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Shelf-life prediction of smoked catfish coated with chitosan and red galangal extract

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Abstract

This research aimed to estimate the shelf-life of smoked shark catfish coated with chitosan and red galangal extract and packed with aluminum foil using the acceleration method. The prediction of the smoked catfish shelf-life was carried out by storing the smoked catfish at temperatures of 35, 45, and 55 °C for 30 days. The parameters observed during storage were color, sensory score of rancidity, and thiobarbituric acid (TBA) value. Data were analyzed using linear regression, and the equations obtained were used to calculate the shelf-life of smoked catfish at 30 °C. The color values of L*, a*, and b* of the smoked catfish coated with chitosan decreased faster, and the shelf-life was shorter than that of the smoked catfish coated with chitosan and red galangal extract. The shelf-life and activation energy of smoked catfish coated with chitosan at 30 °C were 29.63 days and 2873.146 cal/mol, while the smoked catfish coated with chitosan and red galangal extract were 38.52 days and 3380.371 cal/mol, respectively.

Keywords: Acceleration method; Rancidity; TBA value; Chitosan; Red galangal extract; Edible coating; Smoked catfish.

Highlights

- Smoked catfish experienced color loss and an increase in rancidity during storage
- Edible coating delayed color decline and rancidity on smoked catfish during storage
- Shelf-life of smoked catfish coated with chitosan and red galangal extract was longer than that of chitosan

1 Introduction

Shark catfish (*Pangasius hypophthalmus*) is a freshwater fish that is widely cultured and is the most productive aquaculture species in several nations (Sokamte et al., 2020). In Indonesia, this fish is commonly called "Patin", and the familiar processed catfish product is smoked catfish. Smoked fish is fish that is processed through the process of weeding, washing with or without soaking in a salt solution, slicing, with or without the provision of spices, and hot smoking carried out in smoking using wood, coir, or coconut shell (Badan Standardisasi Nasional, 2013). Smoking, known as one of the oldest food preservation techniques, involves subjecting fish to the action of smoke from the slow and incomplete burning of wood and produces a distinctive taste and aroma (smoky aroma and flavor). The smoking fish process goes through 2 stages, the first is to dry the water, and the second is to dry the oil. According to Ayu et al. (2019), the smoked catfish produced in Riau Province, Indonesia, had a moisture content of 32.52%, oil content of 4.35%, and peroxide value of 0.03 meq/g. The water and oil content in smoked catfish still allows for hydrolysis and oxidation reactions during storage and distribution. Although stored in frozen conditions (-20 °C), after three months, smoked *Pangasius* fillets showed a deterioration in their qualitative characteristics, which was evident from the increase in thiobarbituric acid (TBA) value and microbial counts (Mostafa et al., 2023). One of the efforts to maintain quality and overcome problems with smoked catfish is the need to apply an edible coating.

Edible film and coatings are the materials used to cover food products to increase their shelf-life by offering barriers to moisture, oxygen, temperature, and ultraviolet (UV) (Otoni et al., 2017). Their main components in edible film and coatings are biopolymers and lipids, or their mixtures. Biopolymers include proteins, of vegetal or animal origin like soybean proteins, wheat gluten, corn zein, sunflower proteins, gelatin, whey, casein, and keratin; and polysaccharides, such as cellulose derivatives, starches, alginates, pectins, chitosans, carrageenans, gums and fibers (Park et al., 2014). Moreover, different active compounds such as antimicrobials, antioxidants, color agents, flavors, and nutraceuticals are incorporated into film-forming solutions to improve the quality, stability, and safety of packed foods. Those ingredients may provide antibacterial, antifungal, or antioxidant properties of edible material (Salgado et al., 2015).

Chitosan is composed of beta1-4 linked D-glucosamine (deacetylated unit) and N-acetyl-D-glucosamine (acetylated unit), which are randomly distributed inside the polymer. Chitosan also has numerous biological activities, for instance, antimicrobial and antioxidant, because of its biodegradability, biological compatibility, antimicrobial, antioxidant activity, and high safety, therefore chitosan could be used in a large number of applications (Abd El-Hack et al., 2020). Coatings and films made from chitosan are selectively permeable to gases (O_2 and CO_2) and have excellent mechanical properties. Since chitosan-based films and coatings have a high permeability to water vapor, which limits their use in moist environments, the control of moisture transfer is a desired trait. Several studies demonstrated an increase in the effectiveness of chitosan when incorporated with essential oils (Nair et al., 2020).

