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Article

Analysis of Utilization of Liquid Smoke from Agroindustry Waste (Coconut Sheels, Palm Oil Bunches, and Palm Shells)

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A B S T R A C T

The increasing production of oil palm and coconut commodities has intensified environmental challenges associated with agro-industrial solid waste, particularly coconut shells, oil palm fruit bunches, and palm shells. This study aims to analyse the utilization of liquid smoke derived from these agro-industrial wastes and to evaluate their potential applications based on previous research findings. The study was conducted using a descriptive–analytical literature review, in which relevant scientific articles were systematically selected and analysed according to raw material type, pyrolysis process, chemical characteristics, and application of liquid smoke. The results indicate that liquid smoke derived from coconut shells generally exhibits higher phenolic content, making it suitable for antimicrobial, antifungal, and medicinal applications, while liquid smoke from oil palm residues shows strong potential as an organic pesticide, fungal control agent, and natural rubber coagulant due to its organic acid content. These findings demonstrate that agro-industrial waste can be effectively vaporized into value-added products through liquid smoke production, contributing to waste reduction and environmental sustainability. This study provides a comparative framework for selecting appropriate biomass sources for specific liquid smoke applications and supports the development of sustainable waste management strategies.

1. Introduction

The leading plantation commodities in Indonesia are coconut and oil palm. Provisional figures for coconut plantation area in 2021 reached 3,374,347 hectares with a production of 2,853,299 tons, while oil palm plantation area reached 14,663,416 hectares with a total production of 9,370,891 tons (Direktorat Jenderal Perkebunan, 2021).

There is a direct correlation between production levels and the volume of waste generated. The organic content of palm oil and coconut industry waste affects pH, BOD, COD, metal content, and ammonia levels, thereby degrading soil and water quality. The best solution to reduce the volume of palm oil and coconut industry waste in the environment is to process it into liquid smoke (Pratama and Khalimatus, 2022).

Based on research conducted by Izwar Lubis et al. (2022), there has been no comprehensive comparative study of the three main types of waste: coconut shells, palm oil bunches, and palm shells. Therefore, the purpose of this study is to compare these three types of waste.

2. Literature Review

Liquid smoke is obtained by condensing vapors generated during the pyrolysis of biomass rich in cellulose, hemicellulose, and lignin (Soazo et al., 2016). Pyrolysis thermally decomposes organic materials into simpler compounds in an oxygen-limited or oxygen-free environment. The resulting liquid fraction of this process is designated as liquid smoke. A key benefit of pyrolysis is its high liquid yield, which can be up to 75% by weight significantly greater than other thermal conversion techniques like gasification or torrefaction (Souza et al., 2012).

According to Lingbeck et al. (2014), the pyrolysis process unfolds through four distinct stages: the evaporation of water, followed by the sequential decomposition of hemicellulose, cellulose, and finally lignin. The decomposition of hemicellulose and cellulose takes place between 180°C and 350°C, producing carboxylic acids and carbonyls. Meanwhile, lignin breaks down at temperatures from 300°C to 500°C, resulting in phenols. In general, the composition of compounds in various types of biomasses affects the quality of the liquid smoke produced. The decomposition products of compounds contained in biomass are grouped based on their chemical type, namely phenolic compounds, carbonyl compounds, and acids. Phenols are the most important compounds in liquid smoke as antibacterial and colouring agents, carbonyl compounds as colour and flavour formers in smoked products, while acid compounds act as antibacterial agents. Liquid smoke also contains tar and benzopyrene compounds, which are carcinogenic, so further purification is necessary (Shafira and Khalimatus, 2022).

Liquid smoke is classified into three grades according to its purification process and intended application. Grade 3 liquid smoke is produced without purification and has a blackish-brown color due to the presence of carcinogenic tar compounds. This grade is commonly used as a deodorizing agent in latex rubber. Grade 2 liquid smoke undergoes purification and is applied as a preservative in raw foods that are safe for consumption. In contrast, grade 1 liquid smoke is the most refined and transparent product, having been subjected to repeated purification, and is used as a preservative in food products such as noodles, meatballs, tofu, and barbecue seasonings (Rusydi, 2019). Given the extensive body of research on liquid smoke for both food and non-food applications, this paper provides an analysis of its wide-ranging uses from agro-industrial waste, including coconut shells, palm fruit bunches, and palm shells. The study is intended to contribute knowledge on how these by-products can be utilized to support waste control and reduce environmental harm.

Although numerous studies have discussed the production, characteristics, and applications of liquid smoke derived from various biomass sources, most existing literature primarily focuses on descriptive explanations of the pyrolysis process, chemical composition, and general utilization of liquid smoke. The majority of previous studies tend to examine liquid smoke either based on a single type of raw material or a specific application, such as food preservation or antimicrobial activity, without providing a comparative analysis across different agro-industrial waste sources. Furthermore, limited attention has been given to systematically classifying liquid smoke studies according to raw material origin or end-use application, which makes it difficult to identify the relative advantages and limitations of each biomass source.

