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KINETIKA PERUBAHAN MUTU DAN ESTIMASI MASA SIMPAN ABON AYAM BUAH MERAH (*PANDANUS CONOIDEUS L.*) MENGGUNAKAN METODE *ACCELERATED SHELF-LIFE TESTING* (ASLT) DENGAN PENDEKATAN *ARRHENIUS*

KINETICS OF QUALITY CHANGES AND SHELF-LIFE ESTIMATION OF RED FRUIT (PANDANUS CONOIDEUS L.) CHICKEN FLOSS USING THE ACCELERATED SHELF-LIFE TESTING (ASLT) METHOD WITH THE ARRHENIUS APPROACH

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Abstract. *This study aims to determine the shelf-life of red fruit chicken floss and identify the most influential parameter in its shelf-life estimation. The red fruit chicken floss to be analyzed is packaged using aluminum foil and stored at temperatures of 20°C, 30°C, and 40°C. Observations are conducted on moisture content, free fatty acid content, and peroxide value over a period of 18 days. An increase in storage temperature accelerates the rate of spoilage in chicken floss, ultimately reducing its shelf-life. A storage temperature of 40°C results in the highest rate of spoilage, while at 20°C, the rate of spoilage is the slowest. The activation energy calculated for each parameter is 10,346.1 cal/mol for moisture content, 3,564.4 cal/mol for free fatty acid content, and 9,305.9 cal/mol for peroxide value. Among these parameters, the free fatty acid content has the lowest activation energy, making it the basis for shelf-life estimation of chicken floss using the Arrhenius equation, which is y = -1794.8x + 3.05. Based on the free fatty acid parameter and the Arrhenius approach, the estimated shelf-life of red fruit chicken floss is 148 days (5 months) at a storage temperature of 20°C, 121 days (4 months) at 30°C, and 100 days (3 months) at 40°C.*

Keywords : *Arrhenius Approach, Free Fatty Acid, Red Fruit Chicken Floss, Shelf-Life, Storage Temperature*

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INTRODUCTION

Red fruit chicken floss is an innovative product that uses red fruit oil extract as a fortifying ingredient or component in food products, serving as a source of vitamin A. The utilization of red fruit oil has been shown to enhance the nutritional value of abon, as it is rich in beta-carotene and tocopherol. Red fruit oil contains natural antioxidant compounds such as beta-carotene and alpha-tocopherol, as well as several other organic active components that important for providing antioxidants, which help boost the immune system (Roreng, 2014; Santoso *et al.*, 2018).

During storage, chicken floss can undergo deterioration, leading to a decline in quality, which ultimately affects its shelf-life. The production of chicken floss involves frying at high temperatures, which can accelerate oxidation. Oxidation occurs when oxygen reacts with unsaturated fatty acids present in the oils or fats. This process is responsible for the development of rancid odors (off-flavors) in chicken floss during storage. The rancidity is indicated by the peroxide content in the product (Hadiwiyoto, 2003).

Previous research has demonstrated that the use of red fruit oil can help extend the shelf life of food products, primarily by preventing oxidation-related damage. One study found that the degumming process of red fruit oil enhances its oxidative stability, which is crucial for maintaining its quality over time. Furthermore, the incorporation of this oil into food products can improve overall shelf life by delaying oxidation and reducing degradation, especially at higher temperatures, such as in microencapsulated red fruit oil (Sarungallo *et al.*, 2018; Pratiwi, 2020).

Chicken floss containing red fruit is highly recommended for consumption before it starts to deteriorate or reach its expiration date, to avoid any undesirable outcomes. However, it is still unclear exactly how long red fruit chicken floss can be safely consumed, making shelf life estimation a useful method to determine its stability during storage. The shelf life of red fruit chicken floss can be estimated using the Accelerated Shelf Life Testing (ASLT) method. ASLT is a technique that speeds up the quality deterioration process by conditioning the food product outside of its normal storage conditions (Labuza, 2007). In this method, temperature acts as a key parameter influencing food deterioration. As temperature increases, food degradation occurs more rapidly. The relationship between temperature and the rate of quality decline can be modeled using the Arrhenius equation. Therefore, conducting shelf life studies using the ASLT method is essential for predicting the shelf life of red fruit chicken floss.