Red galangal (*Alpinia purpurata* K. Schum) contains phenolic compounds and flavonoids that are a natural source of antioxidants (Azzahra et al., 2013). Phytochemical analyses indicated that galangal contains various compounds that make it a super ingredient for food, culinary, medicine, and cosmetic applications. The main phytochemicals in galangal rhizome are phenolic compounds, polyphenols, flavonoids, saponins, phenylpropanoids, glycosides, diarylheptanoids, sesquiterpenes, and diterpenes (Das et al., 2020). Recent studies on the application of galangal as a preservative and functional ingredient in meat (Juntachote et al., 2007), biscuits (Klunklin & Savage, 2018), and sausages (Półtorak et al., 2019) demonstrated that galangal delays lipid oxidation and extends the shelf-life of foods (Das et al., 2020). According to Utami et al. (2013), the addition of essential oils in edible coating can maintain the quality of catfish fillets better than edible coating treatment without essential oils. Research by Azzahra et al. (2013) regarding the addition of 1% red galangal essential oil to catfish fillets showed that it was more stable for pH value, color values of a*, and b* compared to 0% and 0.1%. The use of edible coating chitosan with the addition of red ginger and red galangal extract can extend the self-life of the smoked catfish longer than the red ginger extract (Efendi et al., 2023). The shelf-life of the smoked catfish coated with edible coating chitosan and red ginger was 32.90 days at 30 °C while the smoked catfish coated with edible coating chitosan, red ginger, and red galangal extract was 37.10 days (Efendi et al., 2023).

Shelf-life is one of the most important types of information because it is related to the safety of food products. Determination of the shelf-life of food products can be done by *extended storage studies* (ESS) and *accelerated shelf-life testing* (ASLT) methods. The ESS method is the determination of the expiration date by storing the product in actual storage conditions and this method requires a long time and large costs. The ASLT method commonly known as the acceleration method requires a relatively short testing time and little quality parameter analysis to save costs. The ASLT method is carried out by storing food products in an environment that causes rapid damage, *i.e.*, at high temperatures (Calligaris et al., 2019). Based on the description above, a study was conducted to estimate the shelf-life of smoked shark catfish applied by chitosan edible coating with the addition of red galangal extract using the acceleration method.

2 Materials and methods

2.1 Materials and chemicals

The materials used were commercial chitosan shrimp shells purchased from CV Sentra Teknosains Indonesia, Yogyakarta, fresh red galangal (*Alpinia purpurata* K. Schum) purchased from traditional markets in Pekanbaru, Indonesia, smoked shark catfish (*Pangasius hypophthalmus*) purchased from the local food industry at Kampar Regency, Riau Province, Indonesia; and aluminum foil (90 µm thickness) for packaging. The traditional smoking process involved placing freshly weeded and washed catfish on a shelf in a smokehouse for over 8 hours. The fish was smoked using firewood without the addition of salt or other additives. After smoking, the catfish was wrapped in black plastic packaging and transported to the laboratory for coating, packaging, and storage. The journey from the local food industry to the laboratory takes 2.5 hours by car. The chemicals used were acetic acid, reagent TBA, HCl, and ammonium thiocyanate. All chemicals were purchased from E-Merck (Darmstadt. Germany).

2.2 Extraction of red galangal extract

Red galangal rhizomes are cleaned under running water, thinly sliced, and dried at 55 °C for 8 hours. The dried red galangal was mashed using a milling blender and a fine powder was obtained. One hundred g of this sample was soaked in 300 mL of ethanol. The mixture was allowed to stand for 24 hours with occasionally stirred. The mixture was filtered to separate the extract from the residue. The filtrate was evaporated at 55 °C with a rotary vacuum evaporator until the extract was obtained.

