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Arrhenius-based shelf-life prediction of *lombok terong* (*Capsicum*) sambal with sodium benzoate and potassium sorbate combination

Eileen Fiona Wijaya, Fransisca Romana Titis Suniati, Oki Krisbianto*, Evelyn Goeyana, Ika Yohanna Pratiwi

Food Technology, Universitas Ciputra, Surabaya, Indonesia

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ABSTRACT

Lombok terong is a variety of chili belonging to the Capsicum genus, and one of its processed products is sambal sauce. Due to its limited shelf life, preservatives must be used to extend it. This study utilized a combination of sodium benzoate and potassium sorbate in a 1:1 ratio. The objective was to identify suitable indicators of quality degradation and critical parameters for predicting the shelf life of lombok terong sambal sauce (LTSS), and to develop a predictive model based on the Accelerated Shelf-Life Testing (ASLT) method using the Arrhenius approach. The study tested samples over 30 days, with observations made every six days. The samples were stored at temperatures of 30°C (S30), 40°C (S40), and 50°C (S50), with two replicates per treatment, and each replicate measured in triplicate. Indicators of quality degradation included color analysis and Total Plate Count (TPC), while water content, water activity, and pH analysis were critical parameters. Based on the experimental results, TPC analysis was selected as the indicator of quality degradation, as significant microbial growth was observed in the sample stored at 50°C by day 18. Meanwhile, pH analysis was identified as the critical parameter due to significant decreases observed across all storage conditions. As a result, the estimated shelf-life equation for lombok terong sambal sauce can be formulated as $t = \frac{(pH_0 - 4.4) \times e^{\frac{3612}{T}}}{1642.542}$.

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* Corresponding author
Email: oki.krisbianto@ciputra.ac.id
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INTRODUCTION

Indonesians are widely known for their strong preference for spicy food. This is evident in the 9.94% increase in chili consumption in 2021 compared to the previous year. One local variety of chili that is not yet widely known or consumed by Indonesian citizens is *lombok terong*, a notable commodity of the Tengger community and belonging to the genus *Capsicum* (Krisbianto et al. 2023). This chili is quite similar to habanero (*Capsicum chinense*) and jalapeño (*Capsicum annuum*). It also exhibits characteristics such as black seeds, a strong, pungent aroma, and significantly higher spiciness than other chili varieties. This chili has the potential to be processed into value-added products, such as sambal sauce.

According to (Fitriani et al. 2021) one of the challenges in producing lombok terong sambal sauce (LTSS) is its short shelf life, which requires special handling to extend its shelf life. Therefore, one potential solution is the addition of preservatives with antimicrobial, antibacterial, and antifungal properties, such as sodium benzoate and potassium sorbate (Kamsina and Three Anova 2021, Song et al. 2022).

Sodium benzoate is a commonly used food preservative in sambal sauce products due to its antimicrobial properties and its effectiveness as an antibacterial agent (Ekhtelat et al. 2020). Meanwhile, potassium sorbate has antimicrobial properties and strong antifungal capabilities, is easily soluble, and works effectively in low-pH environments (Awaad et al. 2023). The combined use of sodium benzoate and potassium sorbate creates a synergistic effect, providing greater protection against damage caused by bacterial and fungal microorganisms compared to using each preservative separately (Heymich et al. 2021).

Therefore, further research is needed to estimate the shelf life of *lombok terong* sambal sauce using a combination of sodium benzoate and potassium sorbate as preservatives. The study will also adhere to regulations on the limits for mixed preservatives, as outlined in the Indonesian Food and Drug Authority Regulation No. 29 of 2021 regarding the requirements for mixed food additives. Additionally, this research modifies previous studies from (Hoang and Vu 2016) to achieve a preservative percentage of 0.05% for each.

Estimating the shelf life of sambal sauce can be achieved using the Accelerated Shelf-Life Testing (ASLT) method. ASLT is a technique for estimating shelf life by subjecting the product to conditions such as elevated temperatures over a specific period (Irfan et al. 2022). The ASLT method can be applied to various food products, particularly those that are prone to spoilage due to chemical processes (Sari and Juwitaningtyas 2022). The ASLT method employs the Arrhenius model, which is commonly used for products susceptible to Maillard reaction, oxidation, and denaturation (Naufalin et al. 2023).