MATERIALS AND METHODS

This research was conducted at the Agricultural Product Processing Laboratory of the Polytechnic of Agricultural Development in Manokwari and the Food Chemistry Laboratory of the Faculty of Agricultural Technology at the University of Papua, from April to June 2023.

1. Tools and Materials

The primary ingredients used in this study are chicken breast fillet and degummed red fruit oil. Additional ingredients include various spices such as galangal, ginger, lemongrass, turmeric, tamarind, shallots, garlic, palm sugar, salt (kapal), pepper, cumin, cooking oil, and ground coriander. The materials for analysis are bipyridine, klorida heksahidrat, phenolphthalein indicator, potassium chromate kalium dikromat, starch indicator, potassium hydroxide (KOH), aquades, 95% alcohol, hexane, butylated hydroxytoluene (BHT), sodium metabisulfite natrium sulfit, concentrated hydrochloric acid (HCl), potassium iodide (KI), chloroform, and aquades.

The equipment used for preparing chicken floss includes a pot, frying pan, plastic containers, a scale, stove, spatula, oil filter, blender, and aluminum containers. The tools used for analysis in this study consist of an oven, petri dishes, burette, measuring cylinders, glass funnel, Erlenmeyer flasks (250-1000 mL), beakers, droppers, spatula, desiccator, water bath, test tubes, rubber suction, Erlenmeyer flask, distillation unit, analytical balance, thermometer, and glass funnel. The equipment used for organoleptic testing includes writing instruments, questionnaires, and sample containers for testing.

2. Research Implementation Phase

The research was conducted in two stages, namely the first stage of making shredded red friut chicken, and determining the shelf life with the *Arrhenius* approach.

3. Preparation of Red Fruit Chicken Floss

In the production stage, chicken floss is made using chicken meat. The meat is mixed with kaffir lime leaves, bay leaves, and lemongrass, and then boiled with 2 liters of water per kilogram of chicken for one hour. The boiled meat is then pounded finely. After the chicken is softened, the blended spices are added and sautéed with a little oil. The shredded meat is combined with the spices and red fruit oil according to the treatment. After everything is well mixed and dry, the cooked meat is fried again until dry and then drained using a spinner. The resulting chicken floss is stored and analyzed (moisture content, free fatty acids, and peroxide value).

4. Storage of Red Fruit Chicken Floss

Chicken shredded weighed as much as 200 grams packed into polypropylene (PP) plastic then stored in three different temperatures of 30°C, 40°C, and 5°C and storage duration (0 days, 3 days, 6 days, 9 days, 12 days, 15 days, 18 days). Observations were made on the parameters of water content, free fatty acid, and peroxide number.

5. **Shelf-Life Determinants According to the Arrhenius Approach**

Each 200 gram portion of chicken floss is stored in a polypropylene standing pouch plastic package lined with aluminum foil at temperatures of 20˚C, 30˚C, and 40˚C. An initial analysis is conducted before storage to measure moisture content, peroxide value, and free fatty acids. The conditions at each temperature are monitored every three days to observe changes in these parameters. A graph of the observations over time is created, and linear regression is applied using the equation y = a + bx, resulting in three regression equations corresponding to the different storage temperatures. In this equation, y represents the characteristic values of the red fruit chicken floss, x is the storage duration, a is the initial property of the chicken floss, and b is the rate of change of these values. Each equation provides a slope (b) and a constant value (k).

To determine the reaction order, zero-order graphs, which represent the relationship between k values and time accumulation, and first-order graphs, which show the relationship between ln k and time accumulation, are analyzed, with the highest R^2 value indicating the reaction order. The Arrhenius method is then applied by plotting k against 1/T (K^{-1}) and ln k according to the linear regression equation $\ln k = \ln k_0 - (E/R)(1/T)$, where $\ln k_0$ is the intercept, E/R is the slope, Ea is the activation energy, R is the ideal gas constant (1.986 cal/mol·K), and T is the temperature in Kelvin.

