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Evaluation of Antioxidant Activity and Optimization of Cookie Shelf Life Prediction with Durian Peel Flour Substitution

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Abstract

Antioxidants are essential elements in scavenging free radicals and are found in many foods. Incorporating fiber-rich durian inner skin flour into cookies not only boosts the fiber content but also introduces antioxidant compounds, which may influence the product's shelf life due to changes in chemical stability. Therefore, this study aimed to determine the antioxidant activity and shelf life of cookies. A randomized block design was adopted, and antioxidants were analyzed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method. The shelf life was estimated using the Accelerated Shelf-Life Testing (ASLT) method with the Arrhenius model during a 28-day storage period based on water content. The results showed that the antioxidant activity of cookies substituted with durian peel flour had IC_{50} values of 36.59 and 36.71 ppm, respectively, indicating a very strong antioxidant effect (IC_{50} < 50 ppm). Furthermore, the shelf life decreased with increasing storage temperature, namely, 26 days at 25 °C, 24 days at 35 °C, and 21 days at 45 °C. In conclusion, the substitution of durian peel flour increased antioxidant activity without significantly affecting shelf life.

Keywords: bioactive compounds; food preservation; functional ingredients; natural antioxidants; thermal degradation

INTRODUCTION

The antioxidant is a compound capable of decreasing the reactivity of free radicals by donating an electron (Nasution et al., 2018). This compound consists of complex molecules, such as superoxide dismutase, catalase, and peroxiredoxin, as well as simpler compounds, including glutathione, vitamins (A, C, E, and β-carotene), flavonoids, albumin, bilirubin, and ceruloplasmin. A non-enzymatic antioxidant originates from both nutritional and non-nutritional sources. It is typically found in dietary sources, including vegetables, fruits, whole grains, and legumes (Hasanuddin et al., 2023). The antioxidant activity of food has garnered growing interest due to its potential in scavenging free radicals, thereby preventing cellular damage and the onset of various degenerative disorders (Wiyono et al., 2023).

Growing public awareness of health-promoting compounds has driven the rapid development of functional foods enriched with antioxidants, particularly through the use of natural ingredients rich in flavonoids and polyphenols (Adawiah et al., 2015). Cookies are popular snack food products enjoyed by people of all ages. However, this product is generally low in dietary fiber and high in calories (Nopriantini et al., 2023). According to a previous study, excessive consumption may lead to health issues, such as constipation (Nugraheni et al., 2017).

An innovative strategy to improve the dietary fiber content in cookies involves substituting

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wheat with durian albedo flour, which is rich in fiber, flavonoids, and various other bioactive constituents (Fuadah et al., 2022). Durian albedo comprises 18.50% starch, 19.40% crude fiber, and different functional compounds, offering potential for improving nutritional profile (Husni et al., 2021). Muhtadi (2019) reported that ethanol extract of durian peel had a total phenolic content (TPC) of 245.33 mg GAE g^{-1} and total flavonoid content (TFC) of 148.60 mg QE g^{-1}, with IC_{50} values of 78.83 µg ml^{-1} (Medan variety) and 72.77 µg ml^{-1} (Monthong variety) based on the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, indicating strong free radical scavenging capacity. Cookies serve as an ideal matrix for substitution due to their independence from gluten and fermentation, allowing for greater flexibility in the addition of alternative ingredients (Affandi and Ferdiansyah, 2017). However, the high fiber content affects the quality and shelf life of cookies due to its hygroscopic nature, which may lead to changes in texture and aroma, as well as an increase in moisture content (Wijaya et al., 2022). An elevated moisture content can also accelerate microbial growth and reduce the crispness and general quality of the product (Asiah et al., 2018).

In this study, antioxidant activity testing was conducted using the DPPH method to assess the capacity of the samples by measuring their ability to scavenge the free radical compound DPPH (Laksono et al., 2023). Furthermore, to maintain product quality and safety during storage, the shelf life was estimated using the Accelerated Shelf-Life Testing (ASLT) method, which employs the Arrhenius model. The effect of temperature on the rate of quality degradation is quantified (Surahman et al., 2020). Higher storage temperatures increase chemical reactions, thereby shortening shelf life (Simanjuntak et al., 2016).

