Analysis of compounds and performance of coconut shell liquid smoke product for controlling *Stenotrophomonas maltophilia*, the causative agent of ice-ice disease in seaweed (*Kappaphycus alvarezii*)

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Abstract. Ice-ice is the main disease in seaweed cultivation and it is caused by *Stenotrophomonas maltophilia*, resulting in seaweed production failure. The newest technology currently available is the use of liquid smoke products from coconut shells. The use of liquid smoke aims to control *S. maltophilia*, which causes seaweed ice-ice disease. In this research, liquid smoke products were obtained from coconut shells using the Taguchi method, namely the coconut shells were dried and placed into pyrolysis and burned and the liquid smoke formed was deposited for 24 h and filtered. Liquid smoke compounds were analyzed using gas chromatography-mass spectrometry and high-performance liquid chromatography. The pathogenic bacterium *S. maltophilia* was cultured in seawater complex culture media. The inhibition test of liquid smoke and supernatant from coconut shells was performed using the Kirby-Bauer method. The research results showed that the compounds contained in liquid smoke that have antimicrobial properties are acetic acid and phenol. Liquid smoke and its supernatant with pyrolysis at different temperatures showed potential as an antimicrobial as indicated by the inhibition zone on *S. maltophilia* that causes ice-ice, with the best inhibition, namely a 5μL concentration of 15.00 mm, at a temperature of 180°C.
Key Words: antimicrobial, bacteria, ice-ice, seaweed, supernatant.

Introduction. Ice-ice disease infects seaweed and causes a significant reduction in production (loss of biomass), with a farm yield loss that can reach 70% and even crop failure (Ward et al 2022). The symptoms of this disease are the appearance of white spots (bleaching) on the talus. Ice-ice diseases are caused by opportunistic bacteria (Egan et al 2017; Kumar et al 2016), which are pathogens that reside in healthy or sick hosts, and can be dangerous if the host is disturbed (weakened) (Brown et al 2012), but can also carry out commensalism interactions (Egan et al 2014). One of these bacteria is *Stenotrophomonas maltophilia*, which has a high pathogenicity against seaweed (Achmad et al 2016).

Several efforts to control ice-ice disease have been carried out by administering NPK fertilizer (Syamsuddin & Rahman 2014), activating genes encoding lysozyme enzymes (Handayani et al 2014) and superoxide dismutase enzymes (Triana et al 2016), inhibiting them with *Sonneratia alba* mangrove leaf extract (Syafitri et al 2017) and with endophytic bacteria from *Avicennia marina* mangrove leaves (in vitro) (Rahman et al 2019), *A. marina* mangrove leaves extract (Rahman et al 2020a) or fermentation liquid (Rahman et al 2022; Rahman et al 2020a; Rahman et al 2020b). One technology used for controlling the causes of ice-ice disease is the use of liquid smoke from coconut shells.

Liquid smoke is the result of condensation of steam resulting from direct or indirect combustion of coconut shells which contain many compounds that have anti-microbial and antioxidant effects, such as phenols, carbonyl, acetic acid, furan, alcohols, and esters (Isa et al 2019). So far, liquid smoke has been used to inhibit the growth of bacteria because it contains compounds that can bind to bacterial proteins through hydrogen bonds, causing the protein structure to become damaged. Another ability of the liquid smoke is to lower the potential hydrogen (pH) in bacterial cells, disrupting their metabolism (Oktavia et al 2019).

Based on this description, the coconut shell smoke liquid is expected to be able to control *S. maltophilia*, that causes ice-ice disease in seaweed, considering that the compounds it contains can inhibit various pathogens. Therefore, this study aimed to evaluate the ability of liquid smoke to control *S. maltophilia* that causes *K. alvarezii* seaweed ice-ice disease on an in vitro scale.

Material and Method

Description of the study sites. This research was carried out from June to August 2023. Liquid smoke was prepared, and an inhibition test for ice-ice causing bacteria was carried out at the Integrated Laboratory, Program Study of Aquaculture, Faculty of Fishery, University of Muhammadiyah Luwuk, while gas chromatography-mass spectrometry analysis of liquid smoke compounds was carried out at the Integrated Laboratory of the Islamic University of Indonesia, Yogyakarta.