2.3 Application of edible coating on smoked catfish

A chitosan solution of 2% was prepared by dissolving 1.5 g of chitosan powder into 30 mL of 1% acetic acid. The solution was homogenized using a magnetic stirrer at 50 °C for 60 minutes until completely dissolved. Edible coating chitosan solution (EC) and edible coating chitosan solution added 1% red galangal extract (ECR) were diluted with water until the volume was 100 mL. The coating solution was homogenized for 15 minutes. EC and ECR were then tested for antioxidant activity using 2,2-diphenyl-1-picryhydrazyl radical (DPPH) method as described by Bonilla et al. (2012).

The smoked catfish was immersed in the coating’s solution for 10 seconds. The smoked catfish was removed and dried using an oven at 35 °C for 12 h. The coated fish was packaged using vacuum aluminum foil and stored for 30 days at 35, 45, and 55 °C. The color, sensory rancidity, and TBA tests were performed on the coated fish during storage.

2.4 Colour of smoked catfish

Colour measurement of smoked catfish was using a colorimeter (NH300 portable colorimeter, 3NH, China) according to Mussi & Pereira (2022). The sample was placed in a container, then pressed the start button so that L, a*, and b* values were obtained. The notations of L*, a*, and b* values represent brightness, mixed red-green, and mixed blue-yellow chromatic colors, respectively.

2.5 Sensory test of rancidity and thiobarbituric acid values

The rancidity sensory test was performed by 10 trained panelists from students of the Department of Agricultural Technology, Riau University. The samples were placed in a clean container and randomly coded. The panelists were asked to assess the rancidity (*off-flavor*) score of the coated fish from 1 (very rancid) to 5 (not rancid).

The TBA values in smoked catfish were measured following the procedure by Ayu et al. (2022) and Efendi et al. (2021, 2023) with slight modifications. The TBA value was obtained by weighing 3 g of the sample and crushed with 50 mL water in a blender. The sample was put into a distillation flask while washing with 48.5 mL of water. A total of ±1.5 mL of HCl 4 N (one part concentrated HCL in two parts water) was added to the sample so that the pH became 1.5. The sample was distilled until 50 mL of distillate liquid was obtained for 10 minutes of heating. The distillate was homogeneously stirred, pipetted into a 5 mL test tube, added with 5 mL of TBA reagent (0.2883 g TBA/100 mL glacial acetic acid 90%), and mixed homogeneously. The sample solution was heated in boiling water for 30 minutes and cooled under running water for 10 minutes. The absorbance of the sample was measured at 528 nm with water as a blank solution.

2.6 Determination of acceptance critical limit and shelf-life calculation

The rancidity score and TBA value of the coated fish during storage were plotted to obtain a linear regression equation. The deterioration rate (k value) of the coated fish was calculated based on the linear regression between rancidity score and TBA values over storage duration. The acceptance critical limit of TBA value was determined when the panelist declared rancid (score 2) on the sensory test of rancidity.

The smoked catfish shelf-life was determined by relating k value and temperature using the Arrhenius equation (Equation 1 and 2):

$$k = k_0 e^{-(\frac{Ea}{RT})} \quad (1)$$

$$\ln k = \ln k_0 - (\frac{Ea}{R}) 1/T \quad (2)$$

Shelf-life was determined from the shortest shelf-life calculated based on the k-value equation and the acceptance critical limit of rancidity score and TBA value (Equations 3 and 4).

$$\text{Shelf-life of order 0: } t = \frac{A_0 - A_t}{k} \quad (3)$$

$$\text{Shelf-life of order 1: } t = \frac{\ln(A_t) - \ln(A0)}{k} \quad (4)$$

where: k = Deterioration rate; E_a = Activation energy (cal/mol); T = Absolute temperature (°K); R = Gas constant (1.986 cal/mol.K); t = Shelf-life (days); A_0 = Initial rancidity score or TBA value; A_t = Critical limit of rancidity score or TBA value.

2.7 Data analysis

Rancidity score and TBA value data were analyzed statistically by analysis of variance (One-Way ANOVA) using the IBM SPSS Statistics 24. The differences between groups were tested according to the student's t-test, performed at the significant level of $p < 0.05$. The relationship between the duration time of storage and parameter analysis was analyzed using Microsoft Excel 16. The deterioration rate and shelf-life of coated catfish were calculated using the Arrhenius equation based on rancidity score and TBA value during storage.

