Journal of Applied Engineering and Technological Science
Vol 5(2) 2024: 791-800

DURIAN RIND-BASED LIQUID SMOKE AS A NATURAL PRESERVATIVE FOR CHICKEN MEATBALLS: EFFECT OF PYROLYSIS TEMPERATURE AND LIQUID SMOKE CONCENTRATION

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Received : 20 July 2023, Revised: 9 December 2023, Accepted : 16 March 2024
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ABSTRACT
Liquid smoke is produced by the pyrolysis of biomass. The use of liquid smoke has numerous advantages over traditional smoking methods. The liquid smoke market is well-established and growing, providing an opportunity to commercialize biomass pyrolysis. This study aimed to investigate the utility of durian rind, biomass waste rich in lignin, cellulose, and hemicellulose, as a natural preservative to extend the shelf life of chicken meatballs and to mitigate environmental problems caused by the disposal of untreated durian rind waste. Dried durian rinds with approximately 10% water content were pyrolyzed at temperatures of 300°C (T1 liquid smoke), 340°C (T2 liquid smoke), and 380°C (T3 liquid smoke) using a slow pyrolysis reactor in batch conditions to produce crude liquid smoke, which was then purified by distillation at 190°C. Chicken meatballs were then soaked in liquid smoke solutions with concentrations of 1%, 2%, and 3% for 15 minutes, and the meatballs checked for signs of spoilage every 4 hours. Tests for total volatile base nitrogen (TVB-N), in addition to the total plate count (TPC) and most probable number (MPN) of Escherichia coli bacteria, were performed to evaluate the preservation ability of the liquid smoke. The results indicated that both the pyrolysis temperature and liquid smoke concentration affected the preservation time, with a pyrolysis temperature of T3 and liquid smoke concentration of 3% optimum for chicken meatball preservation. Under these conditions, the meatballs could be stored for 56 hours with TVB-N, TPC, and E. coli MPN values of 21.01 mg N/100 g, 5.37 × 10^4 CFU/g, and 75 MPN/g, respectively. The findings suggest that liquid smoke derived from durian rinds could be used to preserve chicken meatballs.
Keywords : *Durian rind-based liquid smoke, Pyrolysis, Escherichia coli, TVB, TPC*

1. Introduction

Durian (Durio zibethinus Murray), a common tree species in Southeast Asisa, including Indonesia (Siriphanich, 2011) is prized for its fruit. Only a small portion of the flesh of durian fruit is utilized, while the remainder, including its seeds and rind, is discarded and often burned. The rind constitutes 60−85% of the total durian fruit mass (Permanasari et al., 2020). The disposal of untreated durian waste can lead to environmental problems. Durian rind contains valuable components, such as cellulose, hemicellulose, and lignin, that can be converted into various products, including fuel (Saputro et al., 2018), briquettes (Sari et al., 2018), activated carbon (Yuliusman et al., 2020), biopesticides (Kusumaningtyas et al., 2019), and catalysts (Zhao et al., 2023). In addition, durian rind can be converted into liquid smoke, which can then be used as a food preservative.

A number of techniques, including pyrolysis, can be used for converting lignocellulosic materials (e.g., woody biomass) into liquid smoke, noncondensable gas, and char through heating in an oxygen-free environment (Shahbaz et al., 2020). Liquid smoke produced through pyrolysis is composed of more than 17 chemical compounds, including acetates and phenolics, which possess antimicrobial and antioxidant properties (Faisal et al., 2022). The presence of these compounds makes liquid smoke an attractive option as a food preservative. Liquid smoke has several advantages over other preservation methods, such as direct applicability to foodstuffs, control over the color and taste of the product, a lower risk of carcinogenic substances, and a faster application process (Dien et al., 2019; CT et al., 2020). Liquid smoke has successfully replaced the traditional smoking method, which requires lengthy cooking times, and its production is particularly cost-effective. The use of liquid smoke is more environmentally friendly than traditional smoking methods. It can also reduce food waste by lengthening product shelf lives and produces more consistent results than the conventional smoking methods.

Chicken meatballs, which are made from processed chicken meat, are a popular food item, particularly in Indonesia. They have a high nutritional value, they are low in fat, and they cost less than meatballs made from processed beef (Aslinah et al., 2018). However, chicken meatballs have a short shelf life. Thus, preservatives, such as formalin and borax, are frequently added with the aim of extending their shelf life. These preservatives are not intended for use in foodstuffs and pose a risk to human health (Naudalin et al., 2019). Their use in foodstuffs is banned in some countries due to their harmful properties (Wang et al., 2022). Thus, a natural alternative preservative, such as liquid smoke derived from biomass (e.g., durian rinds), is attractive. To date, liquid smoke produced from various biomass sources has been utilized as a preservative for a range of foods, including beef (Desvita et al., 2020), fish (Faisal & Gani, 2018), meatballs (Desvita et al., 2020), and tuna (Saloko et al., 2014). To the best of our knowledge, the use of liquid smoke from durian rind produced via pyrolysis at various temperatures as a preservative for chicken meatballs is not well documented in the literature. Therefore, this study aimed to evaluate the potential of liquid smoke from durian rind as a natural preservative to increase the shelf life of chicken meatballs.