Therefore, despite the extensive body of research on liquid smoke, a clear research gap remains in terms of comparative evaluation and integrated analysis of liquid smoke derived from different agro-industrial wastes. This study addresses this gap by classifying and analysing the utilization of liquid smoke based on its raw materials namely coconut shells, palm fruit bunches, and palm shells and their potential applications. By doing so, this research not only extends existing knowledge but also highlights the specific contribution of each waste material in supporting waste management strategies and reducing environmental impacts through value added utilization.

3. Research Methodology

Liquid smoke is created by capturing and condensing the vapors generated during biomass pyrolysis. The raw materials used to produce liquid smoke are generally very diverse, including coconut shells, palm fruit bunches, and palm shells. During the liquid smoke production process, these raw materials are reduced in size to 3-5 cm and dried to a constant weight so that the combustion surface area is larger, allowing the pyrolysis process to occur more quickly and evenly (Shafira dan Khalimatus, 2022).

Mustafiah and Nurliah (2017) produced organic insecticides using liquid smoke obtained from the pyrolysis of palm kernel shells and coconut shells mixed with biomass waste, applying palm kernel shell–to–coconut shell ratios of 0:100, 25:75, 50:50, 75:25, and 100:0. Their findings indicated that, from 1000 g of raw material, the percentage yield of liquid smoke rose markedly as the proportion of coconut shells increased. This study yielded a grade C liquid smoke, characterized by its dark brown hue and intense smoky odor. The analytical data for the product's viscosity, pH, density, and acetic acid content confirmed its adherence to the quality criteria set by Japanese specifications. The palm kernel shell and coconut shell liquid smoke samples were highly effective as organic insecticides because they were able to kill insects/pests in a short time.

The research methodology described above outlines the general process of liquid smoke production and presents findings from previous experimental studies. However, the methodology has not yet been systematically structured to clearly reflect the applied research design. The current description tends to emphasize general production procedures and summaries of earlier research rather than explicitly detailing the methodological framework adopted in this study. As noted by Creswell and Creswell (2018), a well-defined methodology should clearly articulate the type of research, sequential research stages, and criteria for data or reference selection to ensure transparency and reproducibility.

Therefore, this study is designed as a descriptive–analytical literature-based research, focusing on the analysis of liquid smoke utilization derived from agro-industrial waste, specifically coconut shells, palm fruit bunches, and palm shells. The research is conducted through several systematic stages: (1) identification and classification of relevant scientific literature related to liquid smoke production and utilization; (2) selection of references based on predefined criteria, including relevance to biomass type, pyrolysis process, and application of liquid smoke; (3) comparative analysis of liquid smoke characteristics and utilization potential according to raw material sources; and (4) synthesis of findings to highlight research trends, limitations, and opportunities for further development. This structured approach enables a clearer understanding of the contribution of each agro-industrial waste type in liquid smoke production and supports a more focused evaluation of its potential applications.

By adopting this methodological framework, the study moves beyond merely describing previous experiments and instead provides a systematic analysis that aligns with the research objectives. This approach also strengthens the validity of the study by ensuring that data and references are selected and analysed consistently, thereby offering meaningful insights into the role of agro-industrial waste valorisation in environmental management and sustainable resource utilization.

4. Results and Discussion

Isa et al. (2019) utilized liquid smoke as an organic pesticide for armyworms. Their research results show that spraying liquid smoke can kill armyworms. This occurs because spraying liquid smoke causes toxins to enter through the corn hairs, which then inhibit cell metabolism in the body, thereby also inhibiting electron transport in the mitochondria. As a result, the formation of energy from food as a source of energy in the cells does not occur, and the cells cannot function, causing the armyworms to die.

Liquid smoke has demonstrated potential in controlling pathogenic fungi that harm plants. Its efficacy is linked to its chemical makeup, with specific components determining how well it inhibits fungal growth (Oramahi et al., 2021). The chemical components that make up liquid smoke are influenced by several factors, such as the chemical components that make up wood (proximate) as raw material, including cellulose, hemicellulose, and lignin content, as well as the pyrolysis temperature in liquid smoke production. The ability of liquid smoke to inhibit fungi depends on the presence of chemical groups like phenols and acids. Furthermore, the temperature applied in pyrolysis is a key factor that alters this chemical composition, specifically the concentration of phenols and their derivatives.

Pangestu et al. (2014) utilized liquid smoke from coconut shells in an in vitro effort to control Phytophthora sp., the cause of cocoa fruit rot disease. The statistical analysis showed that the LC50 value in this study was 0.11%, indicating that coconut shell liquid smoke at concentrations above 0.11% was able to inhibit 50% of *Phytophthora* sp. mycelial growth. Comparable findings were reported by Oramahi et al. (2021), who demonstrated that liquid smoke derived from empty palm fruit bunches effectively acted as an antifungal agent by suppressing the growth of *Phytophthora citrophthora*. The ability of liquid smoke as an antifungal agent is due to the synergy between the organic acid and phenolic content of liquid smoke (Barbero-López et al., 2019). Mahmud et al. (2021) examined the effectiveness of liquid smoke produced from empty palm fruit bunches in suppressing *Ganoderma boninense* and *Curvularia* sp. under in vitro conditions. Their findings indicated that liquid smoke treatment altered the colony diameter of both pathogens. Moreover, the effectiveness of inhibition was significantly influenced by liquid smoke concentration, leading to reduced fungal growth rates and higher antifungal index values against *G. boninense* and *Curvularia* sp.

