Chemical Composition of Liquid Smoke from Mangrove Leaves: Potential Aphrodisiac Effects and Implications for Coastal Ecosystem Sustainability

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Abstract. This study investigates the chemical composition of liquid smoke derived from mangrove leaves (*Avicenna marina*) and explores the bioactive compounds with potential aphrodisiac effects, aiming to promote coastal ecosystem sustainability. Mangrove leaves were chosen due to their abundance in coastal areas and their ecological significance in maintaining ecosystem balance. The liquid smoke production process involved pyrolysis at various temperatures to determine the optimal conditions for extracting bioactive compounds. Gas Chromatography-Mass Spectrometry (GC-MS) analysis revealed that the liquid smoke dominantly consists of phenolic compounds, organic acids, and esters, potentially contributing to aphrodisiac effects. The temperature alteration from 100-200°C to 200-300°C also enhances the composition of organic acids (42.39-42.56%) and phenols (6.22-9.51%). From a sustainability perspective, utilizing mangrove leaves for liquid smoke production can aid in coastal ecosystem conservation by reducing organic waste and enhancing the economic value of mangrove-based products. This study can support the development of environmentally friendly and economically viable coastal resources, contributing to both ecosystem preservation and local economic growth.

Keywords: Aphrodisiac, Coastal ecosystem, Liquid smoke, Mangrove leaves, Sustainability.

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1 Introduction

Coastal ecosystems play a vital role in environmental balance and local economic activities, with mangrove forests being crucial for protecting against erosion, providing habitats for marine life, and supporting nutrient cycling [1]. Beyond their ecological functions, mangroves also offer valuable bioactive compounds that are useful in health, cosmetics, and pharmaceuticals [2]. Recent studies have shown that extracts from mangrove leaves contain bioactive substances like flavonoids and tannins, which have antioxidant properties and potential aphrodisiac effects, further enhancing their significance [3]. These findings support the development of mangrove-based products, such as bioactive liquid smoke, contributing to both ecosystem sustainability and local economic growth.

Mangrove leaves contain various bioactive compounds, including phenols, organic acids, and esters, which have been found to possess significant biological effects. Acetic acid and phenols, for example, are known for their antimicrobial and anti-inflammatory properties, while phenolic compounds exhibit antioxidant activities and potential health benefits [4]. These compounds, especially phenolic substances, have been linked to aphrodisiac effects, offering a natural alternative for enhancing reproductive health [5]. Pyrolysis is a process that involves heating organic material at high temperatures without oxygen [6,7]. It is employed to extract bioactive compounds from mangrove leaves, including flavonoids, phenols, esters, and organic acids. The temperature and duration of the pyrolysis process affect the types of bioactive compounds formed, potentially influencing their biological activities, such as aphrodisiac effects [8,9].

The pyrolysis process generates liquid smoke that could be utilized as a sustainable and eco-friendly product, contributing to coastal ecosystem conservation and local livelihoods. Studies on mangrove biomass, including species like *Avicenna marina*, have shown that pyrolysis produces bioactive compounds with potential aphrodisiac effects, similar to those identified in previous studies on plant-based aphrodisiacs [10]. This study aims to identify the bioactive compounds in liquid smoke derived from mangrove leaves and evaluate their potential as aphrodisiacs, supporting sustainable coastal resource use and local economic development while promoting ecosystem conservation.

2 Materials and methods

2.1 Feedstocks and pyrolysis reactor

Dried mangrove leaves (*Avicenna Marina*) in Figure 1a are shown as the source material for this process. A pyrolysis apparatus, consisting of a pyrolysis reactor equipped with a temperature control system, condenser, and liquid petroleum gas (LPG) stove.

Mangrove leaves (*Avicenna marina*) were collected from coastal areas and dried to reduce moisture content. Pyrolysis was carried out with temperature variations between 100-200°C and 200-300°C to determine the optimal temperature for producing liquid smoke rich in bioactive compounds. Figure 1b depicts the pyrolysis apparatus used for liquid smoke production.

(a) (b)

Fig. 1. Dried Mangrove Leaves (a); Pyrolysis Reactor (b).