2. Literature Review

As the development of technology, research have shown novel approaches to food processing and preservation that are harmless for people, including the use of liquid smoke as a preservative for food. After purification, liquid smoke does not contain potentially toxic compound such as benzopyrene and pAH, it’s safe for food consumption. Table 1 shows the summary of the preservation study by using liquid smoke. Based on previous research, liquid smoke safe for food preservation and consumption. Liquid smoke contains acetic acid and phenol compounds that have antibacterial and antioxidant properties (Desvita et al., 2022). Phenolic substances can denature proteins and harm the development of cell wall membranes of bacteria (Desvita et al., 2021). Several studies reported the ability of liquid smoke as a natural preservative in sausage (Martin et al., 2010), fish (Febriani et al., 2023), and mackerel (Syarif et al., 2023). Due to their antibacterial agent and easy of usage, liquid smoke are becoming more popular in the food business without affecting the flavor and improved smoke's preservation qualities. However, there has been little information investigated the chicken meatballs preserving affect on the pyrolysis temperature and liquid smoke concentration from durian rinds.

Table 1- Summary of Preservation Study by Using Liquid Smoke

No.	Preservatives Material	Result	References
1.	Liquid smoke for sausage preservation	No sensory changes in sausage. Liquid smoke can reduce the growth of *Listeria Monocytogenes* 1 Log rather than sausage without liquid smoke.	Martin et al., 2010
2.	Liquid smoke from coconut shell for barracuda fish preservation	The addition of liquid smoke 5% was able to maintain better quality after the storage of barracuda fish until 12 days.	Febriani et al., 2023
3.	Liquid smoke from Pandanus	Liquid smoke can be used as a natural	Dewi et al., 2023

	conoideus for fish preservation.	preservative for fish because of phenolic and acid compounds.	
4.	Liquid smoke for calabrege sausage preservation	The utilizing liquid smoke for Sausage Calabrese, better than traditional smoking method. Liquid smoke is a safe and promising method to achieve low levels of lipids, protein oxidation, and benzo(a)pyrenes.	Schwert et al., 2020
5.	Liquid smoke from ulin wood sawdust (*Eusideroxylon Zwageri*) as a preservative of mackerel (*Rastrelliger*)	Liquid smoke improved shelf life of mackerel in three days compared to control fish (without liquid smoke).	Syarif et al., 2023

3. Research Methods

Preparation of liquid smoke from durian rinds

Durian rinds were cut and sun-dried to reduce the water content to about 10%. Three kg of dried durian rinds were added to a tightly locked pyrolysis reactor. To produce grade-3 liquid smoke, the rinds were then pyrolyzed at three temperatures: 300°C (T1 liquid smoke), 340°C (T2 liquid smoke), and 380°C (T3 liquid smoke).

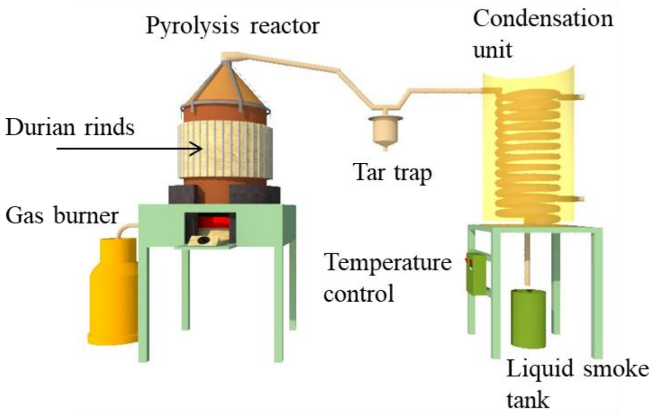

Fig. 1. Liquid Smoke Preparation From Durian Rinds.

The crude liquid smoke was then purified by distillation at 190°C, resulting in the production of food-grade liquid smoke. The procedure for preparing liquid smoke has been described in detail elsewhere (Desvita et al., 2021). Figure 1 outlines the preparation of liquid smoke from durian rinds using a slow pyrolysis reactor (stainless steel, 5 kg capacity, and 50 cm height x 32 cm diameter).

Application of liquid smoke to chicken meatballs

The distilled liquid smoke was diluted with distilled water at concentrations of 1%, 2%, and 3%. Subsequently, chicken meatballs were immersed in liquid smoke for 15 minutes, followed by draining and storage at room temperature for 72 hours. The meatballs were checked for signs of spoilage every 4 hours during this 72-hour period.