In addition to temperature, moisture content, and water activity, these parameters are essential due to their direct impact on product quality and safety (Setiaboma et al., 2020). Shelf life information is crucial for producers, consumers, and distributors to ensure product quality, safety, and efficient distribution (Warsiki, 2018). A study by Adi et al. (2016) showed that dried snake gourd (*Trichosanthes anguina* L.) candy sweetened with sorbitol experienced declines in antioxidant activity, sensory quality, and moisture content over 28 days of storage. The antioxidant activity drastically decreased from 28.26 to 1–2%, while moisture content dropped from 19.26 to approximately 9–12%. Shelf life estimation using the ASLT method with the Arrhenius model showed that the quality of the dried snake gourd candy deteriorated over time and was influenced by storage temperature.

Previous studies have demonstrated that durian (*Durio zibethinus*) pulp, seed, and peel flours are rich in bioactive compounds, including phenolics and flavonoids, that confer considerable antioxidant and anti-inflammatory properties. For example, flour extracts from unripe pulp, inner peel, and seed were found to exhibit strong antioxidant capacity in ABTS, nitric oxide, superoxide, and hydroxyl radical assays (Charoenphun and Klangbud, 2022). Some research has been conducted on substituting wheat flour with durian seed flour in cookies to enhance nutritional value and sensory acceptance (Insani and Dhama, 2020).

There is also research on durian peel flour being used in gluten-free biscuits, evaluating the physical, technological, and nutritional perspectives of high substitution levels. However, critical gaps remain unaddressed: very few studies have combined the substitution of inner durian peel flour in cookies with the measurement of antioxidant activity of the resultant cookie product and employed ASLT using the Arrhenius model to estimate shelf life. Most prior research has focused separately on the antioxidant capacity of extracts or on proximate, fiber, or sensory attributes of substituted cookies. There is limited evidence on how antioxidant properties change during storage under different temperature regimes, or on how these relate to shelf life predictions.

Therefore, the novelty of this current study lies in using inner durian peel flour as a substitute for wheat flour in cookies, evaluating not only sensory and nutritional quality but also specifically measuring the antioxidant activity of the baked cookies, and estimating shelf life through ASLT using the Arrhenius model. This combination provides a more comprehensive insight into both functional attributes and stability over time, filling gaps in both scientific understanding and practical usability of durian peel-substituted cookies. Therefore, this study aimed to evaluate the antioxidant activity and shelf life of cookies stored at temperatures of 25, 35, and 45 °C.

MATERIALS AND METHOD

Materials

The materials used in this study included 10 g of durian inner skin flour obtained from ripe local durian fruit (*Durio zibethinus*), medium protein wheat flour from 'Segitiga Biru' (Bogasari, Indonesia), granulated sugar from 'Gulaku' (Sugar Group Companies, Indonesia), palm sugar from 'Edna' (Edna Gula Palem, Indonesia), and margarine from 'Palmia' (Salim Ivomas Pratama Tbk, Indonesia). Other materials included fresh chicken eggs, butter, choco chips from 'Lagie' (Fajar Mataram Sedayu Tbk, Indonesia), and baking powder from 'Koepoe-Koepoe' (Gunacipta Multirasa, Indonesia). The inner durian skin used was the white part, separated from the outer layer of thorns, and washed clean. The durian peel albedo was then oven-dried at 60 °C for 10 hours until completely dry, after which it was cooled to room temperature and milled into flour using a blender. All ingredients were of food-grade quality and were in a condition suitable for consumption, with no signs of damage (Annisa, 2024).

Making durian peel flour

The process of making durian peel flour begins by separating the white inner part of the durian peel from the outer part. The inner peel is then thoroughly washed to remove any impurities. After cleaning, the inner peel is thinly sliced to facilitate the drying process. The slices are arranged on trays and dried in an oven at 60 °C for 10 hours, until they are dehydrated, then cooled to room temperature. Once dried, the durian peel is ground into a fine powder using a blender. The final step involves sieving the powder through an 80-mesh sieve to obtain durian peel flour with a uniform particle size (Rahmiwati and Az-Zahra, 2025).