3 Results and discussion

3.1 Colour changes of the smoked catfish

Figures 1A, 1B, and 1C show the decrease of lightness (L*), redness (a*), and yellowness (b*) values of coated smoked catfish during 30 days of storage. Temperature accelerated the decrease in L*, a*, and b* values, indicating deterioration of coated smoked fish during storage. The decrease in color values was caused by fat in the smoked catfish that interacted with oxygen (oxidation), causing the lightness, redness, and yellowness color of smoked catfish to fade (Ayu et al., 2022). Previous studies reported that the decrease of L*, a*, and b* values occurred during frozen (-10 °C) (Utami et al., 2013) and refrigerated (4 °C) storage of catfish fillets (Azzahra et al., 2013). Research by Rahmah et al. (2018) showed that during 30 days of storage, there was a decrease in the appearance value of jerked milkfish caused by the oxidation of unsaturated fatty acids, thus decreasing the panelists' favorability level. Red palm oil that undergoes oxidation during storage also shows a fading color, the intensity of light exposure accelerated the color fading of red palm oil (Ayu et al., 2016).

During 30 days of storage, the L*, a*, and b* values of smoked catfish coated with EC decreased faster than the smoked catfish coated with chitosan and ECR (Figure 1). Chitosan coating with the addition of red galangal extract was able to maintain the color intensity in smoked catfish due to increased temperature as shown in Figure 1. Similar results were reported by Utami et al. (2013) and Azzahra et al. (2013), which showed that the color intensity values of coated catfish fillets were more stable with the addition of 1% than that of 0 and 0.1% red galangal essential oil during frozen and refrigerated (4 °C) storage. The red galangal essential oil contains antioxidants and antimicrobial compounds that can inhibit fat oxidation and inhibit fading of catfish fillet pigments during storage (Azzahra et al., 2013). The antioxidant activity of red galangal was significantly higher than white galangal, the results of phytochemical screening showed that red galangal contained alkaloids, flavonoids, phenolics, tannins, saponins, and triterpenoids, while white galangal contained alkaloids, flavonoids, phenolics, tannins, and triterpenoids (Mardhiyyah et al., 2021). Based on DPPH method, EC exhibited an inhibition concentration (IC_{50}) of 64.54 µg/ml, while ECR showed 57.24 µg/mL. The performance of smoked catfish coated with EC and ECR after 30 days of storage at 35, 45, and 55 °C were shown in Figure 2.

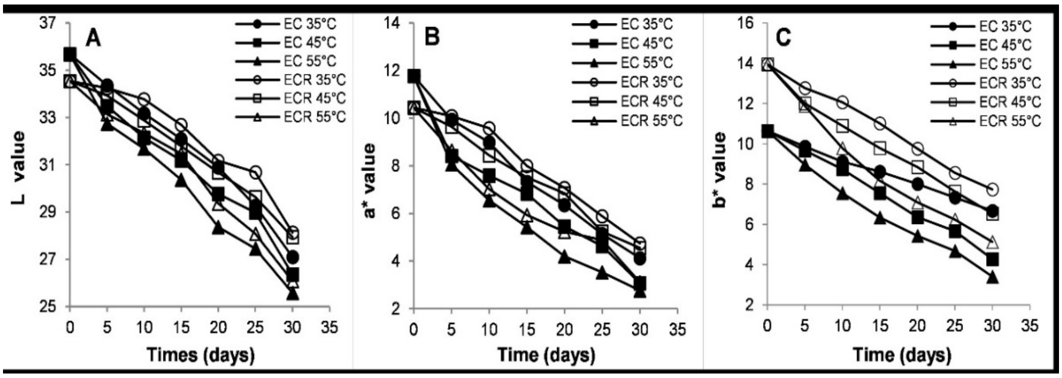

Figure 1. Changes in (A) L*, (B) a*, and (C) b* values of smoked catfish coated with edible coating chitosan (EC) and edible coating chitosan and red galangal extract (ECR) for 30 days of storage at 35, 45, and 55 °C.

