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Shelf-life prediction of pineapple dodol in aluminum foil and polypropylene packaging using accelerated method

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ABSTRACT

Pineapple dodol is a traditional semi-moist food that is susceptible to oxidation and hydrolysis during storage. Appropriate packaging, such as aluminum foil and polypropylene, can reduce rancidity and extend its shelf life. This study aimed to predict the shelf life of pineapple dodol packaged with aluminum foil (K0) and polypropylene (K1) using the Arrhenius model. The experiment was conducted in four stages: storage at 35, 40, and 45 °C for 30 days, determination of critical limits, calculation of deterioration rates, and prediction of shelf life at 25 °C. For each storage temperature, five replicate samples of each packaging type were stored in temperature-controlled boxes and analyzed every 5 days. Rancidity sensory scores and thiobarbituric acid (TBA) values were measured as indicators of quality deterioration. The results showed that the deterioration of pineapple dodol in both K0 and K1 followed first-order kinetics based on rancidity scores and TBA values ($p < 0.05$). To ensure consumer safety, the shortest predicted shelf life was considered. Pineapple dodol packaged in K0 exhibited a k value of 0.0138 d^{-1}, activation energy of 4837.70 cal·mol^{-1}, and a predicted shelf life of 42.39 days at 25 °C, while K1 showed a k value of 0.0300 d^{-1}, activation energy of 2525.40 cal·mol^{-1}, and a predicted shelf life of 27.35 days at 25 °C. A strong correlation between sensory scores and TBA values confirmed the validity of the model ($R^2 > 0.94$).

Contribution/Originality: This study applied integrated sensory and kinetic modeling to pineapple dodol using accelerated shelf-life testing (ASLT), providing a practical tool for traditional food shelf-life assessment. These results emphasize the importance of barrier-type packaging in maintaining the oxidative stability of semi-moist foods rich in lipids.

1. INTRODUCTION

In recent decades, the global food industry has shown increasing interest in traditional foods, not only for their cultural and nutritional value but also for their potential economic contribution to rural and small-scale economies. Dodol is a traditional semi-wet confectionery widely known in Southeast and South Asia, including Malaysia, Indonesia, Thailand, Singapore, the Philippines, Myanmar, and India, where it is known by different local names (Ismail et al., 2021). This chewy, sticky-sweet is typically made from glutinous rice flour, palm sugar, and coconut milk (Seow, Tan, & Easa, 2021). The traditional preparation of dodol involves cooking with several people stirring the dodol for 7–8 hours until the liquid dodol mixture transforms into a sticky and viscoelastic mass. The effects of cooking time, sugar content, and temperature are significant on dodol's textural attributes, including firmness, consistency, cohesiveness, and viscosity index (Nasaruddin, Chin, & Yusof, 2012). In Indonesia, various regional adaptations are developed by incorporating unique ingredients, such as fruits and spices, to create variants like pineapple dodol.

One of the main challenges in preserving traditional semi-moist products like dodol lies in their high moisture content (typically 20–30%) and lipid content (5–10%) derived from coconut milk (Chuah, Nisah, Choong, Chin, & Sheikh, 2007). This composition makes them particularly susceptible to both lipid oxidation and hydrolytic rancidity, leading to undesirable changes in aroma, taste, and appearance. Without preservatives or advanced packaging, dodol typically lasts only 5–7 days at room temperature (Agustini et al., 2023), which severely restricts its market reach and economic potential. However, most previous reports have discussed this perishability qualitatively, with limited application of quantitative modeling or kinetic analysis.

Packaging plays a crucial role in minimizing deterioration and extending the shelf life of perishable products. Materials such as aluminum foil and polypropylene (PP) are widely used for their oxygen, moisture, and light barrier properties (A'yun, Liviawaty, Pratama, & Junianto, 2023; Lamberti & Escher, 2007). Aluminum foil offers excellent protection against oxidative degradation and has been shown to preserve the quality of semi-moist foods such as papaya dodol (Marsigit, Marniza, & Monica, 2020). The use of aluminum foil as food packaging is relatively safe, and the contamination of aluminum foil in food is relatively low, but it can increase through contact with aluminum foil during cooking, at high temperatures, and with prolonged contact time (Bassioni, Mohammed, Al Zubaidy, & Kobrsi, 2012; Ertl & Goessler, 2018; Fermo, Soddu, Miani, & Comite, 2020; Mol & Ulusoy, 2020).