Production of cookies by substituting the inner durian peel flour

The production of cookies with durian peel flour substitution commenced by mixing granulated sugar (40 g), palm sugar (30 g), butter (20 g), and margarine using a high-speed mixer until a homogeneous mixture was achieved. Eggs (55 g) were added, mixed thoroughly, and the dry ingredients, consisting of wheat flour (90 g), durian peel flour (10 g), and baking soda (1 g), were incorporated into the mixture and blended until a uniform consistency was achieved. Choco chips (15 g) were added as an additional ingredient, and the dough was shaped into balls, each weighing approximately 25 g, and arranged on a baking tray lined with parchment paper. The baking process was carried out at 180 °C for 10 minutes. The final product obtained was cookies with durian peel flour as a substitute (Annisa, 2024).

Water content analysis

In moisture content analysis, the materials used included an analytical balance, petri dishes, a spatula, a porcelain mortar, tongs, a desiccator, and an oven. The water content was analyzed using thermogravimetric analysis (TGA), a thermal method that measures changes in sample mass over time and temperature. This procedure follows the AOAC (2005) method as well as the approach described by Ahn et al. (2014), who compared oven-drying methods for moisture determination. The analysis involved several steps, including homogenizing the sample and placing it into a dry, pre-weighed container, and then cooling it in a desiccator. The container with the sample was then weighed and subsequently dried in an oven at 100 to 105 °C for 3 to 5 hours. After drying, the container was cooled in a desiccator and weighed again. This process was repeated to achieve a constant weight, defined as a weight difference of less than 0.2 mg between subsequent measurements. The moisture content was calculated using several parameters, namely the weight of the empty container (a), the weight of the container plus sample before drying (b), the constant weight after drying (c), and sample weight ($d = b - a$). The wet and dry moisture content were calculated using Equation 1.

$$\text{Moisture content} = \frac{a + d - c \times 100}{d} \qquad (1)$$

Antioxidant analysis

DPPH, ethanol, and ascorbic acid (vitamin C) were used for antioxidant analysis. The procedure commenced with the preparation of a DPPH solution by dissolving DPPH powder in methanol. Blank solutions, including antioxidant standards such as vitamin C and quercetin, were also prepared by dissolving each powder in methanol. The absorbance of the blank was measured using a UV-visible spectrophotometer at the optimum wavelength. For sample preparation, 2 ml of each sample solution was transferred into a vial and

mixed with 2 ml of DPPH solution. The mixture was homogenized by vortexing and incubated for 30 minutes in the dark to facilitate the reaction. After incubation, the absorbance of the sample-DPPH mixture was measured at the same wavelength as the blank. Each measurement was taken in duplicate to ensure reproducibility. The percentage of DPPH radical scavenging activity was calculated using Equation 2 (Purwanto et al., 2017).

$$\% \text{ inhibition} = \frac{\text{Control absorbance - Sample absorbance}}{\text{Control absorbance}} \times 100\% \quad (2)$$

Cookie shelf life estimation method

The Arrhenius was analyzed using a linear regression model, and the calculation was performed with Microsoft Excel software using Equation 3 (Nirwana et al., 2022).

$$Y = a + bx \quad (3)$$

Where, Y = analytical value, a = intercept, b = deterioration rate constant (k), x = storage time (days).

The value of the degradation rate constant (K) was then determined using the Arrhenius formulation (Equation 4).

$$\ln K = \ln K_0 - \frac{(Ea/R)}{(1/T)} \quad (4)$$

Where, K = degradation rate constant (% per day), ln k_0 = constant (temperature-independent), Ea/R = slope, Ea = activation energy, R = ideal gas constant (1.986 cal mol·K^{-1}).

The reaction rate model in relation to temperature is determined using Equation 5.

$$K = k0.e^{-Ea/RT} \quad (5)$$

Suppose the rate of quality degradation (K) in the cookies is already known. In that case, the shelf life of cookies with the substitution of inner durian rind flour can then be calculated using Equations 6 and 7.

$$t \text{ zero order} = \frac{A0-At}{K} \quad (6)$$

$$t \text{ first order} = \frac{\ln (A0-At)}{K} \quad (7)$$

Where, t = predicted shelf life (days), At = critical moisture content (%), A0 = initial moisture content (%), K = degradation rate constant (% per day).

