8569$	0.0541	0.0611	1
	35	$y = -0.213x + 6.468$	$y = -0.0363x + 1.8693$	0.6488	0.6476	
	45	$y = -0.026x + 6.276$	$y = -0.0042x + 1.8368$	0.4592	0.4611	
Texture	25	$y = -0.5581x + 6.914$	$y = -0.1005x + 1.9463$	0.8157	0.7904	1
	35	$y = -0.5294x + 7.0148$	$y = -0.093x + 1.9602$	0.8486	0.8162	
	45	$y = -0.6693x + 6.5752$	$y = -0.1254x + 1.8891$	0.8917	0.9298	

3.2.2 Activation Energy

The activation energy value (Ea) is obtained from the slope value, which is the result of plotting the value of ln k with 1/T at each storage temperature used to store white pepper hard candy. The slope value obtained describes the Arrhenius equation curve on the order of zero or order one by connecting the value of ln k with 1/T (1/°K).

The slope of the regression equation, ln k with 1/T, is the activation energy value of each parameter. The slope value obtained from the plotting results is multiplied by the ideal gas constant (R), 1.986 cal/ (mol·K). The following in Table 3 is the result of the regression equation from the value of ln k with 1/T and the value of the activation energy of each parameter.

Table 3. Regression equation of ln k with 1/T and activation energy value for each parameter

Parameter	(T) °C	(1/T) K	K	ln k	Regression equation	Slope	Ea	Ko
Moisture Content	25	0.00336	0.0636	-2.7546	ln k = -11483x + 35.779	11483	22805.238	35.779
	35	0.00325	0.2224	-1.5035				
	45	0.00314	0.7182	-0.3311				
Color	25	0.00336	0.1541	-1.8701	ln k = -5843.8x + 17.744	5843.8	11605.787	17.74
	35	0.00325	0.2913	-1.2334				
	45	0.00314	0.5290	-0.6367				
Aroma	25	0.00336	0.0445	-3.1115	ln k = -1079.5x + 0.511	1079.5	2143.887	0.511
	35	0.00325	0.0501	-2.9939				
	45	0.00314	0.0559	-2.8837				
Flavor	25	0.00336	85.7552	4.4515	ln k = 1795.6x – 10.447	1795.6	3566.062	10.477
	35	0.00325	104.2852	4.6471				
	45	0.00314	125.2685	4.8305				
Texture	25	0.00336	0.5323	-0.6305	ln k = -845.87x + 2.208	845.87	1679.898	2.208
	35	0.00325	0.5837	-0.5383				
	45	0.00314	0.6364	-0.4520				

The texture, which has the lowest activation energy (Ea) value among other quality parameters, was determined as the critical quality parameter (Table 4). It was selected to calculate the shelf-life of food products because it significantly affects the decline in the quality of food products during storage. The lower the activation energy value, the faster the reaction will run, contributing to product deterioration (Nugraha *et al.*, 2022). The activation energy in the texture parameter is 1679.898 (cal/mol), meaning that only the energy of 1679.898 (cal/mol) can trigger a reaction to decrease product quality faster than other sensory quality parameters. The faster the decline in the quality of a product, the faster the product will be damaged.

3.2.3 Determination of Quality Deterioration Constant

After obtaining the Arrhenius equation, the Arrhenius constant (k) value can be calculated at the specified storage temperature (T). The equation used to find the value of k is the equation for the texture parameter as the critical parameter. The following is the value of the quality reduction constant for the critical parameter, as shown in Table 4.

Table 4. Value of quality decline constant critical parameter T(°K)

Temperature (°C)	k value (score/day)
25	0.5323
35	0.5837
45	0.6364

The quality reduction constant is obtained from the regression equation with the lowest activation energy, namely the texture regression equation. Table 4 shows that the most considerable k value in the texture parameter is found at a temperature treatment of 45 °C, followed by a temperature treatment of 35 °C, and the smallest k value was found at a temperature treatment of 25 °C. It means that the temperature that had the most effect on decreasing the texture quality of pepper hard candy was the temperature treatment at 45 °C. Based on the value of the reaction constant calculation in the texture parameter, the increase in temperature is proportional to the rise in the value of the reaction constant. Decreasing the Muntok white pepper hard candy quality is a temperature-dependent reaction. This study's results align with research conducted by Wirani (2017), which showed that the k value of hard candies with the addition of betel leaf extract at high temperatures was more significant than the k value at low temperatures. In addition, Oceanic *et al.* (2017), who observed snake fruit candy, showed the same thing: the value of k at high temperatures was higher than at low temperatures.