Meanwhile, PP plastic, though widely used in food packaging due to its mechanical strength and moisture resistance, is more permeable to oxygen and light, potentially accelerating lipid oxidation in high-fat foods (Hossain et al., 2024). According to Afifah and Ratnawati (2021), the shelf life of pineapple dodol packed with polypropylene plastic was the longest among those wrapped with edible film with and without antimicrobial-antioxidant. Based on the total plate count, the shelf life of dodol wrapped with polypropylene plastic, edible film with antimicrobial-antioxidant, and edible film without antimicrobial-antioxidant were 32, 26, and 22 days, respectively.

Although several studies have examined the shelf life of dodol based on microbial parameters or moisture content (Afifah & Ratnawati, 2021), limited research has focused on modeling oxidative deterioration using kinetic and predictive approaches. Comprehensive comparisons between packaging materials in terms of their influence on oxidation kinetics are also scarce. The application of reaction rate models and the Arrhenius equation provides a powerful tool to predict product stability and estimate shelf life under varying temperature conditions (Afifah & Ratnawati, 2021; Ayu, Effendi, Nopiani, Saputra, & Haryani, 2022; Efendi, Ayu, & Nofaren, 2021). Alternative modeling approaches, such as Weibull models and microbial-based models, have been applied to various food systems. However, these approaches primarily address microbial or physical quality deterioration and may not adequately capture oxidative kinetics in lipid-rich semi-moist foods. In contrast, the present study emphasizes kinetic modeling through the Arrhenius approach, offering a more robust prediction of oxidative shelf-life and highlighting the critical role of packaging materials in controlling lipid oxidation.

There remains a clear lack of predictive shelf-life studies that integrate both sensory and physicochemical indicators with kinetic modeling, particularly for traditional products such as pineapple dodol. This study addresses that gap by applying accelerated shelf-life testing (ASLT) combined with the Arrhenius model to predict shelf life based on thiobarbituric acid (TBA) values and sensory rancidity scores. By comparing aluminum foil and polypropylene packaging, this research provides practical guidance for traditional food preservation and supports the commercial viability of pineapple dodol. Specifically, the study aims to model oxidative deterioration kinetics using the Arrhenius equation and hypothesizes that aluminum foil packaging will extend shelf life more effectively than polypropylene packaging.

2. MATERIALS AND METHODS

2.1. Materials and Chemicals

Pineapple dodol was obtained from a local small-scale producer (Hanisun Cake, Tenayan Raya District, Pekanbaru, Indonesia). The product was freshly made using glutinous rice flour, coconut milk, palm sugar, and pineapple pulp, and stored at 4 °C for no longer than 24 hours prior to testing. The proximate composition was 30.82% moisture and 3.92% fat, determined using AOAC official methods. Two types of food-grade packaging were used: aluminium foil (0.08 mm thickness, 8×12 cm, Alfopack, Jakarta, Indonesia) and polypropylene plastic (0.03 mm thickness, 8×13 cm, PolyPrima, Bekasi, Indonesia). Chemical reagents for TBA analysis included thiobarbituric acid (≥99%), glacial acetic acid (≥99.8%), hydrochloric acid (37%), and diethyl ether (≥99%). All chemicals were obtained from Merck (Darmstadt, Germany), while double-distilled water was freshly prepared in the laboratory.

2.2. Sample Preparation and Storage Conditions

Samples were manually portioned into 25 g units and sealed using a thermal impulse sealer (PCS-300A, Powerpack, Indonesia). For each storage temperature, five replicate samples ($n = 5$) per packaging type were stored in temperature-controlled storage boxes at 35, 40, and 45 °C (±0.2 °C) with 50 ± 5% relative humidity. Storage experiments at 35, 40, and 45 °C for 30 days were designed to simulate accelerated deterioration. Samples were withdrawn every 5 days for analysis over a 30-day period.

