

Optimization of Tamarind Leaf (*Tamarindus indica* L.) Ethanol Extract as a Natural Antioxidant for Improving Coconut Oil Stability and Shelf Life

Sjamsiah*, Amalyah Febryanti, and Mujtahidah Shabir

Chemistry Department, Faculty of Sciences and Technology, Universitas Islam Negeri Alauddin, Makassar, South Sulawesi, Indonesia

*Corresponding Author: sjamsiah.uca@uin-alauddin.ac.id

Received: May, 26, 2026/Accepted: June, 30, 2026

doi:10.24252/al-kimia.v14i1.68485

Abstract: Coconut oil is susceptible to oxidative deterioration during storage, resulting in rancidity, reduced quality, and a shortened shelf life. This study evaluated the effectiveness of tamarind leaf (*Tamarindus indica* L.) ethanol extract as a natural antioxidant for improving the physicochemical stability and shelf life of coconut oil. Tamarind leaves were extracted by ethanol maceration, followed by phytochemical screening and antioxidant activity evaluation using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay. Coconut oil was supplemented with 1%, 2%, and 3% (w/v) extract and analyzed for moisture content, peroxide value, free fatty acid content, and saponification value. Shelf life was estimated using the Accelerated Shelf-Life Testing (ASLT) Arrhenius model. The extract yield was 26.31% and contained flavonoids, tannins, alkaloids, and steroids. The extract exhibited moderate antioxidant activity ($IC_{50} = 125.42$ ppm). Increasing extract concentration improved coconut oil quality by reducing moisture content, peroxide value, and free fatty acid content while increasing the saponification value. The 3% extract treatment provided the greatest preservation effect, extending the predicted shelf life from 37 to 87 days at 25 °C. These findings demonstrate the potential of tamarind leaf extract as an environmentally friendly natural antioxidant for edible oil preservation.

Keywords: *Tamarindus indica* L, Coconut Oil, Natural Antioxidant, Oxidative Stability, Shelf-Life Prediction, Accelerated Shelf Life Testing, DPPH

INTRODUCTION

Coconut oil is widely used in household cooking and food processing due to its nutritional value and desirable flavor. However, coconut oil is highly susceptible to oxidative deterioration during storage, particularly when exposed to oxygen, moisture, heat, and prolonged storage conditions (Jusman & Syamsuddin, 2025). Oxidative degradation leads to the formation of peroxide compounds, aldehydes, ketones, and free fatty acids, which accelerate rancidity and reduce oil quality and shelf life (Machado et al., 2023). Several studies have reported that the deterioration of edible oils can be delayed by adding antioxidants that scavenge free radicals and inhibit oxidation reactions (Ibsch et al., 2020; Song et al., 2023; Zahid et al., 2024). Antioxidants function by donating hydrogen atoms or electrons to reactive oxygen species, thereby stabilizing radical intermediates and slowing oxidation processes (Ruseva et al., 2025). Although synthetic antioxidants such as butylated hydroxytoluene and butylated hydroxyanisole are widely used in the food industry, concerns about their toxicity and potential carcinogenic effects have spurred the search for safer natural antioxidant alternatives (Xue, 2023).

Recent scientific attention has increasingly focused on plant-derived antioxidants because of their safety, biodegradability, sustainability, and multifunctional bioactivities. Natural antioxidants from medicinal plants, herbs, fruits, and spices are considered promising for food applications because they contain phenolic compounds, flavonoids, tannins, and

alkaloids with strong radical-scavenging activity ([Shaaban, 2023](#)). One plant that has attracted considerable attention is tamarind (*Tamarindus indica* L.), particularly its leaves, which possess antifungal, anti-inflammatory, hepatoprotective, wound-healing, and antioxidant activities ([Mukherjee et al., 2024](#)). Previous phytochemical studies revealed that tamarind leaf extract contains flavonoids, tannins, alkaloids, saponins, phenolics, and steroids ([Din et al., 2024](#); [Garba et al., 2023](#)). In addition, [Silalahi et al \(2020\)](#) identified catechin, epicatechin, quercetin, and isorhamnetin as dominant flavonoid compounds in tamarind leaves. These compounds are recognized for their ability to neutralize free radicals, inhibit lipid peroxidation, and reduce oxidative stress ([Mukherjee et al., 2024](#)). Despite the promising antioxidant properties of tamarind leaves, studies investigating their use in preserving coconut oil remain limited. Most previous investigations focused mainly on antioxidant screening using the DPPH method without integrating physicochemical quality evaluation and shelf-life prediction.

Moreover, limited information is available regarding the combined assessment of antioxidant activity, physicochemical quality changes, and shelf-life prediction of coconut oil supplemented with tamarind leaf extract under accelerated storage conditions. The integration of these analytical approaches is important because antioxidant performance in lipid-based food systems cannot be adequately explained by DPPH activity alone but should also be supported by changes in oxidation indicators and shelf-life estimation.

Therefore, this study evaluated the effectiveness of tamarind leaf ethanol extract as a natural antioxidant for improving coconut oil stability through an integrated approach comprising phytochemical screening, DPPH antioxidant evaluation, physicochemical quality analysis, and Accelerated Shelf-Life Testing (ASLT) using the Arrhenius model. The novelty of this work lies not in the use of tamarind leaf extract itself, but in the comprehensive integration of these analytical approaches to evaluate its effectiveness in improving coconut oil stability and predicting shelf life within a single experimental framework.