Data analysis

A one-way ANOVA test was used to observe the differences in the average shelf life of cookie products between temperatures. Statistical significance was set at a *p*-value of 0.05.

RESULTS AND DISCUSSION

Antioxidant activity test

In the antioxidant test analysis, only one test was carried out, in which the antioxidant activity of a substance was expressed through its IC_{50} value obtained from testing (Purwanto et al., 2017), where the IC_{50} indicated the concentration (ppm) required to inhibit 50% of free radicals, a lower IC_{50} value signifying a stronger free radical scavenging ability (Prasetyo et al., 2021). Table 1 presents the results of the antioxidant activity test on cookies with durian peel flour as a substitute.

The comparison between B1 and B2 allowed the evaluation of the effect of different storage temperatures on the antioxidant activity of cookies substituted with inner durian peel flour. This coding system was applied to simplify the presentation and interpretation of data. The antioxidant activity in this study was classified as high with an IC_{50} value category of < 50 ppm (very strong). These results are consistent with those of Tran et al. (2024), who reported very strong antioxidant activity in durian peel extracts with a DPPH IC_{50} of 38.7 µg ml^{-1}, indicating that bioactive compounds from durian peel are heat-stable. The addition of durian peel flour to cookies affected the antioxidant content due to its high antioxidants, with an IC_{50} value of 38.33±0.12 ppm (Kunarto and Sani, 2018).

The addition of durian peel flour contributed to an increase in the fiber and bioactive compounds of cookies, which directly influenced antioxidant activity. The inner part of durian

Table 1. Antioxidant activity results

Code	Antioxidant IC_{50} (ppm)
B1	36.59
B2	36.71

Note: > 200 ppm = Very weak; 150 to 200 ppm = Weak; 100 to 150 ppm = Moderate, 50 to 100 ppm = Strong; < 50 ppm = Very strong (Nasution et al., 2015). B1 = Cookie at 25 °C; B2 = Cookies at 35 °C

peel extract (mesocarp and endocarp) contained a high concentration of bioactive compounds with significant antioxidant activity. A study by Noorhashim et al. (2025) reported that the endocarp of the Durian Kampung variety contained a TPC of 6.261 mg GAE g^{-1} and flavonoids of 32.30 mg QE g^{-1}, with vigorous antioxidant activity shown by a DPPH IC_{50} value of 39.5 µg ml^{-1}. Furthermore, fluorescence recovery after photobleaching (FRAP) analysis revealed a ferric reducing activity of 1,965 µM TE g^{-1}, indicating a high antioxidant capacity. Another study by Tran et al. (2024) optimized the extraction of flavonoids from durian peel, yielding fractions with a flavonoid content of 271 mg QE g^{-1}. These extracts showed vigorous antioxidant activity (DPPH IC_{50} = 38.7 µg ml^{-1}; FRAP IC_{50} = vitamin C of 307.9 µg g^{-1}), with quercetin identified as the dominant compound. Strong negative correlations were observed between TPC and IC_{50} (r = -0.964), as well as between TFC and IC_{50} (r = -0.939), confirming that these compounds are the primary contributors to antioxidant efficacy. Therefore, the inner durian peel had great potential as a functional compound source for use in functional food formulations or nutraceutical supplements.

Conventional cookies typically lack fiber and antioxidants, offering minimal protection against oxidative stress. Adding inner durian peel flour enhances both the fiber content and antioxidant capacity, thereby improving the functional value. The fiber content of durian peel was also known to bind free radicals, acting as a protective matrix for other bioactive compounds and maintaining stability during the baking process.

