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Shelf-Life Prediction of Black Garlic Chili Sauce and "Cahyo" Garlic Chili Sauce with *Accelerated Shelf-Life Testing* (ASLT) Method Based on The *Arrhenius* Model

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A B S T R A C T

Sambal is often found in various menu variants served in the Indonesian food industry; this is a supporting factor for creating bottled chili sauce. In this research, fermented black garlic chili sauce was made with black garlic as raw material to provide added value in the form of antibacterial and antioxidant compounds, as well as giving a novelty value to the product as well as a differentiator in the elements of color, aroma, consistency, and taste of the product. The final product consumers receive is compared to "Cahyo" garlic chili sauce produced by PT. Deltasari Indah Restaurant. Sambal contains oil/fat, which is quickly rancid, thus affecting the element of consumer acceptance. Therefore, it is necessary to predict the shelf life of bottled chili products. This research aims to predict the shelf life of the black garlic chili sauce and "Cahyo" garlic chili sauce products in bottles produced by PT. Deltasari Indah Restaurant with the ASLT method, the Arrhenius model approach; Knowing the difference in the shelf life of bottled chili products stored at different temperature conditions; and determining the proper temperature and storage conditions to get the maximum shelf life for packaged chili products. This study uses the Accelerated Shelf-Life Testing method with the Arrhenius model. Based on the pH value parameter, the shelf life of black garlic chili sauce was 33 days, and "Cahyo" garlic chili sauce was 45 days. These two results are the results of the shelf life obtained from calculations at 20˚C and 25˚C then the average value is taken.

1. INTRODUCTION

1.1. Research Background

The Indonesian food industry today presents a very wide variety of food dishes, many of which involve sambal as a complement to the menu served. Sambal is a ready-to-eat product in solid or semi-solid or powder form made from the main raw material of chili (Capsicum sp) which is crushed or ground or crushed, with the addition of other food ingredients, with or without the addition of permitted food additives and has previously undergone other cooking and/or preservation processes [1]. The increasing trend of people showing interest in spicy food is one of the supporting factors for the creation of a wide variety of bottled chili sauce products, such as "Cahyo" Garlic Chili Sauce and Black Garlic Chili Sauce.

In line with this, it should be noted that chili sauce is a processed food product that contains fat and is prone to rancidity during storage. Rancidity is the damage to or a change in smell and flavor of fat or fatty foodstuffs. Rancidity affects the quality of food products, causing consumers to reject them and harming health [2]. The primary damage to fat is the appearance of a rancid smell and taste, called the process of rancidity. Various types of oil or fat will experience changes in flavor and odor before the rancidity process occurs. A very high peroxide value can indicate rancid oil or fat [3].

Companies and Micro, Small and Medium Businesses that produce bottled chili sauce need to consider this issue to know the final product's optimal shelf life and storage conditions. Even though various variants and brands of packaged chili sauce manufacturers are widely circulated in the market, many products still include expiration dates based on producer estimates, especially Micro, Small and Medium Business producers. This causes these products to circulate in the market in conditions unsuitable for consumption.

One of the information that must be included on food product packaging is the product's expiration date. This is based on Indonesian Food Law No. 18 of 2012 concerning Food and

Indonesian Government Regulation No. 69 of 1999 concerning Food Labels and Advertisements which states that every packaged and traded food product must include the date, month, and year of expiration on each food package. The product's shelf life will be affected by a decrease in the quality of the food product. Food damage can be caused by two things, namely damage by the natural nature of the product which occurs spontaneously and the second is damage due to environmental influences [4]. Decreased product quality can be caused by products exposed to air, oxygen, water vapor, light, and microorganisms or due to temperature changes [5].

Predicting the shelf life of food products can be done using the accelerated method, namely the ASLT (Accelerated Shelf-Life Testing) method. The *Arrhenius* model is used for products that are sensitive to changes in storage temperature, while the critical moisture content model is used for products that are easily damaged due to the absorption of water from the environment during storage [6]. With this method, product storage using three different temperatures can predict shelf life at the desired storage temperature [7].

1.2. Literature Review

1.2.1. *Accelerated Shelf-Life Testing* Method with the *Arrhenius* Model

The Accelerated Shelf-Life Testing method, commonly called the ASLT method, is carried out by storing the product in environmental conditions that can accelerate the decline in product quality (Temperature, Relative humidity) [8]. Determining the shelf life of products using the accelerated method can be carried out using two approaches, namely 1) the critical water content approach using the diffusion theory, namely using changes in water content and water activity as criteria for water content as expiration criteria, and 2) a semi-empirical approach with the help of the *Arrhenius* equation, namely with the theory of kinetics which generally uses order zero or order one for food products [9].

In principle, the *Arrhenius* method stores food products at extreme temperatures, where food product deterioration occurs more quickly. The shelf life is determined based on extrapolation to storage temperatures. Therefore, the shelf life obtained is 'estimated', the validity of which is determined by the mathematical model obtained from the experimental results [10].

The types of damage to foodstuffs that are included in order one reactions are (1) rancidity (for example, in salad oil and dried vegetables); (2) growth of microorganisms (eg in fish and meat, as well as death of micro-organisms due to heat treatment); (3) off-flavor production by microbes; (4) damage to vitamins in canned food and dry food; (5) loss of protein quality (dry food) [11].

Most of the decline in the quality of food ingredients fall into the category of order zero and order one reactions. By evaluating the constant rate (k) at three or more different temperatures, a graph of the *Arrhenius* relationship can be made, namely extrapolation with the straight-line equation of the relationship between ln k vs 1/T to predict the reaction rate (k) from reactions at other temperatures [12].

Wherein k: constant rate of reaction / rate of degradation
T: Time [12].

The chemical reaction rate constant (k), both zero and first order, can be affected by temperature. Because in general, chemical reactions occur faster at high temperatures, the chemical reaction rate constant (k) will be greater at higher temperatures. the magnitude of the chemical reaction rate constant which is affected by temperature, can be seen by using the *Arrhenius* equation model to find the value of k as follows:

$$k = A \, . exp^{-\left(\frac{Ea}{RT}\right)}$$

wherein

- k : constant rate of reaction/rate of degradation
- A : frequency factor (1/s)
- Ea : activation energy (cal/mol)
- R : common gas constant (1.986 cal/mol. K or 8.314 J/mol. K)
- T : absolute temperature (K) [13].

The equation above can be written in a logarithmic form as follows:

$$\ln k = \ln A - \left(\frac{Ea}{RT}\right)$$

or

$$\ln k = \ln k_0 - \left(\frac{Ea}{R}\right)\left(\frac{1}{T}\right)$$

Activation energy is the energy that occurs as a result of the collisions or vibrations of molecules meeting. For this to occur, the molecules must collide with one another and must have activation energy [14].

1.2.2. *The decline in the Quality of Food Products*

Two things can cause food damage, namely damage due to the natural nature of the product, which takes place spontaneously, and the second is damage due to environmental influences [4]. Several factors that may cause a decrease in the quality of a product can be due to chemical reactions (Maillard reaction, lipid oxidation), biological changes that continue during food storage, and simultaneous processes such as growth of microorganisms, enzymatic and non-enzymatic reactions. Changes in product quality and safety during the storage process are strongly influenced by the intrinsic and extrinsic factors of the product [8].

1.2.3. *Correlation Between the Temperature Factor and The Shelf-Life of Chili Sauce*

The ASLT method applies reaction kinetics with the help of the *Arrhenius* equation. The *Arrhenius* model has several assumptions, including: (a) a change in quality factor is only determined by one type of reactor, (b) there are no other factors that result in a change in quality, (c) the quality change process is considered not a result of previous processes, and (d) the storage temperature is considered constant [7].

The ASLT method is the determination of product shelf life by accelerating changes in quality on critical parameters. This method uses environmental conditions that can speed up the reaction of decreasing the quality of food products. Food products are stored in extreme temperature conditions so that the quality of critical parameters decreases due to the influence of heat. In this method, storage conditions are set outside normal conditions so the product can spoil more quickly and the shelf life can be determined [15].

With this method, product storage uses three different temperatures, which are able to predict shelf life at the desired storage temperature [7]. The storage process is carried out with three storage temperature conditions with a certain range, namely at low temperatures (5 - 20˚C) stored in the refrigerator, room temperature (20 - 35˚C) stored indoors, and high temperatures (35 - 60˚C) stored in an oven [16].

1.2.4. Correlation Between pH Value and The Shelf-Life of Chili sauce

The pH value is an important indicator of the quality of a product. Observation of the pH value is important because changes in the pH value will affect the product quality [17]. Changes in the pH value during storage can indicate a reaction or damage to the constituent components in a product so that it can lower or raise the pH value [18].

The pH value needs to be measured to determine the acidity/alkaline level of the product and its relation to the safety and shelf-life of the product. The pH value is an important factor for a food product when it is related to product quality [19].

Most microbes grow best at a pH around neutral and a pH of 4.6-7.0. this is the optimum condition for bacterial growth, whereas mold and yeast can grow at a lower pH. Most microorganisms that can grow in this pH range are molds and yeast. Yeast is more resistant to acids than bacteria and is closely related to the spoilage of fruits, fruit juices, and soft drinks. The effect of pH is used as a parameter of food durability because microbes do not grow during storage. The increase in pH during storage is thought to be due to the fermentation process by the microbes that grow during storage [20].