RESEARCH METHODS

This study employed a laboratory-based experimental design to evaluate the effectiveness of tamarind leaf ethanol extract (*Tamarindus indica* L.) as a natural antioxidant to improve the quality and shelf life of coconut oil. The study included phytochemical screening, antioxidant activity analysis using the DPPH method, physicochemical quality evaluation, and shelf-life estimation using the Arrhenius model for accelerated shelf-life testing.

Materials and Tools

The primary biological material used in this study was tamarind leaves (*Tamarindus indica* L.), collected from Laringgi Village, Marioria District, Soppeng Regency, South Sulawesi, Indonesia. Mature coconuts were obtained from Galesong Market, Takalar Regency, South Sulawesi. Chemical reagents used included ethanol 96%, DPPH (2,2-diphenyl-1-picrylhydrazyl), ascorbic acid, sodium hydroxide (NaOH), sulfuric acid (H₂SO₄), ferric chloride (FeCl₃), potassium iodide (KI), sodium thiosulfate (Na₂S₂O₃), hydrochloric acid (HCl), phenolphthalein indicator, alcoholic potassium hydroxide (KOH), chloroform, glacial acetic acid, and distilled water.

The analytical instruments utilized in this study included a UV–Vis spectrophotometer (Varian Cary 50, Australia), rotary evaporator (Buchi Rotavapor R-100, India), analytical balance (Kern ABJ 220-4 nm), hotplate stirrer (Thermo Scientific, USA),

oven, desiccator, burette, glassware, blender, thermometer, and other standard laboratory apparatus. of manufacture and purify of the materials used, e.g., sigma-aldrich usa.

Methods

Preparation of Coconut Oil

Coconut oil was prepared following the method of [Momuat et al.\(2009\)](#). Mature coconuts were peeled, and the coconut flesh was grated. The grated coconut was mixed with hot water at 70 °C in a 1:1 ratio, then squeezed and filtered to obtain coconut milk. The coconut milk was allowed to stand for 2 h to separate the cream and skim fractions. The cream layer was collected and heated at 80–90 °C until coconut oil was formed. The obtained oil was filtered and stored in dark bottles before analysis.

Extraction of Tamarind Leaves

The extraction procedure was adapted from [Kartikawati et al. \(2021\)](#). Tamarind leaves were dried under indirect sunlight and ground into powder. Approximately 1 kg of powdered leaves was macerated in 96% ethanol for 3x24 h at room temperature. The filtrate was concentrated using a rotary evaporator at 40 °C to obtain a viscous extract. Maceration was selected because it preserves thermolabile phytochemicals and minimizes thermal degradation ([Megawati et al., 2021](#); [Yunita & Khodijah, 2020](#)).

Phytochemical Screening

Qualitative phytochemical screening was conducted to identify alkaloids, flavonoids, tannins, steroids, and terpenoids using standard colorimetric methods. Alkaloids were identified using Mayer and Dragendorff reagents, flavonoids using NaOH and concentrated H₂SO₄, tannins using FeCl₃ solution, and steroids or terpenoids using the Liebermann–Burchard reagent.

Determination of Antioxidant Activity

Antioxidant activity was evaluated using the DPPH radical scavenging assay according to [Kiromah et al. \(2021\)](#) and [Megawati et al \(2021\)](#). A 39.7 ppm DPPH solution was prepared by dissolving 2 mg DPPH in 50 mL ethanol p.a. Tamarind leaf extract stock solution (1000 ppm) was prepared and diluted to concentrations of 20, 40, 60, 80, and 100 ppm. Ascorbic acid was used as the reference standard. 4 mL of sample or standard solution was mixed with 1 mL of DPPH solution and incubated in the dark for 30 min. Absorbance was measured at 517 nm using a UV–Vis spectrophotometer. Antioxidant activity was expressed as percentage inhibition and inhibitory concentration (IC₅₀) values obtained through linear regression analysis.

Formulation of Coconut Oil with Tamarind Leaf Extract

The formulation procedure followed by [Rejeki \(2018\)](#). Coconut oil samples (100 mL) were supplemented with tamarind leaf ethanol extract at 1%, 2%, and 3% (b/v), with untreated oil serving as the control. Each formulation was heated at 90 °C for 15 min with continuous stirring to ensure homogeneous mixing. Samples were then stored under open-air conditions for 15 days before quality evaluation.

Evaluation of Coconut Oil Quality

Physicochemical quality analysis was performed in accordance with the Indonesian National Standard for coconut oil (SNI 3741:2013). Moisture content, peroxide value, free fatty acid content, and saponification value were determined according to the procedures specified in the standard. Moisture content was determined gravimetrically by heating oil samples at 110 °C until constant weight was achieved. Peroxide value was determined by iodometric titration with sodium thiosulfate. Free fatty acid content was analyzed by titration

with 0.1 N NaOH using phenolphthalein as an indicator. The saponification value was determined by refluxing oil samples with alcoholic KOH, then titrating with 0.5 N HCl.

Each physicochemical quality parameter (moisture content, peroxide value, free fatty acid content, and saponification value) was determined using three independent experimental replicates ($n = 3$). The reported values are expressed as mean $\pm$ standard deviation (SD), calculated from the replicate measurements to represent experimental variability.