2.3. Sensory Evaluation of Rancidity

A descriptive sensory evaluation was conducted to assess rancidity, as referred to Ayu et al. (2022) and Efendi et al. (2021). Thirty semi-trained panelists (ages 20–25) from the Agricultural Product Technology Department, Riau University, who had prior exposure to sensory training modules, participated in the test. Panel composition included 18 female and 12 male participants.

Panelists were briefed on the scale and attributes and provided with informed consent forms, complying with the institutional ethical standards. Evaluation was conducted in individual booths under white lighting, neutral odor conditions, and at room temperature (25 ± 1 °C). The relative humidity was controlled at 50 ± 5% using adequate air ventilation and fans. Each panelist assessed each sample once per time point, using a 5-point descriptive scale: 5 = very not rancid, 4 = not rancid, 3 = slightly rancid, 2 = rancid, and 1 = very rancid. Samples (10 g) were served in coded disposable cups, with panelists instructed to rinse their mouths with water between evaluations. Data were analyzed using mean scores and standard deviations.

2.4. Thiobarbituric Acid (TBA) Assay

Lipid oxidation was quantified by the TBA assay based on AOAC procedures. A 10 g sample was homogenized with 50 mL of distilled water and adjusted to pH 1.5 with 2.5 mL of 4 M HCl. The mixture was distilled for 10 minutes, and 5 mL of the distillate was reacted with 5 mL of TBA reagent (0.2883 g TBA in 100 mL 90% acetic acid). Samples were heated in a boiling water bath for 35 minutes, cooled to room temperature, and then analyzed for absorbance at 528 nm with a UV-Vis spectrophotometer (Shimadzu UV-1800, Japan). A standard curve using malondialdehyde (MDA) equivalents was used for quantification. Results were expressed in mg MDA·kg^{-1} sample.

2.5. Determination of The Critical Limit

Determination of the critical limit of pineapple dodol, as referred to Efendi et al. (2021), pineapple dodol was sensorily tested for rancidity score and thiobarbituric acid (TBA) values on 0, 5, 10, 15, 20, 25, and 30 days of storage. The initial sensory value of rancidity and TBA value is expressed as the initial quality value of the product. The threshold value, or critical limit, for the final product was established when the sensory evaluation of rancidity reached a score of 3, which corresponds to a slightly rancid perception. Both rancidity scores and TBA data were then processed through linear regression analysis to support the shelf-life modeling. When a product was declared slightly rancid by panelists (score 3), from the linear regression, the TBA value was also used as the critical limit for the product.

2.6. Deterioration Kinetics and Shelf-Life Prediction

Deterioration kinetics and shelf-life estimations were conducted in accordance with established methodologies (Ayu et al., 2022; Efendi et al., 2021). Both rancidity score data and TBA values were statistically processed through linear regression analysis using Microsoft Excel software. Among the different kinetic orders tested, the one yielding the highest coefficient of determination (R^2) was considered the most appropriate and subsequently applied to calculate the deterioration reaction rate and to predict shelf life. The regression slope corresponding to the selected order was interpreted as the deterioration rate constant (k) at the respective storage temperature.

A linear regression was performed between ln k and $1 \cdot T^{-1}$ in the selected kinetic order so that the values of intercept (a), slope (b), and coefficient of determination (R^2) were obtained. The values of a and b are used to calculate the activation energy (Ea) and k values at the specified storage temperature (25 °C) based on the Arrhenius equation (Calligaris, Manzocco, Anese, & Nicoli, 2019). The calculation of activation energy and k value at storage temperature based on the Arrhenius equation was as follows.

$$\mathrm{k} = k_0 . \mathrm{e}^{-E_a/\mathrm{RT}} \qquad (1)$$

or in logarithmic form: $$\ln \mathrm{k} = \ln k_0 - \left(\frac{E_a}{\mathrm{R}}\right) 1 \cdot \mathrm{T}^{-1} \qquad (2)$$

After obtaining the Arrhenius equation, enter the predetermined temperature value, namely 25 °C, into the Arrhenius equation to calculate the k value. Once the k value is known, the shelf life can be determined.

