SYNERGISM OF OPEFB-DERIVED LIQUID SMOKE, NEEM EXTRACT, GELATIN AND CHITOSAN IN EDIBLE COATINGS. EFFECTS OF LIQUID SMOKE CONCENTRATION AND PYROLYSIS TEMPERATURE ON FISH BALL SHELF LIFE

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This study evaluated the potential of an edible coating formulated using oil palm empty fruit bunch (OPEFB) liquid smoke, neem extract, gelatin and chitosan as a natural preservative to extend the shelf life of fish balls. The treatments varied the liquid smoke pyrolysis temperature (300, 340, and 380 °C) and concentration (1, 2, and 3%), each combined with fixed 2% neem extract, 1% gelatin and 1% chitosan. Fish ball quality during storage was assessed using Total Volatile Base Nitrogen (TVB-N), Total Plate Count (TPC), and sensory evaluations (color, texture, aroma). Results showed that both pyrolysis temperature and liquid smoke concentration significantly influenced preservation performance. The A3LS3 formulation (380 °C; 3%) best preserved product freshness, maintaining TVB-N levels for 96 hours, microbiological safety (TPC) for 48 hours, and sensory acceptability for 72 hours of storage. These findings show that an edible coating combining OPEFB liquid smoke, neem extract, gelatin and chitosan serves as an effective natural preservative for maintaining quality and extending the shelf life of fish balls, offering a safe and environmentally friendly alternative for the fish processing industry.

Keywords: chitosan, edible coating, fish balls, gelatin, natural preservative, neem extract

INTRODUCTION

Fish balls are one of the most popular fish-based products in Indonesia. Their pleasant taste, low fat content, and considerable nutritional value contribute to their high consumer appeal. However, their high moisture and nutrient content also make them highly perishable, with a shelf life of less than 24 hours at room temperature.[1] To prolong shelf life, harmful chemical preservatives, such as formalin and borax, which are strictly prohibited for use in foods, are still found in some commercial fish balls in traditional markets. These substances are carcinogenic and can cause severe health issues, including kidney damage, abdominal pain, chronic inflammation of the stomach and intestines, and even death.[2] Therefore, there is an urgent need for safer natural preservation techniques, such as edible coatings.

Edible coating is a preservation technique applied to food products including vegetables, fruits, cheese, meat, and fish based products, which uses antimicrobial substances to form surface films that inhibit microbial growth.[3] A promising

material for such coatings is liquid smoke, particularly when combined with other natural agents, like neem extract, gelatin, and chitosan. Liquid smoke, produced through the pyrolysis of biomass, contains organic compounds such as phenols and acetic acid, which exhibit antimicrobial and antioxidant properties.[4,5] Oil palm empty fruit bunches (OPEFB) represent an abundant and potential biomass source for liquid smoke due to their content of lignin (16.49%), cellulose (45%), and hemicelluloses (22.84%).[6] Pyrolysis of these components yields a liquid smoke with significant antimicrobial activity.[7]

Neem leaf extract also functions as a natural antioxidant by inhibiting lipid oxidation that leads to rancidity. In addition to its antioxidant properties, neem extract shows strong antibacterial activity,[8] which is attributed to its polyphenolic compounds that exhibit broad spectrum antibacterial effects against various pathogens.[9] Another promising biopolymer for edible coatings is chitosan, which possesses inherent antimicrobial and excellent film forming capabilities. The semi-permeable film formed by chitosan acts as an effective oxygen barrier, thereby delaying spoilage. Its antioxidant, hypolipidemic, and hypoglycemic properties contribute to protecting coated foods from microbial deterioration.[3]