Statistical analyses were conducted using one-way analysis of variance (ANOVA) to evaluate differences among extract concentration treatments. When significant differences were detected ($p < 0.05$), Tukey's Honestly Significant Difference (HSD) test was applied for multiple comparisons of treatment means. Regression analysis was used to determine IC_{50} values from DPPH assay data and to establish kinetic models for Arrhenius-based shelf-life prediction. All statistical analyses were performed at a significance level of 95% ($p < 0.05$).

Shelf-Life Estimation Using the ASLT Arrhenius Model

Shelf-life estimation was conducted using the Arrhenius model for accelerated shelf-life testing, following the methods of [Rejeki \(2018\)](#), Hasany et al. (2017) and [Susanti \(2016\)](#). Coconut oil containing the optimal extract concentration was stored at 25 °C, 29–31 °C, and 38–41 °C for 30 days, and analyses were performed every 5 days.

Free fatty acid content was selected as the critical quality parameter because it reflects hydrolytic and oxidative deterioration during storage. Zero-order and first-order kinetic models were applied to determine the deterioration kinetics. The model with the highest correlation coefficient (R^2) was selected for Arrhenius modelling, and shelf-life prediction was calculated based on the Arrhenius equation.

RESULTS AND DISCUSSION

Extraction Yield and Phytochemical Profile of Tamarind Leaf Extract

Tamarind leaf ethanol extract (*Tamarindus indica* L.) was successfully obtained by maceration with 96% ethanol. The initial dry sample weight was 1,132 g, and the extraction process yielded 298.36 g of concentrated extract, corresponding to a 26.31% yield. The relatively high extraction yield indicates that ethanol effectively extracted bioactive compounds from tamarind leaves. According to [Senduk et al \(2020\)](#), extraction yields greater than 10% indicate efficient recovery of phytochemical constituents from plant materials. The high yield obtained in this study is likely due to ethanol's polarity, which enables the efficient extraction of phenolic compounds, flavonoids, tannins, alkaloids, and other polar secondary metabolites.

Qualitative phytochemical screening (Table 1) demonstrated the presence of several important secondary metabolites in the tamarind leaf extract, including alkaloids, flavonoids, tannins, and steroids. Positive alkaloid reactions were observed in the Dragendorff test, resulting in an orange precipitate. Flavonoid compounds were identified based on brown and dark brown coloration after reaction with NaOH and concentrated H_2SO_4 , respectively. Tannins were indicated by greenish-brown coloration following $FeCl_3$ addition, while steroids were identified through blue-green coloration in the Liebermann–Burchard reaction. In contrast, terpenoid compounds were not detected in the extract.

Table 1. Phytochemical Screening Result of Tamarind Leaf Ethanol Extract (*Tamarindus indica* L.)

Compound Group	Reagent	Obsrvation	Note/Result
Alkaloids	Mayer	Brown precipitate	Negatif (-)
	Dragendorf	Orange precipitate	Positive (+)
Flavonoids	NaOH 10%	Brown	Positive (+)
	Concentrated H ₂ SO ₄	Blackish-brown	Positive (+)
Tannis	FeCl ₃ 1%	Greenish-brown	Positive (+)
Steroids	Liebermann-Burchard	Greenish-blue	Positive (+)
Terpenoids	Liebermann-Burchard	Greenish-blue	Negatif (-)

The presence of flavonoids and phenolic compounds strongly supports the antioxidant potential of tamarind leaf extract. Previous studies reported that flavonoids act as effective hydrogen donors capable of stabilizing free radicals through resonance mechanisms ([Megawati et al., 2021](#)). Similarly, Buanasari et al. (2018) and [Husain et al. \(2022\)](#) confirmed that tamarind leaves contain diverse bioactive compounds with antioxidant properties. Therefore, the phytochemical profile obtained in this study supports the suitability of tamarind leaves as a natural antioxidant source for preserving edible oils.

Antioxidant Activity of Tamarind Leaf Ethanol Extract

The antioxidant activity of tamarind leaf ethanol extract (Table 2) was evaluated using the DPPH radical scavenging assay. Increasing extract concentration resulted in a corresponding increase in the inhibition percentage, indicating concentration-dependent antioxidant activity. At concentrations of 20, 40, 60, 80, and 100 ppm, the inhibition percentages were 10.437%, 14.099%, 25.149%, 25.810%, and 29.682%, respectively.

Linear regression analysis yielded the equation $y = 0.351x + 5.9751$, with a correlation coefficient (R^2) of 0.9167, indicating a strong positive relationship between extract concentration and antioxidant activity. Based on this regression equation, the IC₅₀ value of tamarind leaf ethanol extract was calculated to be 125.42 ppm. According to common antioxidant classification standards, IC₅₀ values of 101–150 ppm indicate moderate antioxidant activity. It should be noted that the calculated IC₅₀ value (125.42 ppm) was obtained by linear extrapolation because the tested concentration range (20–100 ppm) did not achieve 50% inhibition. Consequently, the reported IC₅₀ should be interpreted as an estimated value rather than an experimentally interpolated value. Although this approach provides a preliminary indication of antioxidant activity, extending the concentration range beyond 100 ppm would improve the accuracy and reliability of IC₅₀ determination. Therefore, future studies should include higher extract concentrations (e.g., up to 150 ppm or higher) to obtain an interpolated IC₅₀ value.

Ascorbic acid was used as a reference antioxidant standard and exhibited significantly stronger activity than the tamarind leaf extract. The regression equation for ascorbic acid was $y = 6.258x + 45.701$, with an R^2 value of 0.9945, yielding an IC₅₀ of 0.68 ppm. The substantially lower IC₅₀ value demonstrates ascorbic acid's superior radical-scavenging efficiency compared with the plant extract.