Ramadhan et al. (2022) showed that a mixture of liquid smoke produced from coconut shells and oil palm fronds is effective as a natural rubber coagulant. Their findings indicated that this coagulation method produced rubber with an optimal dry rubber content of 35.15%, suggesting that liquid smoke has strong potential as an alternative coagulant for farmers to enhance rubber quality. These research results are relevant to the findings of Asmawit et al. (2011), which show that the treatment of empty palm fruit bunches with liquid smoke produces rubber products that are superior in terms of color, odor, and drying time compared to the treatment with formic acid and battery acid that has been practiced by farmers.

Antimicrobial and antibacterial liquid smoke indicates that liquid smoke is also effective as an antibiotic. The study by Tarawan et al. (2016) focused on using liquid smoke produced from coconut shells for burn management. Their findings indicate that this liquid smoke is effective as a topical agent in rats with burn injuries. These findings still require additional investigation to assess the fractionated compounds in liquid smoke, and clinical trials are necessary to establish coconut shell liquid smoke as an alternative topical treatment for accelerating burn wound healing. Mawaddah et al. (2019) then attempted to assess the effectiveness of liquid smoke as an external medicine. Their findings indicated that liquid smoke derived from coconut shells contains phenolic compounds that may help treat infectious conditions such as abrasions and scabs. This method provides a practical, cost-effective alternative that is simple to manufacture.

Although the results and discussion section successfully compile findings from various studies on the application of liquid smoke in agriculture, rubber processing, and medical fields, the discussion remains largely descriptive and lacks a deeper analytical synthesis. Most previous studies report the effectiveness of liquid smoke in specific applications, such as pest control, antifungal activity, rubber coagulation, or antimicrobial treatment, without critically comparing the performance of liquid smoke derived from different raw materials. As a result, the relative effectiveness of liquid smoke produced from coconut shells, palm fruit bunches, and palm shells across diverse applications remains insufficiently explored.

A comparative analysis indicates that liquid smoke derived from coconut shells generally exhibits higher phenolic content, which contributes to its strong antimicrobial, antifungal, and medicinal properties, as evidenced by its effectiveness against Phytophthora sp. and its potential in wound treatment (Pangestu et al., 2014; Tarawan et al., 2016). In contrast, liquid smoke produced from oil palm residues, particularly empty fruit bunches and palm fronds, has demonstrated significant potential in agricultural and industrial applications, such as antifungal agents against Ganoderma boninense and as natural rubber coagulants, owing to its higher organic acid content (Mahmud et al., 2021; Ramadhan et al., 2022). These findings suggest that differences in chemical composition resulting from the type of raw material and pyrolysis conditions play a crucial role in determining the suitability of liquid smoke for specific applications.

Therefore, rather than viewing liquid smoke as a uniform product, it should be considered a material with application-specific potential depending on its biomass origin and chemical characteristics. This study contributes to the existing literature by synthesizing and critically comparing previous findings to highlight how agro-industrial waste type influences the functional performance of liquid smoke. Such an analytical approach not only clarifies inconsistencies among previous studies but also provides a clearer framework for selecting appropriate raw materials for targeted applications, thereby supporting more efficient waste valorization and sustainable utilization strategies.

5. Conclusion

This study analyzed the utilization of liquid smoke derived from agro-industrial waste, specifically coconut shells, palm fruit bunches, and palm shells, with a focus on its production process, chemical characteristics, and application potential. The findings from the reviewed studies indicate that liquid smoke produced from different biomass sources exhibits varying functional properties, primarily due to differences in chemical composition influenced by raw material type and pyrolysis conditions. Liquid smoke derived from coconut shells tends to have higher phenolic content, making it particularly effective for antimicrobial, antifungal, and medicinal applications. In contrast, liquid smoke obtained from palm-based waste, especially empty fruit bunches and palm shells, shows strong potential in agricultural and industrial applications, such as pest control, antifungal agents, and natural rubber coagulation, largely due to its organic acid content.

The results demonstrate that agro-industrial waste can be effectively valorized into value-added products through liquid smoke production, contributing to waste reduction and environmental sustainability. By synthesizing and comparing previous research, this study highlights that liquid smoke should not be considered a uniform product but rather a material whose effectiveness is application-specific and dependent on its biomass origin. This finding addresses the research objective of evaluating the utilization of liquid smoke from different agro-industrial wastes and provides a clearer framework for selecting appropriate raw materials for targeted applications.

In practical terms, the utilization of liquid smoke from coconut and palm-based waste offers an environmentally friendly alternative to synthetic chemicals in agriculture, food preservation, and industrial processing. For future research, experimental studies are recommended to quantitatively compare liquid smoke from different biomass sources under standardized pyrolysis conditions, as well as to evaluate its economic feasibility and environmental impacts at a larger scale. Further investigation into purification techniques and safety aspects is also necessary to expand the application of liquid smoke, particularly in food and medical fields.

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