The results of this study showed that substituting wheat flour with durian peel flour in cookies produced very high antioxidant activity. Based on general classification, these IC_{50} values fell into the firm category (IC_{50} < 50 ppm), indicating that the cookie formulation had a high ability to scavenge free radicals even after undergoing thermal processing. The stability of the antioxidant activity suggests that the bioactive compounds in durian peel flour, including polyphenols and flavonoids, are resistant to heat degradation. In some cases, effectiveness may even increase due to the release of bound compounds and the formation of antioxidant Maillard reaction products such as melanoidins. This result was consistent with the report of Mahloko et al. (2019), who formulated biscuits by adding 4% banana peel flour and prickly pear. The study reported an increase in TPC to 11.81 mg GAE g^{-1} and flavonoids to 33.74 mg QE g^{-1}; however, the antioxidant activity of the final product was still considered low in absolute terms, with DPPH inhibition and FRAP values of 9.69% and 0.71 mg g^{-1}, respectively. Despite the increased phenolic and flavonoid content, the low antioxidant activity in the biscuits was due to the low substitution level (4%), the instability of bioactive compounds to heat, and the interaction of phenolic compounds with the food matrix during baking. Additionally, the specific chemical characteristics of the phenolic compounds used could affect the effectiveness in scavenging free radicals. This implies that an increase in bioactive content does not always directly correlate with the antioxidant capacity of the final product.

Shelf life determination

Moisture content is a crucial physical parameter that significantly impacts the quality and shelf life of cookies. Table 2 presents the changes in moisture content of cookies stored at various temperatures (25, 35, and 45 °C) over a period of 5 weeks. Measurements were taken at weekly intervals using the thermogravimetric method. The results showed fluctuating patterns at all temperatures, with both increases and decreases in moisture content observed across the storage period.

Based on the analysis, moisture content varied over time, showing both increases and decreases.

Table 2. Moisture content observation of cookies from the selected formulation

Length of storage (Day)	Moisture content		
	25 °C	35 °C	45 °C
0	8.67±0.10	7.84±0.32	7.50±1.21
7	8.61±0.29	7.80±0.82	7.83±1.87
14	8.49±0.54	7.78±1.23	7.91±2.26
21	8.45±0.99	7.84±1.63	7.89±2.74
28	8.91±0.88	8.07±1.64	7.15±2.76

These changes were influenced by storage temperature and ambient humidity. As the storage period lengthens, moisture content generally rises (Solihin et al., 2015). Moisture levels fluctuated in all storage conditions, which is influenced by temperature, humidity, and interactions between cookies and their packaging. To maintain moisture stability, use airtight packaging, maintain stable temperatures, and consider the type and composition of the cookies (Muhandri et al., 2018). Higher storage temperatures caused the moisture content to fluctuate more, likely because a manually controlled electric oven produced unstable and inconsistent heat. This inconsistent heat hurt the storage environment and significantly impacted the cookies' moisture (Simanjuntak et al., 2016).

In general, the changes in moisture content tended to be more volatile at 35 and 45 °C, suggesting that higher storage temperatures could intensify water migration due to increased molecular mobility and evaporation rates. Similar results were reported by Heryani et al. (2020), who observed moisture reduction in high-temperature storage conditions due to hydrogen bond disruption in starch–protein matrices. However, the moisture content of cookies at 25 °C showed a general increasing trend. According to Setiaboma et al. (2020), cookies stored at room temperature with high ambient humidity tend to absorb water vapor, particularly through microcracks or porous surfaces, leading to texture softening and increased water content. The observed moisture content data were plotted into zero-order and first-order kinetic models to determine which best estimated cookies' shelf life. The rate of moisture content change in zero-order and first-order kinetics was shown in Figures 1 and 2, respectively.

Kinetic modeling was applied to better understand changes in moisture content and their implications for shelf life. Zero-order and first-order models were used to evaluate the rate of change. Table 3 shows the coefficient of determination (R^2) values for both models at each storage temperature.

Based on the results in Table 3, the zero-order kinetic model showed a better fit than the first-order model at all storage temperatures, particularly at 25 °C (R^2 = 0.7807). At higher temperatures, the R^2 values decreased slightly, with 0.1377 at 35 °C and 0.001 at 45 °C, indicating that increasing the storage temperature reduced the linearity of the model and accelerated moisture changes. Therefore, zero-order kinetics was selected to model the changes in moisture content in this study. These results were consistent with a previous report by Solihin et al. (2015), which found that zero-order models were often suitable for describing moisture gain in packaged foods during storage under ambient conditions. The rate constants (K) derived from the zero-order model were then transformed into natural logarithms (ln K) and plotted against reciprocal temperature (1/T in Kelvin^{-1}) to generate an Arrhenius plot (Figure 3).