After obtaining the pre-exponential factor (k_0) and activation energy (Ea), the Arrhenius equation for the rate of change in the characteristics of red fruit chicken floss is expressed as equation $K = K_0 \cdot e^{(\frac{-Ea}{RT})}$, allowing the Arrhenius constant value to be calculated for each storage temperature. The parameter with the lowest activation energy is considered the main parameter, following a modification of Dewi (2010). Finally, the shelf life of the red fruit chicken floss is calculated using the reaction equation based on its reaction order. By inserting the temperature values into the formula $\ln k = \ln k_0 - (E/R)(1/T)$, the k values generated are substituted into the reaction order equation to determine the shelf life of the chicken floss.

RESULTS AND DISSCUSION

1. **Changes in water content of chicken floss during storage**

Moisture content indicates the percentage of water in red fruit chicken floss. Water is one of the factors that can trigger spoilage; the higher the moisture content in the floss, the greater the likelihood of deterioration (Reh *et al.*, 2003). Changes in the moisture content of red fruit chicken floss are presented in Table 1.

Based on the data in Table 1, the moisture content of red fruit chicken jerky tends to increase during storage at three different temperatures. The moisture content significantly increases at higher temperatures (30-40°C).

Table 1. Changes in Water Content of Red Fruit Chicken floss Storage at 20˚C, 30˚C, and 40˚C.

Storage Time (Days)	Temperature 20˚C (moisture content %)	Temperature 30˚C (moisture content %)	Temperature 40˚C (moisture content %)
0	2.93	2.93	2.93
3	3.32	2.95	3.01
6	2.8	3.38	3.08
9	2.83	3.49	3.37
12	2.76	3.41	4.65
15	4.24	3.96	4.5
18	3.42	6.07	5.13

Higher temperatures tend to accelerate the change in moisture content compared to lower temperatures (20°C). This is suspected to be due to the slower evaporation process of water from the material at lower temperatures. At 30°C, the moisture content is higher compared to 40°C during the 18-day storage period. This is believed to be because materials stored at 30°C are better at retaining moisture, as this temperature is closer to the optimal temperature for many food materials to absorb moisture. In contrast, at higher temperatures, in addition to evaporation, the material may undergo structural changes that reduce its ability to retain water. As stated by Sabila *et al.* (2017), higher temperatures tend to accelerate evaporation and environmental factors such as relative humidity and the interaction between the material and surrounding air also play a role in changes in moisture content. According to the Indonesian National Standard (SNI) 01-3707-1995, the maximum allowed moisture content for jerky quality is 7%, so the red fruit chicken jerky stored for 18 days at various temperatures still meets the SNI standard.

2. Free Fatty Acids (FFA)

The free fatty acid content will increase during the storage of chicken floss and will rise more at higher storage temperatures because, during storage, free fatty acids undergo hydrolysis and oxidation processes. Higher temperatures make the lipase enzyme more active. This enzyme accelerates the breakdown of fats into free fatty acids and glycerol, resulting in an increase in free fatty acid content. Based on the data in Table 2, the free fatty acid (FFA) content in red fruit chicken floss tends to increase during storage at three different temperatures. The FFA content starts at 2.47% on day 0 and increases over the 18-day storage period: at 20˚C it rises to 5.24%, at 30˚C to 6.60%, and at 40˚C to 7.61%.

Table 2. Changes in Free Fatty Acid (FFA) Content of Red Fruit Chicken floss Storage at 20°C, 30°C, and 40°C.

Storage Time (Days)	20^0C (FFA %)	30^0C (FFA %)	40^0C (FFA %)
0	2.47	2.47	2.47
3	2.63	2.65	2.60
6	3.85	3.22	3.41
9	3.82	4.04	4.20
12	4.11	4.71	5.59
15	5.62	6.10	6.41
18	5.24	6.60	7.61

This increase in FFA indicates the continuous formation of free fatty acids during storage due to the hydrolysis process in the jerky. Hydrolysis leads to hydrolytic rancidity, which results in a rancid flavor in fats or oils. High temperatures, pressure, and excess water accelerate hydrolysis, causing the reaction of water and fat to form free fatty acids and glycerol (Lawson, 2005). High temperatures also accelerate fat oxidation, which breaks down triglycerides into free fatty acids. At higher temperatures, oxidation reactions occur faster, contributing to the increase in free fatty acids, as seen at 40˚C, where the FFA content continues to rise with storage time (Zhang *et al.*, 2020).