Previous studies have explored edible coating formulations combining liquid smoke and other natural materials to extend the shelf life of perishable foods, especially fish-based products. For example, Swastawati *et al*.[10] developed an edible coatings from liquid smoke and chitosan applied to barracuda fish sausages, which effectively maintained product quality for up to 12 days at 5 °C. Widayat *et al*.[11] formulated an edible coating using liquid smoke and carrageenan, successfully preserving beef meatballs for up to 21 days at room temperature. Additionally, the effectiveness of coconut shell–derived liquid smoke for preserving fish balls was reported in the literature.[12] Unlike these previous studies, the present research introduces a novel approach by synergistically combining liquid smoke and neem extract as antimicrobial agents, with chitosan and gelatin as film-forming materials. The interaction between multiple natural antimicrobial agents and film-forming compounds in a single coating system has not been widely studied. The inclusion of neem extract as both an antimicrobial and antioxidant component is a distinctive feature that has not been previously reported for fish balls preservation.

Accordingly, this study aimed to evaluate the effectiveness of an edible coating composed of OPEFB liquid smoke, neem extract, gelatin and chitosan in extending the shelf life of fish balls; and determine the influence of pyrolysis temperature and liquid smoke concentration on preservative performance. The shelf life of fish balls was assessed through Total Volatile Base Nitrogen (TVB-N), Total Plate Count (TPC), and sensory evaluations of color, texture, and aroma.

EXPERIMENTAL

Preparation of liquid smoke

Dried oil palm empty fruit bunches were cut into pieces of approximately 3–4 cm and subjected to pyrolysis at temperatures of 300 °C, 340 °C, and 380 °C, following the procedure described by Faisal *et al*.[13] The crude (grade 3) liquid smoke produced from pyrolysis was then purified by distillation at 190 °C to obtain grade 1 liquid smoke, which is free from tar and suitable for preservation applications. Each treatment was replicated three times.

Formulation of edible coating

The edible coating formulation followed the method applied by Suharto *et al*.,[14] with slight modifications. The coating solution consisted of liquid smoke at concentrations of 1%, 2%, and 3% (v/v), gelatin at 1% (w/w), chitosan at 1% (w/w), and neem extract at 2% (v/v) in distilled water. The symbols for each combination of pyrolysis temperature and liquid smoke concentration are presented in Table 1.

Table 1
Sample coding based on pyrolysis temperature and liquid smoke concentration

Pyrolysis temperature	Liquid smoke concentration
A1 = 300 °C	LS1 = 1%
A2 = 340 °C	LS2 = 2%
A3 = 380 °C	LS3 = 3%

The mixture was homogenized and heated on a hot plate at 70 °C. Neem extract, gelatin, and chitosan were gradually added while stirring with a magnetic stirrer until fully homogeneous. The prepared fish balls were dipped in the coating solution for 60 seconds, then dried in an oven at 40 °C for 2 hours. The samples were stored

and observed every 24 hours. Shelf life was evaluated based on Total Volatile Base Nitrogen (TVB-N), Total Plate Count (TPC). Each treatment was performed in triplicate.

Sensory evaluation

The shelf life of the coated samples was evaluated during storage by monitoring changes in their sensory and color characteristics. The samples were stored at room temperature for five days and evaluations were conducted at predetermined storage intervals of 1, 2, 3, 4, and 5 days. At each sampling interval, the samples were evaluated for color, texture, and aroma to determine changes in their sensory quality throughout the storage period.

A colorimeter based on the CIELAB color standard was used to measure color. The colorimeter was calibrated using a standard white calibration tile in accordance with the manufacturer's instructions prior to measurement. Three standard characteristics were used to describe color: L* (lightness), a* (red–green), and b* (yellow–blue).

A Texture Analyzer (TA.XT Plus, Stable Micro Systems, UK) in compression mode was used to do instrumental texture analysis. The samples were placed on the instrument platform and subjected to a compression test under controlled operating conditions. The pre-test speed was set at 3.0 mm/s, the test speed at 1.0 mm/s, and the post-test speed at 3.0 mm/s. The compression distance/strain was set at 5 mm/50%.