Liquid smoke from coconut shells. The liquid smoke procedure from the coconut shells was carried out based on the Taguchi method. Coconut shells were dried in the sun, subjected to pyrolysis, burned indirectly and the temperature was determined. Then the liquid smoke formed was settled for 24 h and filtered to reduce the tar content in the liquid smoke. Next, the purification process was carried out at the distillation temperature (100°C≤T1≤125°C), and the purified liquid smoke was put into bottles and stored at room temperature (28°C) (Siswanto 2020; Siswanto et al 2022). The purified liquid smoke was then used for phytochemical analysis to test its inhibitory ability against *S. maltophilia*.

Pathogenic bacterial culture. The pathogenic bacteria that cause ice-ice was identified from research results (Achmad et al 2016), namely *S. maltophilia*, which has the highest pathogenicity against seaweed. Confirmation of the level of pathogenicity of this bacterium was performed using the Koch postulate test. Bacterial isolates were cultured in sea water complex (SWC) media and incubated at 28°C for 24 h. One bacterial cell was taken from the solid culture media to be cultured in liquid SWC media and then homogenized using a shaker at 140 rpm for 24 h.

Analysis of coconut shell liquid smoke compounds. The compounds in liquid smoke were analyzed using gas chromatography–mass spectrometry (GC–MS). The acetic acid and phenol compounds were identified by high-performance liquid chromatography (HPLC) using the method of Saputra et al (2021).

Inhibition test of coconut shell liquid smoke and its supernatant against bacteria that cause ice-ice disease. The coconut shell liquid smoke and its supernatant were tested by centrifuging the liquid smoke sample at 10.000 rpm for 10 min, and the resulting supernatant was filtered using 0.22 μm filter paper. Next, the inhibition test of liquid smoke and supernatant was performed using paper discs with a diameter of 6 mm (Whatman no. 41). The disc paper was placed on SWC agar media, which had been inoculated with *S. maltophilia* 106 CFU mL^{-1}. Each paper disc was dripped with liquid smoke and supernatant at three different doses: 5, 10, and 15 μL. As a control, a paper disc was dripped with 10 μL of phosphate-buffered saline (PBS). Both treatment and control groups were then incubated for 24 h at 28°C, and the inhibition diameters were measured and analyzed.

Statistical analysis*.* Data on the inhibition of liquid smoke and supernatant were analyzed using analysis of variance (ANOVA). Statistical analyses were performed using the SPSS version 20 statistical software. If there was a significant effect (P<0.05), then the Tukey test was performed.

Results

Analysis of coconut shell liquid smoke compounds*.* The results of the coconut shell liquid smoke compound test using GC-MS revealed the following compounds: acetic acid, ethyl acid, vinegar acid, ethanoic acid, glacial acetic acid, methane carboxylic acid, CH_3COOH, components of phenol, ENT 1814, PhOH, benzenol, oxybenzene, monophenol, phenic acid, and carbolic acid (Table 1). Coconut shell liquid smoke can inhibit diseases or bacteria, depending on the chemicals contained in it. The two compounds in liquid smoke that are known to have bacteriostatic and bactericidal properties are acetic acid and phenol.

Table 1

Compound of coconut shell liquid smoke

Compounds	*Quantitative results (%)*		
	Liquid smoke temperature 100°C	*Liquid smoke temperature 150°C*	*Liquid smoke temperature 180°C*
Acetic acid (CAS)	98.8	95.9	90.9
Phenol	1.20	4.10	9.10

The results of the analysis of the liquid smoke compounds above show that liquid smoke had the highest levels of acetic acid at a temperature of 100°C followed by 150°C and 180°C, namely 98.8, 95.90, and 90.9%, respectively, whereas phenol levels in the three treatments were the opposite, namely the highest at the temperature of 180°C (9.10%), followed by 150°C (4.10%), and 100°C (1.20%). This indicates that liquid smoke at different pyrolysis temperatures affects the composition of the liquid smoke.

Liquid smoke inhibition test. Coconut shell liquid smoke (Table 2) and its supernatant (Table 3) inhibited *S. maltophilia*. The inhibitory strength depends on the concentration and temperature of the liquid smoke used.