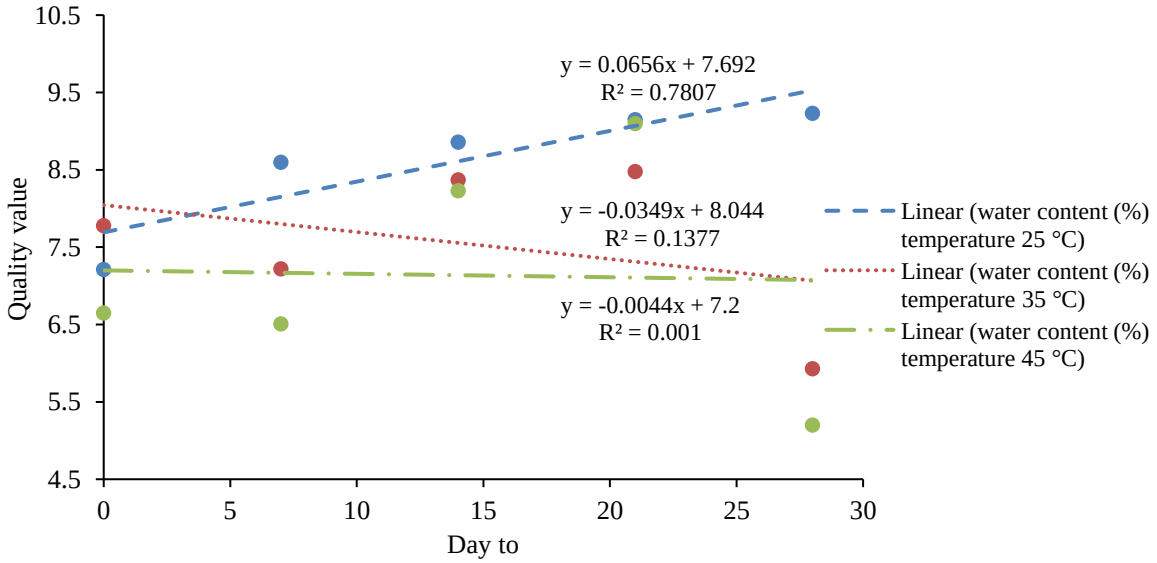

Figure 1. Zero-order kinetics of moisture content change

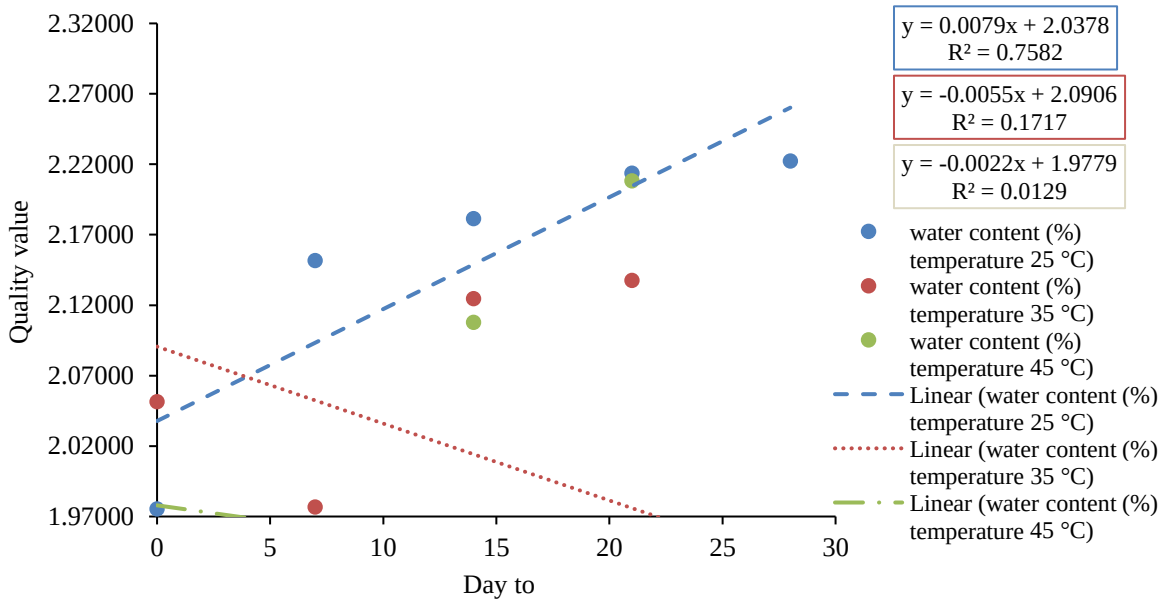

Figure 2. First-order kinetics of moisture content change

The zero-order kinetic model was selected as it provided the highest R^2 values across all storage temperatures, showing the best fit for describing the linear changes in moisture content over time. This result was consistent with the suggestion of Anggraini et al. (2019) that zero-order models were appropriate for systems with a constant rate of quality degradation. The graph showing the relationship between ln K and 1/T for moisture content yielded a linear regression equation of $y = 12{,}724x - 45.177$, with an R^2 of 0.9027. This equation was then applied to calculate ln K_o, Ea/R, and the activation energy (Ea). The calculated Ea value of 25,262.39 cal mol^{-1} showed moderate sensitivity of moisture content to temperature. This suggested that changes in moisture were not only caused by evaporation but also resulted from the release of bound water within the food matrix, consistent with results from other low-moisture products. Subsequently, the quality degradation constant (K) was derived from the values of ln K and Ea/R, and incorporated into the Arrhenius equation to estimate the shelf life of cookies at each storage temperature. These results further support the applicability of the Arrhenius kinetic method for shelf-life prediction. However, the