2.2 Chemical analysis

The chemical composition of the liquid smoke was analyzed using gas chromatography-mass spectrometry (GC-MS). Each liquid smoke sample, produced at different temperatures, was tested to identify the main compounds, especially those with potential aphrodisiac effects. The total phenolic content and flavonoid content were assessed by respective assays to determine their concentrations. The metabolic composition of the extracts was analyzed by GC-MS using a PerkinElmer Clarus 600 Gas Chromatograph and established methods. GC-MS spectra were obtained using Turbo Mass software version 5.4.0, which allows for the identification and comparative analysis of the compounds contained in the extracts.

3 Results and discussion

3.1 Chemical composition of liquid smoke from mangrove leaves

Figure 2 presents liquid smoke produced from pyrolysis mangrove leaves. The observation was conducted on liquid smoke processed at temperatures of 100-200°C and 200-300°C. GC-MS analysis results show that pyrolysis temperature significantly influences the chemical composition of the liquid smoke. At 100-200°C, phenolic compounds and organic acids are the main components, with ester compounds starting to be detected at 200-300°C. The results are in line with several studies regarding biomass pyrolysis for bio-oil production. The phenolic and esters in the liquid smoke are known to have bioactive properties, which are suspected to contribute to its aphrodisiac effects [11]. Additionally, organic compounds such as carboxylic acids and alcohols were found in significant amounts, which may offer therapeutic benefits for diabetic patients [12].

Fig. 2. Liquid Smoke from *Avicenna marina*.

3.2 Chemical composition of liquid smoke from pyrolysis mangrove leaves at 100-200°C

This process serves as the primary substrate for the biosynthesis of flavonoids or H-lignin, two key metabolites branching from *phenylpropanoid* biosynthesis. CHS is known to be the initial step in flavonoid biosynthesis, producing *dihydrokaempferol* [13]. The main components, characteristic of liquid smoke, are acetic acid, phenol, and carbamate. Phenol, which plays a significant role in liquid smoke, has antibacterial and antifungal properties and inhibits fat oxidation [14,15]. Liquid smoke contains components derived from the thermal degradation of lignin, such as phenol, which acts as an antioxidant, acids with antimicrobial properties, guaiacol, syringol, and their derivatives, and alkyl aryl compounds [16].

Figure 3 shows that peaks 2, 3, 4, 5, and 13 correspond to acetic acid, accounting for 42%. Detailed information can be found in Table 1. Alcohol, phenol, and acetic acid are indicated as compounds that perform synergistically as protein denaturants and can break down lipids, damaging fungal cell membranes and inactivating enzymes secreted by fungi.

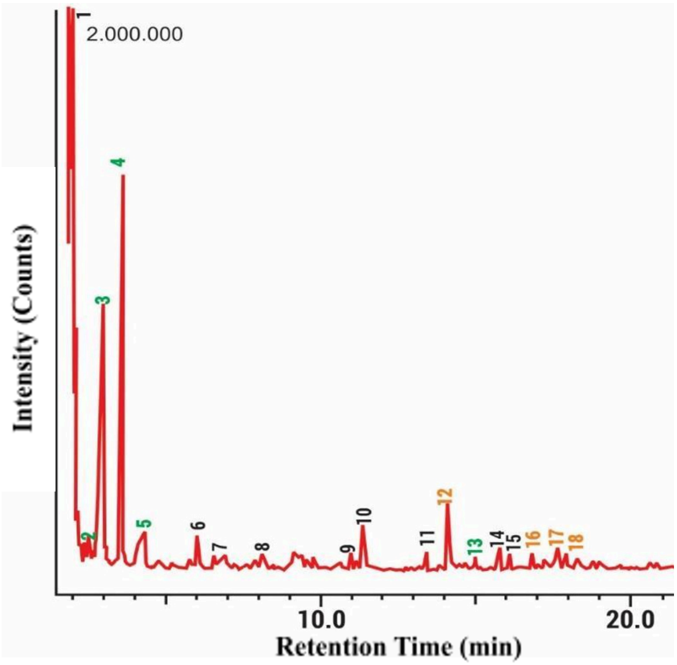

Fig. 3. GC-MS Chromatogram of Liquid Smoke from Pyrolyzed Mangrove Leaves at 100-200°C.