Total volatile basic nitrogen (TVB-N)

The TVB-N value is a measure of food quality, and a food item is considered to be inedible if its TVB-N value exceeds the acceptable limit of 20 mg N/100 g. The TVB-N values were tested according to Indonesian National Standard no. 2354.8:2009 (SNI, 2009).

Total plate count (TPC)

To test the TPC, a diluted sample (meatballs) was added to a petri dish filled with Natrium agar (NA) media. The dish was held near a Bunsen and covered with plastic wrap before being incubated for 24−48 hours at 37°C. Finally, the colony counting process was performed using a colony counter.

Most probable number (MPN)

The MPN was determined using an MPN test performed in accordance with Indonesian National Standard no. 2897:2008, using 3-3-3 dilution series method (SNI, 2008)

4. Results and Discussions

TVB-N

The effects of the pyrolysis temperatures (T1, T2, and T3) and liquid smoke concentrations (1%, 2%, and 3%) on the shelf life of chicken meatballs are shown in Figures 2−4. As shown in the figures, both the pyrolysis temperature and concentration of liquid smoke affected the shelf life. The shelf life of the meatballs increased in direct proportion to the increase in both the pyrolysis temperature and liquid smoke concentration. For example, the shelf life of the samples immersed in T1 liquid smoke concentrations of 1%, 2%, and 3% was 36 hours, 40 hours, and 44 hours, respectively, with TVB-N values of 19.89, 19.33, and 19.89 mg N/100 g, respectively. Sample freshness based on the TVB-N value remained within the safe limit for consumption (i.e., not exceeding 20 mg N/100 g) (Desvita et al., 2020). The samples immersed in T2 liquid smoke concentrations of 2% and 3% retained their freshness for up to 44 hours, whereas those immersed in T3 3% liquid smoke retained their freshness for up to 52 hours. In contrast, the chicken meatball samples exposed to no treatment remained fresh for only 24 hours, with a TVB-N value of 19.30 mg N/100 g. The high nutrient content (e.g., protein and carbohydrates) of meatballs can result in the growth of pathogenic microorganisms, such as *E. coli*, Salmonella spp., and Listeria, which can cause the breakdown of nutrients into amino acids and their derivatives, leading to spoilage (Puke & Galoburda, 2020). The addition of liquid smoke can increase the shelf life of perishable meatballs by inhibiting the growth of microorganisms. Two components of liquid smoke, phenols and organic acids, possess bacteriostatic properties (Budaraga, 2019). These two components can impact the growth of bacteria. The antibacterial effects of phenols and organic acids include protein coagulation and interference with peptidoglycan production, which affect bacterial cell formation and culminate in bacterial cell death (Li et al., 2023). A previous study that used liquid smoke from durian rinds to preserve mackerel found that adding 3% liquid smoke increased the shelf life of the fish, with the fish remaining fresh for up to 54 hours (Faisal et al., 2019).

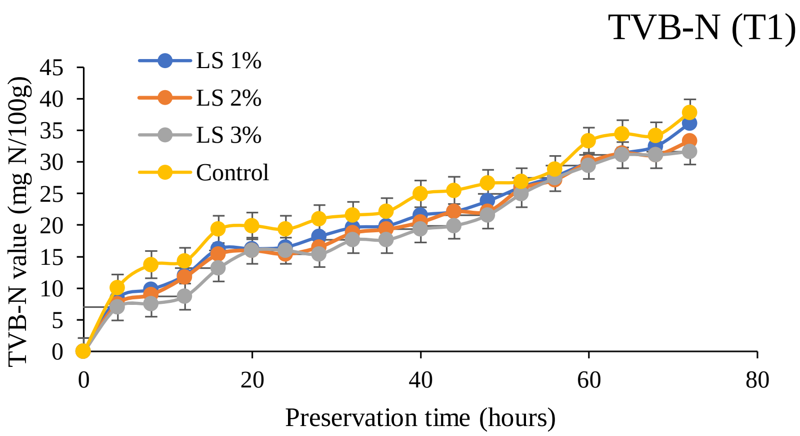

Fig. 2. Effect of the different liquid smoke concentrations on the TVB-N value and shelf life of chicken meatballs immersed in T1 liquid smoke.