accuracy of the model could be enhanced by incorporating other factors, such as water activity and relative humidity inside the packaging. Table 4 shows the results of the shelf life estimation based on moisture content.

At 25, 35, and 45 °C, the cookies had shelf lives of 26, 24, and 21 days, respectively. The moisture content data clearly showed that higher storage temperatures accelerate quality deterioration, shortening shelf life. At low or room temperature, moisture content tended to rise due to faster respiration and increased evaporation (Murtiwulandari et al., 2020). Specifically, at room temperature, the moisture content in cookies can increase due to high ambient humidity (Setiaboma et al., 2020). Water vapor from the air can enter cookies through pores or cracks, making them softer and increasing their moisture content (Rutkowska et al., 2023).

Additionally, a relatively stable or slightly increased moisture content at room temperature can slow down certain chemical reactions, such as lipid oxidation, which typically occur faster under dry and high-temperature conditions (Sirait and Nasution, 2024). High ambient humidity reduced

Table 3. The R^2 values of moisture content

Temperature (°C)	R^2 value	
	Zero-order	First-order
25	0.7807	0.7582
35	0.1377	0.1717
45	0.0010	0.0129

Table 4. Shelf life estimation results

Temperature (°C)	Constant of quality degradation (K)	Shelf life (Day)
25	11.93	26.93
35	0.86	24.42
45	2.47	21.80