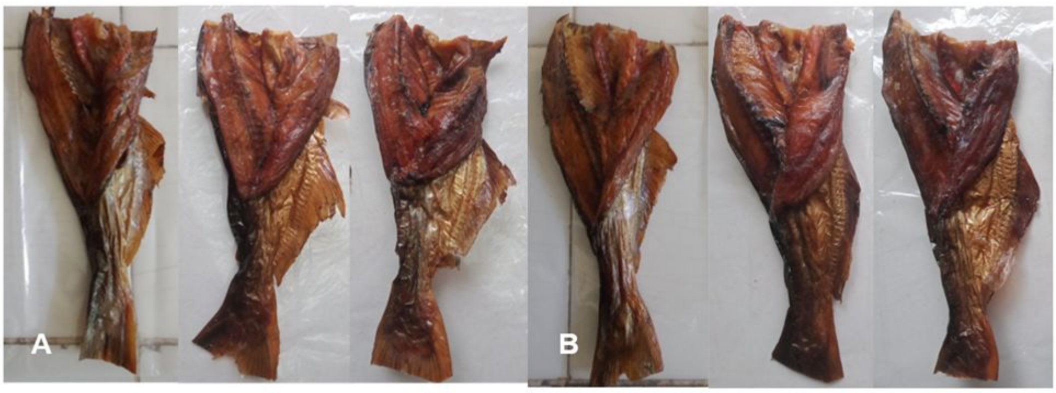

Figure 2. The performance of smoked catfish coated with (A) Edible coating chitosan (EC) and (B) Edible coating chitosan and red galangal extract (ECR) after 30 days of storage at 35, 45, and 55 °C (from left to right).

3.2 Determination of smoked catfish deterioration rate

During 30 days of storage at 35, 45, and 55 °C, no microbiological damage was observed (Figure 2). However, the rancidity score and TBA value of smoked catfish changed, as shown in Figure 3. The smoked catfish coated with EC showed faster rancidity compared to smoked catfish coated with ECR. This was indicated by a decrease in the panelists' assessment score of rancid aromas (Figure 3A) and an increase in the TBA value (Figure 3B) of EC compared to ECR as temperature and storage duration increased. The rancidity score of EC on day 0 to day 30 storage at 35 °C decreased from 4.00 (not rancid) to 2.00 (rancid), at 44 °C from 4.00 (not rancid) to 1.70 (rancid), and at 55 °C from 4.00 (not rancid) to 1.50 (rancid). The rancidity score of ECR-coated smoked catfish on day 0 to day 30 storage at 35 °C decreased from 4.00 (not rancid) to 2.30 (rancid), at 45 °C from 4.00 (not rancid) to 2.00 (rancid), and at 55 °C from 4.00 (not rancid) to 1.70 (rancid). The TBA values of EC-coated smoked catfish on day 0 to day 30 storage at 35 °C increased from 0.386 to 1.208 mg.mal/kg, at 45 °C from 0.386 to 1.385 mg.mal/kg, and at 55 °C from 0.386 to 1.405 mg.mal/kg. The TBA values of ECR-coated smoked catfish on day 0 to day 30 storage at 35 °C increased from 0.388 to 0.903 mg.mal/kg, at 45 °C from 0.386 to 0.975 mg.mal/kg, and at 55 °C from 0.386 to 1.215 mg.mal/kg.

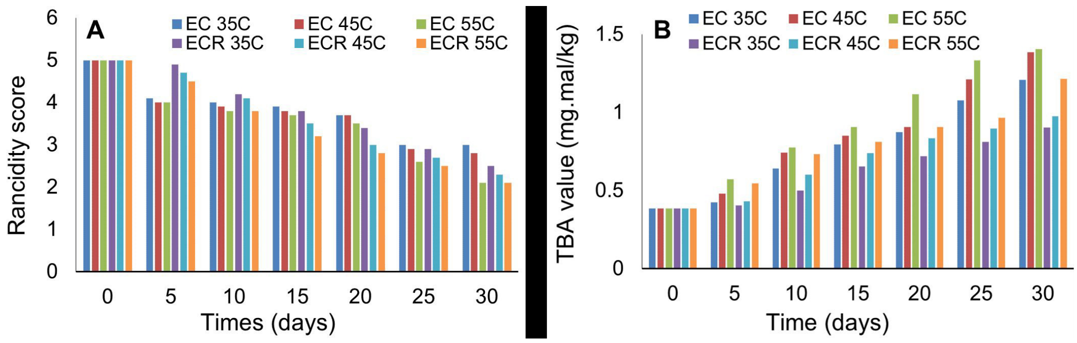

Figure 3. (A) Rancidity score and (B) TBA value of smoked catfish coated with edible coating chitosan (EC) and edible coating chitosan and red galangal extract (ECR) for 30 days storage at 35, 45, and 55 °C.