Sensory evaluation was performed by 35 panelists, comprising 20 trained and 15 untrained panelists. 35 panelists, 20 trained and 15 untrained performed the sensory examination. To reduce potential bias, the samples were coded with random three digit numbers and presented to the panelists in a random order prior to evaluation. Using a five-point hedonic scale, from 1 (very dislike) to 5 (extremely like), the panelists assessed the samples' aromas. The sensory evaluation was conducted at each predetermined storage interval to monitor changes in aroma acceptability during storage.

RESULTS AND DISCUSSION

Shelf-life evaluation of fish balls with edible coating

TVB-N analysis

The TVB-N test measures the freshness of fish or other perishable products by assessing spoilage resulting from microbial degradation of lipids or proteins.[15] Figures 1–3 show the effect of pyrolysis temperature and liquid smoke concentration on the TVB-N values of fish balls.

The TVB-N values of the fish balls treated with edible coating are presented in Figures 1–3. In samples A1, A2, and A3, treated with liquid smoke concentrations of 1%, 2%, and 3% respectively, the data indicate that higher liquid smoke concentrations resulted in lower TVB-N values, demonstrating stronger antibacterial effects.

For sample A1 (1% liquid smoke), the fish balls began to lose freshness after 48 hours, with a TVB-N value of 0.212 mg N/100 g, which remained within the acceptable range for consumption. Samples treated with 2% and 3% liquid smoke maintained quality up to 72 hours, with TVB-N values of 0.207 and 0.190 mg N/100 g, respectively. In sample A2, all concentrations maintained freshness up to 72 hours, yielding TVB-N values of 0.207, 0.201, and 0.179 mg N/100 g, respectively. For sample A3, the 1% concentration maintained stability for 72 hours (0.190 mg N/100 g), while 2% and 3% concentrations extended freshness to 96 hours with TVB-N values of 0.212 and 0.196 mg N/100 g. In contrast, the untreated control fish balls reached a TVB-N value of 0.240 mg N/100 g after only 24 hours of storage, indicating spoilage.

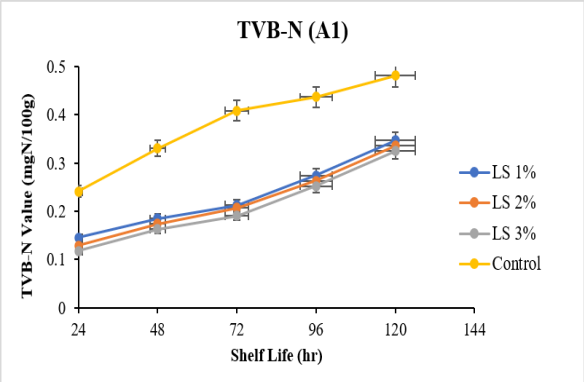


Figure 1: Effect of liquid smoke concentration on TVB-N value and storage time of fish balls (Sample A1 = Pyrolysis temperature of 300 ºC)

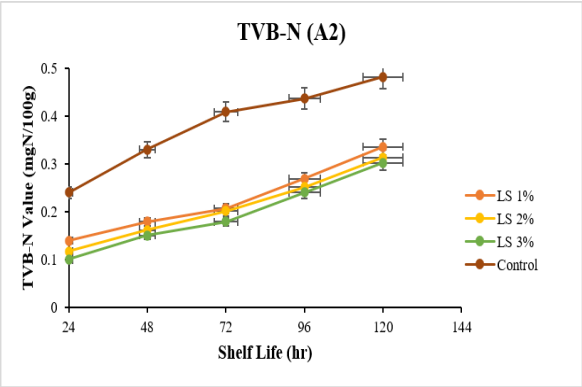


Figure 2: Effect of liquid smoke concentration on TVB-N value and storage time of fish balls (Sample A2 = Pyrolysis temperature of 340 ºC)