This study aims to identify quality degradation indicators and critical parameters for lombok terong sambal sauce (LTSS) and to formulate an Arrhenius equation to predict the product's shelf life. The research includes experiments to identify the causes of sambal sauce degradation, determine the formulation, and establish the concentration of preservatives.

METHODS

Materials and Equipment

The primary ingredient used in this study is *lombok terong*, sourced from Wonokitri Village, Tosari District, Pasuruan Regency, East Java. The food preservatives used are sodium benzoate (Koepo-Koepo, PT. Gunacipta Multirasa, Tangerang) and potassium sorbate (PS-1000 Mupro, Jiangsu Mupro IFT Corp., Jiangsu, China) at the same time, other ingredients are obtained from local markets in Surabaya. The sambal sauce is stored in 25 mL plastic containers. Additionally, for sample analysis, materials such as Plate Count Agar (PCA) (Merck, Merck KGaA, Germany), buffered peptone water (BPW) (Merck, Merck KGaA, Germany), and distilled water are utilized.

The equipment used includes a wooden storage box (40 x 30 x 35 cm^3) equipped with a thermometer and LED lights to maintain internal temperatures of 30°C, 40°C, and 50°C, as shown in Figure 1. Other instruments used are the pH meter pH 450 (Butech, Thermo Fisher Scientific Inc., USA) and the moisture analyzer MOC63u (Shimadzu, Shimadzu Corporation, Japan), a_w meter BWA-3A (Biobase, Jinan Biobase Biotech Co., Ltd., China), colorimeter CS-10 (CHNSpec, CHNSpec Technology (Zhejiang) Co., Ltd., China), and incubator MC000921 (Friocell, MMM Medcenter Einrichtungen GmbH, Germany).



Figure 1 Lombok Terong Sambal Sauce Storage Box

Research Methodology

Preparation of Raw Materials

Lombok terong is transported to Surabaya under conditions where the temperature ranges from 20℃ to 35℃ for approximately 30 hours. The chilis used are those that have turned red. They are then cleaned and sorted to remove any damaged ones before being packed in closed styrofoam containers and stored in a refrigerator at 4℃ until processing, which occurs within five days of storage.

Preparation of Lombok Terong Sambal Sauce

The sambal sauce is made from 30.8% *lombok terong* chili, with other ingredients added to make up the total volume to 100%. The preservative mixture constitutes 0.1% w/w, calculated based on the total weight. The production process involves removing any non-consumable parts of the fresh raw materials and chopping them into smaller pieces. Afterward, the chopped ingredients are mixed and cooked with the other components.

Addition of Preservatives

A combination of sodium benzoate and potassium sorbate is added at concentrations of 0.05% each. The total preservative concentration of 0.1% is chosen because the allowable limit for preservatives set by BPOM (2021) is 1 gram per 1 kg of the product, equivalent to 0.1% of the total ingredients. The formula used to calculate the amount of food additives in a mixture is given in Equation (1).

$$\text{Usage Amount } \left(\frac{mg}{kg}\right) = \frac{1}{\left(\frac{\frac{\%Food\ Additive\ 1}{100}}{\frac{Maximum\ Limit}{Food\ Additive\ 1}}\right)+\left(\frac{\frac{\%Food\ Additive\ 2}{100}}{\frac{Maximum\ Limit}{Food\ Additive\ 2}}\right)} \quad (1)$$

Half-Life Testing Procedure

The shelf life of LTSS is assessed using the Accelerated Shelf-Life Testing (ASLT) method at 30℃ (S30), 40℃ (S40), and 50℃ (S50). The control storage period lasts until changes indicating sample degradation are observed. The samples are stored for a total of 30 days, with observations made every 6 days.