Shelf life of zero order: $$t = \frac{A_0 - A_t}{\mathrm{k}} \qquad (3)$$

Shelf life of first order: $$t = \frac{\ln(A_t) - \ln(A_0)}{\mathrm{k}} \qquad (4)$$

t = Shelf life (d).
A_0 = Initial quality value.
A_t = Final quality value or critical limit.
k = Deterioration rate constant.
Ea = Activation energy ($cal \cdot mol^{-1}$)
T = Absolute temperature (K).
R = Gas constant 1.986 $cal \cdot mol^{-1} \cdot K^{-1}$)

2.7. Data Analysis

All statistical analyses were conducted using GraphPad Prism 9.0 and verified in Microsoft Excel 365. Linear regression analysis was employed to model rancidity scores and TBA values over time and to determine the deterioration rate constants (k) for both zero- and first-order kinetics. The goodness-of-fit for each model was evaluated using the coefficient of determination (R^2), and the order with the highest R^2 was selected for further kinetic and shelf-life modeling.

To validate temperature dependence, the natural logarithm of the selected deterioration rate constants (ln k) was regressed against the reciprocal of absolute temperature ($1 \cdot T^{-1}$) to obtain Arrhenius parameters, including the activation energy (Ea) and pre-exponential factor (A).

Error analysis included the calculation of mean ± standard deviation (SD) from five independent replicates (n = 5), and 95% confidence intervals (CI) were computed for slope, intercept, and predicted shelf-life estimates. Differences in rancidity scores and TBA values between packaging types and storage conditions were statistically analyzed using one-way analysis of variance (ANOVA), followed by Tukey's Honestly Significant Difference (HSD) post-hoc test to determine pairwise significance. Statistical significance was determined at a p-value threshold of less than 0.05.

3. RESULTS AND DISCUSSION

3.1. Lipid Oxidation and Sensory Deterioration

Dodol, a confection made from glutinous rice flour, palm sugar, and coconut milk (Seow et al., 2021) is particularly vulnerable to oxidation processes during storage because of its coconut milk component. The oxidation reaction damage occurred in pineapple dodol during storage at 35, 40, and 45°C, as illustrated in Figure 1. The pattern was characterized by lower sensory rancidity scores and higher TBA measurements. These trends indicate the progression of lipid oxidation, where unsaturated fatty acids in coconut milk undergo peroxidation, producing aldehydes such as malondialdehyde (MDA), a known marker of rancidity.

Sensory scores decreased more rapidly ($p < 0.05$) at higher temperatures, particularly in samples packaged with polypropylene (K1). After 30 days at 45 °C, K1 samples had a mean score of 2.3 (rancid), whereas K0 (aluminum foil) samples showed a slightly higher score of 2.5 (somewhat rancid), suggesting better oxidative protection by K0. In parallel, TBA values increased significantly ($p < 0.05$) in both packaging types over time, with the highest value (1.3299 mg MDA·kg^{-1}) observed in K1 at 45 °C. These increases were statistically significant across all temperature points, reinforcing the observed sensory degradation.