3. Perioxide Values

The peroxide value plays an important role in determining the shelf life of a product. The higher the peroxide value, the faster the product deteriorates, while a lower peroxide value allows for a longer shelf life (Budijanto *et al.*, 2001). The peroxide value serves as a key indicator of the level of damage to fats or oils due to oxidation. The quality of oil can be assessed through its oxidation value, which reflects the extent to which the oxidation process has occurred.

During the oxidation process, unsaturated fatty acids react with oxygen to form peroxides, which eventually break down into ketones and aldehydes. The presence of these compounds is responsible for the development of a rancid odor. Therefore, an increase in peroxide levels serves as an early warning that the oil has begun to undergo rancidity (Ketaren, 2005).

Based on the data in Table 3, the peroxide value of red fruit chicken floss tends to increase during storage at three different temperatures. The peroxide value starts at 0.04 mg/g on day 0 and continues to rise over the 18-day storage period. At 20˚C, the peroxide value increases to 0.47 mg/g, at 30˚C to 0.52 mg/g, and at 40˚C to 1.10 mg/g.

Table 3. Changes in Perioxide Numbers of Red Fruit Chicken floss Storage at 20^{0}C, 30^{0}C and 40^{0}C.

Storage Time (Days)	20^{0}C (PV mg/g)	30^{0}C (PV mg/g)	40^{0}C (PV mg/g)
0	0.04	0.04	0.04
3	1.10	0.72	0.47
6	1.39	0.84	0.49
9	0.74	0.55	0.54
12	0.57	0.79	0.93
15	0.38	0.55	1.04
18	0.47	0.52	1.10

This trend aligns with the findings of Montesqrit & Ovianti (2013), who stated that during storage, double bonds in unsaturated fatty acids break down, either forming free fatty acids or undergoing oxidation to produce peroxide compounds. Longer storage time increases the likelihood of oxidation or hydrolysis of fats. Kusnandar (2006) further explains that, in addition to storage duration, temperature also significantly affects the peroxide value. Higher temperatures accelerate oxidation reactions, leading to the formation of more peroxide compounds in the product.

The high peroxide values observed on days 3 and 6 at all three storage temperatures may be attributed to the early phase of oxidation. During this phase, reactive oxygen species (ROS) rapidly interact with fats, leading to the formation of peroxides. This process tends to occur more quickly at higher temperatures. After a few days, the rate of oxidation may slow down due to a reduction in the amount of available fat for oxidation or because peroxides begin to decompose into secondary products, such as aldehydes and ketones (Budiyanto, 2010).

4. Kinetics of Quality Changes of Red Fruit Chicken floss Storage Reaction Order Determination

An essential aspect of reaction kinetics is determining the reaction order, which refers to the sum of the exponents of the reactant concentrations in the reaction rate equation. This process aims to identify whether the decomposition kinetics follow a linear or logarithmic pattern (Toledo, 2007). Changes in product quality are influenced by parameters such as moisture content, free fatty acid (FFA) levels, and peroxide value. If the degradation rate is constant or linear, the reaction follows a zero-order pattern. Conversely, if the degradation rate is logarithmic or exponential, the reaction follows a first-order pattern (Arif *et al.*, 2014).

The determination of the reaction order is crucial for predicting product quality degradation, which plays a vital role in estimating shelf life. In the case of changes in moisture content, free fatty acids, and peroxide value in red fruit chicken jerky, the reaction order is calculated using the R^2 value from the regression equation (Figure 4). A higher R^2 value indicates that the mathematical model is more accurate in predicting the actual product quality. This is because R^2 measures how much of the variability in the dependent variable (product quality) can be explained by the independent variables in the model.