1.3. Research Objective

The purpose of this study was to predict and figure out the shelf-life of bottled black garlic chili sauce and "Cahyo" garlic chili sauce products using the *Accelerated Shelf-Life Testing* (ASLT) method with the *Arrhenius* model treated at 3 different temperature conditions, as well as to determine the ideal temperature and storage conditions to get the maximum shelf-life for both bottled chili sauce products.

2. MATERIALS AND METHODS

2.1. Materials and Tools

The raw materials used in this study were large chilies, small chilies, shallots, garlic, black garlic, sugar, salt, cooking oil, monosodium glutamate, chicken seasoning, sodium benzoate, and "Cahyo" garlic chili sauce produced by PT. Rumah Makan Deltasari Indah. The materials used for analysis were physiological saline solution, Plate Count Agar (Oxoid), Potato Dextrose Agar (Oxoid), starch/starch indicator, 0.1 N sodium thiosulphate solution, glacial acetic acid-isooctane solution, potassium iodide solution and sterile distilled water. Other materials used in the study were 70% alcohol, denatured alcohol, lighters, sterile distilled water, aluminum foil, PET plastic packaging bottles and their covers, plastic wrap, and labels.

The tools used in making black garlic sauce and this research are Food dehydrator/microwave, refrigerator, incubator, autoclave, vortex mixer, analytical balance, 50ml Erlenmeyer, 250ml Erlenmeyer, 100ml measuring cup, 1.5ml Eppendorf tube and Eppendorf tube rack, test tube 20 ml and test tube rack, test tube lid, watch glass, petri dish, Bunsen burner, blender, chopper, 100-1000 µl micropipette, blue tip and yellow tip, UV Sterilizer box, room thermometer, digital pH-meter, latex gloves , stove, pan, pot and stirrer.

2.2. Design of Experiment and Analysis

This research was conducted by estimating the shelf-life of black garlic chili sauce and "Cahyo" garlic chili sauce in PET bottles produced by PT. Rumah Makan Deltasari Indah with storage temperatures of 10˚C, 30˚C and 50˚C for 16 days and observations every 4 days at the BSL - 2 (Bio Safety Level 2) Laboratory, Airlangga University.

The analysis used the Accelerated Shelf-Life Testing (ASLT) method with the *Arrhenius* model based on the Labuza equation (1982) with chemical parameters, namely measuring pH values and peroxide values. Microbiological parameters, namely calculating the total number of microbes, molds and yeast using the Total Plate Count (TPC) method and organoleptic parameters using hedonic scale tests including aspects of color, aroma and texture.

2.3. Research Procedure

2.3.1. Making Black Garlic Chili Sauce

Making black garlic chili sauce began with sterilizing a 150-gram PET bottle and peeling the shallots and garlic, then washing the large chilies, small chilies, shallots, and garlic, and after washing, then weighing 670 grams of large chilies, 1000 grams of small chilies, 670 grams of shallots, 350 grams of garlic, 350 grams of black garlic, 17 grams of sugar, 50 grams of salt, 35 grams of monosodium glutamate, 35 grams of chicken seasoning, 1500 mg of sodium benzoate and mixing it in a blender and operating the blender until smooth. Once smooth, the contents are transferred to a frying pan, adding 1 liter of cooking oil, then cooking for ± 90 minutes over high heat at ± 120˚C. The last step in making black garlic sauce in this study was filling the black garlic sauce into 150-gram PET plastic bottles using a funnel after letting it cool for ± 1 hour. The filling is done by leaving a headspace (the distance between the product and the bottle cover) of about 2 cm. The next step is double closing on the bottle with an aluminum seal and plastic cover on the bottle, lastly labeling the bottle and sealing the bottle using a plastic seal which is shrunk using a heat gun.

2.3.2. Chemical Analysis

The chemical analysis consists of testing the pH value and peroxide value. Peroxide value testing was carried out using the iodometric titration method. A total of (5 ± 0.05) g of sample (W) was weighed into a dry Erlenmeyer 250 mL. 50 mL of glacial acetic acid-isooctane solution was added, then the Erlenmeyer was closed and stirred until the solution was homogeneous. After stirring, 0.5 mL of saturated potassium iodide solution was added using a measuring pipette, then shaken for 1 minute.

Then 30 mL of distilled water was added, and the Erlenmeyer was closed immediately. The Erlenmeyer is shaken and titrated with 0.1 N sodium thiosulphate solution until the yellow color almost disappears, then 0.5 mL starch indicator is added and continued titration, shaken vigorously to release all iodine from the solvent layer until the blue color disappears. The analysis was carried out 2 repetitions for each sample. Next is the determination of blanks. The following formula can calculate the peroxide value:

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$$Peroxide\ value\ \left(meq\ {}^{O_2}/_{kg}\right) = \frac{1000\ x\ N\ x\ (V_0 - V_1)}{W}$$

Wherein:

N is the normality of a standard solution of 0.01 N sodium thiosulfate (Na2S2O3), expressed in normality, (N);

V0 is the volume of 0.1 N sodium thiosulphate solution required for ***sample*** titration, expressed in milliliters (mL);

V1 is the volume of 0.1 N sodium thiosulphate solution required for ***blank*** titration, expressed in milliliters (mL);

W is the weight of the sample, expressed in grams (g). [21]

2.3.3. Microbiological Analysis

The microbiological analysis includes Total Plate Count (TPC) values and mold and yeast values. [22] The Total Plate Count (TPC) test uses solid media with the result in colonies that can be observed visually in the form of numbers in colonies (cfu) per ml/g or colonies/100ml.

One gram of the sample was weighed and homogenized in 9 ml of 0.85% NaCl solution to make 10-1 to 10-6. A total of 50 µl of samples from each dilution was dripped onto the surface of a sufficiently dry sterile PCA agar (for TPC) and PDA agar (for mold and yeast) medium and incubated at 37°C for 18-24 hours.

2.3.4. Organoleptic Analysis

The organoleptic analysis aims to determine the shelf life by the organoleptic response. The aspects observed included color, aroma, and texture until the bottled garlic chili sauce became spoiled with a characteristic color that tends to be darker and has a sour aroma. The texture was not like before or deviated.

The organoleptic analysis involves a minimum of 25 panelists. The Indonesian National Standard for Sambal/Chili Sauce [1] states that a good chili sauce has a normal color, taste, and aroma. Deviations from these standards indicate that the chili sauce has degraded and started spoiling.

2.4. Analytical methods

Shelf-life prediction was carried out by analyzing the parameters that influence the calculation of the estimated shelf-life based on Labuza's equation (1982). Obtained observational data for determining shelf-life were then tabled and plotted in the form of a regression curve so that a linear regression would be obtained using the *Microsoft Excel 2019* program.

The *Arrhenius* model is implemented by storing food products at a minimum of three extreme temperatures. Experiments with the *Arrhenius* method aim to determine the reaction rate constant (k) at several extreme storage temperatures, then extrapolate to calculate the reaction rate constant (k) at the desired storage temperature using the *Arrhenius* equation (*equation 1*).

From this equation, the value of k (decreased quality constant) at the storage temperature of the shelf life can be determined. The following is the equation used to determine shelf life based on the *Arrhenius* model approach (Labuza, 1982):

$$k = k_0 . exp^{-\left(\frac{Ea}{RT}\right)} \dots\dots\dots\dots (1)$$

or

$$k = A\ .exp^{-\left(\frac{Ea}{RT}\right)} \dots\dots\dots\dots (1)$$

Wherein:

k : reaction rate constant/degradation rate

k_0/A : frequency factor (1/s)

Ea : activation energy (cal/mol)

R : common gas constant (1.986 cal/mol. K or 8.314 J/mol. K)

T : absolute temperature (K)

Referring to the equation above, a series of studies were carried out in stages. The stages of this research are based on determining the value of each factor that influences the shelf-life calculation, namely pH value test, peroxide value test, total microbial count, total mold and yeast count, and hedonic scale test.

Table 1. Example of bottled chili sauce analysis results during storage

Temp	Observation Time	Response			
		pH Value	TPC	Mold & Yeast	Peroxide Value
10˚C	Day 0				
	Day 4				
	Day 8				
	Day 12				
	Day 16				
30˚C	Day 0				
	Day 4				
	Day 8				
	Day 12				
	Day 16				
50˚C	Day 0				
	Day 4				
	Day 8				
	Day 12				
	Day 16				

The data obtained from the analysis of each parameter is then plotted against the observation time (days) and a linear equation is obtained, so that the equation for each product storage temperature condition is obtained with the following equation:

$$y = bx + a \dots\dots\dots\dots (2.1)$$

Wherein:

y = analysis value (pH, peroxide value, or microbial count)
x = storage time (days)
a = analysis value at the start of storage
b = analysis value rate (degradement constant)

Selection of the reaction order for a parameter is done by comparing the regression value (R^2) of each linear equation at the same temperature. The reaction order with the larger (R^2) value is the reaction order used by that parameter.

Having obtained a linear equation for each storage temperature, then the slope value (equation 2.1), which indicates changes in product characteristics, is calculated as (k) and converted into (ln k) to be plotted on the *Arrhenius* equation (equation 2.2). In the *Arrhenius* equation, the (ln k) value is plotted against 1/T(K^{-1}).