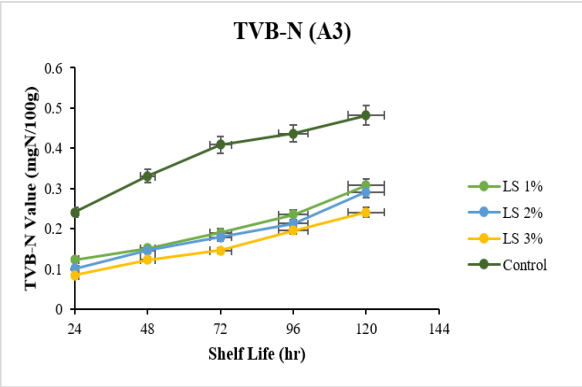


Figure 3: Effect of liquid smoke concentration on TVB-N value and storage time of fish balls (Sample A3 = Pyrolysis temperature of 380 ºC)

These findings align with those of Vatria *et al*.,[16] who reported that fish fillets coated with 3% edible coating maintained acceptable TVB-N levels (below 30 mg N/100 g) after 96 hours of storage. The increase in TVB-N values is primarily due to microbial activity. Microorganisms decompose proteins and nitrogen-containing compounds during growth, releasing volatile nitrogenous bases, such as ammonia, trimethylamine, and dimethylamine, which are measured as TVB-N.

Additionally, enzymatic proteolysis releases amino acids and short peptides that contribute to off odors, while lipid oxidation forms peroxides and hydroperoxides that intensify spoilage. The bacterial degradation of muscle tissue further accelerates TVB-N accumulation. However, the phenolic compounds present in liquid smoke inhibit bacterial enzymes and oxidative reactions, thereby slowing spoilage process.[17]

Total Plate Count (TPC) analysis

The TPC test quantifies viable mesophilic bacteria by counting colonies grown on agar media, providing an indicator of the microbial load in a food product.[18] According to the Indonesian National Standard (SNI 7388.2009), the maximum acceptable TPC for food products is 1×10^5 CFU/g or 5 log CFU/g.

As shown in Tables 2-4, edible coatings containing liquid smoke produced at higher pyrolysis temperatures and higher concentrations were more effective at suppressing bacterial growth, thereby extending the product's shelf life.

Fish balls coated with liquid smoke derived at 300 °C remained microbiologically safe for 2 days at 2% and 3% concentrations, whereas 1% coating was effective for only 1 day. Coatings prepared from liquid smoke produced at 340 °C and 380 °C maintained microbial safety for up to 2 days at all concentrations tested.

This indicates that edible coatings formulated from liquid smoke, neem extract, and chitosan effectively delayed bacterial growth and extended shelf life. Furthermore, the results show that TPC values increased with longer storage time, reflecting the natural proliferation of bacteria during storage. By the third to fifth day, all treatments exceeded the SNI microbial threshold, marking the end of the acceptable storage period.

Table 2
TPC values at 300 °C pyrolysis with different liquid smoke concentrations

Temperature of liquid smoke	Storage time (day)	Total plate count (CFU/g)		
		Liquid smoke concentration		
		LS1	LS2	LS3
A1	1	4.6×10^4	3.5×10^4	2.7×10^4
	2	1.1×10^5	1×10^5	6.8×10^4
	3	9.9×10^5	7.5×10^5	5.9×10^5
	4	4.7×10^6	4×10^6	3.8×10^6
	5	TNTC	TNTC	TNTC

Note = TNTC: Too numerous to count; : suitable for consumption

Table 3
TPC values at 340 °C pyrolysis with different liquid smoke concentrations

Temperature of liquid smoke	Storage time (day)	Total plate count (CFU/g)		
		Liquid smoke concentration		
		LS1	LS2	LS3
A2	1	$2x10^4$	$1.8x10^4$	$1.4 x10^4$
	2	$5.6x10^4$	$4.8x10^4$	$3.2x10^4$
	3	$1.6 x10^5$	$4.3 x10^5$	$3.9x10^5$
	4	$2.3 x10^6$	$2 x10^6$	$2 x10^6$
	5	TNTC	TNTC	TNTC

Note = TNTC: Too numerous to count; : suitable for consumption

Table 4
TPC values at 380 °C pyrolysis with different liquid smoke concentrations