Determination of Shelf Life Indicators

Predicting the shelf life of a sample requires factors established as indicators of quality degradation. In this study, the selected quality degradation indicators are color analysis and microbiological analysis. Delta-E (ΔE) calculation is used for color analysis, which can be performed using the calculator at https://colormine.org/delta-e-calculator/cie2000. Microbiological observation is conducted using the Total Plate Count (TPC) method.

Color Analysis

Color analysis is performed using a colorimeter. The Delta-E value is calculated using the CIE2000 calculator. Delta-E is a standard for measuring a product's color deviation. Color deviation in a sample can occur due to temperature conditions during storage (Zehra & Bashir, 2019). Additionally, hue and chroma values are also calculated to assess the sample's color trends.

Microbiological Analysis

Microbiological analysis is conducted using the Total Plate Count (TPC) method as outlined by the National Standards Agency (1992) and according to SNI 01-2967-2006 for sambal sauce (Standar Nasional Indonesia 2006). This analysis employs Plate Count Agar (PCA) as the microbial growth medium.

Determination of Critical Parameters

This study uses three candidate critical parameters: moisture content, water activity, and pH. The results of these indicators are used to calculate the Arrhenius equation.

Moisture Content Analysis

The moisture content analysis is carried out using a *moisture analyzer*. (Nurhidajah et al. 2021). Testing is conducted every six days over a thirty-day sample storage period.

Water Activity Analysis

The water activity analysis is performed using an a_w meter (Nurhidajah et al. 2021). Water activity testing is conducted every six days over a thirty-day sample storage period.

pH Analysis

The pH analysis is conducted using the National Standard method in accordance with SNI 01-2976-2006 (Standar Nasional Indonesia 2006). The pH data is collected using a pH meter in a laboratory setting. The testing is performed every six days during the storage period of the chili sauce samples.

Calculation of the Arrhenius Equation

The analysis is conducted over one week, and the method follows the standard procedure (Nurminabari et al., 2022) with a temperature modification as the parameter. The data analysis will produce a regression equation $Y = a + bx$. From this regression equation, the value of *k* will be obtained. The *ln k* values for each temperature condition will be tabulated into the Arrhenius parameter given in Equation (2).

$$\frac{1}{T}(k^{-1}) \quad (2)$$

The intercept and slope will be derived from the linear regression equation in Equation (3).

$$ln\ k = ln\ k_0 - \left(\frac{Ea}{R}\right) . \left(\frac{1}{T}\right) \quad (3)$$

Using the linear regression equation obtained from the curve, k_0 and Ea will be determined and used in the Arrhenius equation in Equation (4).

$$k = k_0 . e^{-(Ea/RT)} \quad (4)$$

The obtained value of k will be used to estimate the product's shelf life for zero-order kinetics in Equation (5) and first-order kinetics in Equation (6).

$$\left(t_s = \frac{(Q_0 - Q_1)}{k}\right) \quad (5)$$

$$\left(t_s = ln\frac{(Q_0 - Q_1)}{k}\right) \quad (6)$$

RESULTS AND DISCUSSION

Determination of the Quality Degradation Limit

Discoloration and the number of microorganisms are two candidates for indicators of quality degradation in LTSS. These candidates were selected because discoloration during storage and microbial growth in LTSS indicate quality degradation.

Color Analysis

According to Table 1, discoloration for S30 is noticeable at a glance on days 6, 12, and 18. On days 24 and 30, more significant color changes occur. In contrast, discoloration for S40 and S50 on day 6 is distinct compared to day 0, and subsequent days show similar but slightly different color changes. Thus, it can be observed that as the sambal's storage time increases, the samples' color change becomes more pronounced compared to day 0. Additionally, higher storage temperatures accelerate the discoloration.