The antioxidant activity observed in the tamarind leaf extract is likely due to the presence of flavonoids, tannins, and other phenolic compounds. Flavonoids are recognized as important antioxidant agents because they donate hydrogen atoms to neutralize DPPH

radicals, forming more stable radical intermediates (Nurhayati et al., 2022). Tunny et al (2020) previously reported an IC₅₀ value of 143.278 ppm for the tamarind leaf methanol extract, consistent with the moderate antioxidant activity observed in the present study.

Although the DPPH assay classified the extract as having moderate antioxidant activity, this does not necessarily limit its practical effectiveness in lipid-based food systems such as coconut oil. The DPPH assay measures radical-scavenging capacity in a homogeneous solution, whereas lipid oxidation in edible oils is influenced by multiple factors, including the partitioning behavior of antioxidants, interactions among phenolic constituents, and the ability of antioxidants to interrupt free-radical chain reactions within the lipid matrix. Consequently, extracts exhibiting only moderate DPPH activity may still provide substantial protection against oxidative deterioration during storage. This interpretation is supported by the present findings, where increasing concentrations of tamarind leaf extract significantly reduced moisture content, peroxide value, and free fatty acid formation while improving the saponification value, indicating enhanced oxidative stability of coconut oil.

Although the antioxidant capacity was lower than that of ascorbic acid, the extract still demonstrated sufficient radical-scavenging activity to inhibit oxidative reactions in coconut oil. These findings support previous studies indicating that plant-derived phenolic compounds may serve as effective alternatives to synthetic antioxidants in edible oil preservation (Megawasti et al., 2021).

Table 2. Antioxidant Activity Result of Tamarind Leaf Ethanol Extract (*Tamarindus indica* L.)

Control	Concentration (ppm)	Absorbance	Average Absorbance	% Inhibition	Regression Equation	IC ₅₀ (ppm)
		0.5550				
	20	0.5553	0.5552	10.437		
		0.5554				
		0.5324				
	40	0.5323	0.5325	14.099		
		0.5327				
		0.4639			y = 0.351x +	
0.6199	60	0.4640	0.4640	25.149	5.9751	125.42
		0.4640				
		0.4590			R ² = 0.9167	
	80	0.4599	0.4599	25.810		
		0.4609				
		0.4342				
	100	0.4359	0.4359	29.682		
		0.4375				

A limitation of the present study is the absence of a positive control using commercially available synthetic antioxidants such as butylated hydroxytoluene (BHT) or butylated hydroxyanisole (BHA). Consequently, although tamarind leaf extract demonstrated

beneficial effects on the physicochemical stability of coconut oil, its performance cannot be directly compared with widely used synthetic antioxidants under identical experimental conditions. Therefore, the present findings should be interpreted as evidence of the antioxidant potential of tamarind leaf extract rather than definitive proof that it can replace synthetic antioxidants in edible oil preservation. Future studies incorporating BHT or BHA as positive controls are recommended to enable a more rigorous comparative evaluation of antioxidant efficacy.

Effect of Tamarind Leaf Extract Concentration on Coconut Oil Quality

The addition of tamarind leaf ethanol extract significantly influenced the physicochemical quality of coconut oil after storage. Coconut oil samples containing 1%, 2%, and 3% extract concentrations were compared with a control sample without antioxidant addition (Table 3).

Table 3. Effect of Various Concentrations of Tamarind Leaf Ethanol Extract (*Tamarindus indica* L.) on Coconut Oil Quality

Coconut Oil Quality Test	Control	1%	2%	3%	Reference Standard
Moisture Content (%)	1.09±0.07 ^a	0.68±0.02 ^b	0.46±0.02 ^c	0.44±0.03 ^c	SNI 3741:2013
Peroxide value (meq/g)	0.43±0.01 ^a	0.39±0.00 ^a	0.33±0.04 ^b	0.22±0.01 ^c	SNI 3741:2013
Free fatty acids (%)	3.29±0.21 ^a	2.978±0.27 ^a	2.177±0.36 ^b	1.936±0.11 ^b	SNI 3741:2013
Saponification value (meq/g)	191.05±3.10 ^a	241.73±2.80 ^b	250.51±1.90 ^c	261.33±2.80 ^d	SNI 2902:2011

Note: Different superscript letters within the same column indicate significant differences according to Tukey's HSD test ($p < 0.05$).

Moisture Content

The moisture contents of coconut oil samples containing 0%, 1%, 2%, and 3% extract were 1.09%, 0.68%, 0.46%, and 0.44%, respectively. One-way ANOVA showed that tamarind leaf extract concentration significantly affected the moisture content of coconut oil ($p < 0.05$). Tukey's HSD test indicated that the 3% extract treatment differed significantly from the control, whereas the 2% and 3% treatments were not significantly different from each other ($p > 0.05$).

The results demonstrate that increasing extract concentration reduced moisture accumulation in coconut oil. Nevertheless, the measured moisture content remained above the maximum limit specified in SNI 3741:2013 (max. 0.15% b/b) for edible vegetable oils. This finding suggests that, although the extract effectively reduced moisture accumulation, further optimization of the oil processing procedure, particularly the dehydration step, is required to fully comply with the quality standard. The residual moisture may have resulted from incomplete water removal during oil preparation or moisture absorption during storage rather than from the antioxidant treatment itself.