From the *Arrhenius* equation, the slope and intercept values of the linear regression equation are obtained as follows:

$$\ln k = \ln k_0 - \frac{\left(\frac{Ea}{R}\right)}{\left(\frac{1}{T}\right)} \dots\dots\dots\dots (2.2)$$

Wherein: ln k0 = intercept

Ea/R = slope
Ea = activation energy
R = gas constant (1.986 cal/mol)

From this equation, the value of the constant (k_0) is obtained, an exponential factor indicating a decrease in quality stored at normal temperatures and the value of activation energy (Ea) for the reaction to changes in product characteristics. Next, a model of the reaction rate equation against temperature is determined, the value of (k) indicates a decrease in product quality which the following equation can calculate:

$$k = K_0 . e^{-\left(\frac{Ea}{RT}\right)} \ldots\ldots\ldots (2.3)$$

Wherein:
k = degradation constant
K_0 = constant (does not depend on temperature)
e = base logarithm (2.718282)
Ea = energy of activation
T = absolute temperature (C + 273)
R = gas constant (1.986 cal/mol)

Based on the *Arrhenius* equation (equation 2.2) and the calculation of the (k) value (equation 2.3), the shelf life of the black garlic chili sauce and "Cahyo" garlic chili sauce can be calculated by the equation of the reaction order as follows:

$$t\ order\ zero = \frac{\Delta A(A_0 - A_t)}{k} \ldots\ldots\ldots (2.4)$$

$$t\ order\ one = \frac{lnA_0 - lnA_t}{k} \ldots\ldots\ldots (2.5)$$

Wherein:
t = prediction of shelf life (days)
ΔA = change in product quality
A0 = initial product quality value
A = value of product quality remaining at (t) time
K = constant deterioration at normal temperature

3. RESULT AND DISCUSSION

Determination of the shelf life of black garlic chili sauce and "Cahyo" garlic chili sauce was carried out using the ASLT method. To accelerate the degradation rate in the garlic chili sauce, the product is stored in three different room temperature conditions, namely at 10˚C, 30˚C and 50˚C. The storage temperature was chosen because garlic chili sauce is generally stored at room temperature or refrigeration temperature, while high temperatures are chosen to accelerate the decline in product quality.

Ref. [23] The results of experiments to determine shelf life should be able to provide information about shelf life under ideal conditions, shelf life under non-ideal conditions, and shelf life under conditions of normal distribution and storage and use by consumers. The normal temperature for storage is the temperature that does not cause damage or decrease in product quality. Extreme or abnormal temperatures will accelerate the decline in product quality and are often identified as product shelf-life test temperatures. [16] The storage process is carried out with three storage temperature conditions with a certain range, namely at low temperature (5 – 20˚C) stored in the refrigerator, room temperature (20 – 35˚C) stored indoors, and high temperature (35 – 60˚C) which is stored in the oven.

3.1. Determining The Critical Value of Each Parameter

The quantitative value of the quality parameter at the time of production (A_o) is the result of observations on the total parameters of mold and yeast, TPC, pH value, peroxide value, and hedonic scale test value on bottled black garlic chili sauce and "Cahyo" garlic chili sauce. The limits on value of quality parameter for acceptable products (A_t) or cut-off products are determined based on quality requirements that have been enforced. The critical value of damage to bottled black garlic chili sauce and "Cahyo" garlic chili sauce products was obtained from various sources of standard requirements that apply to the quality parameters observed.

Determining the expiration date, apart from being related to the feasibility and acceptance of product quality by consumers, is also related to consumer satisfaction with the product and the benefits that consumers receive from the product.

Table 2. Initial value and critical value of black garlic chili sauce and "Cahyo" garlic chili sauce based on each parameter

Parameter	Initial Value (A_0)		Critical Value (A_t)	Source of Referral
Total Mold & Yeast	BGC	$2.67x10^2$	10^3 Colonies/g	[1]
	CGC	$2.94x10^2$		
Total Plate Count	BGC	$3.10x10^2$	10^4 Colonies/g	[1]
	CGC	$2.69x10^2$		
pH Value	BGC	5.5	4.0	[21]
	CGC	5.4		
Peroxide Value	BGC	2	10 meq O_2/kg	[24]
	CGC	3		
Hedonic Scale Test	BGC	3.41	3 (Neutral)	[1]
	CGC	4.51		

*BGC signifies Black Garlic Chili Sauce, while CGC signifies "Cahyo" Garlic Chili Sauce

3.2. Determining The Reaction Order

The linear curve shows the reaction order zero and the exponential-shaped curve shows the reaction order one. Determination of the order of this reaction is related to the rate of change in quality. If the resulting parameter reaction order is reaction order zero, then the damage rate is constant. If the parameter reaction order that applies is reaction order one then the damage rate is logarithmic or exponential.

The reaction order was selected by plotting the degradation data following the reaction order zero and reaction order one, then creating a linear regression equation. The selected reaction order is the reaction order with the largest (R^2) value. The closer the (R^2) value is to 1, the better the correlation between data. The equation values of the graphs and the (R^2) values of the quality parameters at various storage temperatures are shown in Table 3.

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Table 3. The linear regression equation of the correlation between changes in product quality and storage temperature in reaction order zero and reaction order one

Parameter	Temp (˚C)		Reaction Order Zero		Reaction Order One		Chosen Reaction Order	
			Equation	R^2	Equation	R^2		
Total Molds and Yeasts	BGC	10	**Y= 5040.9**x - 14692	0.8987	Y = 0.3612x + 5.9919	0.9221	1	
		30	**Y = 23175**x - 88988	0.7027	Y = 0.4268x + 6.2729	0.9538		
		50	**Y = 462596**x - 2E+06	0.7419	Y = 0.5175x + 8.1056	0.9626		
	CGC	10	**Y = 2708.4**x – 8077.8	0.8792	Y = 0.3238x + 5.8389	0.9588		
		30	**Y = 15806**x - 64805	0.5889	Y = 0.3919x + 6.0117	0.9162		
		50	**Y = 406755**x - 2E+06	0.7252	Y = 0.5285x + 7.9321	0.9094		
Total Plate Count	BGC	10	**Y = 4957.7**x - 19556	0.7085	Y = 0.3857x + 4.9272	0.9266	1	
		30	**Y = 8295.5**x - 31161	0.7833	Y = 0.4153x + 5.181	0.9444		
		50	**Y = 299945**x - 1E+06	0.6734	Y = 0.6076x + 6.1997	0.979		
	CGC	10	**Y = 1665.1**x – 4961.9	0.8719	Y = 0.3239x + 5.2366	0.9628		
		30	**Y = 20765**x - 89875	0.5736	Y = 0.4678x + 4.7951	0.9678		
		50	**Y = 141302**x - 530651	0.7878	Y = 0.5654x + 6.2728	0.9596		
pH Value	BGC	10	**Y = -0.0529**x + 5.5938	0.9835	Y = -0.0104x +1.7243	0.9774	0	1
		30	**Y = -0.0604**x + 5.5349	0.9916	Y = -0.012x + 1.7136	0.9951	1	
		50	**Y = -0.0837**x + 5.4064	0.9868	Y = -0.0178x + 1.693	0.9935	1	
	CGC	10	**Y = -0.0312**x + 5.376	0.9533	Y = -0.0061x +1.6825	0.9592	1	1
		30	**Y = -0.0341**x + 5.3198	0.9798	Y = -0.0068x +1.6722	0.9826	1	
		50	**Y = -0.0657**x + 5.3591	0.937	Y = -0.0139x +1.6837	0.9251	0	
Peroxide Value	BGC	10	**Y = 0.1333**x + 1.607	0.9187	Y = 0.0477x + 0.5666	0.9531	1	
		30	**Y = 0.2921**x + 1.3046	0.9291	Y = 0.0777x + 0.5793	0.9832		
		50	**Y = 0.3964**x + 1.3494	0.9808	Y = 0.0908x + 0.6654	0.9902		
	CGC	10	**Y = 0.0939**x + 2.6298	0.7514	Y = 0.0259x + 0.9983	0.773		
		30	**Y = 0.2935**x + 2.0932	0.891	Y = 0.0624x + 0.9302	0.9463		
		50	**Y = 0.3985**x + 2.0325	0.9462	Y = 0.0744x + 0.9745	0.9899		

3.3. Changes in Organoleptic Quality of Black Garlic Chili Sauce and "Cahyo" Garlic Chili Sauce

Sensory evaluation was carried out on several attributes of the food product: appearance, aroma, consistency and texture, and taste. Furthermore, sensory evaluation can be used for various purposes such as product quality maintenance, optimization, and product quality improvement, new product development, and potential market prediction [25].

The hedonic scale test was carried out on the aspects of color, aroma, and texture of the Black Garlic Chili Sauce and "Cahyo" Garlic Chili Sauce products attended by 29 untrained panelists. The panelist's assessment is written in a hedonic scale of 1-5 with a level of preference that increases as the scale number increases. The scale / level of preference used is 1) Highly unfavored, 2) Unfavored, 3) Neutral, 4) Favored, and 5) Highly favored.

3.3.1. Color Aspect in Organoleptic Quality Changes

The color aspect value of the "Cahyo" garlic chili sauce hedonic test was found to range from 4.31 – 3.96 for a temperature of 10˚C with a description of favored to neutral, a range of 4.31 – 4 for a temperature of 30˚C with a description of favored and a range of 4.27 – 3.89 for 50˚C with a favored description. The graph of the hedonic test results for the color aspect of "Cahyo" garlic chili sauce for each temperature treatment can be seen in Figure 1.

As for the hedonic test results for the color aspect of black garlic chili sauce, the range is 3.10 – 2.65 with neutral to unfavored descriptions for temperature 10˚C, range 3.27 – 2.48 with neutral to an unfavored description for temperature 30˚C, and a range of 3.00 – 2.31 with a neutral to unfavored description for a temperature of 50˚C. The graph of the hedonic test results for the color aspect of black garlic chili sauce for each temperature treatment can be seen in Figure 2.