Temperature of liquid smoke	Storage time (day)	Total plate count (CFU/g)		
		Liquid smoke concentration		
		LS1	LS2	LS3
A3	1	$1 x10^4$	$9x10^3$	$6.5x10^3$
	2	$2.3x10^4$	$1.8x10^4$	$1.3 x10^4$
	3	$1.9x10^5$	$1.7 x10^5$	$1.3 x10^5$
	4	$1.9x10^6$	$1.7 x10^6$	$1.3 x10^6$
	5	$1.1 x10^7$	$9.4 x10^6$	$4.1 x10^6$

Note = TNTC: Too numerous to count; : suitable for consumption

As noted by F. Tarlak,[19] food safety and shelf life are closely related, as shelf life is determined by the rate of quality degradation, which is strongly influenced by microbial activity. The lower the microbial growth rate, the longer the product can be preserved.

Faisal *et al.*[13] also reported that combining 3% liquid smoke with 2-6 g turmeric effectively maintained the TPC of beef meatballs below the SNI limit for three days of storage. The current findings are consistent with those results, confirming that the synergistic use of liquid smoke and chitosan reduces microbial proliferation.

Sensory evaluation

Color evaluation

In food products, color serves as the first indicator of quality, and is assessed visually prior to other attributes like texture, taste and aroma. Objective color measurements were obtained using a colorimeter, based on three standard parameters: L* (lightness), a* (red–green), and b* (yellow–blue). The results are presented in Table 5.

L (Lightness)*

Lightness is a key parameter for determining the quality of coated food products. Table 5 shows that the L values of the coated fish balls decreased gradually during storage, ranging between 75.99 and 83.62. The highest lightness value was recorded in treatment A3 (77.62), while the lowest was observed in the control sample (75.11) after five days of storage. Liquid smoke produced at a pyrolysis temperature of 380 °C inhibited browning more effectively, which is attributed to its higher acidity compared to liquid smoke derived from 300 °C and 340 °C pyrolysis. A similar trend was reported by Gedif *et al.*,[20] who observed a gradual reduction in L* values during storage of carp fish fillet coated with edible films.

A (Redness)*

The redness index (a*) represents the red-green component, where positive values indicate red tones and negative values indicate green tones.[21] As shown in Table 5, the a* values of all samples decreased with longer storage duration. The control sample showed the highest initial redness value (3.6 on day 1), while the lowest value was recorded in A3 (1.21 on day 5). This suggests that edible coating application helped maintain redness stability compared to the uncoated samples. According to Izzah *et al.*,[22] discoloration during storage occurs due to oxidative changes in hemoglobin and myoglobin pigments, forming methemoglobin and metmyoglobin, which cause a brownish or grayish appearance. Pelaes Vital *et al.*[23] also reported that edible coatings applied to

lamb patties slowed color deterioration by reducing lipid oxidation and pigment degradation.

b (Yellowness)*

The yellowness parameter (b*) measures the intensity of yellow-blue coloration. Positive values indicate yellow, while negative values indicate blue tones. As shown in Table 5, b* values decreased gradually over the storage period. The highest b* value was recorded in the control sample (4.57 on day 1), while the lowest occurred in treatment A3 (2.25 on day 5). All samples maintained positive b* values, indicating that the fish balls remained within the yellow color range. Similar observations were reported by Nanda and Riyadi,[24] who found that the b* values (yellowness) of mackerel fish balls decreased with longer storage time. Suharto *et al.*[14] also noted that extended storage reduced yellowness, shifting samples toward bluish tones. In this study, however, the five-day storage only caused mild fading of the yellow color without turning the fish balls blue.