Higher moisture content promotes hydrolysis of triglycerides into glycerol and free fatty acids, thereby accelerating oil deterioration. [Dimzon et al. \(2011\)](#) reported that elevated water content in coconut oil increases hydrolytic degradation and lowers product quality. The

reduced moisture levels observed after antioxidant addition indicate that tamarind leaf extract contributed to improved oil stability during storage. The hygroscopic properties of oxidation products may also explain the higher moisture accumulation observed in untreated samples.

Peroxide Value

Peroxide value analysis showed that antioxidant addition effectively reduced primary oxidation products in coconut oil. The peroxide values for control, 1%, 2%, and 3% extract samples were 0.431, 0.393, 0.327, and 0.225 meq/g, respectively. All samples remained below the maximum SNI limit of 10 meq/kg (Indonesia & Nasional, 2013); however, the 3% extract treatment produced the lowest peroxide value.

The decreasing peroxide values observed with increasing extract concentration indicate that the antioxidant compounds in tamarind leaves effectively inhibited lipid oxidation. According to [Gunstone \(1984\)](#), peroxide formation occurs when unsaturated fatty acids react with oxygen, producing unstable hydroperoxides that contribute to rancidity. The ability of tamarind leaf extract to reduce peroxide accumulation, therefore, demonstrates its effectiveness in suppressing oxidative deterioration. Flavonoids and phenolic compounds likely acted as hydrogen donors, interrupting free-radical chain reactions during lipid oxidation ([Kerem et al., 2006](#)).

Free Fatty Acid Content

In SNI 3741:2013, the quality requirement is expressed as acid value rather than free fatty acid (FFA) content. Therefore, for comparison with the present data, the acid value limit was converted to FFA expressed as lauric acid, resulting in an equivalent maximum limit of 2.14%. The FFA content decreased from 3.29% in the untreated control to 2.98%, 2.18%, and 1.94% after the addition of 1%, 2%, and 3% tamarind leaf ethanol extract, respectively.

Based on the converted SNI limit, only the 3% extract treatment complied with the requirement, while the 2% treatment was very close to the limit and the control and 1% treatments remained above the standard. This result indicates that increasing extract concentration effectively suppressed free fatty acid formation, although sufficient compliance with the converted SNI requirement was achieved only at the 3% extract concentration.

The reduction in FFA content with increasing antioxidant concentration indicates improved resistance against hydrolytic degradation. [Tape et al. \(2023\)](#) explained that free fatty acids are formed through triglyceride hydrolysis initiated by water and enzymatic activity. Higher moisture content accelerates hydrolysis ([Lourençon et al., 2022](#)); the lower FFA values obtained in antioxidant-treated samples further confirm the stabilizing effect of tamarind leaf extract. These findings suggest that antioxidant addition contributed to both oxidative and hydrolytic stabilization mechanisms in coconut oil.

Saponification Value

Unlike moisture content, peroxide value, and acid value, the saponification value is not included as a quality parameter in SNI 3741:2013. Therefore, the results were evaluated based on the specification provided in SNI 01-2902-2011, which recommends a saponification value of 248–265 mg KOH g⁻¹. Based on this criterion, coconut oil containing 2% and 3% tamarind leaf extract complied with the recommended range, whereas the control and 1% extract treatments remained below the specified values.

Higher saponification values indicate greater stability of fatty acid components within the oil matrix. The increase in saponification value after antioxidant addition suggests

that tamarind leaf extract effectively protected triglyceride structures from oxidative degradation. Oils with higher saponification values generally indicate better preservation of triglyceride integrity and reduced decomposition ([Villarruel et al., 2023](#)). Overall, among all tested treatments, the 3% extract concentration demonstrated the best physicochemical quality characteristics.

It should be noted that the formulation process involved heating the coconut oil–extract mixture at 90 °C for 15 min to ensure homogeneous dispersion of the extract within the oil matrix. Such thermal treatment may have caused partial degradation of thermolabile phenolic compounds, including flavonoids, which are known to contribute to antioxidant activity. Consequently, the antioxidant capacity of the formulated oil may have been lower than that of the fresh extract. Nevertheless, the treated samples still exhibited improved physicochemical stability compared with the untreated control, suggesting that sufficient antioxidant compounds remained active to inhibit oxidative deterioration during storage. Future studies should investigate lower-temperature formulation methods or alternative incorporation techniques to minimize thermal degradation of bioactive constituents while maintaining formulation homogeneity.

Shelf-Life Estimation Using the ASLT Arrhenius Model

Shelf-life estimation was conducted using the Accelerated Shelf Life Testing (ASLT) method with the Arrhenius kinetic model. Coconut oil containing the optimal extract concentration (3%) was stored at 25 °C, 29–31 °C, and 38–41 °C for 30 days. Free fatty acid content was selected as the critical quality parameter for determining deterioration kinetics because it reflects both hydrolytic and oxidative degradation during storage ([Sarungallo et al., 2023](#)).

Regression analysis of storage time versus quality degradation was performed using zero-order and first-order kinetic models (Fig 1). The zero-order model produced higher correlation coefficients (R^2) than the first-order model across all storage conditions, indicating that coconut oil deterioration followed zero-order reaction kinetics. The R^2 values for zero-order kinetics at control, 25 °C, 29–31 °C, and 38–41 °C were 0.9397, 0.9944, 0.8906, and 0.8542, respectively.