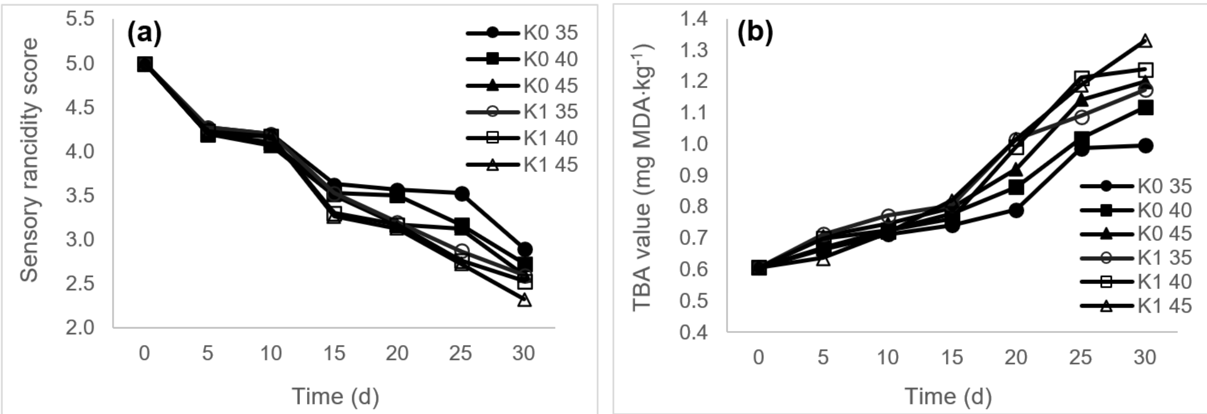

Figure 1. Changes in rancidity score (a) and TBA value (b) of pineapple dodol packaged with aluminium foil (K0) and polypropylene (K1) during 30 d of storage at 35, 40, and 45 °C. Rancidity score; 1=Very rancid, 2=Rancid, 3=Somewhat rancid, 4=Not rancid, and 5=Very not rancid.

The aroma of pineapple dodol changed from fresh (very not rancid) to noticeably rancid, and there was an increase in malonaldehyde content in pineapple dodol from 0.6071 to 1.3299 mg MDA·kg^{-1}. Figure 1a shows the changes in the rancidity score in K0 and K1 pineapple dodol during storage at 35, 40, and 45 °C are as follows. Sensory evaluation indicated that increasing the storage temperature resulted in reduced rancidity scores, reflecting a stronger perception of rancid aroma in pineapple dodol. For K0 samples, rancidity scores declined from 5.0 to 2.9, 2.7, and 2.5 at 35, 40, and 45 °C, respectively. The K1 pineapple dodol also experienced a decrease in rancidity score from 5.0 to 2.6, 2.5, and 2.3 at 35, 40, and 45 °C, respectively.

Figure 1b shows the TBA value of K0 and K1 pineapple dodol for 30 days of storage at 35, 40, and 45 °C. The K0 pineapple dodol at 35 °C experienced an increase in TBA values ranging from 0.6071 to 0.996, at 40 °C from 0.6071 to 1.118, and at 45 °C from 0.6071 to 1.199. The K1 pineapple dodol at 35 °C experienced an increase in TBA values ranging from 0.6071 to 1.1739, at 40 °C from 0.6071 to 1.2389, and at 45 °C from 0.6071 to 1.3299 after being stored for 30 days. An increase in storage temperature caused a reduction in rancidity scores while simultaneously raising the TBA values of pineapple dodol. The treatment at 45 °C produced the highest TBA measurement, signifying the greatest extent of lipid oxidation.

Rancidity is oxidation damage characterized by changes in the smell and taste of foodstuffs. According to Atmaka, Anandito, and Amborowati (2012), rancidity in jenang dodol can occur due to the oxidation reaction of oil derived from coconut milk exposed to high temperatures during storage. Rancidity in fat-containing products occurs when lipids interact with air, leading primarily to oxidative changes. The polyunsaturated fatty acids present in these foods are especially susceptible, reacting with oxygen to generate peroxides. These unstable intermediates decompose further to produce aldehydes, ketones, and additional volatile substances, which impart the undesirable rancid smell and taste (Belitz, Grosch, & Schieberle, 2009; Sebranek & Neel, 2008).

Statistical analysis revealed that all increases in TBA values and decreases in sensory scores were significant ($p < 0.05$). These findings indicate that oxidative deterioration is both temperature-dependent and strongly influenced by packaging material. Polypropylene's higher oxygen and light permeability likely accelerated oxidation compared to the more protective aluminum foil, which aligns with previous reports of its superior barrier properties (Lange & Wyser, 2003; Wijayanti, Surti, Anggo, & Susanto, 2016).

3.2. Kinetic Modeling and Reaction Order Determination

The kinetics of rancidity and TBA development were best described by first-order reaction models, as indicated by higher R^2 values in all treatments (Table 1). This suggests that the deterioration rate is proportional to the remaining quality attributes consistent with lipid oxidation dynamics in semi-moist, fat-rich foods.

Table 1. Reaction order and deterioration rate of pineapple dodol for 30 d of storage at 35, 40, and 45 °C.