Table 5
Color test results of meatball samples with edible coating

Storage time (day)	Parameter	Color Analysis Results			
		Control	A1LS3	A2LS3	A3LS3
1	L	83.01	83.16	83.263	83.62
2		82.11	82.37	82.56	82.74
3		80.12	80.30	80.52	80.58
4		79.08	79.25	79.30	79.42
5		75.11	75.99	77.08	77.62
1	a	3.6	2.86	2.94	2.51
2		1.81	2.38	1.82	1.77
3		1.65	1.57	1.65	1.60
4		1.67	1.53	1.56	1.52
5		1.62	1.46	1.38	1.21
1	b	4.57	4.16	3.85	3.46
2		4.50	3.25	3.11	2.68
3		3.82	3.03	2.99	2.50
4		3.25	2.95	2.58	2.40
5		3	2.87	2.32	2.25

Texture evaluation

Texture is a critical quality attribute that reflects the physical and mechanical properties of food products, including hardness, cohesiveness, springiness, and chewiness. The textural characteristics of the fish balls with edible coating are summarized in Table 6.

Table 6
Texture evaluation results of meatball samples with edible coating

Storage time (day)	Sample	Hardness (kg)	Cohesiveness	Springiness	Chewiness
1	A1LS1	2.5 ± 0.22^{BC}	0.74 ± 0.00^{A}	0.89 ± 0.04^{B}	1.62 ± 0.16^{B}
	A1LS2	2.40 ± 0.19^{BC}	0.74 ± 0.00^{B}	0.88 ± 0.03^{AB}	1.57 ± 0.12^{B}
	A1LS3	1.94 ± 0.32^{A}	0.74 ± 0.00^{B}	0.87 ± 0.03^{AB}	1.25 ± 0.16^{A}
	A2LS1	2.69 ± 0.48^{BC}	0.74 ± 0.00^{AB}	0.90 ± 0.03^{BC}	1.79 ± 0.26^{BC}
	A2LS2	2.39 ± 0.13^{BC}	0.75 ± 0.00^{BC}	0.91 ± 0.01^{BC}	1.62 ± 0.1^{B}
	A2LS3	2.46 ± 0.24^{BC}	0.75 ± 0.00^{C}	0.92 ± 0.04^{BC}	1.67 ± 0.1^{BC}
	A3LS1	1.99 ± 0.29^{A}	0.74 ± 0.00^{B}	0.90 ± 0.03^{BC}	1.31 ± 0.18^{AB}
	A3LS2	2.10 ± 0.25^{B}	0.74 ± 0.00^{B}	0.83 ± 0.01^{A}	1.40 ± 0.11^{AB}
	A3LS3	2.67 ± 0.17^{BC}	0.73 ± 0.00^{A}	0.87 ± 0.00^{AB}	1.69 ± 0.13^{BC}
2	A1LS1	1.64 ± 0.16^{A}	0.74 ± 0.00^{A}	0.88 ± 0.05^{AB}	1.06 ± 0.05^{AB}
	A1LS2	1.78 ± 0.20^{AB}	0.74 ± 0.01^{AB}	0.91 ± 0.01^{B}	1.21 ± 0.13^{B}