The Arrhenius regression equation obtained from the relationship between $\ln k$ and $1/T$ was $y = -2958x + 6.7306$ with an R^2 value of 0.7001. Based on this equation, the activation energy (E_a) of coconut oil deterioration was calculated to be 5.8746 kcal/mol. The estimated shelf life of untreated coconut oil was 37 days. In contrast, coconut oil containing 3% tamarind leaf extract exhibited significantly longer shelf life at all storage temperatures. Shelf-life predictions for antioxidant-treated oil were 87 days at 25 °C, 63 days at 29–31 °C, and 42 days at 38–41 °C.

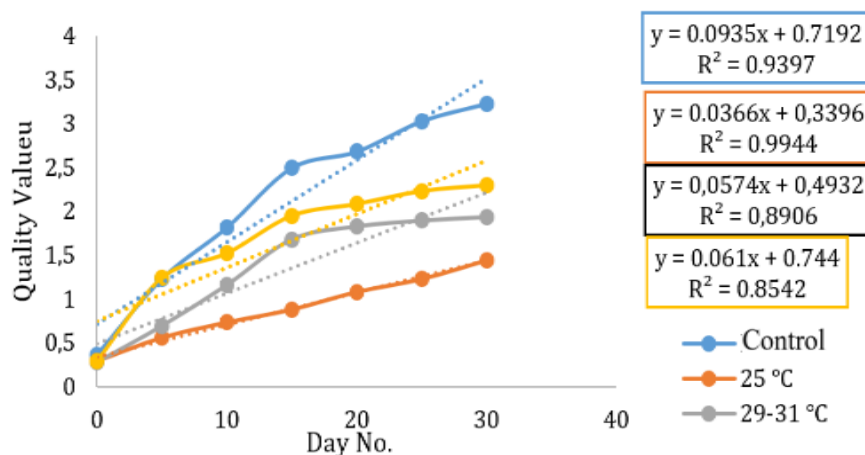


Figure 1. The Relationship between Storage Duration and Quality Degradations for Zero-Order Kinetics

These results demonstrate that storage temperature strongly influenced coconut oil stability (Fig 2). Higher temperatures accelerated oxidation and hydrolysis, leading to faster quality deterioration and a shorter shelf life. Conversely, lower storage temperatures effectively slowed deterioration kinetics and prolonged product stability. The extended shelf life observed after the addition of tamarind leaf extract confirms the effectiveness of natural antioxidants in delaying oxidative degradation in edible oils.

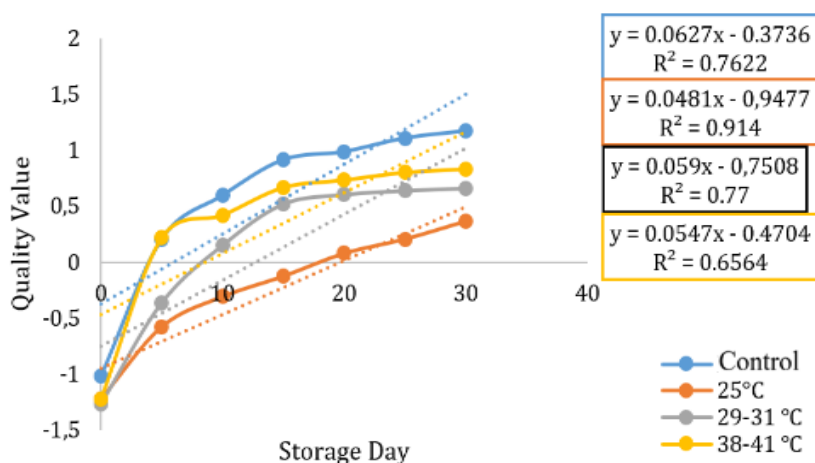


Figure 2. The Relationship between Storage Duration and Quality Degradations for First-Order Kinetics

Overall, this study demonstrates that tamarind leaf ethanol extract exhibits significant antioxidant activity and enhances the physicochemical stability and storage performance of coconut oil. Among the tested formulations, the 3% extract concentration provided the most

effective protection against oxidative deterioration and produced the longest shelf life under all storage conditions. These findings support the growing use of plant-derived antioxidants as safer, more sustainable alternatives to synthetic food preservatives.

Compared with previous studies that primarily reported the antioxidant activity of tamarind leaf extract using in vitro assays, the present study extends current knowledge by evaluating its practical performance in a lipid-based food system through simultaneous assessment of physicochemical quality parameters and Arrhenius-based shelf-life prediction. This integrated evaluation provides broader insight into the applicability of tamarind leaf extract for edible oil preservation.

CONCLUSIONS

This study demonstrated that tamarind leaf ethanol extract (*Tamarindus indica* L.) has strong potential as a natural antioxidant to improve the physicochemical stability and extend the shelf life of coconut oil. The extract exhibited moderate antioxidant activity due to the presence of flavonoids, tannins, alkaloids, and steroids, which effectively inhibited oxidative and hydrolytic deterioration during storage. Among the tested formulations, the 3% extract concentration showed the best preservation performance by reducing moisture content, peroxide value, and free fatty acid formation while increasing the saponification value and extending the predicted shelf life of coconut oil.

The findings highlight the potential application of tamarind leaf extract as an environmentally friendly natural antioxidant for edible oil preservation. This study also contributes to food chemistry and natural product research by integrating phytochemical screening, DPPH antioxidant evaluation, physicochemical quality assessment, and Arrhenius-based shelf-life prediction within a single experimental framework. However, the absence of a synthetic antioxidant control (e.g., BHT or BHA) and the moderate goodness-of-fit of the Arrhenius model indicate that the results should be interpreted within the limitations of the present study.