Table 2

Inhibition activity of liquid smoke against *Stenotrophomonas maltophilia*

Product	*Inhibition diameter (mm)*
Control	0.00±0.00[a]
Liquid smoke temperature 100°C	13.33±0.58[b]
Liquid smoke temperature 150°C	18.33±2.08[c]
Liquid smoke temperature 180°C	18.67±1.15[c]

Different superscripts in the same column indicate significantly different results (P<0.05).

The inhibition of liquid smoke at different pyrolysis temperatures against *S. maltophilia* is presented in the table above. The highest inhibition diameter (P<0.05) was observed in the liquid smoke treatment at 180°C (18.67 mm), followed by the liquid smoke treatment at 150°C (18.33 mm), and liquid smoke treatment at 100°C (13.33 mm). This trend suggests that higher pyrolysis temperatures enhance the antimicrobial activity of liquid smoke. The increased inhibition may be attributed to the higher concentration of phenolic and acidic compounds formed during pyrolysis at elevated temperatures, which are known to contribute to the antibacterial properties of liquid smoke.

Table 3

Inhibition activity of liquid smoke supernatant against *Stenotrophomonas maltophilia*

Product	*Inhibition diameter (mm)*
Control	0.00±0.00[a]
Liquid smoke supernatant at 100°C	15.33±0.58[b]
Liquid smoke supernatant at 150°C	13.67±0.58[d]
Liquid smoke supernatant at 180°C	16.67±0.58[c]

Different superscripts in the same column indicate significantly different results (P<0.05).

The results of the analysis of variance showed that there were significant differences (P<0.05) between liquid smoke supernatants at 100, 150, and 100°C. The Tukey's test results for the supernatants at different liquid smoke pyrolysis temperatures showed significant differences (Table 3). The test results of the liquid smoke supernatant at 180°C had an average resistance of 16.67 mm, followed by the liquid smoke supernatant, with 100°C at 15.33 mm, and the liquid smoke supernatant at 150°C, with 13.67 mm. The results of the liquid smoke test against *S. maltophilia* showed different abilities for each liquid smoke type at different temperatures and concentrations (Table 4).

Table 4

Inhibition activity of liquid smoke against *Stenotrophomonas maltophilia*

Product	*Inhibition diameter (mm)*		
	Concentration 5 μL	*Concentration 10 μL*	*Concentration 15 μL*
Control	0.00±0.00[a]	0.00±0.00[a]	0.00±0.00[a]
Liquid smoke temperature 100°C	10.33±0.58[bc]	11.33±0.58[b]	14.33±0.58[b]
Liquid smoke temperature 150°C	10.00±0.00[b]	11.33±0.58[b]	11.33±0.58[c]
Liquid smoke temperature 180°C	11.00±0.00[c]	12.67±0.58[c]	15.00±1.00[b]

Different superscripts in the same column indicate significantly different results (P<0.05).

The use of liquid smoke at different concentrations had different effects on the inhibition diameter of *S. maltophilia*. The antibacterial test results showed that all concentrations of liquid smoke had inhibitory effects against *S. maltophilia* in the strong and moderate categories. High concentrations of 15 and 10 μL of liquid smoke had a strong response in terms of bacterial growth inhibition, while concentrations of 5 μL of liquid smoke still had a moderate response. The strongest inhibition diameter was liquid smoke at 180°C and liquid smoke at 100°C, respectively 15.00 and 14.33 mm at a concentration of 15 μL.

Discussion. Acetic acid and phenol compounds play a more dominant role as antimicrobials. Phenolic compounds and acetic acid are the two main compounds in liquid smoke that have bactericidal and bacteriostatic effects (Anggraini & Yuniningsih 2017). Acidic compounds can acidify the cytoplasm of bacterial cells and damage the cell membrane permeability (Cortesia et al 2014). Phenolic compounds act as antioxidants and antimicrobials (Assidiq et al 2018) and can damage bacterial cell membrane walls by denaturing proteins and dissolving lipids (Sabbineni 2016). According to Volk & Wheeler (1990), phenol at a concentration of 12.5% is bacteriostatic, while at higher concentrations it is bactericidal. Acetic acid compounds have stronger inhibition than phenol against bacterial growth. However, if the two compounds are combined in the form of liquid smoke, they will produce a greater inhibitory ability than either compound alone. This is in line with the opinion of Pszczola (1995), who stated that the combination of phenol and an organic acid (acetic acid) in liquid smoke is more effective in controlling microbial growth. The contents of acetic acid and phenol and the combination of both are thought to be important factors in inhibiting *S. maltophilia*. According to Oramahi &