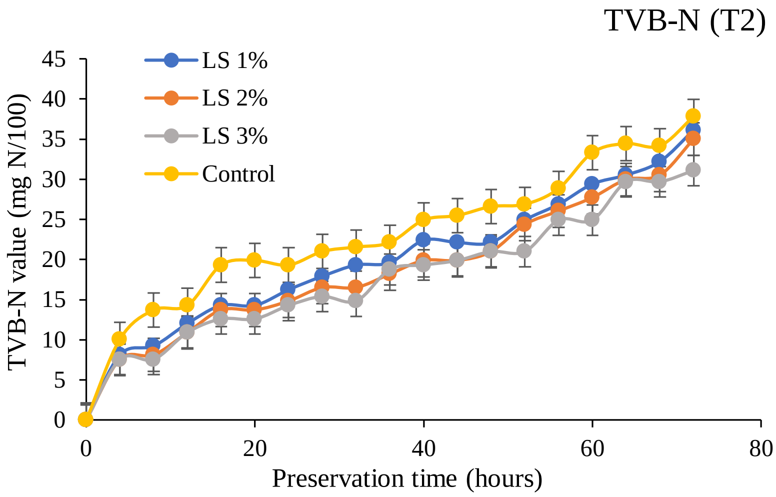

Fig. 3. Effect of the different liquid smoke concentrations on the TVB-N value and shelf life of chicken meatballs immersed in T2 liquid smoke.

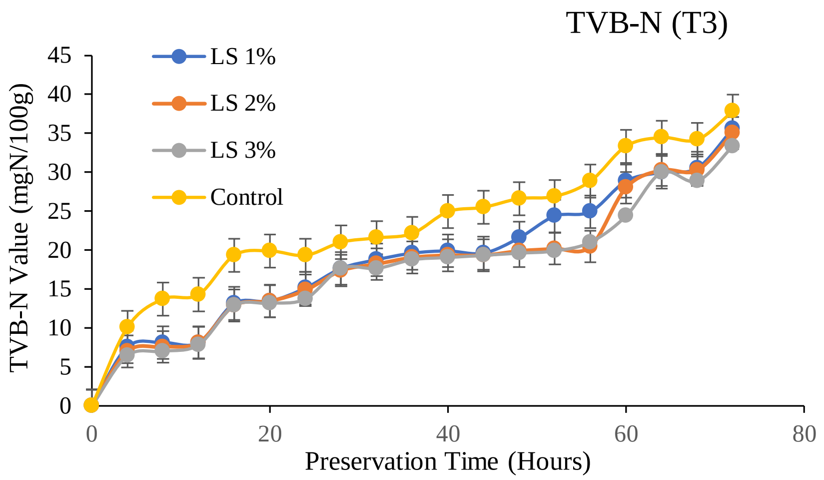

Fig. 4. Effect of the different liquid smoke concentrations on the TVB-N value and shelf life of chicken meatballs immersed in T3 liquid smoke.

TPC

The TPC denotes the number of bacterial colonies present in a food sample. It is used as a measure of the freshness of foodstuffs. According to Indonesian National Standards (SNI, 1992), to be considered safe for consumption, the TPC of foodstuffs should not exceed 5×10^5 CFU/g. The results of the TPC test are shown in Tables 2−4. They show that the chicken meatball samples immersed in T1 liquid smoke had a TPC value of 5.22×10^4 CFU/g and that the samples remained fresh for up to 40 hours. The samples treated with liquid smoke produced at higher pyrolysis temperatures (Table 2) remained suitable for consumption for up to 56 hours, with the same TPC value (5×10^5 CFU/g). In contrast, the samples exposed to no treatment were not suitable for consumption 24 hours later (Table 3).

According to Dien et al. (2019), in the early stages of microbial growth, cells do not divide, but after adapting to their environment, they grow and divide exponentially. An increase in the number of microbes can negatively impact the quality of foodstuffs. Phenolic compounds and organic acids, such as acetic acid, can work together to inhibit microbial growth. Acetic acid can penetrate bacterial cell walls and disrupt the normal function of cells, leading to inhibition of bacterial growth (Janairo & Amalin, 2018). Widayat et al. (2018) reported that meatballs immersed in liquid smoke remained fresh for more than 12 hours.

Table 2 - TPC test results of the T1 samples with various concentrations of liquid smoke

Observation Time (hours)	Total Plate Count (CFU/g) Liquid Smoke Concentration 1%	2%	3%
4	3.87×10^4	3.72×10^4	3.52×10^4
8	4.07×10^4	3.82×10^4	3.67×10^4
12	4.22×10^4	4.07×10^4	3.72×10^4
16	4.17×10^4	4.17×10^4	3.92×10^4
20	4.32×10^4	4.22×10^4	4.07×10^4
24	4.72×10^4	4.52×10^4	4.27×10^4
28	5.12×10^4	4.77×10^4	4.42×10^4
32	5.52×10^5	4.92×10^4	4.67×10^4
36	3.27×10^5	5.22×10^4	4.97×10^4
40	3.97×10^5	3.77×10^5	5.22×10^4
44	4.02×10^5	3.82×10^5	3.27×10^5
48	4.37×10^5	4.02×10^5	3.67×10^5
52	4.57×10^5	4.32×10^5	3.62×10^5
56	5.02×10^5	4.27×10^5	4.07×10^5
60	5.12×10^5	4.87×10^5	4.32×10^5
64	5.67×10^5	5.02×10^5	4.77×10^5
68	4.02×10^6	5.17×1^5	$4.82 \text{ X } 10^5$
72	4.22×10^6	4.42×10^6	$5.02 \text{ X } 10^5$

Note: : Safe for consumption.