Future studies are recommended to include direct comparisons with commercial synthetic antioxidants, extend the DPPH concentration range to obtain an interpolated IC₅₀ value, characterize the major phenolic constituents using chromatographic techniques such as HPLC or LC–MS, and evaluate alternative formulation and shelf-life prediction approaches to further validate the practical application of tamarind leaf extract in edible oil preservation.

ACKNOWLEDGMENTS

The authors sincerely thank the leadership of Universitas Islam Negeri for their support during this research. Appreciation is also extended to all contributors and to the Chemistry Laboratory for providing the facilities and technical support necessary for this study.

REFERENCES

- Badan Standardisasi Nasional (BSN). (2013). SNI 3741:2013 Minyak Goreng. Jakarta: Badan Standardisasi Nasional.
- Badan Standardisasi Nasional (BSN). (2011). SNI 2902:2011 Minyak Goreng. Jakarta: Badan Standardisasi Nasional
- Dimzon, I. K. D., Valde, M. F., Santos, J. E. R., Garrovillas, M. J., Dejarne, H. M., Remollo,

- J. M. W., & Dayrit, F. M. (2011). *Physico-Chemical and Microbiological Parameters in the Deterioration of Virgin Coconut Oil*. 140(1), 89–103. <https://archium.ateneo.edu/cgi/viewcontent.cgi?article=1147&context=chemistry-faculty-pubs>
- Din, S. U., Khan, Z., Hussain, E., Waqas, M., Talha, M., & Fayaz, S. (2024). *Qualitative evaluation of phytochemicals in tamarix aphylla: a preliminary investigation*. 2(1 (Life)), 81–87. <https://doi.org/10.71000/adl5e3>
- Garba, Y., Bello, N. U., Bashir, M., & Mohammed, S. Y. (2023). *In vitro and in vivo analysis of the antioxidant potentials of methanolic extract of Tamarindus indica leaves*. 38(3). <https://doi.org/10.4314/njbmb.v38i3.1>
- Gunstone, F. D. (1984). Reaction of oxygen and unsaturated fatty acids. *Journal of the American Oil Chemists' Society*, 61(2), 441–447. <https://doi.org/10.1007/BF02678811>
- Hasany, M. R., Afrianto, E., & Pratama, I. (2017). *Pendugaan Umur Simpan Menggunakan Metode Accelerated Shelf Life Test (Aslt) Model Arrhenius Pada Fruit Nori*. VIII(1), 48–55.
- Husain, P., Risfianty, D. K., Ihwan, K., Atika, B. N. D., & Ihsan, Muhammad SohibulDewi, I. R. (2022). *identifikasi kandungan.pdf. Jurnal Inovasi Pendidikan Dan Sains*, 3(2), 78–82.
- Ibsch, R. B. M., Reiter, M. G. R., Bertoli, S. L., & de Souza, C. K. (2020). Study of pure and combined antioxidants for replacing TBHQ in soybean oil packed in pet bottles. *Journal of Food Science and Technology-Mysore*, 57(3), 821–831. <https://doi.org/10.1007/S13197-019-04112-X>
- Indonesia, S. N., & Nasional, B. S. (2013). *Minyak goreng*.
- Jusman, J., & Syamsuddin, S. (2025). *Oxidative Stability and Shelf-Life Estimation of Virgin and Refined Coconut Oils during Storage: A Comparative Approach*. 745–759. <https://doi.org/10.63680/hbhlpo982s3uj>
- Kartikawati, E., Deswati, D. A., & Pramudita, B. (2021). Uji Efek Analgetik Ekstrak Etanol Daun Asam Jawa (*Tamarindus indica* L) pada Mencit Putih Jantan Galur Swiss Webster. *Jurnal Sabdariffarma*, 9(1), 11–18.
- Kerem, Z., Chetrit, D., Shoseyov, O., & Regev-Shoshani, G. (2006). Protection of Lipids from Oxidation by Epicatechin, trans-Resveratrol, and Gallic and Caffeic Acids in Intestinal Model Systems. *Journal of Agricultural and Food Chemistry*, 54(26), 10288–10293. <https://doi.org/10.1021/JF0621828>
- Kiromah, N. W., Husain, S., & Rahayu, T. P. (2021). *Uji Aktivitas Antioksidan Ekstrak Etanol Daun Ganitri (Elaeocarpus Ganitrus Roxb.) dengan Metode DPPH (2, 2 Difenil-1-Pikrilhidrazil) Antioxidant Activity Test of Ganitri (Elaeocarpus Ganitrus Roxb.) Leaf Ethanol Extract Using the DPPH (2, 2 Difen*. 18(1), 60–67.
- Lourençon, T. V., Altgen, M., Pääkkönen, T., Guccini, V., Penttilä, P. A., Kontturi, E., & Rautkari, L. (2022). Effect of Moisture on Polymer Deconstruction in HCl Gas Hydrolysis of Wood. *ACS Omega*, 7(8), 7074–7083. <https://doi.org/10.1021/acsomega.1c06773>
- Machado, M., Rodriguez-Alcala, L. M., Gomes, A. M., & Pindtado, M. (2023). Vegetable oils oxidation: mechanisms, consequences and protective strategies. *Food Reviews International*, 39(7), 4180–4197. <https://doi.org/10.1080/87559129.2022.2026378>
- Megawati, Sukmawati, & Aminah. (2021). *Uji Aktivitas Antioksidan Fraksi Etil Asetat Daun Asam Jawa (Tamarindus Indica L) Dengan Metode DPPH(1,1 Diphenyl-2-Picrylhydrazil)*. 02(02), 95–102.