Table 1. Acetic Acid Components in Liquid Smoke from Pyrolyzed Mangrove Leaves.

Peak	%Area	Organic Compound
2	0.46	2-Butanone (CAS) Methyl ethyl ketone
3	28.73	Acetic acid
4	8.86	2-Propanone
5	3.93	Propanoic acid (CAS) Propionic acid
13	0.41	Butanoic acid
	42.39	Total Acid

In the meantime, Table 2 shows that the pyrolysis liquid smoke also contains phenolic compounds. Phenolic compounds have aphrodisiac potential due to their biological activity, which supports cardiovascular health and sexual function. Studies have shown that phenolic compounds, such as those found in pomegranates and other plants, can improve blood flow by reducing oxidative stress and increasing nitric oxide (NO) production, contributing to vasodilation. This increased blood flow is important for erectile function and overall sexual health. In Figure 3, phenolic compounds are highlighted in orange to aid visibility. The detected phenols are shown at peaks 12, 16, 17, and 18, marked in green. Mboumwa et al. reported that the pro-sexual and aphrodisiac properties of flavonoids, alkaloids, steroids, terpenes, tannins, glycosides, phenols, and saponins have been widely documented. The implications of these bioactive components on sexual function and reproductive parameters have been well-studied [17].

Table 2. Phenol Components in Liquid Smoke from Pyrolyzed Mangrove Leaves.

Peak	% Area	Organic Compound
12	3.56	Phenol
16	0.83	Phenol
17	1.23	Phenol
18	0.6	Phenol
	6.22	Total Phenol

Studies have demonstrated that polyphenols in pomegranate juice can increase nitric oxide (NO), which supports vasodilation, increases blood flow, and helps erectile function. These benefits have been observed in animal and human models [18,19]. Phenolics are known for their antioxidant activity, reducing oxidative stress in the cardiovascular system, and supporting sexual function by increasing blood flow and protecting tissues. Several traditional herbs, such as *Eurycoma longifolia*, contain phenolic and other bioactive compounds associated with improved libido and sexual function. These compounds work by increasing testosterone levels and blood flow [11].

Phenolic enhances sexual function through antioxidant activity, modulation of nitric oxide synthase enzymes, and improved blood quality. This suggests that phenol-rich foods or extracts can be used as adjunctive therapy for sexual dysfunction. The phenolic compounds found in various plant sources have been tested in animals and humans to assess their effects on libido and sexual performance. However, broader scientific evidence is still needed for further validation.

3.3 Chemical composition of liquid smoke from pyrolysis mangrove leaves at 200-300°C

Acetic acid is responsible for antimicrobial activity. The dominant components in vinegar vary depending on the type of biomass and the pyrolysis temperature. Overall, the main compounds in vinegar include acetic acid, 2-propanone, 2-furancarboxaldehyde, butyric acid, formic acid, butanoic acid, 4-methylphenol, 2-methoxy-4-methylphenol, and 2,6-dimethoxyphenol [20]. GC-MS analysis has shown that rice husk liquid smoke contains various chemicals such as acetic acid, 2-propanone, butanal, propanoic acid, 2-cyclopentene, and phenolic compounds, as reported by [16]. The pyrolysis product of *Aesculus chinensis* is rich in organic acids, aldehydes, and ketones, which can be used as raw materials for the production of vegetable oils, as it contains batilol, pregnenolone, benzoic acid, butyrolactone, and propanoic acid. These compounds can be used in biological medicine, chemical raw materials, and industrial reagents.

The pyrolysis product can be used in biomedical applications by 15.78%, including batilol, pregnenolone, and benzoic acid. The remaining 84.22% is primarily used in the chemical industry, and many of these materials can serve as raw materials for chemical and industrial use, such as acetic acid, formic acid, and acetone [21]. The analysis of the liquid smoke from mangrove leaves in this study reveals organic compound contents such as propionic acid and acetic acid, which are consistent with previous research, as seen in Table 3.

Table 3. Organic Component Content of Acetic Acid at 200-300°C.