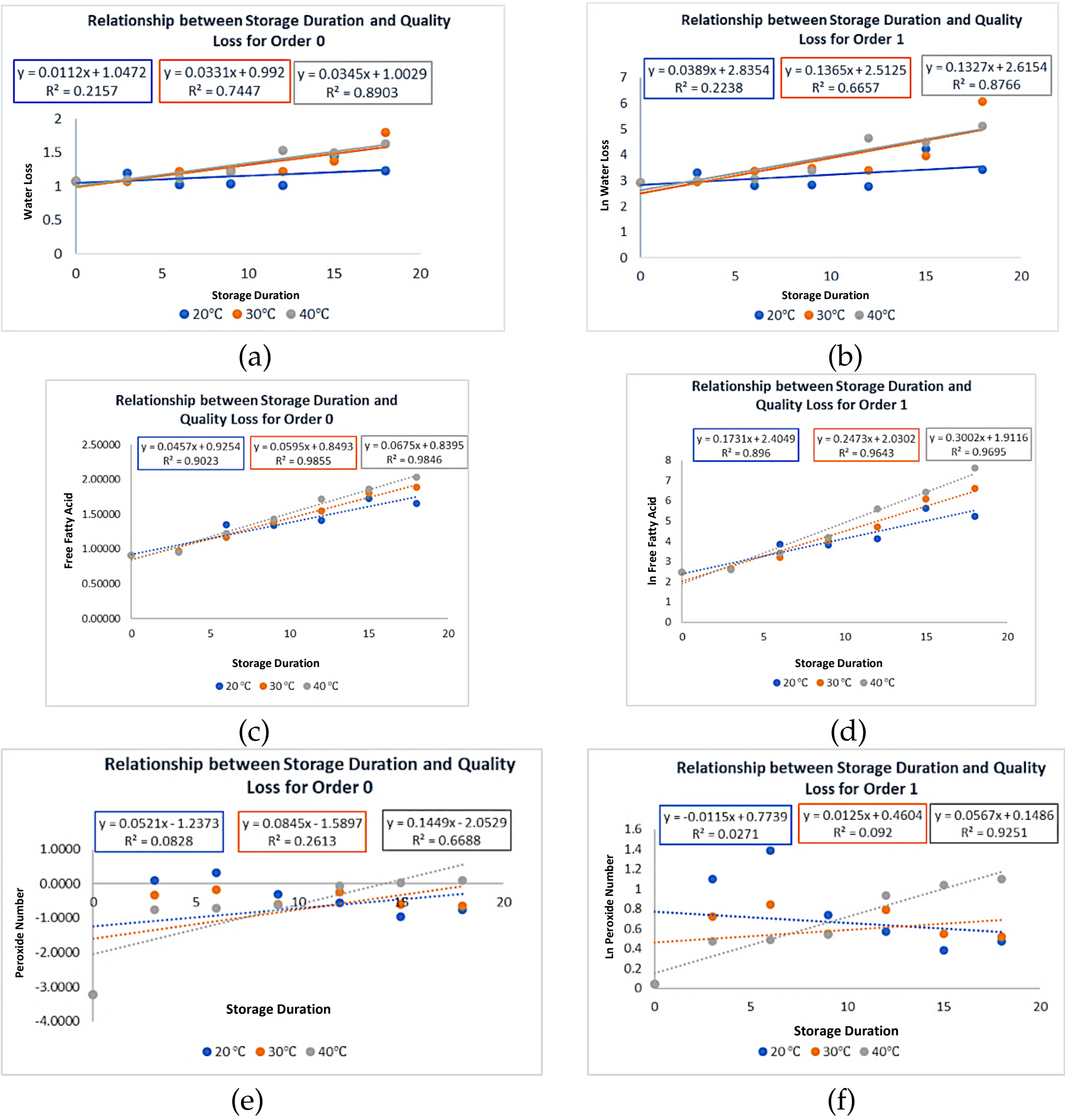


Figure 1. The relationship curve between storage time and the changes or each quality parameter of Abon Ayam Buah Merah (a) moisture content order 0; (b) moisture tontent order 1; (c) free fatty acid order 0; (d) free fatty acid order 1; (e) perioxide number orde 0; (f) perioxide number orde 1.

Table 4. The order used in the quality reduction based on the content parameter water, free fatty acids and perioxide number.