The relationship between rancidity score and TBA value of smoked catfish coated with EC and ECR during storage is shown in Figure 4. Storage caused a decrease in rancidity score and an increase in the TBA value of smoked catfish. The higher storage temperatures accelerated the decline in rancidity scores and the increase in TBA values. This shows that storage temperature accelerated the formation of aldehyde compounds characterized by the emergence of rancid aroma and taste due to oxidation reactions. According to Fauzi et al. (2016), the occurrence of a rancid aroma in milkfish fillets (*Chanos chanos* Forsk.) during cold storage is due to the peroxide compounds formed will degrade and produce advanced compounds that are unstable and easily broken producing volatile compounds such as aldehydes and ketones. The acceptance critical limit of TBA value was determined based on the rancidity score limit of 2 (rancid). Based on the regression between rancidity score and TBA value (Figure 4), the critical limit of TBA in EC-coated smoked catfish was 1.211 mg.mal/kg and ECR-coated smoked fish was 1.036 mg.mal/kg.

The smoked catfish stored at 55 °C became rancid more quickly than those stored at 35 and 45 °C. Temperature accelerated oxidation reactions that cause food to become rancid. Over 30 days of storage, the smoked catfish coated with EC had a lower rancidity score, but a higher TBA value compared to the ECR-coated smoked catfish (Figure 3). This indicated that as temperature increased, the ECR-coated smoked catfish had a lower reaction rate so that the smoked catfish would not be damaged quickly. The calculation of the reaction rate (k value) based on rancidity score showed that the EC-coated smoked catfish followed first-order with a k value of 0.0246 (R^2 = 0.94), 0.0310 (R^2 = 0.96), and 0.0327 (R^2 = 0.97) at 35, 45 and 55 °C, respectively, while the ECR-coated smoked catfish followed zero-order with a k value of 0.0571(R^2 = 0.87), 0.0671 (R^2 = 0.91), and 0.0800 (R^2 = 0.95) at 35, 45 and 55 °C, respectively (Table 1).

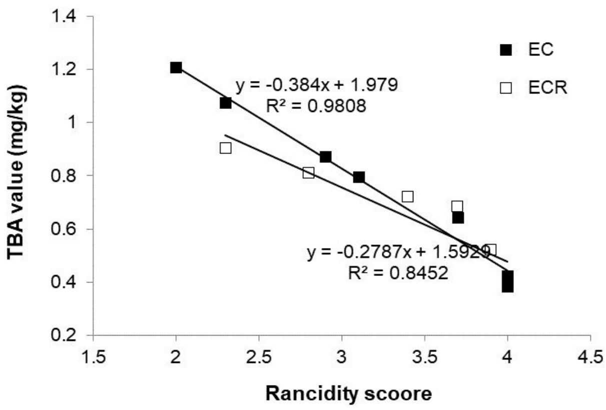

Figure 4. Relationship between rancidity score and TBA value of smoked catfish coated with edible coating chitosan (EC) and edible coating chitosan and red galangal extract (ECR) during storage.