Table 1 Lombok Terong Sambal Sauce Delta-E (ΔE) Values

ΔE	30°C	40°C	50°C
$\mathbf{\Delta E_{0-6}}$	6.51	9.39	4.82
$\mathbf{\Delta E_{0-12}}$	7.45	12.72	18.41
$\mathbf{\Delta E_{0-18}}$	10.46	14.37	23.99
$\mathbf{\Delta E_{0-24}}$	11.01	15.56	28.10
$\mathbf{\Delta E_{0-30}}$	14.71	19.68	30.73

Notes:
Clarity Perception: ΔE0-n = Discoloration of the sample on day-n compared to day 0 (H0) at the same temperature ≤1,0 = Not distinguishable by the normal eye; 1-2 = Visible through close observation; 2-10 = Noticeable at a glance; 11-49 = Color is more similar; 100 = Contrasting color (Minaker et al. 2021).

Table 2 Lombok Terong Sambal Sauce Total Plate Count Values

Days	30°C	40°C	50°C
0	$3.6x10^4$	$1.4x10^4$	$2.6x10^4$
6	-	-	$3.0x10^{0*}$
12	-	-	$8.3x10^{0*}$
18	-	$0.8x10^{0*}$	$5.2x10^2$
24	$0.3x10^{0*}$	$2.5\ x10^{0*}$	$1.4x10^3$
30	$0.5\ x\ 10^{0*}$	$0.8\ x\ 10^{0*}$	$3.7x10^4$

Notes:
H-*n* = Testing conducted on day-n.
Data marked with an asterisk (*) indicates data that did not meet the bacterial count requirements (<25 colonies).

The calculation of hue (h*) and chroma (C*) values is used to determine the differences in color, changes in color absorbance, as well as the intensity of hue. The calculations are performed using the following formulas $C* = \sqrt{(a*)^2 + (b*)^2}$ for chroma and $h* = (\tan)^{-1}\left(\frac{b*}{a*}\right)$ for hue. The calculation results indicate that the samples experienced a color change from red to red-orange. The decrease in hue value on the final day caused some areas of the samples to show a more intense red color, and the liquid released was yellow. The color change in the samples may be attributed to the presence of phenolic compounds, particularly flavonoids, found in the chili peppers. According to (Purnomo et al. 2023) these phenolic compounds are generally very sensitive to temperature, which can lead to the degradation of carotenoid compounds during storage. Carotenoids, such as beta-carotene, degrade when exposed to high temperatures, causing the sample color to deteriorate and change to yellow.

Total Plate Count Analysis

Based on Table 2, the TPC test results for S30 and S40 show a decrease in the number of microorganisms from day 0. The slow growth of microbes could be attributed to several factors, such as the addition of preservatives and the antimicrobial properties of the raw materials. In general, plants with the *Capsicum* genus, such as chili peppers, contain capsaicin, which has antimicrobial properties. Capsaicin can combat various types of pathogens, including fungi such as *Candida* spp., parasites, and other viruses (Ananta and Anjasmara 2022, Periferakis et al. 2023). On the other hand, bacterial growth was observed in S50 on days 18 and 24. The total plate count was still below the maximum safe standard for consumption. However, by day 30, the total plate count for S50 increased up to 3.7 x 10^4 CFU/mL, exceeding the SNI standard of 1 x 10^4 CFU/mL, indicating that it is no longer safe for consumption.

The increase in microorganism count may be due to the growth of lactic acid bacteria, which lowers the pH value, and the presence of thermophilic acid-producing microorganism species. According to (Lobo et al. 2019), of the various bacteria and fungi that can grow in acidic environments, one in four cases of food spoilage is caused by lactic acid bacteria, while the other three are due to yeasts. Therefore, based on the TPC results, it can be concluded that the quality reduction of the LTSS sample occurred in S50 on day 18, as microbial growth was observed at that point.

Determination of Quality Degradation Limit

Color and microbiological analyses are candidate indicators for determining the quality degradation of samples. However, a more accurate analysis is needed to establish a reliable quality degradation indicator. Color analysis showed that changes occurred on day 6, indicating a quality degradation. However, color analysis was not chosen as the indicator because the change of color started as early as day 6, which could be caused by Maillard reactions, enzymatic processes, and oxidation due to high temperatures. On the other hand, TPC analysis clearly indicates quality degradation due to microbial growth observed in S50 on day 18. Therefore, TPC analysis is selected as the quality degradation indicator, as microbial growth can lead to food spoilage, resulting in disease and poisoning (Cao et al. 2023).