- Momuat, L. I., Wuntu, A., Hatidja, D., Runtu, M., & Lengkong, V. (2009). Kualitas Minyak Kelapa dengan Penambahan Ekstrak Tomat pada Beberapa Waktu Penyimpanana dan Suhu Pemanasan. *Jurnal Ilmiah Sains*, 9(1).
- Mukherjee, D., Deb, J., Deb, N. K., Saha, S., & Chakraborty, S. (2024). Ethnopharmacological, Phytochemical and Pharmacological Review on *Tamarindus indica* L. *Journal of Pharmacognosy and Phytochemistry*, 13(1), 120–126. <https://doi.org/10.22271/phyto.2024.v13.i1b.14820>
- Nurhayati, G. S., Indriatmoko, D. D., Kristiadi, E. W., & Fitriani, A. (2022). *Chimica et Natura Acta Antioxidant Activity of Nutmeg Mace (Myristica fragrans) Graded Extract*. 10(1), 1–5.
- Rejeki, D. P. (2018). *Lantanida Journal*. 6(2), 103–202.
- Ruseva, N., Bakalova, A., Cherneva, E., Ruseva, N., Bakalova, A., & Cherneva, E. (2025). Functional groups and structural features of antioxidants: a review. *Journal of Chemical Technology and Metallurgy*, 60(6), 881–912. <https://doi.org/10.59957/jctm.v60.i6.2025.1>
- Sarungallo, Z. L., Santoso, B., Letsoin, Y. Y. D., & Epriliati, I. (2023). Deterioration Kinetics Of Neutralized Red Fruit (*Pandanus conoideus* L.) Oil During Storage. *Jurnal Teknologi*, 85(5), 103–112. <https://doi.org/10.11113/jurnalteknologi.v85.19526>
- Senduk, T. W., Montolalu, L. A. D. Y., Dotulong, V., Ratulangi, S., Ratulangi, U. S., & Bahu, K. U. (2020). *Rendemen Ekstrak Air Rebusan Daun Tua Mangrove Sonneratia alba (The rendement of boiled water extract of mature leaves of mangrove Sonneratia alba)*. 11(1), 9–15.
- Shaaban, H. A. (2023). Natural Antioxidants from Herbs and Spices and their effects for Improving the Functionality and Shelf Life of food and Dairy products: A Review. *Journal of Multidisciplinary Research*, 3(1), 6–23. <https://doi.org/10.37022/tjmdr.v3i1.430>
- Silalahi, M., Biologi, P. P., & Indonesia, U. K. (2020). *Bioaktivitas Asam Jawa (Tamarindus indica) dan Pemanfaatannya*. 7(2), 85–91.
- Song, X., Sui, X., & Jiang, L. (2023). Protection Function and Mechanism of Rosemary (*Rosmarinus officinalis* L.) Extract on the Thermal Oxidative Stability of Vegetable Oils. *Foods*, 12(11), 2177. <https://doi.org/10.3390/foods12112177>
- Susanti, I. (2016). *Karakterisasi dan Pendugaan Daya Tahan Simpan Bio Oil (Minyak Alpukat dan Minyak Buah Merah)*. 33(2), 57–65.
- Tape, J. S., Houphouet, K. R., Kadjo, A. C., Yao, K., Kedjebo, K. B. D., Koné, K. M., Guehi, T. S., & Montet, D. (2023). Free Fatty Acids and Cocoa Butter Quality Traits: Causes and Impact on Consumers' Health. *Journal of Advances in Microbiology*, 23(3), 21–32. <https://doi.org/10.9734/jamb/2023/v23i3713>
- Tunny, R. T., Mahulauw, M. A. H., & Darmanta, K. (2020). *Identifikasi Kandungan Senyawa Fitokimia dan Uji Aktivitas Antioksidan Ekstrak Metanol Daun Asam Jawa (. 10(2), 1–5*.
- Villarruel, E. M. O., de Carvalho Filho, J. F. S., Garcia, M. A. S., de Almeida, J. M. A. R., Aranda, D. A. G., & Romano, P. N. (2023). Maintaining high-triglyceride content and reducing free fatty acids in distillers corn oil: A catalyst-free multivariate strategy. *Journal of the American Oil Chemists' Society*. <https://doi.org/10.1002/aocs.12802>
- Xue, S. (2023). *Effects of natural antioxidants on oxidation stability and application in food*. 12789, 127891L. <https://doi.org/10.1117/12.3000134>
- Yunita, E., & Khodijah, Z. (2020). Pengaruh Konsentrasi Pelarut Etanol saat Maserasi

terhadap Kadar Kuersetin Ekstrak Daun Asam Jawa (*Tamarindus indica* L.) secara. *PHARMACY: Jurnal Farmasi Indonesia (Pharmaceutical Journal of Indonesia)*, 17(02), 273–280.

Zahid, M., Khalid, S., Raana, S., Amin, S., Javaid, H., Arshad, R., & Jahangeer, A. (2024). Unveiling the anti-oxidative potential of fruits and vegetables waste in prolonging the shelf stability of vegetable oils. *Future Foods*. <https://doi.org/10.1016/j.fufo.2024.100328>