The panelists' rejection criteria for the color aspect through the hedonic test were in the range of a score of 2 (unfavored) which indicated that the three black garlic chili sauces at 10˚C, 30˚C and 50˚C were not accepted by the panelists.

Ref. [26] The red pigment in chili contains carotenoids of 30 – 60% of the total fruit. This statement is backed by [27] which reported that carotenoids are easily damaged by acids and free halogens, especially when exposed to light and high temperatures. Carotenoids are readily oxidized in the presence of oxygen or other oxidizing agents.

Damage to carotenoids in black garlic chili sauce and "Cahyo" garlic chili sauce causes a change in the color of the chili sauce, which becomes slightly brownish. This is because carotenoids have a polyene structure, making these components reactive to heat and light [27].

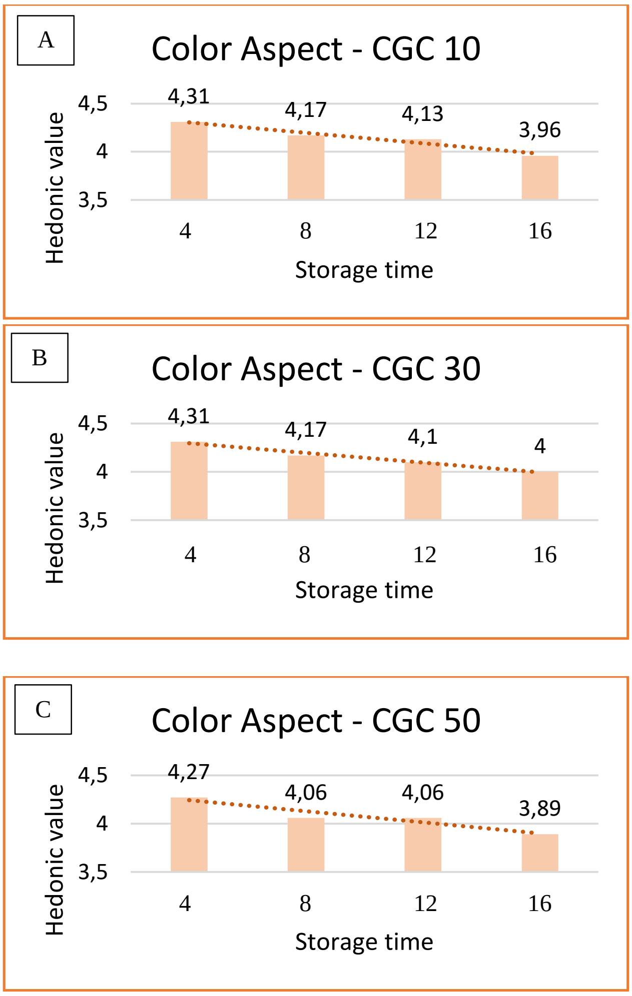


Fig. 1. Color aspect changes in "Cahyo" garlic chili sauce: (A) at 10˚C, (B) at 30˚C, and (C) at 50˚C.

3.3.2. Aroma Aspect in Organoleptic Quality Changes

Aroma is one of the criteria that can be used to determine the freshness or quality condition of a food ingredient or product. According to [28] aroma is an attribute that comes out due to the presence of volatile compounds that easily evaporate and can be felt by the sense of smell. [29] If the aroma has been accepted, then the next determination of the acceptance of the product is based on taste in addition to texture.

The average value of the hedonic test for garlic chili sauce "Cahyo" was obtained for the aroma aspect ranging from 4.13 - 3.79 for a temperature of 10˚C with a description of favored to neutral, a range of 4.44 - 3.82 for a temperature of 30˚ C with descriptions favored to neutral and the range 4.10 – 3.72 with descriptions favored to neutral. The three treatment temperatures did not have a significant effect on the quality of the aroma aspect because the panelists still gave a neutral scale response as indicated by number 3. The graph of the hedonic test results for the aroma parameters of garlic chili sauce "Cahyo" at each temperature treatment can be seen in Figure 3.

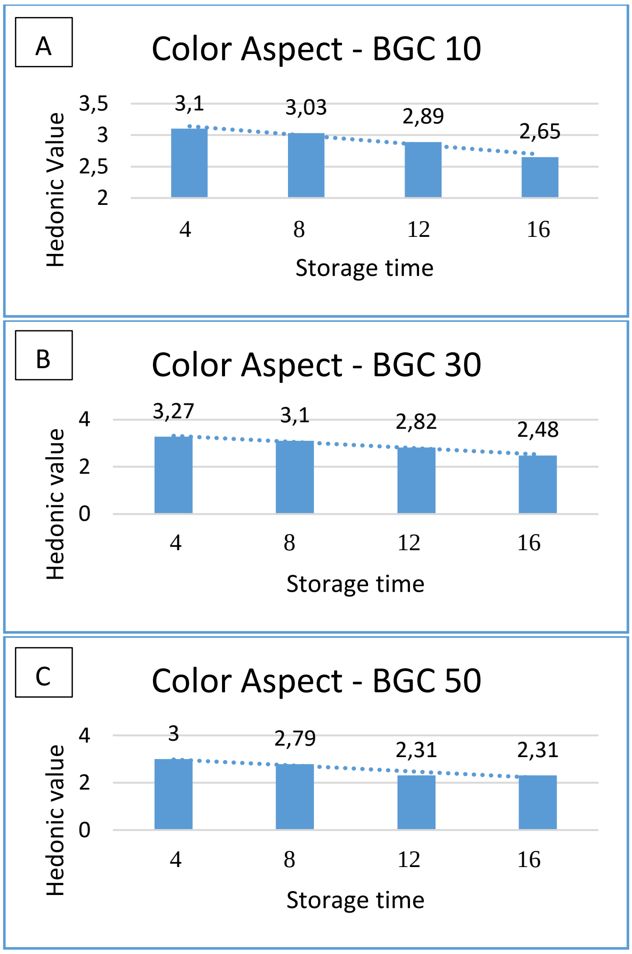
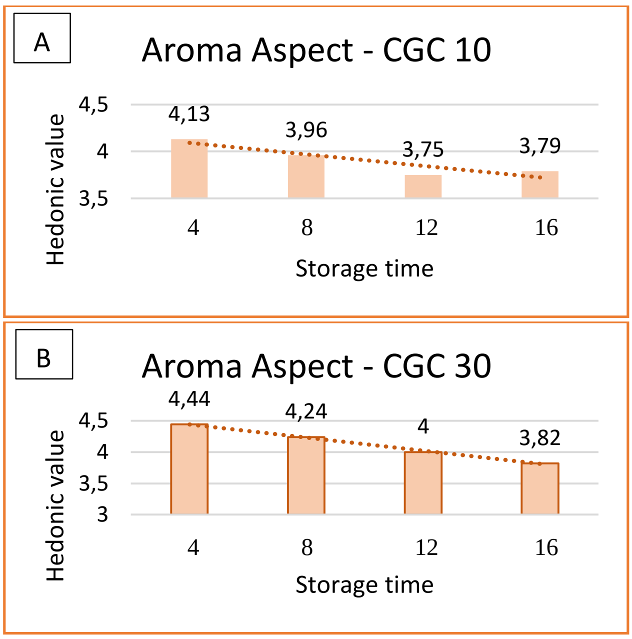


Fig. 2. Color aspect changes in black garlic chili sauce: (A) at 10˚C, (B) at 30˚C, and (C) at 50˚C.



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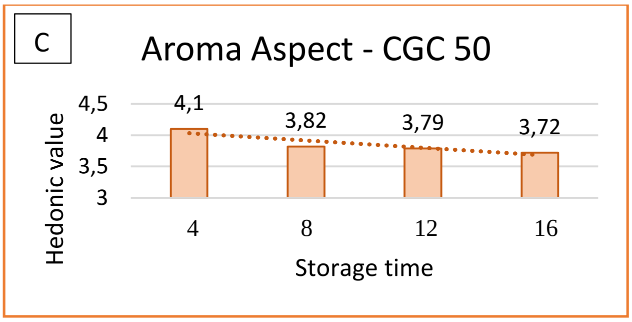


Fig. 3. Aroma aspect changes in "Cahyo" garlic chili sauce: (A) at 10˚C, (B) at 30˚C, and (C) at 50˚C.

As for the hedonic test results for the aroma aspect of black garlic chili sauce, the range is 3.65 – 3.17 with a description of the neutral level for a temperature of 10˚C, a range of 3.44 – 3.03 with a description of the neutral level for a temperature of 30˚C and a range of 3.27 – 2.79 with a neutral to unfavored description for a temperature of 50˚C. The graph of the hedonic test results on the aroma aspect of black garlic chili sauce for each temperature treatment can be seen in Figure 4.