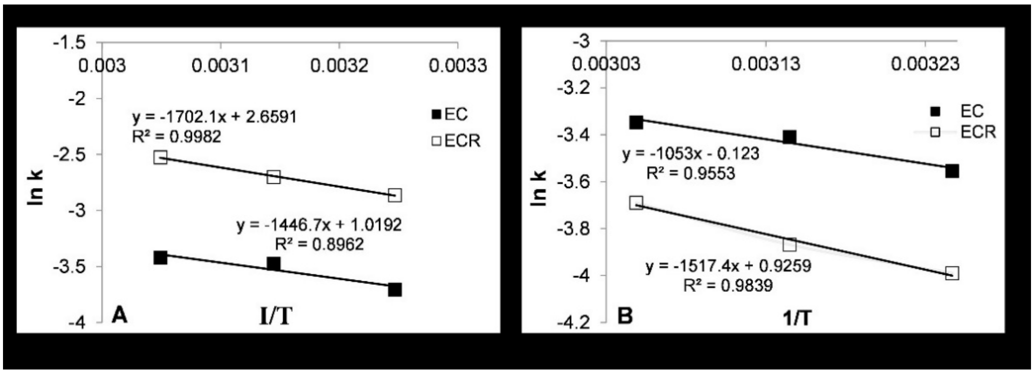

Figure 5. Relationship between ln k and 1/T in selected orders based on (A) rancidity score and (B) TBA value of smoked catfish coated with edible coating chitosan (EC) and edible coating chitosan and red galangal extract (ECR).

The calculation of k value based on TBA value showed that the EC-coated smoked catfish followed zero-order with k value of 0.0286 (R^2 = 0.99), 0.0331 (R^2 = 0.979), and 0.0352 (R^2 = 0.999) at 35, 45 and 55 °C, respectively, while the ECR-coated smoked catfish followed zero-order with k value of 0.0185 (R^2 = 0.98), 0.0209 (R^2 = 0.98), and 0.0250 (R^2 = 0.97) at 35, 45 and 55 °C, respectively (Table 1). Similar results were reported by Utami et al. (2013), that the addition of 1% red galangal essential oil provided better inhibitory power against oxidative damage than 0% and 0.1% red galangal essential oil on the catfish fillet. This inhibition of oxidative damage was related to the antioxidant activity of red galangal essential oil.

Next, the relation between ln k and 1/T was determined based on k values of rancidity score and TBA value at each storage temperature, as shown in Figure 5. Based on the rancidity score, the regression between ln k and 1/T on EC and ECR-coated smoked catfish had k values of -1446.7 and -1702.1, respectively. Based on the TBA value, the regression between ln k and 1/T on EC and ECR-coated smoked catfish had k values of -1517.4 and -1503, respectively. ECR-coated smoked catfish had a higher k-value rancidity score but a lower k-value TBA value than EC-coated smoked catfish. This indicated that ECR-coated smoked catfish are better able to prevent oxidation damage in smoked catfish during storage. Red galangal essential oil in ECR contains antioxidants and antimicrobial compounds that are high enough to inhibit the oxidation process (Azzahra et al., 2013). Red galangal rhizome is a rich source of total phenolic and flavonoid contents, and possesses great antioxidant activity and, therefore, could have high nutritional, and health potential (Aljobair, 2022), and also varied pharmacological and medicinal properties (Das et al., 2020; Khairullah et al., 2020). According to Rialita et al. (2019) and Aljobair (2022), red galangal essential oil also had antimicrobial activity against Gram-positive and Gram-negative bacteria so it had the potential to be used as a natural preservative in the food industry.

Table 1. Deterioration rate of smoked catfish based on rancidity score and TBA value.

Deterioration rate of smoked catfish based on rancidity score					
Coated with	Temperature (°C)	Zero-order		First-order	
		R^2	k	R^2	k
Chitosan (EC)	35	0.9321	0.0721	0.9443*	0.0246
	45	0.9636	0.0857	0.9565*	0.0310
	55	0.9441	0.0850	0.9745*	0.0327
Chitosan and red galangal extract (ECR)	35	0.8734*	0.0571	0.8367	0.0179
	45	0.9121*	0.0671	0.8629	0.0222
	55	0.9515*	0.0800	0.9071	0.0285
Deterioration rate of smoked catfish based on TB value					
Coated with	Temperature (°C)	Zero-order		First-order	
		R^2	k	R^2	k
Chitosan (EC)	35	0.9856*	0.0286	0.9652	0.0399
	45	0.9746*	0.0331	0.9610	0.0421
	55	0.9923*	0.0352	0.9512	0.0424
Chitosan and red galangal extract (ECR)	35	0.9813*	0.0185	0.9717	0.0307
	45	0.9759*	0.0209	0.9425	0.0326
	55	0.9685*	0.0250	0.9298	0.0342

*The highest R^2.

3.3 Prediction of smoked catfish shelf-life

Based on Figure 5, the slope and intercept values from the regression equation were then used to determine the activation energy (Ea) and shelf-life of coated smoked catfish at 30 °C. The activation energy is the minimum energy that must be met for the reaction to proceed. The smaller the energy value of product activation, the greater the rate of product quality degradation so that the product will be damaged faster, and the shelf-life of the product will be shorter, and vice versa.