3.2.4 Determination of the Value of the Reaction Acceleration Factor (Q_{10}) and Estimation of Shelf-life

Estimating shelf-life can be done by knowing the value of the product's initial and final quality and the value of k at the critical parameters of each storage temperature. In this case, the reaction order followed is reaction order 0, so the shelf-life value can be determined using Equation 5. The results of the calculation of shelf-life at temperatures of 25 °C, 35 °C, and 45 °C are presented in Table 5.

Table 5. Shelf-life of Muntok White Pepper Hard Candy at Different Storage Temperatures

Temperature (°C)	k value (score/day)	Shelf-life (days)
25	0.5323	40
35	0.5837	37
45	0.6364	33

Products stored at 25 °C had the longest shelf-life, followed by products stored at 35 °C and 45 °C. The study results show several factors can affect the shelf-life of Muntok white pepper hard candy. One of the main factors that affect shelf-life is storage temperature. The lowest temperature (25 °C) had a longer shelf-life compared to 35 °C and 45 °C. It is because low temperatures can inhibit the deterioration of food products. Moreover, according to (Haryati *et al.*, 2015), an increase in temperature can cause a more significant reaction speed indicated by the sharper line slope and the greater the value of the quality degradation constant. If the reaction rate is substantial, the concentrations of reactants and products will also be greater, so the products will be damaged more quickly. Therefore, if the product spoils quickly, its shelf-life will be shorter. That is in line with Wirani (2017) that hard candy with the addition of betel leaf extract in all treatments stored at lowest storage temperature (25 °C) had the most extended shelf-life compared to 35 °C and 40 °C. In addition to temperature, several factors can affect the shelf-life, including raw materials, production processes, types of packaging, and product distribution processes. According to Asiah *et al.* (2018), several factors closely related to the shelf-life of a food product include food composition, the processing process, the type of packaging, storage conditions, distribution mechanisms, handling at retailers and consumers.

A similar study by Sulaiman *et al.* (2024), using the ASLT method, estimated the shelf-life of nutmeg candy to be 51 days under 35 °C storage conditions. In contrast, our study showed that the hard candy had a shorter shelf-life (36 days) under the same conditions reported by Sulaiman. This difference may be due to variations in ingredients, production techniques, or packaging, all of which can greatly affect the product's stability and durability.

The value of Q_{10} is the acceleration factor for the degradation reaction to temperature. The Q_{10} model is a further utilization of the Arrhenius model. This model estimates the reaction rate changes or the rate of food quality deterioration if the product is stored at specific temperatures. In determining the value of Q_{10}, we can use Equation 7, which involves activation energy and two storage temperatures. The Q_{10} value obtained is 1.1. If 10 °C increases the storage temperature, the reaction acceleration is 1.1 times. From the results obtained, it can be seen that the higher the storage temperature, the shorter the product's shelf-life.

On the other hand, the lower the storage temperature, the longer the shelf-life of Muntok white pepper hard candy. That is in line with Oceanic *et al.* (2017), which states that the expiration time of snake fruit candies gets longer with lower temperatures during storage. The increasing shelf-life of the product with the lower storage temperature is because, at low temperatures, it can inhibit the damage to the Muntok white pepper candy product. According to Blongkod *et al.* (2016), storage temperature is crucial in determining and extending product shelf-life. The higher the storage temperature, the faster the rate of deterioration of food products, resulting in shorter shelf-life.

4. Conclusion and Recommendation

The decreased quality of the moisture content in Muntok white pepper hard candy is influenced by temperature and storage time differences. The results of shelf-life estimation obtained a Q_{10} value of 1.1. The texture is the most deteriorated parameter compared to moisture content, color, aroma, and taste. The higher the storage temperature, the shorter the shelf-life of Muntok white pepper hard candy. The shelf-life of Muntok white pepper hard candy at 25 °C was 40 days. For further research, sensory analysis to observe quality degradation should be carried out by trained panelists or followed with the help of tools for more precise accuracy. In addition, it is necessary to test the shelf-life with different packages to compare which packaging is better to maintain product quality and make the shelf-life longer.

5. Acknowledgement

The authors would like to thank Alfeddy Hernandy, SH from Bumdesma Mitra Lada Bersatu, Bangka Belitung Province, Indonesia for providing the raw materials of Muntok White Pepper.

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