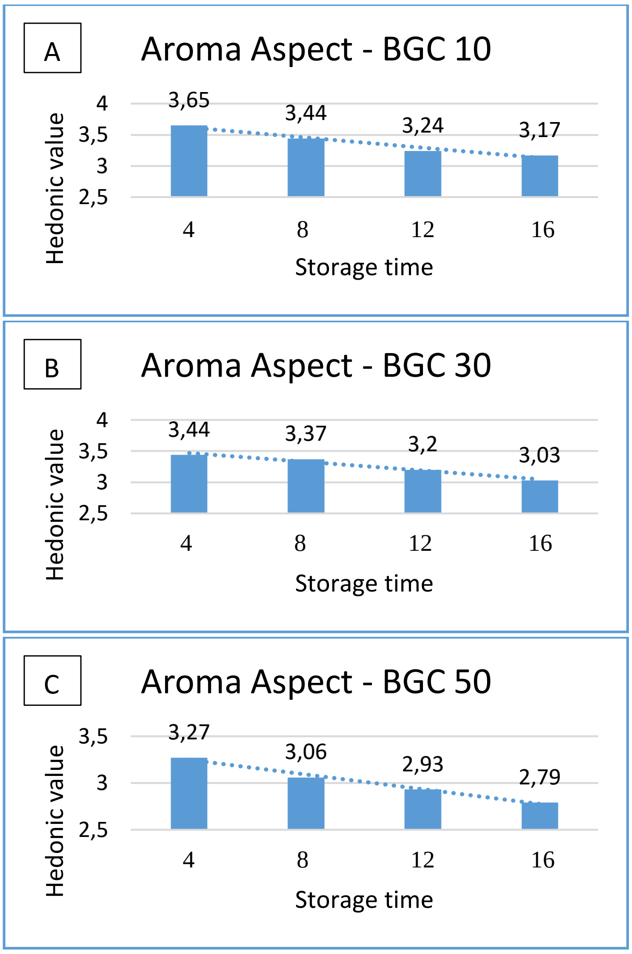


Fig. 4. Aroma aspect changes in black garlic chili sauce: (A) at 10˚C, (B) at 30˚C, and (C) at 50˚C.

Aromas that deviate from the original aroma during storage can be caused by microbial activity, in line with the increasing number of microbes in the "Cahyo" garlic chili sauce (Table 4) and black garlic chili sauce (Table 5) during the storage process at each temperature treatment so that the Microbial activity also increases and is one of the causes of the aroma deviation in the chili sauce. According to [30], foodstuff microbes can change food ingredients' composition by hydrolyzing starch and cellulose into smaller fractions, hydrolyzing fats and causing rancidity, causing sugar fermentation and breaking down proteins into ammonia resulting in a foul odor. Some microbes can form mucus, gas, colored foam, acids, toxins, etc.

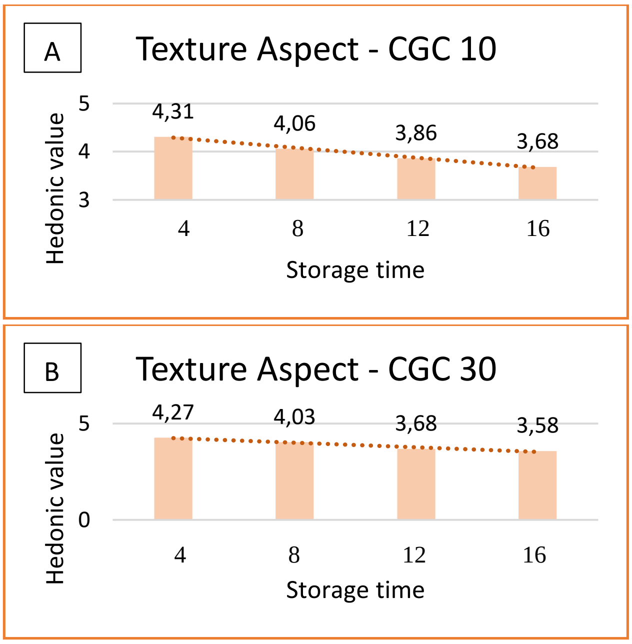
The deviating aroma from the original aroma during storage of garlic chili sauce can also be caused by an oxidation reaction (peroxide value) (Figure 9). According to [31] oxidation reactions are chain reactions forming radicals which release hydrogen and cause fat breakdown and cause a rancid smell and taste which is called the process of rancidity. [32] in [33] also added that the results of fat oxidation in food produce an unpleasant taste and smell and can also reduce food's nutritional value.

3.3.3. *Texture Aspect in Organoleptic Quality Changes*

The texture is a sensation of pressure observed with the mouth (when biting, chewing, and swallowing) or by feeling with the fingers. The state of texture is an important physical property of food ingredients. Texture is a characteristic of a material as a result of a combination of several physical properties which include size, shape, quantity, and elements of the formation of the material that can be felt by the senses of touch and taste, including the senses of the mouth and sight [34]. According to [35] The texture of a food product includes the viscosity used for homogeneous Newtonian liquids, non-Newtonian liquids or heterogeneous liquids, solid products, and semi-solid products.

As for the average hedonic test on "Cahyo" garlic chili sauce, the preference scale values for the texture aspect ranged from 4.31 - 3.68 with a description of favored to neutral for a temperature of 10˚C, a range of 4.27 - 3.58 with description favored to neutral for a temperature of 30˚C and a range of 3.93 – 3.72 with a neutral level description for a temperature of 50˚C.

The criteria for rejecting the texture aspect in this hedonic test are in the range of 2 (unfavored). The panelists' acceptance of all three garlic chili sauce "Cahyo" products at the end of the storage temperature 10˚C, 30˚C and 50˚C was in the range of number 3 (neutral). The graph of the hedonic test results on the texture aspect of the "Cahyo" garlic chili sauce at each temperature treatment can be seen in Figure 5.



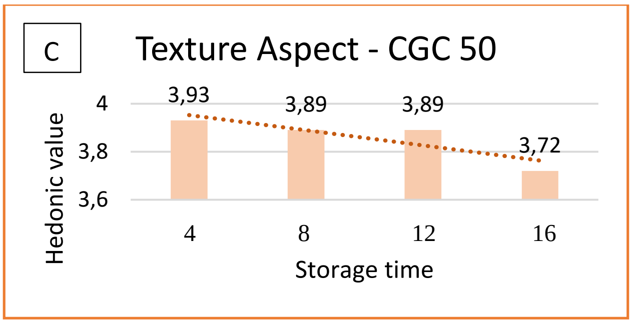


Fig. 5. Texture aspect changes in "Cahyo" garlic chili sauce: (A) at 10˚C, (B) at 30˚C, and (C) at 50˚C.

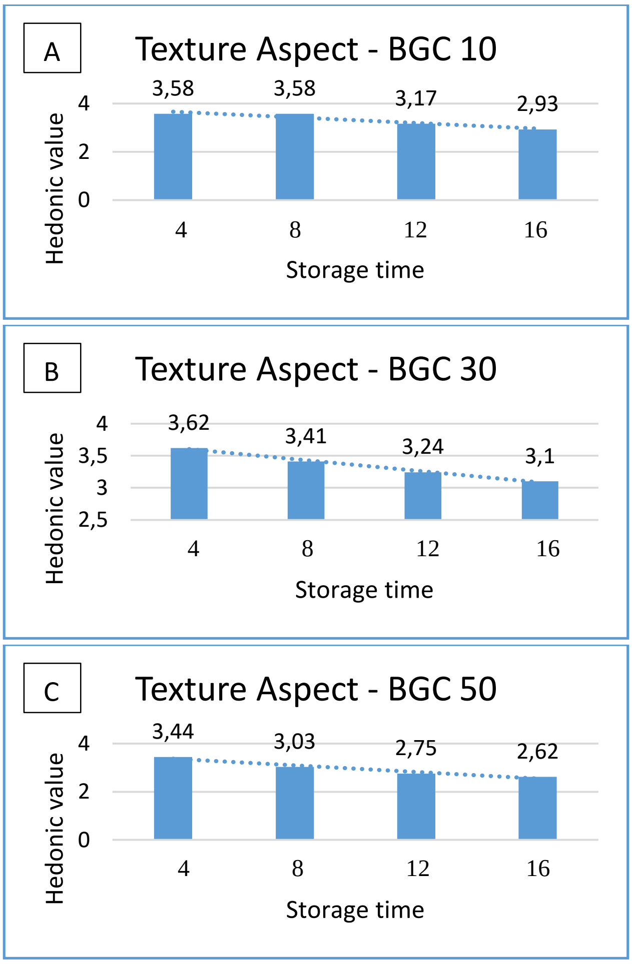


Fig. 6. Texture aspect changes in black garlic chili sauce: (A) at 10˚C, (B) at 30˚C, and (C) at 50˚C.

As for the hedonic test results for the textural aspect of black garlic chili sauce, the range is 3.58 – 2.93 with a description of neutral to unfavored for a temperature of 10˚C, a range of 3.62 – 3.1 with a description of a neutral level for a temperature of 30˚ C and a range of 3.44 – 2.62 with a neutral to unfavored description for a temperature of 50˚C.

There was a decrease in the average panelist acceptance/favorability of the texture of the black garlic chili sauce product during the storage treatment at 10˚C, 30˚C and 50˚C and the texture aspect rejection criteria in this hedonic test was in the range of 2 (unfavored) which indicate that two of the three black garlic chili sauce, namely at 10˚C and 50˚C, were not accepted by the panelists. The graph of the hedonic test results on the texture aspects of black garlic chili sauce for each temperature treatment can be seen in Figure 6.

3.4. Changes in Chemical Quality of Black Garlic Chili Sauce and "Cahyo" Garlic Chili Sauce

The observed chemical characteristics of the black garlic chili sauce and the "Cahyo" garlic chili sauce included an analysis of the pH value and peroxide value. These parameters were chosen because both can be changed by the influence of temperature treatment. pH value is considered as an important index for the degradation of food products including black garlic chili sauce and "Cahyo" garlic chili sauce, according to[36] because it can be an indirect way to show internal changes in products such as microbial activation.