Table 3 - TPC test results of the T3 samples with various concentrations of liquid smoke ults of TPC tests on the T3 sample with various concentrations of liquid smoke.

Observation Time (hours)	Total Plate Count (CFU/g) Liquid Smoke Concentration 1%	2%	3%
4	3.27×10^4	3.12×10^4	3.02×10^4
8	3.37×10^4	3.17×10^4	3.07×10^4
12	3.42×10^4	3.37×10^4	3.22×10^4
16	3.72×10^4	3.52×10^4	3.47×10^4
20	3.97×10^4	3.67×10^4	3.57×10^4
24	4.22×10^4	4.17×10^4	3.62×10^4
28	4.42×10^4	4.22×10^4	4.12×10^4
32	4.77×10^4	4.37×10^4	4.22×10^4
36	5.02×10^4	4.52×10^4	4.32×10^4
40	5.32×10^4	4.72×10^4	4.62×10^4
44	3.62×10^5	5.07×10^4	4.87×10^4
48	4.02×10^5	5.47×10^4	5.02×10^4
52	4.12×10^5	3.62×10^5	5.32×10^4
56	4.22×10^5	3.87×10^5	5.37×10^4
60	4.42×10^5	4.07×10^5	3.57×10^5
64	4.67×10^5	4.27×10^5	3.82×10^5
68	4.82×10^5	4.62×10^5	4.07×10^5
72	5.12×10^5	4.72×10^5	4.42×10^5

Note: : Safe for consumption.

Table 4 - Results of TPC analysis on the T0 sample.

Observation Time (hours)	Total Plate Count (CFU/g) Liquid Smoke Concentration Control
4	3.97×10^4
8	4.12×10^4
12	4.72×10^4
16	5.07×10^4
20	5.32×10^4
24	5.57×10^4
28	4.12×10^5

Note: Safe for consumption

MPN of chicken meatballs

As E. coli bacteria are known for their durability compared to other bacteria, the presence of *E. coli* in a sample can indicate the presence of other bacteria as well (Fransiska, 2022). Table 5 summarizes the results of the MPN test for *E. coli*. As the storage time increased, the MPN value for *E. coli* also increased, indicating an increase in bacterial growth. However, the liquid smoke treatment suppressed *E. coli* growth and extended the shelf life of the meatballs. In a previous study, the authors reported that the bactericidal properties of the phenolic compounds and organic acids in liquid smoke helped to prevent the growth of *E.coli* and other harmful bacteria (Dien et al., 2022). This finding is in line with the results of the present study where the MPN values of the meatball samples treated with T3 liquid smoke decreased in accordance with increasing concentrations of liquid smoke (1%: 290 MPN/g; 2%: 249 MPN/g; 3%: 210 MPN/g). This finding indicated that the meatball samples remained safe for consumption, as they did not exceed the maximum MPN value limit of 1×10^5 MPN/g for food items (Faisal, et. al., 2022). However, after 68 hours, the *E. coli* count in all the meatball samples at various liquid smoke concentrations reached the maximum limit, with an MPN value of over 1×10^5 MPN/g, making the meatballs no longer safe for consumption. Consuming *E. coli*-contaminated foodstuffs, especially in high amounts, can pose a health risk (Mentang et al., 2022). In a previous study, Hadanu et al. (2019) used coconut shell liquid smoke to preserve smoked fish. They found that after immersion in 3% liquid smoke for 30 minutes, the fish was free from harmful microbes, such as Staphylococcus spp., Salmonella spp., Coliforms, and *E. coli*. Another study used smoke powder to preserve chicken meatballs and showed that the meatballs remained safe for consumption for up to 68 hours after storage (Faisal et al., 2022).

Table 5 - Results of the MPN test on chicken meatball samples.