Stage of Determining Critical Parameters

Three analyses, moisture content, water activity, and pH, are used as testing parameters for Accelerated Shelf Life Testing (ASLT). These

three types of analyses can affect the characteristics of food products and the quality degradation of sambal sauce.

Moisture Content Analysis

Observations of moisture content every 6 days over 30 days show a gradual decrease, with S50 experiencing the most significant degradation. The moisture content of S30 remains relatively stable compared to the other temperatures. When comparing the three temperatures, a decrease of 2.94% was observed at 30°C, 8.20% at 40°C, and 18.21% at 50°C. The comparison indicates that moisture content decreases with longer storage time and higher temperatures. High temperatures can cause samples to lose moisture as water bonds in carbohydrates and proteins break down. Samples stored at 40°C and 50°C are suspected to experience denaturation, leading to the breakdown of hydrophilic groups that bind water and releasing hydrophobic groups (Tultabayev and Zhumanova 2023).

The moisture content data was then plotted on a graph with a linear regression equation, resulting in three equations, as shown in Figure 2. Based on these equations, the values of k for each temperature were obtained as 0.092, 0.252, and 0.622, respectively, S30, S40, and S50. The obtained k will produce ln k, which will be plotted against the Arrhenius T^{-1}, resulting in a linear regression equation, as shown in Figure 2. From the linear regression equation on the graph in *ln k* versus T^{-1}, the intercept and slope values of 28.50 and 9363, as shown in Figure 3, respectively, are obtained. These values will be used to calculate the constants k_0 and *Ea,* which will then be substituted into the formula to determine the quality degradation constant. The predicted shelf life will be calculated, resulting in 87 days for S30, 32 days for S40, and 13 days for S50.

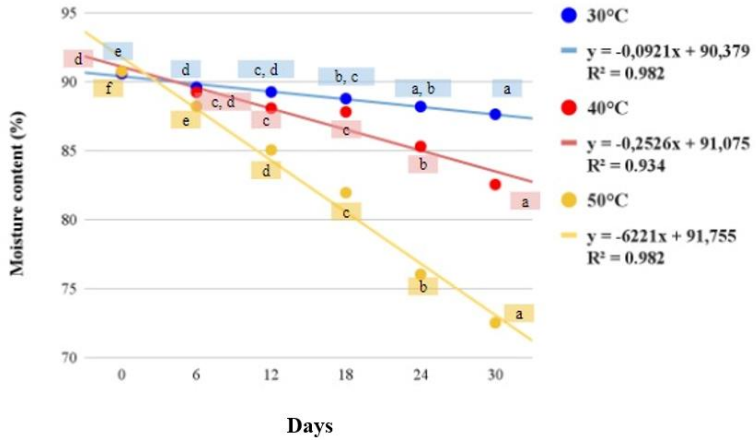


Figure 2 Moisture Content at Three Temperature Points with Linear Regression Graph.

Notes: Different notation on the same column indicates a significant difference at $p < 0,05$.

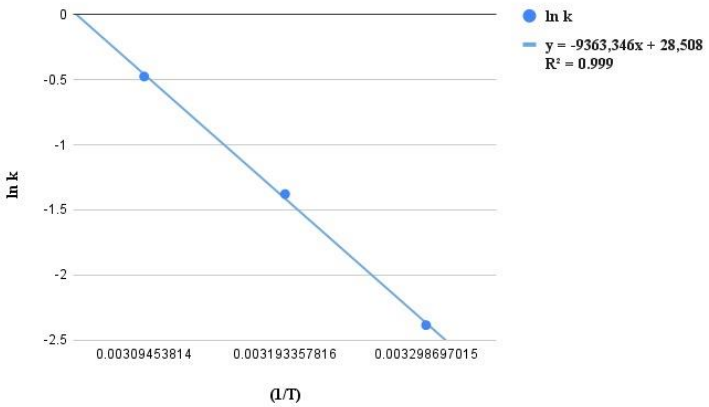


Figure 3 Relationship Between ln k and (1/T) for Moisture Content at Three Temperature Points Graph.