Wardoyo (2018), the inhibition of liquid smoke on the growth of microorganisms is greatly influenced by the chemical components of liquid smoke, which are in turn influenced by the pyrolysis temperature, especially the acid and phenol content. Haji et al (2006) reported that phenol, which has a high boiling point in liquid smoke, is a highly antibacterial substance.

Increasing the pyrolysis temperature increased the inhibitory compounds in *S. maltophilia*. The supernatant inhibited *S. maltophilia*, as determined by the inhibition zone produced in each supernatant. The effectiveness of antimicrobial compounds from the supernatant in inhibiting microbial growth varies, as estimated by the content of antimicrobial compounds in the supernatant, which experiences the deposition of antimicrobial compounds, thus affecting the inhibition against *S. maltophilia* compared to liquid smoke at different pyrolysis temperatures. The inhibitory ability of the supernatant was still influenced by the presence of antimicrobial compounds, even though it experienced a decrease in inhibition compared to liquid smoke. The active compounds identified in the liquid smoke were mainly acetic acid and phenol. However, all liquid smoke supernatants at different pyrolysis temperatures showed strong inhibition against *S. maltophilia*. According to Rahman et al (2020a), the supernatant showed a decrease in antibacterial inhibition because some antimicrobial compounds were lost or precipitated during the centrifugation process, resulting in a lower concentration of active compounds remaining in the supernatant.

The resistance diameter is categorized as strong. According to Sumpono (2018) and David & Stout (1971), if the inhibition zone formed in the agar diffusion test is less than 5 mm, then the inhibitory activity is categorized as weak. If the inhibition zone measures 5-10 mm it is categorized as moderate, at 10-19 mm it is categorized as strong and >20 mm or more is categorized as very strong. The inhibition level was positively correlated to the treatment temperature and to the concentration level of the liquid smoke given to *S. maltophilia*. Alfiah et al (2015) showed that the size of the inhibitory zone is influenced by the concentration of the bacterial growth inhibitor and by the bacterial sensitivity. The higher the concentration of liquid smoke, the higher the phenol and acetic acid levels. Also, the more active ingredients with antibacterial properties, the higher the ability to inhibit bacterial growth.

Antimicrobial compounds at certain concentrations can inhibit bacterial colonies growth and even kill microbes, but no single antimicrobial compound fits all purposes, due to differences in the sensitivity of microbial cells to antimicrobial compounds. Furthermore, Pelczar & Chan (2005) explained that the size of the inhibition zone is also influenced by antibacterial activity, with a small inhibition zone indicating low antibacterial activity, while a large inhibition zone indicates high antibacterial activity.

Phenolic compounds and their derivatives also play a role in precipitating bacterial cell proteins. The phenol compounds contained in liquid smoke interact with bacterial cells through adsorption, which results in the formation of hydrogen bonds. At low levels, protein-phenol complexes are formed with weak bonds and immediately undergo decomposition, followed by penetration of phenol into bacterial cells which causes protein denaturation. At high levels, phenol causes protein coagulation and membrane lysis. Apart from containing phenol compounds, coconut shell liquid smoke also contains acid compounds. Organic acids function as bacteria growth reducers by lowering the pH to a level that inhibits bacterial growth. The principle of bacterial inhibition by organic acids is that the undissociated portion of the acid can penetrate the bacterial cell wall to disrupt the normal physiology of the cell.

Conclusions. The antimicrobial compounds contained in liquid smoke are acetic acid and phenol. Liquid smoke and supernatant with high-temperature pyrolysis have great potential for controlling *S. maltophilia*. Liquid smoke with different concentrations at different pyrolysis temperatures was able to better inhibit *S. maltophilia* (an inhibition zone diameter of 15.00 mm) at the concentration of 15 μL, at a temperature of 180°C.