The peroxide value is also an important analysis in estimating shelf life because the peroxide value is an indicator of the degree of rancidity of oil in food products. According to [37] the formation of a rancid odor is due to the presence of fatty acids, aldehydes and ketones, not by peroxides, so that an increase in the peroxide number is an indicator that the fat in food will smell rancid. Then, [38] stated that the consumption of oils containing peroxide will form free radicals in the body. Free radicals are compounds that are harmful to the body's health because they can cause damage to cell DNA, cell death and have the potential to cause cancer. Free radicals can trigger lung cancer, skin cancer, colon cancer and esophageal cancer.

3.4.1. pH value as A Parameter in Chemical Quality Changes

The pH value was measured using a digital pH meter calibrated with phosphate buffer at pH 4 and 7. Based on the comparison of linear regression results, the pH value parameter followed reaction order one. The changes in pH values during storage treatment in black garlic chili sauce and "Cahyo" garlic chili sauce can be seen in Figure 7, while the results of changes in pH values based on reaction order one can be seen in Figure 8.

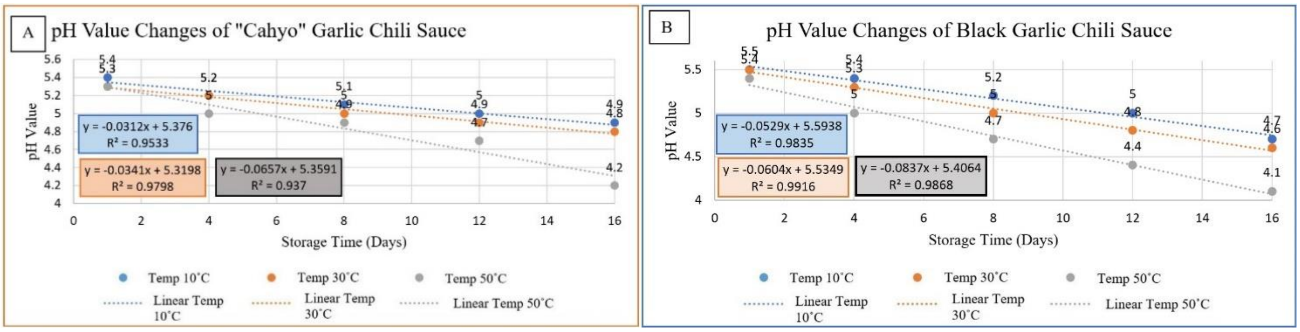


Fig. 7. Changes in pH value of: (A) "Cahyo" garlic chili sauce, and (B) black garlic chili sauce at 10˚C, 30˚C and 50˚C.

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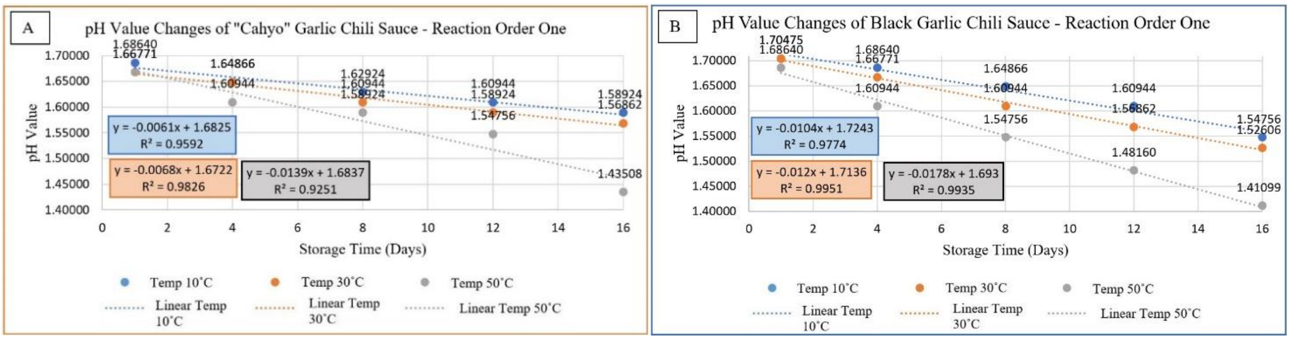

Fig. 8. Changes in pH value of: (A) "Cahyo" garlic chili sauce, and (B) black garlic chili sauce based on reaction order one.

Changes in the pH value of the "Cahyo" garlic chili sauce can be seen in Figure 7A, where it is known that a decrease in the pH value varies at each storage temperature. The biggest change in pH value was at 50˚C temperature treatment, from the original pH value of 5.3 to 4.2 at the end of the storage treatment.

Changes in the pH value of black garlic chili sauce (Figure 7B) indicate a decrease in quality during the storage treatment process at each different treatment temperature. In Figure 7B the pH value changed most drastically at 50˚C, from the original pH value of 5.4 to 4.1 at the end of the storage treatment. [39] Stated that pH is one of the main controlling factors for microbial growth in foodstuffs. In general, the pH value of foodstuffs ranges from 3-8. The pH value of both bottled chili sauce can be affected by the activity of microorganisms such as mold.

According to [36] pH value is considered an important index for products as it can indirectly indicate internal changes to products such as microbial activation. According to [40], adding salt to food products (chili sauce) causes water and nutrients such as sugar to be pulled out by osmosis from the vegetable cells. The sugar from these foodstuffs becomes nutrition for lactic acid bacteria. The microbes then carry out the activity of breaking down proteins, carbohydrates, fats, and other organic substances in the product so that they become organic acids which cause a decrease in the pH value [41].

3.4.2. *Peroxide value as A Parameter in Chemical Quality Changes*

The Government of Indonesia stipulates in [21] that the final limit for peroxide value for cooking oil is 10 meq O2/kg. [42] stated that palm oil is a substance that is easily damaged due to oxidation by oxygen. This oxidation causes the oil to become rancid and not suitable for consumption, so it is necessary to determine the shelf life. According to [32] oxidation is usually initiated by the formation of peroxides and hydroperoxides.

Oxidation reactions not only destroy the fatty acids or fats themselves; they also damage carotenoids [43]. The peroxide value within certain limits will give unwanted aroma or taste or the product will experience organoleptic deviation [44]. Based on the comparison of linear regression results, the peroxide number parameter follows reaction order one. The results of changes in peroxide value during storage treatment in black garlic chili sauce and "Cahyo" garlic chili sauce can be seen in Figure 9, while the results of changes in peroxide values based on reaction order one can be seen in Figure 10.

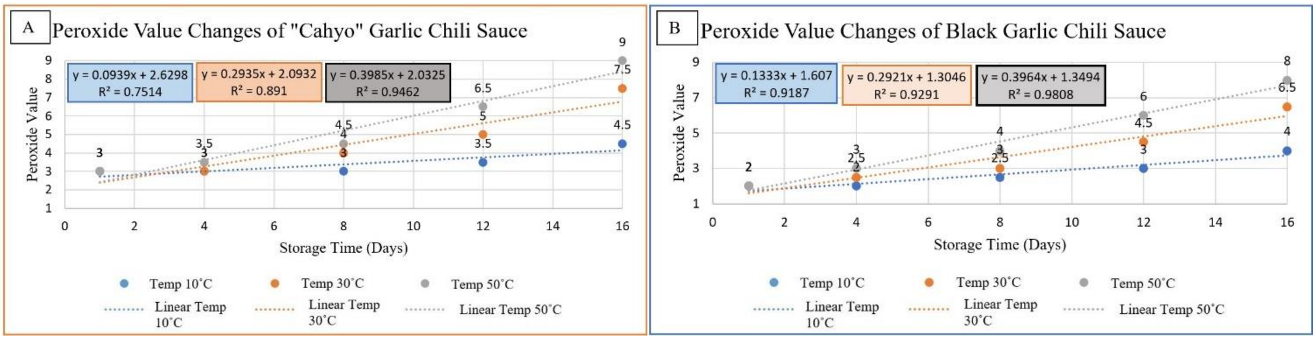

Fig. 9. Changes in peroxide value of: (A) "Cahyo" garlic chili sauce, and (B) black garlic chili sauce at 10˚C, 30˚C and 50˚C.

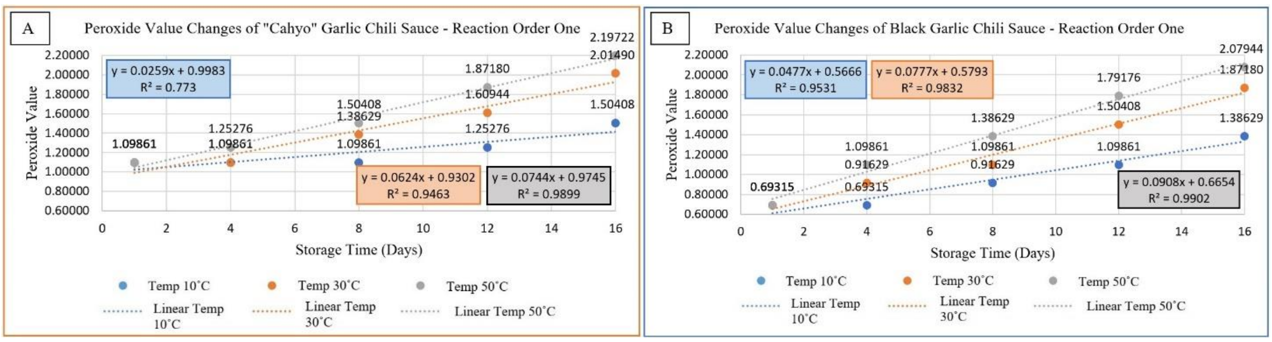

Fig. 10. Changes in peroxide value of: (A) "Cahyo" garlic chili sauce, and (B) black garlic chili sauce based on reaction order one.