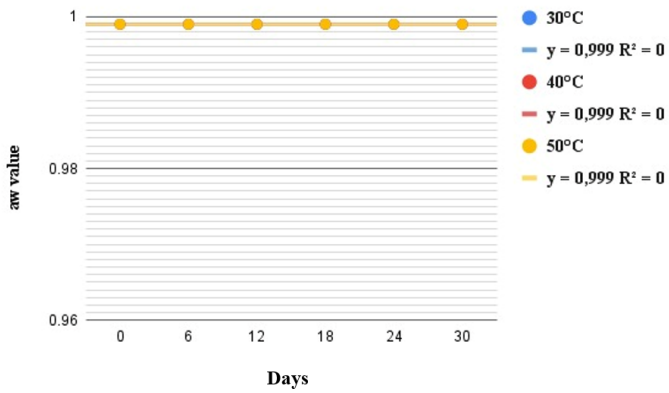


Figure 4 Water Activity at Three Temperature Points with Linear Regression Graph.

Water Activity Analysis

The samples' water activity did not change from day 0 to day 30. Figure 4 shows that the results are consistent across the three storage temperatures, with an R^2 value of 0 and a linear regression equation of y = 0.999. This regression equation indicates that there is no change in the water activity characteristics due to the absence of a slope (b).

Increased water activity is typically associated with increased moisture content (van Boekel 2023). However, the correlation between water activity and moisture content is not linear (Juarez-Enriquez et al. 2019). According to (Dunlop et al. 2016) if water activity is high in a sample, it will remain constant while the moisture content changes with temperature variations. High water activity in sambal sauce can result from syneresis in samples stored at high temperatures for extended periods (Setiarto 2021). Although high water activity can contribute to food spoilage, bacterial growth is also influenced by other factors such as pH, temperature, pressure, and atmospheric conditions (Ndahawali 2016, Nurtekto 2022).

pH Analysis

The pH data for the sambal sauce samples over 30 days indicate a gradual and significant decrease in acidity. Figure 5. shows that the pH level correlates directly with the duration of sample storage. Additionally, higher storage temperatures lead to a more pronounced decrease in pH. Despite this, the pH decrease at all three temperatures does not fall below the standard set by SNI, which is pH 4.0.

To estimate the shelf life of samples based on acidity (pH), the pH values need to be plotted on a graph using a linear regression equation. Based on this equation, the k values obtained are 0.011, 0.016, and 0.024 for S30, S40, and S50, respectively. These k values will be used to calculate $ln\ k$, which will be plotted against the Arrhenius parameter T^{-1}, resulting in a linear regression equation as shown in Figure 6.

Based on the linear regression equation of $ln\ k$ versus T^{-1}, the intercepts obtained are 7.404 and 3612.254. These values allow for the calculation of the constants k_0 and Ea, which are then substituted into the quality degradation constant formula. The predicted shelf lives are calculated as 61 days at 30°C, 42 days at 40°C, and 29 days at 50°C. The decrease in pH during storage can be attributed to temperature fluctuations in the surrounding environment (Esmeralda et al. 2019). This is because storage temperature influences the growth of microorganisms such as lactic acid bacteria, molds, and yeasts (Jerry and Bright 2019). These microorganisms can cause fermentation and spoilage, leading to a degradation in pH (Ansar et al. 2019). pH is a critical internal factor in food products that affects the growth rate of spoilage microorganisms (Racchi et al. 2020, Chacón-Flores et al. 2023) Additionally, the use of preservatives like sodium benzoate and potassium sorbate in sambal sauce can also affect pH values during storage (Musyoka et al. 2018).

Determination of Critical Parameters

There were three types of analyses used as indicators: water content, water activity, and pH to assess the quality degradation of the samples. When determining the appropriate indicator for quality degradation, several factors must be considered, such as data validity and the coefficient of determination (R^2) for each analysis. According to Table 3, pH was chosen as the indicator for quality degradation because it had the highest R^2 value compared to the other analyses.