Parameters	Temperature (^{0}C)	R^2 Order 0	R^2 Order 1	Order Used
Water Content	20	0,2157	0,2238	Order 0
	30	0,7447	0,6657	
	40	0,8903	0,8766	
Free Fatty Acids	20	0,9023	0,8960	Order 0
	30	0,9855	0,9643	
	40	0,9846	0,9695	
Perioxide Numbers	20	0,0271	0,0828	Order 0
	30	0,0920	0,2613	
	40	0,9251	0,6688	

The reaction order for the increase in moisture content, free fatty acids, and peroxide value in red fruit chicken jerky follows a zero-order reaction (Table 6) because the R^2 values for the linear equations at all three temperatures are the highest. This indicates that the increase in moisture content, free fatty acids, and peroxide value follows a linear reaction rate, meaning that quality degradation consistently occurs during storage (Toledo, 2007).

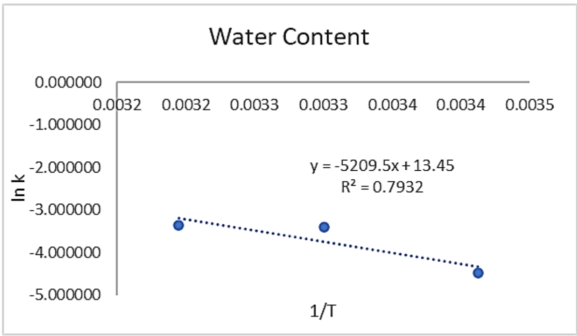
5. Reaction Rate (k value) and Activation Energy (Ea value)

The regression results for the quality deterioration of red fruit chicken jerky during storage were then used to determine the reaction rate constant (k). The reaction rate constant (k) was obtained from the absolute value of the slope in the linear equations for each order. The calculation of k and 1/T for the quality change reaction of red fruit chicken jerky at temperatures of 20°C, 30°C, and 40°C is presented in (Table 5).

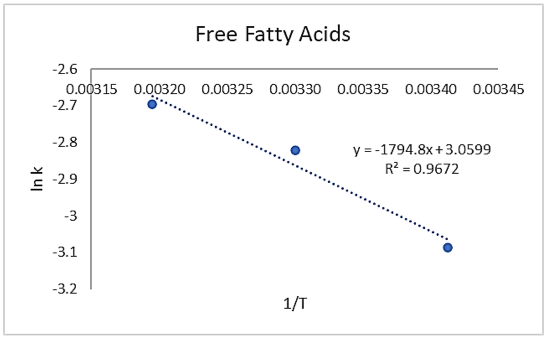
Data in Table 5 shows that the peroxide value (k) tends to increase for each parameter at each storage temperature. This indicates that the peroxide value of chicken floss is sensitive to storage temperature. In other words, the peroxide value easily reacts because it is influenced by temperature, making the chicken floss more prone to deterioration during storage. The higher the storage temperature, the greater the k value (rate of quality decline). Sathivel *et al.* (2002) also reported that both temperature and storage time affect the rate of fat oxidation in oils. The reaction rate constant (k) values for the three parameters, moisture content, free fatty acids, and peroxide value, were then converted to natural logarithmic values (ln k) and plotted against 1/T (in Kelvin), resulting in an Arrhenius curve shown in Figure 2.

Table 5. Calculation of k and In k values of the reaction of changes in moisture content, free fatty acids and perioxide number of red fruit chicken floss storage at 20⁰C, 30⁰C, and 40⁰C.

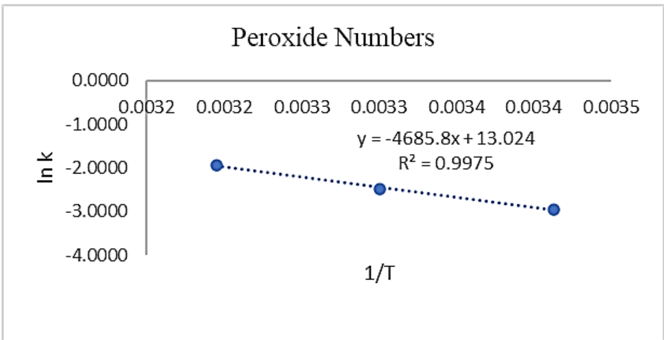
Parameters	T (⁰C)	T (K)	1/T	Value of k	In k
Water Content	20	293	0,0034	0,0112	-4,4918
	30	303	0,0033	0,0331	-3,4082
	40	313	0,0032	0,0345	-3,3667
Free Fatty Acids	20	293	0,0034	0,0457	-3,0856
	30	303	0,0033	0,0595	-2,8217
	40	313	0,0032	0,0675	-2,6956
Perioxide Numbers	20	293	0,0034	0,0521	-2,9546
	30	303	0,0033	0,0845	-2,4710
	40	313	0,0032	0,1449	-1,9317