Storage time (day)	Sample	Hardness (kg)	Cohesiveness	Springiness	Chewiness
	A1LS3	1.29±0.15^{A}	0.73±0.01^{A}	0.92±0.00^{BC}	0.89±0.11^{A}
	A2LS1	2.18±0.23^{B}	0.75±0.01^{BC}	0.90±0.01^{B}	1.48±0.16^{BC}
	A2LS2	1.71±0.15^{AB}	0.75±0.01^{BC}	0.82±0.09^{A}	1.09±0.39^{AB}
	A2LS3	2.45±0.23^{BC}	0.74±0.01^{AB}	0.85±0.07^{AB}	1.56±0.24^{C}
	A3LS1	2.38±0.47^{BC}	0.74±0.01^{B}	0.89±0.02^{AB}	1.56±0.17^{C}
	A3LS2	2.29±0.14^{BC}	0.74±0.00^{BC}	0.89±0.05^{AB}	1.57±0.15^{C}
	A3LS3	2.11±0.38^{BC}	0.75±0.00^{BC}	0.88±0.5^{AB}	1.41±0.27^{BC}
3	A1LS1	1.90±0.48^{AB}	0.72±0.00^{A}	0.81±0.05^{AB}	1.1±0.30^{B}
	A1LS2	2.15±0.12^{B}	0.72±0.019^{BC}	0.88±0.02^{B}	1.4±0.11^{BC}
	A1LS3	2.34±0.34^{A}	0.72±0.00^{BC}	0.80±0.04^{A}	1.4±0.23^{BC}
	A2LS1	1.53±0.29^{BC}	0.66±0.03^{A}	0.80±0.05^{AB}	0.8±0.24^{AB}
	A2LS2	2.06±0.31^{B}	0.72±0.00^{BC}	0.81±0.09^{AB}	1.2±0.15^{B}
	A2LS3	1.92±0.22^{C}	0.72±0.00^{BC}	0.88±0.06^{B}	1.2±0.08^{B}
	A3LS1	1.56±0.19^{C}	0.70±0.01^{B}	0.89±0.06^{BC}	1.0±0.14^{AB}
	A3LS2	2.19±0.11^{BC}	0.66±0.03^{A}	0.89±0.04^{BC}	1.3±0.12^{BC}
	A3LS3	1.34±0.12^{BC}	0.67±0.03^{AB}	0.83±0.07^{B}	0.5±0.02^{A}
4	A1LS1	1.40±0.16^{AB}	0.74±0.00^{A}	0.90±0.04^{BC}	0.90±0.13^{B}
	A1LS2	1.94±0.07^{C}	0.75±0.00^{A}	0.90±0.00^{BC}	0.75±0.00^{A}
	A1LS3	1.48±0.08^{B}	0.75±0.013^{AB}	0.86±0.02^{B}	1.00±0.07^{BC}
	A2LS1	1.38±0.24^{AB}	0.74±0.00^{A}	0.86±0.03^{AB}	0.88±0.12^{AB}
	A2LS2	1.66±0.11^{BC}	0.74±0.00^{A}	0.87±0.02^{B}	1.08±0.08^{BC}
	A2LS3	1.92±0.22^{C}	0.72±0.00^{AB}	0.85±0.03^{AB}	1.04±0.05^{BC}
	A3LS1	1.32±0.10^{AB}	0.71±0.01^{A}	0.83±0.02^{A}	1.02±0.03^{BC}
	A3LS2	1.25±0.10^{A}	0.72±0.01^{A}	0.84±0.01^{A}	0.75±0.04^{A}
	A3LS3	1.45±0.12^{B}	0.74±0.00^{AB}	0.88±0.00^{B}	0.95±0.07^{B}

Hardness, which represents the force required to deform a product and reflects its compactness, ranged from 1.29 to 2.69 kg. The highest values were observed on day 1, followed by a gradual decrease until day 4 of storage. ANOVA results ($\alpha < 0.05$) indicated significant differences among treatments. Similar findings were reported by Bastomy and Rahmadhia[25] for sausages, where hardness decreased with extended storage due to microbial activity that degraded protein structures and weakened texture integrity.

Cohesiveness, which describes the degree to which a material can withstand compression before breaking, ranged between 0.66 and 0.75. ANOVA results ($\alpha < 0.05$) confirmed significant differences between treatments with liquid smoke produced at different pyrolysis temperatures and concentrations. These results agree with a study by Debora *et al*.,[26] which reported similar effects in oyster mushroom meatballs. Higher cohesiveness values indicate a more compact and uniform internal structure.

Statistical analysis ($\alpha < 0.05$) revealed significant differences among treatments. Dong *et al.*[27] reported similar results in red sausages coated with chitosan based edible films. Higher springiness values are associated with greater elasticity and freshness.[28]

Chewiness, indicating the total energy required to chew a food item until it is ready for swallowing, ranged from 0.50 to 1.69 kg mm, with significant differences among treatments ($\alpha < 0.05$). As shown in Table 6, samples treated with higher concentrations of liquid smoke exhibited higher chewiness values.[29] This aligns with the findings of Chang *et al*.,[30] who reported that edible coatings improved chewiness in fish balls compared with uncoated samples.