This R^2 value can be interpreted as the percentage of the relationship between the independent and dependent variables (Chicco et al. 2021). A high R^2 value indicates a significant influence of the parameter on the quality degradation of the sambal sauce. This study is also in line with (Laksono et al. 2023), which identified pH as the critical parameter in determining the shelf life of Black Garlic Chili Sauce and "Cahyo" Garlic Chili Sauce. The selection of pH was based on the consideration that fluctuations in pH significantly affect both product quality and safety.

Water activity could not be used as an indicator of quality degradation because it showed constant results from day 0. In contrast, water content analysis showed a decrease, which was contrary to the expected result of an increase. This is because high water content is generally associated with increased microorganism growth (Rahmadhani and Kurniawati 2022). The observed decrease in water content is suspected to be due to the drying process of the samples at temperatures of 40°C and 50°C (Sutharsan et al. 2023). Therefore, water content analysis was not chosen to indicate LTSS quality degradation. Based on the evaluation of the three analyses, pH analysis was selected as the critical parameter indicating the quality degradation of LTSS.

Calculation of Quality Degradation Equation

The quality degradation equation is based on TPC analysis with pH as the indicator parameter. The core formula used in developing the quality degradation equation is the Arrhenius equation. pH data can be plotted by applying the Arrhenius method to obtain results as shown in Figure 4. This will yield the slope of the linear regression equation, as shown in Equation (7).

$$y = \alpha + bx \quad (7)$$

α : Intercept
b : Slope = k value

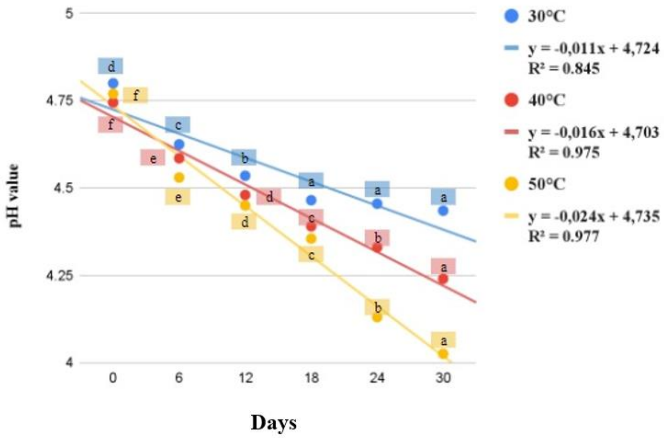


Figure 5 pH at Three Temperature Points with Linear Regression Graph.

Notes: Different notations on the same column indicate a significant difference at $p < 0,05$.

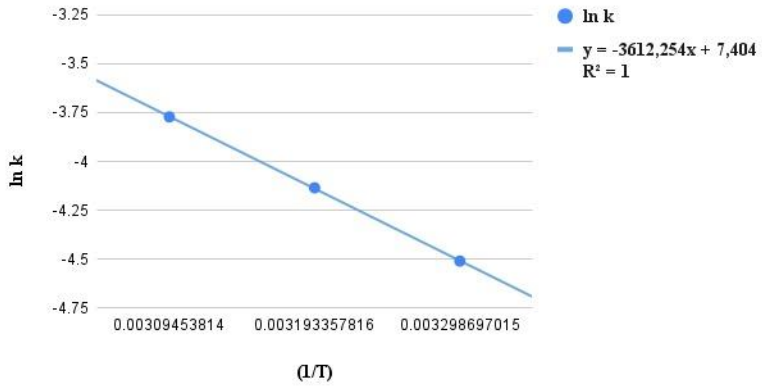


Figure 6 Relationship Between ln k and (1/T) for pH at Three Temperature Points with Linear Regression Graph.