Sample	Observation Time	MPN (MPN/g)		
		Liquid Smoke Concentration		
		1%	2%	3%
T_1	0	0	0	0
T_2		0	0	0
T_3		0	0	0
T_1	24	14	11	3
T_2		11	3	<3
T_3		3	3	<3
T_1	48	64	43	36
T_2		43	36	35
T_3		38	29	27
T_1	56	240	210	180
T_2		210	160	120
T_3		160	120	75
T_1	60	460	290	290
T_2		460	240	240
T_3		290	240	210
T_1	64	>1100	1100	1100
T_2		1100	1100	460
T_3		1100	1100	460
T_1	68	>1100	>1100	>1100
T_2		>1100	>1100	>1100
T_3		>1100	>1100	1100

5. Conclusion

The liquid smoke made from durian rinds has the potential to be used as a preservative in chicken meatballs. Chicken meatballs preserved in liquid smoke derived from durian rinds retained their freshness for longer than normal. The extended preservation time (i.e., longer shelf life) is attributed to the antibacterial properties of organic acids and phenolic compounds in liquid smoke. Both the pyrolysis temperature and concentration of liquid smoke used as a preservative affected the shelf life. The TVB-N and TPC values of liquid-smoked chicken meatballs were lower than those of the control (without liquid smoke). The use of a low concentration of liquid smoke (1%) extended the shelf life of the chicken meatballs, allowing them to remain fresh for up to 40 hours after storage. The chicken meatballs treated with T3 liquid smoke and a higher liquid smoke concentration (3%) remained fresh for over 56 hours, with TVB-N, TPC, and MPN values that remained within acceptable limits.

Acknowledgement

This research was funded by the Ministry of Education, Culture, Research, and Technology of Indonesia (Grant no. 062/E5/PG.02.00.PL/2023). The authors would like to express their heartfelt appreciation to the Department of Chemical Engineering at Universitas Syiah Kuala for providing the facilities.

References

Adzaly, N. Z., Jackson, A., Kang, I., & Almenar, E. (2016). Performance of a novel casing made of chitosan under traditional sausage manufacturing conditions. *Meat science, 113*, 116-123. https://doi.org/10.1016/j.meatsci.2015.11.023

Aslinah, L. N. F., Mat Yusoff, M., & Ismail-Fitry, M. R. (2018). Simultaneous use of adzuki beans (Vigna angularis) flour as meat extender and fat replacer in reduced-fat beef meatballs (bebola daging). *Journal of food science and technology, 55*, 3241-3248. https://doi.org/10.1007%2Fs13197-018-3256-1

Budaraga, I. K. (2019, November). Influence of Liquid Smoke Cinnamon Against Attacks Leaf Rot Disease (*Phytophthora Infestans*) on Potato (*Solanum Tuberosum L.*). In *IOP Conference Series: Earth and Environmental Science* (Vol. 347, No. 1, p. 012036). IOP Publishing. http://dx.doi.org/10.1088/1755-1315/347/1/012036

CT, N., Sekhar Chatterjee, N., CG, J., TR, A., Mathew, S., & TK, S. G. (2020). Source-dependent compositional changes in coconut flavoured liquid smoke and its application in traditional Indian smoked fishery products. *Food Additives & Contaminants: Part A*, *37*(10), 1610-1620. https://doi.org/10.1080/19440049.2020.1798030

Dewi, F. C., Tuhuteru, S., Aladin, A., & Yani, S. (2023, May). Potential utilization of liquid smoke Pandanus conoideus as a natural preservative of fish during storage. In *AIP Conference Proceedings* (Vol. 2596, No. 1). AIP Publishing. https://doi.org/10.1063/5.0120215

Desvita, H., Faisal, M., Mahidin., & Suhendrayatna. (2022). Antimicrobial potential of wood vinegar from cocoa pod shells (*Theobroma cacao L.*) against Candida albicans and Aspergillus niger. *Materials Today: Proceedings*, *63*, S210-S213. https://doi.org/10.1016/j.matpr.2022.02.410.

Desvita, H., Faisal, M., Mahidin, M., & Suhendrayatna, S. (2021, March). Preliminary study on the antibacterial activity of liquid smoke from cacao pod shells (*Theobroma cacao L*). In *IOP Conference Series: Materials Science and Engineering* (Vol. 1098, No. 2, p. 022004). IOP Publishing. http://doi.org/10.1088/1757-899X/1098/2/022004.

Desvita, H., Faisal, M., Mahidin., & Suhendrayatna. (2021). Characteristic of liquid smoke produced from slow pyrolysis of cacao pod shells (*Theobroma cacao L*). *GEOMATE Journal*, *20*(80), 17-22. http://doi.org/10.21660/2021.80.6154.

Desvita, H., Faisal, M., Mahidin., & Suhendrayatna. (2020). Preservation of meatballs with edible coating of chitosan dissolved in rice hull-based liquid smoke. *Heliyon*, *6*(10). http://doi.org/10.1016/j.heliyon.2020.e05228.

Desvita, H., Faisal, M., Mahidin., & Suhendrayatna. (2020). Edible coating for beef preservation from chitosan combined with liquid Smoke. *International Journal of Technology*, *11*, 817-829. http://doi.org/10.14716/ijtech.v11i4.4039.