(a)



(b)



(C)

Figure 2. Relationship between ln K and 1/T of the reaction (a). change in water content, (b) change in free fatty acids and (c) changes in peroxide number of red fruit chicken floss

Table 6. Linear equation of the regression results of ln k and 1/T from the reaction of quality changes in red fruit chicken floss degumming

Parameters	Linear Equaation	Slope (Ea/R)	Ea (Cal/mol)
Water content	y = -5209.5x + 13.45	5209,5	10.346,1
Free Fatty Acids	y = -1794.8x + 3.05	1794,8	3.564,4
Perioxide Number	y = -4685.8x + 13.024	4685,8	9.305,9

Description: R= 1,986 Cal/mol.

The data from the linear equation in Figure 2. and the calculation of the Ea value are summarized in Table 6. The interpretation of Ea (activation energy) provides insight into the extent of temperature's effect on the reaction. The Ea value indicates the energy required to change a quality characteristic. The higher the Ea value, the more energy is needed for the reaction, meaning the quality change will occur more slowly. Conversely, the lower the Ea value, the less energy is required, and the quality change will happen more quickly (Arpah & Syarief, 2000).

The data in Table 6 shows that the Ea value for free fatty acids (3.564 kcal/mol) is the lowest among the three quality parameters of red fruit chicken floss tested. This low Ea value indicates that red fruit chicken floss is more easily hydrolyzed than oxidized, while it takes longer for the chicken floss to absorb water. Therefore, shelf life is determined based on the kinetics of quality changes during storage, specifically focusing on the free fatty acid parameter.

6. **Estimation of Shelf Life of Red Fruid Chicken Baton by ASLT Method**

The ASLT (*Accelerated Shelf Life Testing*) method is a method that accelerates food determination by increasing the storage temperature and calculating the expiration date. The ASLT method can be applied to all food deterioration processes that have valid kinetics models. The deterioration process can be chemical, physical, and /or microbiological. The approach made in the ASLT method is how to get real damage at a certain time interval, which model to use and how to predict the actual shelf life of the product (Kilcast & Subraiman, 2000). The result of shelf life estimation conducted at 20^0C, 30^0C, and 40^0C can be seen in Table 7.

The data in Table 7 shows that the red fruit chicken floss stored at 20˚C has a shelf life of 148 days or 5 months, at 30˚C it lasts 121 days or 4 months, and at 40˚C it lasts 100 days or 3 months. Storage temperature affects the shelf life of red fruit chicken floss. This indicates that an increase in storage temperature will shorten the shelf life of the chicken floss.

Table 7. Estimated Shelf Life of Red Fruit Chicken Shredded at 20^0C, 30^0C, and 40^0C based on free fatty acid parameters.

Temperature	ALB Critical Point	Initial ALB	ALB Quality Decrease Rate (K)	Shelf Life (Days)	Shelf Life (Month)
20	9.31	2,4	0.046621323	148	5
30	9.31	2,4	0.057066824	121	4
40	9.31	2,4	0.068956093	100	3

This is supported by Suyitno (1995), who found that increasing temperature can accelerate the rate of reaction, as evidenced by the increased slope of the line and the constant rate of quality decline.

CONCLUSION

The study showed that the higher the storage temperature, the faster the shredded chicken deteriorated and the shorter the shelf life. The earliest deterioration of shredded red fruit chicken occurated at 40^0C and the slowest at 20^0C. The activation energy of each parameter was 10346.1 cal/mol for the water content value; the free fatty acid content was 3564.4 cal/mol and the perioxide number was 9305.9. the lowest activation energy value is found in the free fatty acid value parameter which is used to calculated the shelf life of shredded chicken with the Arrhenius equation y = -1794.8x + 3.05. the shelf life of shredded red fruit chicken calculated by Arrhenius method based on the parameter of free fatty acid value was obtained 148 days (5 month) at a storage temperature of 20^0C.

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