Table 3 Coefficient of Determination (R^2) Values for Chemical Analysis of Samples

Analysis	R^2
pH	0,991
Water Content	0,988
Water Activity (a_w)	-0,6

Notes:
The R^2 value indicates how well the model fits the observed data
An R^2 value close to 1 indicates a strong fit between the regression prediction and the observed data, demonstrating a high level of accuracy in the model's predictions.

The gradient value of the linear regression (k) was found to be 0.011 at 30°C, 0.016 at 40°C, and 0.023 at 50°C. The ln k values were plotted against the parameter (1/T), resulting in a linear graph as shown in Figure 5. This graph reveals an intercept ($ln\ k_0$) of 7.404 and a slope (Ea/R) of 3612. These intercept and slope values were used to calculate the exponential factor and determine the product degradation rate using the Arrhenius equation in Equation (8).

$$k = k_0 . e^{-(Ea/RT)} \quad (8)$$

k : Rate constant,
k_0 : Pre-exponential factor,
e : Exponential
Ea : Activation energy
R : Gas constant (1,986 kal/mol K)
T : Temperature (°K)

The shelf life of the samples can be predicted using the following equations based on the Arrhenius model presented in Equation (9).

$$\left(t_s = \frac{(Q_0 - Q_1)}{k}\right) \quad (9)$$

t_s : Shelf life (days)
Q_0 : Initial quality
Q_1 : Final acceptable quality

Based on the calculation of the equations, the estimated shelf life of the sambal sauce sample is 61 days at 30°C, 42 days at 40°C, and 29 days at 50°C. This prediction estimates the time until the product is no longer suitable for consumption. According to (Lestari, S., Yuniarti, S., Mutmainah, H., Maureen., Hidayah 2021), the application of 1 g/kg sodium benzoate in chili paste resulted in an estimated shelf life of 31 days. Therefore, this study confirms the synergistic effect of sodium benzoate and potassium benzoate in extending the shelf life of LTSS. The quality degradation of the sample can be calculated using the degradation rate formula and substituted into the formula for calculating the change in quality shown in Equation (10).

$$pH_{(t)} = pH_{(0)} - (k \times t) \quad (10)$$

$a\ pH_{(t)}$: pH value at time
$pH_{(0)}$: Initial pH value measured at the time of sample preparation
k : Degradation rate constant
t : Predicted time for quality degradation

The term "termination pH" refers to the increase in microbial growth observed in the samples on day 18. The determination of this pH considers the growth factor comparison at 40°C and 50°C. This is because the 50°C temperature indicates a higher microbial count, while the 40°C temperature shows microbial growth within the acceptable range of 25-250 colonies (Azzahra et al. 2021). Despite this, the chosen termination pH is based on the 40°C condition, as microbial growth at this temperature indicates the limit of the benzoate-sorbate preservative mix's ability to inhibit microbial growth. The prediction of quality degradation over time at different temperatures can be determined using the k_0 value, activation energy, and the gas constant through equation (11).

$$k = 1642.542 \times e^{-\frac{3612}{T}} \quad (11)$$

k : Degradation rate constant
T : Storage temperature (°K)

The final equation for determining quality degradation is shown in Equation (12).

$$t = \frac{(pH_0 - 4.4) \times e^{\frac{3612}{T}}}{1642.542} \quad (12)$$

t : Predicted time to quality degradation (days)
$pH_{(0)}$: Initial pH measured on the day of sample preparation
T : Storage temperature (°K)
Therefore, the above equation can be used to estimate the quality degradation of LTSS.

CONCLUSION

Based on the research findings, Total Plate Count (TPC) was identified as the indicator for determining the shelf life of the sample, while pH was established as the critical parameter for

estimating the shelf life of *lombok terong* sambal sauce (LTSS). The final equation to calculate the predicted quality degradation time for *lombok terong* sambal sauce (LTSS) is: $t = \frac{(pH_0 - 4.4) \times e^{\frac{3612}{T}}}{1642.542}$. Further research is recommended to investigate the effectiveness of alternative food preservative combinations to identify specific strains of lactic acid bacteria present in the product to evaluate their potential benefits, risks, and opportunistic behavior.

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