Reaction order and rate of deterioration of pineapple dodol were determined by									
Rancidity score						TBA value			
Packaged with	Temperature (°C)	Zero order		First order		Zero order		First order	
		k	R^2	k	R^2	k	R^2	k	R^2
K0 (Aluminium foil)	35	0.0601	0.9186	0.0156	0.9242*	0.0135	0.9186	0.0170	0.9445*
	40	0.0676	0.9490	0.0181	0.9622*	0.0169	0.9598	0.0203	0.9839*
	45	0.0731	0.9541	0.0200	0.9682*	0.0201	0.9447	0.0229	0.9692*
K1 (Polypropylene)	35	0.0786	0.9744	0.0216	0.9861*	0.0193	0.9684	0.0222	0.9731*
	40	0.0809	0.957	0.0226	0.9743*	0.0228	0.9178	0.0254	0.9420*
	45	0.0856	0.9642	0.0246	0.9746*	0.0225	0.9559	0.0282	0.9789*

Note: *The highest R^2.

Notably, the rate constants (k) increased with storage temperature, conforming to the Arrhenius model. Across all temperature conditions, K1 exhibited consistently higher k values than K0, further confirming the less protective nature of polypropylene packaging. For instance, at 45 °C, the TBA-based k value for K1 was 0.0282 d^{-1}, whereas for K0 it was only 0.0229 d^{-1}.

The deterioration rate was consistently higher in K1, suggesting greater permeability to oxygen and light, which accelerates lipid oxidation. This is consistent with findings in the literature showing that aluminum foil has superior barrier properties, including lower oxygen transmission rates and better light protection compared to polypropylene packaging (Lamberti & Escher, 2007; Lange & Wyser, 2003). Wijayanti et al. (2016) stated that aluminum foil stand pouches had the lowest O_2 transmission rates among different types of packaging (plastic polypropylene bag, polystyrene jar, and aluminum foil stand pouch) and were the best packages for maintaining water, protein, fat, and lysine content of milkfish floss during storage. The low rate of O_2 transmission had the ability to slow down the entry of O_2 into the product, which can inhibit the oxidation process. Furthermore, aluminum foil inhibited the penetration of light better than polypropylene (PP) and polyethylene terephthalate (PET) plastics, which are more transparent. The amount of light that enters accelerates the oxidation process of fat in the product and causes faster deterioration (Afifah, Sholichah, Widyawati, Khudaifanny, & Budiarti, 2021).

These results reinforce the relationship between packaging permeability and reaction kinetics: aluminum foil's lower oxygen transmission rate and light-blocking capacity delayed the formation of rancid compounds. The consistency of first-order fits across both sensory and instrumental data supports its application for predictive modeling in similar food systems.

3.3. Correlation Between Sensory and Instrumental Measurements

The data in Figure 2 demonstrate that rancidity scores were strongly and linearly related to TBA values in both packaging systems, with R^2 exceeding 0.94. This indicates that sensory perceptions of rancidity were closely aligned with objective lipid oxidation measurements.

Critical TBA limits were derived from the regression equations corresponding to a rancidity score of 3.0 (slightly rancid), yielding values of 0.9972 mg MDA·kg^{-1} for K0 and 1.0315 mg MDA·kg^{-1} for K1. While these values support the use of TBA as a reliable quality indicator, the inclusion of regression equations and *p-values* would strengthen this correlation claim in future studies.