The application of the edible coating with varying liquid smoke concentrations and pyrolysis temperatures resulted in statistically significant differences in the textural parameters of the fish ball samples. Higher concentrations of liquid smoke contributed to increased hardness, cohesiveness, springiness, and chewiness, likely due to phenolic compounds in liquid smoke forming crosslinks with free amino groups in proteins, resulting in a denser matrix. This, in turn, increases the density of the food structure.[31] In addition, chitosan contributed to improved cohesiveness by forming a protective layer that reinforced the product structure and retained

moisture, leading to enhanced elasticity and chewability.[32]

Aroma evaluation

Aroma plays a crucial role in determining consumer preference, as it directly influences the perception of freshness and quality. The aroma evaluation results of the coated fish balls are presented in Table 7.

As shown in Table 7, the application of edible coating formulated with liquid smoke (pyrolyzed at 300 °C, 340 °C, and 380 °C) with varying concentrations (1%, 2%, and 3%) had a notable impact on the fish balls' aroma. Higher pyrolysis temperature reduced the rate of undesirable odor development during storage. Panelists generally preferred the aroma of coated samples compared to the control. The control samples maintained acceptable aroma for up to 48 hours, whereas those with edible coatings remained acceptable up to 72 hours of storage. The optimal condition was observed in treatment A3LS3 (highest pyrolysis temperature and liquid smoke concentration). Panelist comments indicated that higher pyrolysis temperatures and smoke concentrations resulted in more stable and appealing aroma profiles.

Table 7
Aroma evaluation results of edible-coated meatball samples

Temperature of liquid smoke (°C)	Liquid smoke concentration (%)	Storage time (day)				
		1	2	3	4	5
A1	Control	5	3.5	2.3	2	1.2
	LS1	5	4.8	3.1	2.3	2
	LS2	5	4.8	3	2.3	2.1
	LS3	5	4.9	3.2	2.4	2.2
A2	Control	5	3.5	2.3	1.9	1.2
	LS1	5	4.9	3	2.5	2.3
	LS2	5	4.9	3.1	2.6	2.4
	LS3	5	5	3.1	2.5	2.5
A3	Control	5	3.5	2.3	1.9	1.2
	LS1	5	4.9	4.7	3.4	1.8
	LS2	5	5	4.9	3.6	2
	LS3	5	5	4.8	3.7	2.2

These findings are consistent with those of Rakhmawati and Handayani,[33] who reported that chicken meatballs coated with edible films containing virgin coconut oil retained acceptable aroma for 48 hours at room temperature. According to Faisal *et al*.,[7] odors indicate product deterioration caused by improper processing or storage. The antioxidant compounds in liquid smoke help prevent lipid oxidation in fish balls, thereby extending shelf life. Moreover, the organic acids present in liquid smoke influence not only aroma, but also taste, texture, and microbial stability of the coated products.

CONCLUSION

This study demonstrated that an edible coating formulated with liquid smoke from OPEFB, combined with neem extract and chitosan, effectively preserved the quality and extended the shelf life of fish balls. Higher pyrolysis temperatures and liquid smoke concentrations significantly enhanced preservative efficacy. The optimal treatment, A3LS3 (380 °C pyrolysis temperature, 3% concentration), maintained product freshness for up to 96 hours based on TVB-N and ensured microbiological safety for 48 hours based on TPC, while also preserving acceptable sensory attributes. Overall, this formulation presents strong potential as a natural preservative system and a sustainable alternative to synthetic additives for extending the shelf life of fish based processed products.

This study has several limitations, including storage conducted only at room temperature, which may not reflect typical refrigerated conditions in real applications. Nevertheless, the formulation shows potential for scale-up due to the abundance of OPEFB and its simple application process, though industrial feasibility and cost require further evaluation.

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