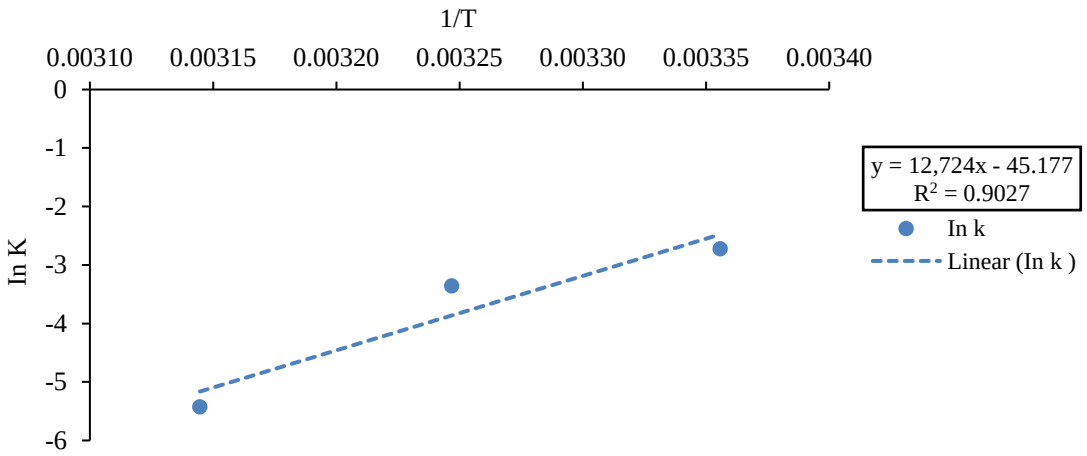

Figure 3. Graph of the relationship between In K and 1/T for moisture content

the quality of the cookie texture. However, in some cases, increased moisture extended shelf life, provided the levels remained below the threshold that triggered microbial growth or physical degradation (Hidayah et al., 2023). At high temperatures, the product's moisture content decreased more rapidly. This was caused by increased evaporation rates of water from the product as well as the release of bound water due to the disruption of hydrogen bonds in cookie components, such as proteins and starches (Heryani et al., 2020). Cookies, being low-moisture, porous products, were highly susceptible to moisture loss, particularly under high-temperature storage conditions. Therefore, storage at high temperatures resulted in a lower moisture content, thereby increasing the risk of damage and shortening the shelf life (Asgar, 2017).

A study predicted a shelf life of 26 days at 25 °C, 24 days at 35 °C, and 21 days at 45 °C for cookies using the Arrhenius model and ASLT. Water content was the main predictor of physical quality changes. High water content caused hydrolysis, oxidation, and textural changes, resulting in faster quality deterioration and a loss of crispness (Jakubczyk et al., 2008). This result was consistent with a previous study by Anggraini et al. (2019), who reported shelf lives of 134.81, 79.18, and 59.14 days at 25, 37, and 45 °C, respectively, using the Arrhenius model. This longer shelf life was due to a lower initial water content and raw materials with different hygroscopic properties. The food matrix structure of the fiber and starch combination in millet provided superior physicochemical stability against changes in storage temperature (Eshteiwy, 2025).

The results of the one-way ANOVA test on the shelf life of cookies with durian peel flour substitution indicated that the data passed the normality and homogeneity tests with *p*-values greater than 0.05. The test yielded a significance score of 0.458 (Table 5), which is greater than 0.05. Therefore, there was no significant difference in the shelf life of cookies with durian peel flour substitution stored at 25, 35, and 45 °C. These findings align with the work of Shafi et al. (2022), who reported that cookies formulated with banana peel flour substitution also exhibited stable storage properties, with no significant differences observed across various storage temperatures.

In addition, the study by Mailoa et al. (2024) reported that the substitution of durian seed flour improved the protein and ash content while reducing the moisture content of cookies; however, this study did not thoroughly evaluate changes in shelf life across different storage temperatures. Although the statistical analysis revealed no significant difference among the storage temperatures, the conclusion highlights 25 °C as the preferred condition, as cookies stored at this temperature exhibited the longest shelf life. In other words, while the overall moisture changes were not statistically different, the practical implication is that storage at 25 °C is more favorable for maintaining product quality over time, making it the most relevant recommendation for real storage conditions.

From this comparison, it can be concluded that the findings of the present study are consistent

Table 5. One-way ANOVA test result on the shelf life of cookies with durian peel flour

Parameter	Df	Means±SD	F-value	Sign.
Shelf life	2	27.583±5.88	0.710	0.458

with previous literature: functional ingredients derived from durian (both peel and seed) tend to provide good quality stability even when storage temperature increases. Although the statistical analysis did not reveal significant differences in temperatures, storage at 25 °C remains the best option, as it provides the most extended shelf life and represents practical storage conditions.

CONCLUSIONS

The antioxidant activity of cookies with inner durian peel flour substitution shows IC_{50} values of 36.59 and 36.71 ppm, which are categorized as very strong. The analysis also indicates that the shelf life of cookies at 25, 35, and 45 °C is 26, 24, and 21 days, respectively. This result indicates that storage temperature affects shelf life, with higher storage temperatures resulting in shorter cookie shelf lives. Therefore, it is recommended to store cookies at a temperature of 25 °C to maintain quality and a longer shelf life.

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