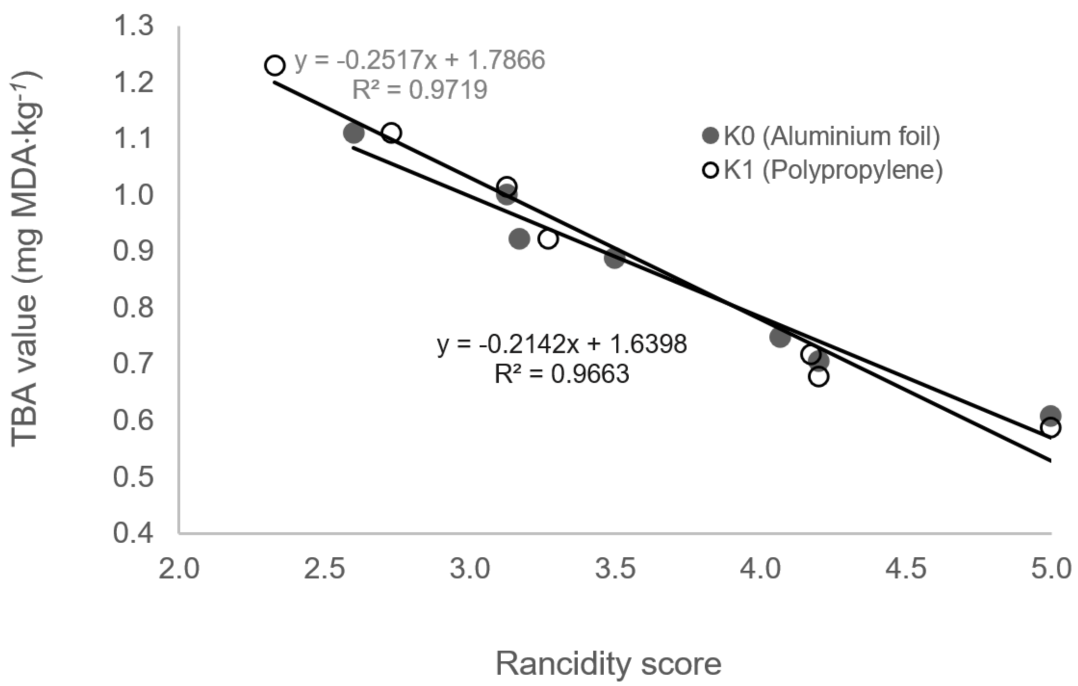

Figure 2. Correlation between rancidity scores and TBA values of pineapple dodol stored for 30 days in aluminum foil (K0) and polypropylene (K1) packaging.

3.4. Shelf-Life Estimation

The deterioration rate constants (k) increased with temperature across all samples, in line with the Arrhenius model. Notably, K1 samples (polypropylene) consistently exhibited higher k values than K0 (aluminum foil), indicating a faster degradation rate (Table 1).

Arrhenius plots (ln k vs 1·T^{-1}) demonstrated strong linear relationships (Figure 3), allowing for the estimation of activation energy (Ea) and projected k values at 25 °C. Aluminum foil (K0) exhibited higher Ea values of 4837.70 cal·mol^{-1} (based on rancidity score) and 5800.51 cal·mol^{-1} (based on TBA value) compared to polypropylene (K1), which had Ea values of 2525.40 and 4656.17 cal·mol^{-1}, respectively. These results confirm that aluminum foil offers a greater energy barrier against oxidative deterioration, enhancing product stability during storage.

Shelf-life estimates at 25 °C based on rancidity scores were 42.39 days for K0 and 27.35 days for K1. When calculated using TBA values, the predicted shelf lives were slightly longer, 43.44 days for K0 and 32.06 days for K1.

For consumer safety, the more conservative estimates based on sensory perception were adopted as the final shelf-life values.