Table 2 shows that based on the rancidity score, at 30 °C, the EC-coated smoked catfish had an activation energy of 2873.146 cal/mol and a shelf-life of 29.63 days, while ECR-coated smoked catfish had an activation energy of 3380.371 cal/mol and shelf-life of 38.53 days. Based on the TBA value, at 30 °C, the EC-coated smoked catfish had an activation energy of 2091.258 cal/mol and shelf-life of 30.14 days, while ECR-coated smoked catfish had an activation energy of 3013.556 cal/mol and shelf-life of 38.52 days. EC-coated smoked catfish had lower activation energy and shorter shelf-life compared to ECR-coated smoked catfish. The addition of red galangal essential oil in ECR had an antioxidant activity on the coated smoked catfish during storage so that the rancidity in coated smoked fish tends to be slower and extends its shelf life.

Table 2. Shelf-life estimation of smoked catfish during storage at 30 °C based on rancidity score and TBA value.

Shelf-life estimation of smoked catfish at 30 °C based on rancidity score				
Coated with	Linear equations ln k vs 1/T	Activation energy (cal/mol)	k	Shelf-life at 30 °C (days)
Chitosan (EC)	y = -1446.7x + 1.0192 R^2 = 0.8962	2873.146	0.0234	29.63
Chitosan and red galangal extract (ECR)	y = -1702.1x + 2.6591 R^2 = 0.9982	3380.371	0.0519	38.53
Shelf-life estimation of smoked catfish at 30 °C based on TBA value				
Coated with	Linear equation ln k vs 1/T	Activation energy (cal/mol)	k	Shelf-life at 30 °C (days)
Chitosan (EC)	y = -1053x - 0.123 R^2 = 0.9553	2091.258	0.0273	30.14
Chitosan and red galangal extract (ECR)	y = -1517.4x + 0.9259 R^2 = 0.9839	3013.556	0.0169	38.52

The addition of red galangal extract was able to increase the antioxidant activity of the chitosan edible coating. Antioxidants capture free radicals through different mechanisms based on the types of free radicals and phenolic compounds of the antioxidant ingredients. However, it generally occurs through the donation of hydrogen from the hydroxyl group of the phenolic compound, by which a stable free radical complex is formed and hence prevents lipid peroxidation (Aljobair, 2022). Red galangal essential oil has an antioxidant activity (% DPPH radical capture) of 22.22% (Utami et al., 2013), galangal rhizome extract possessed high antioxidant activity, as assessed by DPPH (77.76%), ABTS (8.66 mmol TE/g), and FRAP (3.99 mmol TE/g) (Aljobair, 2022). The most abundant phenolic compound in the extract was gallic acid, followed by (+)-catechin, quercetin, catechol, isorhamnetin, trans-cinnamic acid, and protocatechuic acid (Aljobair, 2022).

Recapitulation of coated catfish shelf-life based on the calculation of rancidity score and TBA value showed that ECR-coated smoked catfish had a longer shelf-life than EC (Table 2). For consumer safety and the quality of smoked catfish, the shortest shelf-life was selected as the shelf-life of coated smoked catfish, which was based on the rancidity score. The shelf-life of EC-coated smoked catfish was 29.63 days and ECR was 38.52 days at 30 °C.

4 Conclusions

Storage at temperatures of 35, 45, and 55 °C can be used to estimate the shelf-life of smoked catfish coated with edible coating chitosan (EC) and EC with the addition of red galangal extract (ECR) at 30 °C using the Arrhenius approach based on sensory of rancidity and TBA value. The EC-coated smoked catfish experienced faster color changes and shorter shelf-life than that of the ECR-coated smoked catfish, along with increasing storage temperature. The estimated shelf-life at 30 °C for EC-coated smoked catfish was 29.63 days, while ECR-coated smoked catfish was 38.52 days. The addition of red galangal extract into the chitosan edible coating can extend the shelf-life of smoked catfish, thereby increasing the added value of smoked catfish. However, this research needs to be continued to study the changes in nutritional composition during storage.

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