Dien, H. A., Montolalu, R. I., & Berhimpon, S. (2019, May). Liquid smoke inhibits growth of pathogenic and histamine forming bacteria on skipjack fillets. In *IOP Conference Series: Earth and Environmental Science* (Vol. 278, No. 1, p. 012018). IOP Publishing. http://doi.org/10.1088/1755-1315/278/1/012018.

Dien, H. A., Montolalu, R. I., Mentang, F., Berhimpon, S., & Nurkolis, F. (2022). Inhibition of microencapsulated liquid smoke on the foodborne pathogens and histamine-forming bacterias' growth in tuna loin sashimi: inhibition of liquid smoke microencapsulation. *Open Access Macedonian Journal of Medical Sciences (OAMJMS)*, *10*(A), 1200-1206. http://doi.org/10.3889/oamjms.2022.10182.

Faisal, M., & Gani, A. (2018). The effectiveness of liquid smoke produced from palm kernel shells pyrolysis as a natural preservative in fish balls. *GEOMATE Journal*, *15*(47), 145-150. http://doi.org/10.21660/2018.47.06109.

Faisal, M., Desvita, H., & Abubakar, Y. (2022). A Preliminary study on the use of rice husk-based Smoke powder for meatball preservatives. *Journal of Food Quality*, *2022*. http://doi.org/10.1155/2022/7915258.

Faisal, M., Gani, A., & Mulana, F. (2019). Preliminary assessment of the utilization of durian peel liquid smoke as a natural preservative for mackerel [version 6; peer review: 2 approved]. *F1000Research*, *8*. http://doi.org/10.12688/f1000research.18095.6.

Febriani, Y., Swastawati, F., & Fahmi, A. S. (2023, August). Effectiveness of liquid smoke as a preservative agent of barracuda fish cake during cold storage. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1224, No. 1, p. 012033). IOP Publishing. DOI 10.1088/1755-1315/1224/1/012033.

Fransiska, F. (2022). Uji most probable number (mpn) bakteri coliform dan organoleptik yoghurt bengkoang (Pachyrhizus erosus). *Agrofood*, *4*(2), 15-23.

Hadanu, R., & Lomo, C. P. (2019, November). Organoleptic test analysis and effect of liquid smoke concentration on smoked fish. In *IOP Conference Series: Earth and Environmental Science* (Vol. 382, No. 1, p. 012017). IOP Publishing. http://dx.doi.org/10.1088/1755-1315/382/1/012017.

Janairo, J. I. B., & Amalin, D. M. (2018). Volatile chemical profile of cacao liquid smoke. *International Food Research Journal*, *25*(1), 213-216.

Kusumaningtyas, R. D., Wulansarie, R., Astuti, W., Hartini, N., & Richana, S. (2019, June). Community empowerment on the biopesticide production from durian peel waste. In *ISET 2019: Proceedings of the 5th International Conference on Science, Education and Technology, ISET 2019, 29th June 2019, Semarang, Central Java, Indonesia* (p. 350). European Alliance for Innovation. http://dx.doi.org/10.4108/eai.29-6-2019.2290429.

Li, K., Zhong, W., Li, P., Ren, J., Jiang, K., & Wu, W. (2023). Antibacterial mechanism of lignin and lignin-based antimicrobial materials in different fields. *International Journal of Biological Macromolecules*, 126281. http://doi.org/10.1016/j.ijbiomac.2023.126281.

Martin, E. M., O'Bryan, C. A., Lary Jr, R. Y., Griffis, C. L., Vaughn, K. L., Marcy, J. A., & Crandall, P. G. (2010). Spray application of liquid smoke to reduce or eliminate Listeria monocytogenes surface inoculated on frankfurters. *Meat science*, *85*(4), 640-644. http://doi.org/10.1016/j.meatsci.2010.03.017.

Mentang, F., Montolalu, R. I., Dien, H. A., Ayub, M. E. K. O., & Berhimpon, S. (2022). Shelf life and presence of pathogens in liquid-smoked skipjack pampis packed in vacuum packaging (vp), modified atmosphere packaging (map), and stored at ambient temperature. *Nutrición Clínica y Dietética Hospitalaria*, *42*(4). https://doi.org/10.12873/424.

Naufalin, R. (2019, April). Natural preservation opportunities and challenges in improving food safety. In *AIP Conference Proceedings* (Vol. 2094, No. 1). AIP Publishing. http://doi.org/10.1063/1.509750.

Permanasari, A. R., Husna, A., Fuadah, R., Sihombing, R. P., Yulistiani, F., & Wibisono, W. (2020, December). The effect of durian husk and coconut shell combination in the liquid smoke generation: A Review. In *International Seminar of Science and Applied Technology (ISSAT 2020)* (pp. 496-501). Atlantis Press. http://doi.org/10.2991/aer.k.201221.082.