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Conflict of interest. The authors declare that there is no conflict of interest.

References

Achmad M., Alimuddin A., Widyastuti U., Sukenda S., Suryanti E., Harris E., 2016 Molecular identification of new bacterial causative agent of ice-ice disease on seaweed *Kappaphycus alvarezii*. PeerJ Preprints 4:e2016v1.

Alfiah R. R., Khotimah S., Turnip M., 2015 [The effectiveness of methanol extract of creeping sembung leaves (*Mikania micrantha* Kunth) on the growth of *Candida albicans* fungus]. Jurnal Protobiont 4(1):52-57. [in Indonesian]

Anggraini S. P. A., Yuniningsih S., 2017 [Optimizing the use of liquid smoke from coconut shells as a natural preservative for fresh fish]. Jurnal Reka Buana 2(1):11-18. [in Indonesian]

Assidiq F., Rosahdi T. D., Viera B. V. E., 2018 [Utilization of coconut shell liquid smoke in preserving beef]. al-Kimiya 5(1):34-41. [in Indonesian]

Brown S. P., Cornforth D. M., Mideo N., 2012 Evolution of virulence in opportunistic pathogens: generalism, plasticity, and control. Trends in Microbiology 20(7):336-342.

Cortesia C., Vilcheze C., Bernut A., Contreras W., Gomez K., de Waard J., Jacobs W. R., Kremer L., Takiff H., 2014 Acetic acid, the active component of vinegar, is an effective tuberculocidal disinfectant. MBio 5(2):1-4.

David W. W., Stout T. R., 1971 Disc plate method of microbiological antibiotic assay. Applied Microbiology 22(4):659–665.

Egan S., Fernandes N. D., Kumar V., Gardiner M., Thomas T., 2014 Bacterial pathogens, virulence mechanism and host defence in marine macroalgae. Environmental Microbiology 16(4):925-938.

Egan S., Kumar V., Zozaya-Valdez E., Gardiner M. E., Hudson J., Deshpande N., Campbell A. H., Thomas T., 2017 Breaking bad: opportunistic bacterial pathogens of seaweeds. Phycologia 56(4, Supplement):48.

Haji A. G., Mas'ud Z. A., Lay B. W., Sutjahjo S. H., Pari G., 2006 [Characterization of liquid smoke pyrolyzed from solid organic waste]. Jurnal Teknologi Industri Pertanian 16(3):1–8. [in Indonesian]

Handayani T., Alimuddin, Widyastuti U., Suryati E., Parenrengi A., 2014 Binary vector construction and Agrobacterium tumefaciens-mediated transformation of lysozyme gene in seaweed *Kappaphycus alvarezii*. Biotropia 21:80-90.

Isa I., Musa W. J. A., Rahman S. W., 2019 [Utilization of coconut shell liquid smoke as an organic pesticide against armyworm mortality (*Spodoptera litura* F.)]. Jambi Journal Chemical 1(1):15–20. [in Indonesian]

Johnson B., Gopakumar G., 2011 Farming of the seaweed *Kappaphycus alvarezii* in Tamil Nadu coast-status and constraints. Marine Fisheries Information Service T&E Service 208:1-5.

Kumar V., Zozaya-Valdez E., Kjelleberg S., Thomas T., Egan S., 2016 Multiple opportunistic pathogens can cause bleaching disease of the red seaweed *Delisea pulchra*. Environmental Microbiology 18(11):3962-3975.

Oktavia D. A., Fitria A., Anggraini S. P. A., Yuniningsih S., 2019 [Application of coconut shell liquid smoke on organoleptic test of fresh fish as a natural preservative]. eUREKA 3(1):19-27. [in Indonesian]

Oramahi H. A., Wardoyo E. R. P., Kustiati K., 2018 [Efficacy of liquid smoke produced from bengkirai wood against on *Phytophthora citrophthora*]. Jurnal Perlindungan Tanaman Indonesia 22(2):160-166. [in Indonesian]

Pelczar M. J., Chan E. C. S., 2005 [Fundamentals of microbiology]. Universitas Indonesia Press, Jakarta, Indonesia, 997 p. [in Indonesian]

Pszczola D. E., 1995 Tour highlights production and uses of smoke-based flavors. Food Technology (Chicago) 49(1):70-74.