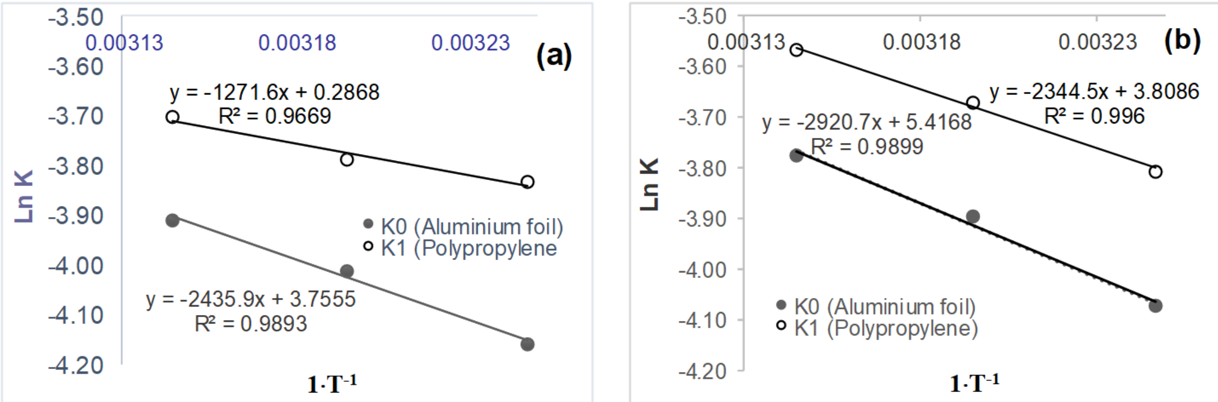

Figure 3. Relationship of ln k versus 1/T in selected reaction orders based on (a) Rancidity evaluation and (b) TBA measurement for pineapple dodol packaged in aluminum foil (K0) and polypropylene (K1) during 30 days of storage.

Table 2. Prediction of pineapple dodol shelf life at 25 °C using rancidity evaluation and thiobarbituric acid (TBA) measurements.

Prediction of pineapple dodol shelf life using rancidity scores					Prediction of pineapple dodol shelf life using TBA value			
Packaged with	**Linear equations ln k vs 1·T^{-1}**	**Activation energy (cal·mol^{-1})**	**k**	**Shelf-life at 25 °C (d)**	**Linear equations ln k vs 1·T^{-1}**	**Activation energy (cal·mol^{-1})**	**k**	**Shelf-life at 25 °C (d)**
K0 (Aluminium foil)	y = -2435.9x+3.7555	4837.70	0.0138	42.39	y = -2920.7x+5.4168	5800.51	0.0147	43.44
K1 (Polypropylene)	y = -1271.6x+0.2868	2525.40	0.0200	27.35	y = -2344.5x+3.8086	4656.17	0.0197	32.06

Regression slope and intercept values used in the Arrhenius calculations are detailed in Figure 3, while corresponding kinetic parameters and shelf-life predictions are presented in Table 2. As expected, products with higher energy activation values exhibited slower deterioration and, therefore, longer shelf life. These findings reinforce the superior oxidative protection provided by aluminum foil packaging, particularly for semi-moist, fat-containing traditional foods like pineapple dodol.

Compared to previous studies focusing on microbial and hydrolytic deterioration study Afifah and Ratnawati (2021) oxidative degradation was found to proceeded more rapidly in pineapple dodol under the tested conditions. This suggests that lipid oxidation may serve as a more critical limiting factor for shelf-life determination than microbial growth in such semi-moist products. However, this study focused solely on oxidation parameters. Limitations include the absence of microbiological, water activity, or texture analyses. In addition, while the first-order model and Arrhenius approach fit well, alternative models like Weibull could offer more flexibility and robustness under non-isothermal or variable humidity conditions. Future research should incorporate indicators of microbial and physical degradation, evaluate a wider range of packaging materials, and involve more diverse sensory panels to enhance the generalizability of the findings.

4. CONCLUSION

Results indicated that the use of accelerated shelf-life testing (ASLT) together with first-order kinetic modeling, formulated according to the Arrhenius equation, is a reliable approach for predicting the shelf life of pineapple dodol. The findings confirmed that aluminum foil packaging provides superior protection against oxidative deterioration compared to polypropylene, as reflected by lower degradation rate constants, higher activation energy, and longer predicted shelf life.

A strong correlation between thiobarbituric acid (TBA) values and sensory rancidity scores validated the use of instrumental indicators as reliable proxies for sensory quality. With predicted shelf lives of 42.39 days (aluminum foil) and 27.35 days (polypropylene) at 25°C, the study underscores the critical role of barrier packaging in preserving the quality of lipid-rich traditional foods while offering practical guidance for small-scale producers.

Although the study did not include microbial, texture, or water activity analyses, it establishes a quantitative framework for predictive shelf-life estimation in semi-moist foods. Future work should integrate these additional spoilage indicators and explore packaging innovations to provide a more comprehensive understanding of quality degradation in traditional products. Expanding the scope of predictive models to include multiple quality indicators will strengthen the commercialization potential of pineapple dodol and similar products.

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Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
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