Figure 9A and Figure 9B show that the higher the storage time and temperature of the product, the higher the peroxide value, as seen from the results of storage at 50˚C in black garlic chili sauce which has a peroxide value of 2 at the start of storage, becoming 8 at the end of the storage treatment and in "Cahyo" garlic chili sauce which originally had a peroxide number of 3 to 9 at the end of the storage treatment, which still had not exceeded the limit set by [21] INS for Cooking Oil 3741-2013 (10 meq O2/ kg). This is supported by [45] where the rate of fat oxidation increases with increasing temperature and decreases with decreasing temperature. The rate of peroxide accumulation in the oil aeration process at a temperature of 100-115˚C is two times greater than that at a temperature of 10˚C.

It is also stated by [32] that the peroxide number is the most important value to determine the degree of damage to oil or fat due to oxidation, where unsaturated fatty acids can bind oxygen to their double bonds to form peroxides which can cause damage. This form of rancidity damage is caused by the spontaneous action of oxygen on fats, starting with the formation of peroxides and hydroperoxides. Peroxide does not produce rancidity, so an increase in the peroxide value is only an indicator and a warning that the oil will start to smell rancid.

3.5. Changes in Microbiological Quality of Black Garlic Chili Sauce and "Cahyo" Garlic Chili Sauce

Microbiological testing can be used to predict the durability of a food product and as an indicator of the sanitation and safety of the food. Total Plate Count (TPC) testing, as well as the mold and yeast number test on black garlic chili sauce and "Cahyo" garlic chili sauce products was carried out to determine the amount of mold and yeast and the total number of microbes in the product during the storage period.

In chili products, it is possible that extrinsic factors play a more dominant role so that spoilage microbial growth is still found. Some putrefactive microbes produce physiological activity in the form of slime formation by lactic acid bacteria (*Lactobacillus*, *Enterococcus*, *Bacillus*), acid formation by bacteria (*Lactobacillus*, *Bacillus*, *Pseudomonas*, *Micrococci*), discoloration by mold growth (*Aspergillus sp.*, *Rhizopus sp.*), and changes in odor by various bacteria due to the formation of ammonia and H2S [46].

3.5.1. Total Plate Count (TPC) as A Parameter in Chemical Quality Changes

During the storage period, bottled chili products were observed by conducting the TPC test and yeast mold number test for 16 days with sampling every 4 days. According to [47] the number of colonies that grow is the total number of microbes present in foodstuffs such as bacteria, molds, and yeast. Food quality is considered low if the TPC value is high, because it can be dangerous if consumed, related to the safety of food products. Changes in TPC values in black garlic chili sauce and "Cahyo" garlic chili sauce during the storage period can be seen in Table 4 and Table 5.

Table 4. Microbes' population in "Cahyo" Garlic Chili Sauce

Storage Time (Days)	**Treatment Temperature**		
	10˚C	**30˚C**	**50˚C**
	Colonies/gram		
1	2.69x102	3.31x102	4.17x102
4	5.80x102	6.44x102	9.12x103
8	2.21x103	3.0x103	6.86x104
12	1.73x104	2.30x104	8.42x105
16	2.31x104	3.75x105	2.22x106

Table 5. Microbes' population in Black Garlic Chili Sauce

Storage Time (Days)	**Treatment Temperature**		
	10˚C	**30˚C**	**50˚C**
	Colonies/gram		
1	3.10x102	3.76x102	4.62x102
4	7.14x102	9.28x102	9.44x103
8	9.61x102	1.91x103	8.81x104
12	2.10x104	5.11x104	9.77x105
16	8.25x104	1.30x105	5.10x106

Based on the two tables above, an increase in temperature during the storage period can cause an increase in the microbial population in both black garlic chili sauce and "Cahyo" garlic chili sauce. This is due to the growth of microbes during storage supported by optimal temperature for growth during storage. According to [39] Mesophyll microbes grow maximum at temperatures of 40 – 47˚C and optimum at temperatures of 30 – 40˚C. Then, according to [48] Microbes that grow and develop at room temperature conditions are the mesophyll group which has a growth temperature range of 20 - 40˚C and the thermophilic group at high temperatures, namely 40 - 60˚C.

The results of the TPC test showed that the number of microbes contained in "Cahyo" garlic chili sauce was still safe for consumption until the 8th day for 10˚C and 30˚C, and until the 4th day for the 50˚C temperature treatment because it had passed the limit for microbiological quality requirements on [1] is 1×10^4 colonies/gram. In black garlic chili sauce, the number of microbes was still safe for consumption until the 8th day for 10˚C and 30˚C, and until the 4th day for 50˚C treatment. The increase in the number of microbes in the two bottled chili sauce was due to the various nutritional content in them so that they could become a source of microbial food to support their growth. According to [49], one type of damage that follows an order one reaction kinetics is microbial growth. The highest growth in the number of microbes during storage was found in black garlic chili sauce, namely at $5{,}10 \times 10^6$ on the 12th day with a temperature of 50˚C at the end of the storage treatment period.

3.5.2. Total of Molds and Yeasts as A Parameter in Chemical Quality Changes

According to [50] Mold and yeast contamination of food can cause food spoilage which is indicated by the presence of stains of various sizes and colors, musty smell, presence of white cotton mycelium or abnormal aroma and odor. Total mold and yeast are the analyses used to calculate the amount of mold and yeast that grows in both black garlic chili sauce and "Cahyo" garlic chili sauce using PDA (Potato Dextrose Agar) media. Based on research results, temperature plays a role in affecting the growth of mold and yeast. Bottled chili sauce stored at 50˚C had the fastest increase in total molds and yeast.

According to [51], the intrinsic factors for mold growth are the optimum temperature of 25 – 30˚C with an optimum pH between 4.0 – 4.5. This is supported by [52] that several factors affect the growth of mold, such as the nutrient content of the substrate, pH, temperature, availability of oxygen and presence or absence of inhibitory compounds. This is what can cause damage to bottled chili products, as can be seen in Figure 7A that in "Cahyo" garlic chili sauce the pH value has reached 4.4 on the 12th day and 4.1 on the 16th day, whereas in Figure 7B on the black garlic chili sauce it was found that the pH value had reached 4.2 on the 16th day. Changes in the total values of mold and yeast in black garlic chili sauce and “Cahyo” garlic chili sauce during the storage period can be seen in Table 6 and Table 7.

Table 6. Molds and yeasts population in “Cahyo” garlic chili sauce

Storage Time (Days)	Treatment Temperature		
	10˚C	30˚C	50˚C
	Colonies/gram		
1	2.94x102	3.13x102	1.27x103
4	1.61x103	5.39x103	6.43x104
8	7.15x103	1.00x104	4.73x105
12	1.95x104	2.23x104	1.64x106
16	4.21x104	2.86x105	6.80x106

Table 7. Molds and yeasts population in black garlic chili sauce

Storage Time (Days)	Treatment Temperature		
	10˚C	30˚C	50˚C
	Colonies/gram		
1	2.67x102	3.91x102	2.58x103
4	3.19x103	6.63x103	4.37x104
8	9.36x103	1.87x104	3.60x105
12	4.80x104	8.75x104	2.12x106
16	7.24x104	3.92x105	7.59x106

The limit for mold and yeast contamination in chili sauce has been regulated in the INS of Chili Sauce 4865-2018 [1] and the Regulation of the Food and Drug Supervisory Agency Number. 13 of 2019 (BPOM 2019) in the Food Category - Non-Emulsion Sauce and Food Type - Chili Sauce namely from 10^2 colonies/g to 10^3 colonies/g. The value of 10^2 colonies/g indicates an acceptable limit for mold and yeast in the final product, which indicates that the food processing process meets good processed food production practices. Meanwhile, 10^3 colonies/g indicates the final product's maximum limit for mold and yeast [53].

From these two reference points, it can be concluded that the results of testing the total number of molds and yeast in “Cahyo” garlic chili sauce are still safe for consumption until the first day for temperatures of 10˚C and 30˚C. In contrast, at 50˚C they are no longer feasible. for consumption because it has passed the limit of quality requirements. The amount of mold and yeast in the black garlic chili sauce was still safe for consumption until the 1st day for temperatures of 10˚C and 30˚C only, while for temperatures of 50˚C it had exceeded the quality requirements. Test results for total molds and yeast that pass the limits set by INS of Chili Sauce 4865-2018 [1] and BPOM Regulation No. 13 of 2019 compared to the TPC test shows that molds and yeast are easier to spoil bottled chili sauce, especially at temperatures of 30 - 50˚C. This is because the optimum temperature for yeast growth ranges from 25 - 35˚C and can grow at even higher temperatures [54].

3.6. *The Criteria for Selection of The Critical Parameter to Calculate Shelf-Life*

According to [23] there are several criteria in the selection of quality parameters to determine product shelf life, namely: 1) the parameter that decreases the fastest during storage, indicated by the absolute coefficient (k) or the largest coefficient of determination (R^2); 2) the most sensitive quality parameters to changes can be seen from the slope value of the *Arrhenius* equation or as seen from the lowest activation energy (E_a); 3) if there is more than one quality parameter that meets the criteria, then the quality parameter that has the shortest shelf-life is selected.