Puke, S., & Galoburda, R. (2020). Factors affecting smoked fish quality: A review. *Proceedings of the Research for Rural Development*, *35,* 132-139. http://doi.org/10.22616/rrd.26.2020.020.

Saloko, S., Darmadji, P., Setiaji, B., & Pranoto, Y. (2014). Antioxidative and antimicrobial activities of liquid smoke nanocapsules using chitosan and maltodextrin and its application on tuna fish preservation. *Food Bioscience*, *7*, 71-79. http://doi.org/10.1016/j.fbio.2014.05.008.

Saputro, H., Liana, D. N., Firdaus, A., Mahmudin, M., Evan, B., Karsa, B. S., ... & Fitriana, L. (2018, November). Preliminary study of pellets refuse derived fuel (RDF-5) based on durian waste for feedstock in fast pyrolysis. In *IOP Conference Series: Materials Science and Engineering* (Vol. 434, No. 1, p. 012184). IOP Publishing. http://doi.org/10.1088/1757-899X/434/1/012184.

Sari, E., Khatab, U., Desmiarti, R., & Ariansyah, R. (2018, March). Studies of carbonization process on the production of durian peel biobriquettes with mixed biomass coconut and palm shells. In *IOP Conference Series: Materials Science and Engineering* (Vol. 316, No. 1, p. 012021). IOP Publishing. http://doi.org/10.1088/1757-899X/316/1/012021.

Schwert, R., Verlindo, R., Soares, J. M., Silva, P. F., Cansian, R. L., Steffens, C., ... & Valduga, E. (2020). Effect of liquid smoke extract on the oxidative stability, benzopyrene and sensory quality of calabrese sausage. *Current Nutrition & Food Science*, *16*(3), 343-353. https://doi.org/10.2174/1573401315666190126120749

Shahbaz, M., AlNouss, A., Parthasarathy, P., Abdelaal, A. H., Mackey, H., McKay, G., & Al-Ansari, T. (2020). Investigation of biomass components on the slow pyrolysis products yield using Aspen Plus for techno-economic analysis. *Biomass Conversion and Biorefinery*, 1-13. http://doi.org/10.1007/s13399-020-01040-1.

Siriphanich, J. (2011). Durian (Durio zibethinus Merr.). In *Postharvest biology and technology of tropical and subtropical fruits* (pp. 80-116e). Woodhead Publishing. http://doi.org/10.1533/9780857092885.80.

Standar Nasional Indonesia 02-2725:1992. Batas minimum cemaran mikroba pada daging. Dewan Standarisasi Nasional , Jakarta. 1992.

Standar Nasional Indonesia 2354.8:2009. Penentuan kadar total volatil base nitrogen (TVB-N) dan trimetil amin nitrogen (TMA-N) Pada Produk Perikanan. Dewan Standarisasi Nasional, Jakarta. 2009.

Standar Nasional Indonesia 2897: 2008. Metode pengujian cemaran mikroba dalam daging, telur dan susu, serta hasil olahannya, Dewan Standarisasi Nasional, Jakarta. 2008.

Syarif, T., Aladin, A., Modding, B., Wiyani, L., & Dewi, F. C. (2023, May). Application of liquid smoke from pyrolysis byproducts of ulin wood sawdust (Eusideroxylon Zwageri) as a preservative of mackerel (Rastrelliger). In *AIP Conference Proceedings* (Vol. 2596, No. 1). AIP Publishing. https://doi.org/10.1063/5.0118742.

Wang, Y., Lv, H., Lan, J., Zhang, X., Zhu, K., Yang, S., & Lv, S. (2022). Detection of sodium formaldehyde sulfoxylate, aluminum, and borate compounds in bread and pasta products consumed by residents in Jilin Province, China. *Journal of Food Protection*, *85*(8), 1142-1147. http://doi.org/10.4315/JFP-22-011.

Widayat, W., Yaqin, N., & Al Baarri, A. N. (2018). Study of utilization liquid smoke and carrageenan as a natural antibacterial in manufacturing beef meatballs. In *IOP Conference Series: Earth and Environmental Science* (Vol. 102, No. 1, p. 012060). IOP Publishing. http://doi.org/10.1088/1755-1315/102/1/012060.

Yuliusman, Y., Ayu, M. P., Hanafi, A., & Nafisah, A. R. (2020, May). Activated carbon preparation from durian peel wastes using chemical and physical activation. In *AIP Conference Proceedings* (Vol. 2230, No. 1). AIP Publishing. https://doi.org/10.1063/5.0002348.

Zhao, C., Chen, H., Wu, X., & Shan, R. (2023). Exploiting the waste biomass of durian shell as a heterogeneous catalyst for biodiesel production at room temperature. *International Journal of Environmental Research and Public Health*, *20*(3), 1760. http://doi.org/10.3390/ijerph20031760.