Rahman S. A., Sukenda S., Widanarni W., Alimuddin A., Ekasari J., 2019 Isolation and identification of endophytic bacteria from the mangrove leaves of *Avicennia marina* and evaluation of inhibition to bacterium causing ice-ice disease. AACL Bioflux 12(3):941-952.

Rahman S. A., Mutalib Y., Sangkia F. D., Athirah A., Marlan, Kadir M., Pattirane C. P., 2020a Evaluation of inhibitory potential of mangrove leaves extract *Avicennia marina* for bacteria causing ice-ice disease in seaweed *Kappaphycus alvarezii*. IOP Conference Series: Earth and Environmental Science 564:1-6.

Rahman S. A., Sukenda S., Widanarni W., Alimuddin A., Ekasari J., 2020b Characterization of fermentation liquid from mangrove leaves *Avicennia marina* and its inhibitory potential for bacterium causing ice-ice disease. Jurnal Akuakultur Indonesia 19(1):1-9.

Rahman S. A., Djawa S. K., Syahrul, 2022 [The use of fermented liquid products from mangrove leaves to control ice-ice disease and increase seaweed production of *Kappaphycus alvarezii*]. Monsu'ani Tano 5(1):133-142. [in Indonesian]

Sabbineni J., 2016 Phenol-an effective antibacterial agent. Journal of Medicinal & Organic Chemistry 3(2):182-191.

Saputra N. A., Komarayati S., Gusmailina G., 2021 [Organic chemical components of five types of liquid smoke]. Jurnal Penelitian Hasil Hutan 39(1):39-54. [in Indonesian]

Siswanto S., 2020 [Optimization of making quality liquid smoke from coconut shell and coconut fiber as organic pesticides using the Taguchi method]. Seminar dan Konferensi Nasional IDEC, pp. 1–10. [in Indonesian]

Siswanto S., Wiroto N., Herdianzah Y., Rahman S. A., 2022 [Optimization of making liquid smoke from coconut shell as organic disinfectant using Taguchi method]. Journal of Industrial Engineering Management 7(2):149-155. [in Indonesian]

Sumpono S., 2018 [Antioxidant and antibacterial activity test of liquid smoke from oil palm shells]. Seminar Nasional Pendidikan Sains, pp. 171-178. [in Indonesian]

Syafitri E., Prayitno S. B., Radjasa O. K., Ma'ruf W. F., 2017 The performance of mangrove leaf extract (*Sonneratia alba*) in combating bacterial associated with ice–ice disease of seaweed (*Kappaphycus alvarezii*). Advanced Science Letters 23(7): 6413-6415.

Syamsuddin R., Rahman S. A., 2014 [Control of ice-ice disease in Kappaphycus alvarezii seaweed through the use of N, P, and K fertilizers]. Simposium Nasional I Kelautan dan Perikanan, Makassar 2(1):1-9. [in Indonesian]

Triana S. H., Alimuddin, Widyastuti U., Suharsono, Suryati E., Parenrengi A., 2016 [Improvement method of gene transfer in *Kappaphycus alvarezii*]. Jurnal Ilmu dan Teknologi Kelautan Tropis 8(1):249-258. [in Indonesian]

Trono G. C. J., 1993 Effect of biological, physical and socio-economic factors on the productivity of *Eucheuma*/*Kappaphycus* farming industry. Proceedings of the Second RP-USA Phycology Symp./Workshop, Cebu Cityand Dumaguete City, Philippines, pp. 239-245.

Volk W., Wheeler M. F., 1990 [Basic microbiology]. Erlangga, Jakarta, Indonesia, 341 p. [in Indonesian]

Ward G. M., Kambey C. S. B., Faisan J. P. Jr., Tan P., Daumich C. C., Matoju I., Stentiford G. D., Bass D., Lim P. E., Brodie J., Poong S. W., 2022 Ice-Ice disease: An environmentally and microbiologically driven syndrome in tropical seaweed aquaculture. Reviews in Aquaculture 14:414–439.

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