The coefficient of determination data (R^2), activation energy value (E_a), and shelf-life estimation based on several parameters can be seen in Tables 8 and 9.

Table 8. Coefficient of determination data (R^2), activation energy value (E_a) and shelf-life estimation in the selected reaction order in “Cahyo” garlic chili sauce

Parameter	R^2	Ea (kcal/mol	Shelf-Life (Days)		
			10˚C	30˚C	50˚C
pH Value	0.8186	3.318	61	40	27
Peroxide Value	0.9218	6.633	14	8	5
TPC	0.9793	20.185	30	23	17
Total Molds and Yeasts	0.9731	22.564	34	26	21

Table 9. Coefficient of determination data (R^2), activation energy value (E_a), and shelf-life estimation in the selected reaction order in black garlic chili sauce

Parameter	R^2	Ea (kcal/mol	Shelf-Life (Days)		
			10˚C	30˚C	50˚C
pH Value	0.9117	2.060	41	31	24
Peroxide Value	0.9563	4.986	14	10	7
TPC	0.8415	18.286	30	24	20
Total Molds and Yeasts	0.9937	20.334	31	26	22

The pH value parameter is the parameter that meets the requirements to be selected as a reference in estimating shelf life. This is because the combination of the lowest activation energy (Ea) and the relatively high R2 value is present in this parameter, the pH value parameter was chosen as the critical parameter in estimating the shelf life of black garlic chili sauce and “Cahyo” garlic chili sauce products.

3.7. *Determination of Product Shelf-Life and Expiration Date on The Critical/Key Parameter*

The determination of the shelf life of black garlic chili sauce and “Cahyo” garlic chili sauce in this research was not only the calculation of the shelf life at the research storage conditions (10˚C, 30˚C and 50˚C). According to [55] the calculation of shelf life can also be extended to various other temperatures by correlating the value (k) and temperature in the previous calculation. The results of the previous calculations are the shelf life of black garlic chili sauce and "Cahyo" garlic chili sauce at various storage temperatures that allow storage to occur and temperatures to accelerate quality deviations in the product. These data can be used to estimate the shelf life of products under real storage conditions in general.

3.7.1. Determination of Shelf-Life on The Selected Parameter with The Arrhenius Model

Ref. [55] states that the shelf-life calculation can be extended to various other temperatures by using the connection between the (k) value and temperature in the previous calculations. However, using this connection can only be done from various conditions with the same sample treatment.

The calculation of shelf life is carried out by following the selected parameters, namely the pH value parameter. This is to maintain the quality of the product by selecting parameters that have the smallest activation energy (Ea) and a large coefficient of determination (R2) which indicates that these parameters are the most sensitive to change and react more quickly to quality deviations during storage treatment in black garlic chili sauce products. and "Cahyo" garlic chili sauce. The value (k) obtained in the previous calculation for the pH value parameter is related to temperature using the *Arrhenius* equation:

$$k = K_0 . exp^{-\left(\frac{Ea}{RT}\right)}$$

The graph of the relationship between ln k (as the ordinate y) and (1/T) as the abscissa of x, will give a straight-line equation of the form y = bx + a. The slope of or (b) will be equal to (Ea/RT) and the intercept of or (a) will be equal to ln k0. The temperature value in the *Arrhenius* equation is in the Kelvin (K) scale.

Table 10. Temperature (˚K), (1/T), Slope (k) and ln k of "Cahyo" garlic chili sauce at 3 different storage temperatures - pH value Parameter in Reaction Order One

Temp (˚C)	Temp (˚K)	(1/T)	Slope (k)	Ln K
10	283	0.00353	0.0061	-5.09947
30	303	0.00330	0.0068	-4.99083
50	323	0.00310	0.00139	-4.27587

Table 11. Temperature (˚K), (1/T), Slope (k) and ln k of black garlic chili sauce at 3 different storage temperatures - pH value Parameter in Reaction Order One

Temp (˚C)	Temp (˚K)	(1/T)	Slope (k)	Ln K
10	283	0.00353	0.0104	-4.56595
30	303	0.00330	0.012	-4.42285
50	323	0.00310	0.0178	-4.02856

By regressing the ln k value with the value (1/T), the line equation will be obtained as in Figure 11Aa and Figure 11B. The *Arrhenius* equation calculates the value (k) of various storage temperatures. Thus, it will be possible to determine the shelf-life under various storage conditions during post-production by knowing the storage temperatures of black garlic chili sauce and "Cahyo" garlic chili sauce.

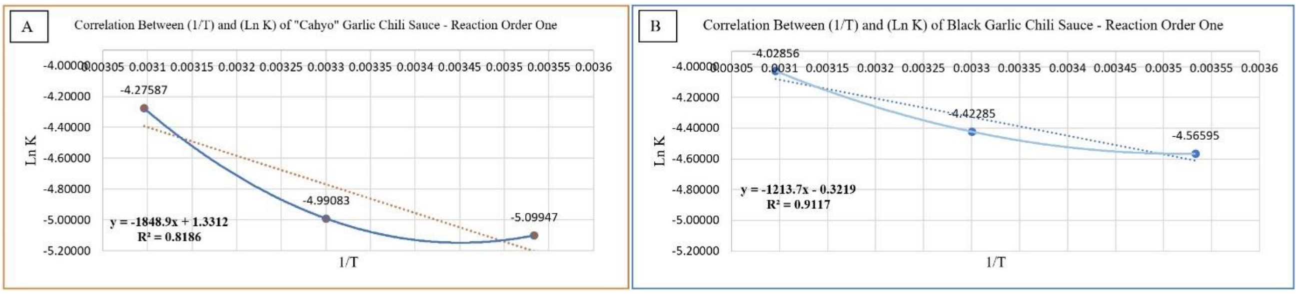

Fig. 11. *Arrhenius* plot graphic – connection between (1/T) and (Ln K) of: (A) "Cahyo" garlic chili sauce, and (B) black garlic chili sauce based on reaction order one

Post-production black garlic chili sauce and "Cahyo" garlic chili sauce will go through the process of storage in warehouses, distribution conditions, and storage in retail stores before reaching consumers, so it is necessary to convert shelf life into expiration time considering storage conditions. Thus, it is expected that the selection of each temperature of 20˚C and 25˚C will have an effect of 50% respectively on the determination of the expiration date of black garlic chili sauce and "Cahyo" garlic chili sauce.

The following is the calculation of the shelf-life of black garlic chili sauce and "Cahyo" garlic chili sauce stored at 20˚C or 293˚K and 25˚C or 298˚K, as representatives of storage temperatures in supermarkets/minimarkets or retail stores.

For CGC at 20˚C / 293˚K:
ln k = -1848.9 (1/T) + 1.3312
ln k = -1848.9 (1/293) + 1.3312
ln k = -4.979038908
k = 0.006880672

$$t = \frac{\ln A_0 - \ln A}{k}$$

$$t = \frac{\ln 5.4 - \ln 4.0}{0.006880672}$$

t = 48 days

For CGC at 25˚C / 298˚K:
ln k = -1848.9 (1/T) + 1.3312
ln k = -1848.9 (1/298) + 1.3312
ln k = -4.873162416
k = 0.007649137

$$t = \frac{\ln A_0 - \ln A}{k}$$

$$t = \frac{\ln 5.4 - \ln 4.0}{0.007649137}$$

t = 43 days

https://doi.org/ 10.29165/ajarcde.v7i1.227

For BGC at 20˚C / 293˚K:

ln k = -1213.7 (1/T) – 0.3219

ln k = -1213.7 (1/293) – 0.3219

ln k = -4.464220819

k = 0.011513663

$$t = \frac{\ln A_0 - \ln A}{k}$$

$$t = \frac{\ln 5.4 - \ln 4.0}{0.011513663}$$

t = 35 days

For BGC at 25˚C / 298˚K:

ln k = -1213.7 (1/T) – 0.3219

ln k = -1213.7 (1/298) – 0.3219

ln k = -4.394718792

k = 0.012342351

$$t = \frac{\ln A_0 - \ln A}{k}$$

$$t = \frac{\ln 5.4 - \ln 4.0}{0.012342351}$$

t = 32 days

Assuming that the two temperatures above each have a 50% effect on storage in supermarkets/minimarkets or retail stores, the expiration dates of black garlic chili sauce and "Cahyo" garlic chili sauce based on the pH value parameter can be calculated by calculating the average of the two shelf lives as follows:

$$expiration\ date\ for\ CGC = \frac{48 + 43\ days}{2} = 45.5\ days$$

$$expiration\ date\ for\ CGC = \frac{35 + 32\ days}{2} = 33.5\ days$$

Thus, it can be concluded that the expiration times of each black garlic chili sauce and "Cahyo" garlic chili sauce stored in supermarkets/minimarkets with an estimated combined storage temperature of 20˚C and 25˚C are 33 days and 45 days based on the selected parameters, namely the pH value.

4. CONCLUSION

The shelf life of black garlic chili sauce and "Cahyo" garlic chili sauce was obtained through the pH value parameter based on the lowest activation energy (Ea) compared to other parameters. Based on the calculation results, the shelf life of black garlic chili sauce was 35 days at 20˚C storage temperature and 32 days at 25˚C storage temperature. Whereas in "Cahyo" garlic chili sauce, a shelf life of 48 days was obtained at a storage temperature of 20˚C and 43 days at a storage temperature of 25˚C. The lower the storage temperature, the longer the product's shelf life.

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