Peak	% Area	Organic compound
3	1.18	*Oxirane*
4	0.56	*Oxirane*
5	33.89	Acetic acid
6	1.49	Propanoic acid (CAS) Propionic acid
8	1.33	2-Propanone
9	1.53	2-Propanone
12	0.43	Isovaleric Acid
24	0.76	Heptanoic acid (CAS) Heptoic acid
31	0.42	Heptanoic acid (CAS) Heptoic acid
32	0.97	cis-2,3-Epoxyheptane
	42.56	Total Acid

Figure 4 reveals the phenolic content marked at peaks 18, 22, 23, 25, 30, and 33, with further details provided in Table 4. A review of herbal materials such as *Eurycoma longifolia* mentions bioactive compounds, including phenolics, as agents to improve sexual health. Although the focus is on other plants, this effect provides a basis for the exploration of other phenolic sources [22]. Several chemical groups highlighted include organic acids, phenolic acids, flavonoids, coumarins, fatty acids, lipids, sesquiterpene lactones, terpenoids, and anthraquinones. *Jatropha macrantha* may be useful as a promising herbal medicine for erectile dysfunction or as an aphrodisiac [23].

Table 4. Phenol Content in Liquid Smoke from Pyrolysis at 200-300°C.

Peak	% Area	Organic compound
18	4.35	Phenol (CAS)
22	0.67	Phenol
23	1.15	Phenol
25	0.94	Phenol
30	0.57	Phenol
33	1.83	Phenol
	9.51	Total Phenol

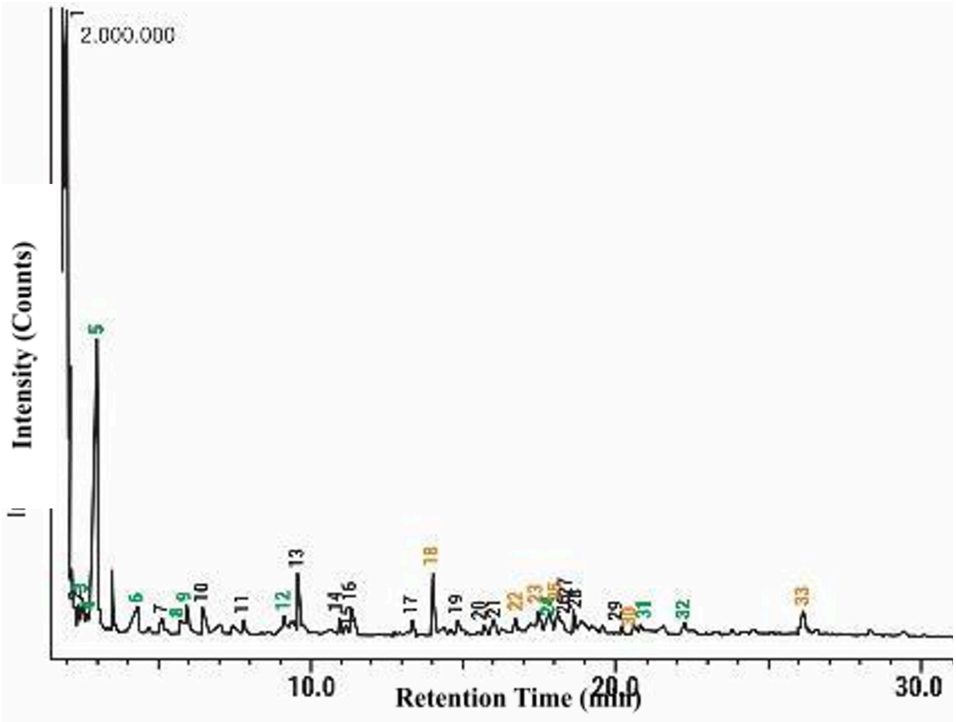

Fig. 4. GC-MS Chromatogram of Liquid Smoke from Pyrolyzed Mangrove Leaves at 200-300°C.

Liquid smoke, a product of the pyrolysis process, contains components such as phenol, furfural, and ketones, and has acidic characteristics. Liquid smoke from various biomass sources has been used as a natural preservative worldwide and is reported to be advantageous for human health benefits (in silico, in vitro, or in vivo). Specifically, it has benefits as an anti-inflammatory, antibacterial, anti-diabetic, and wound-healing agent, and has anti-periodontitis activity. Meanwhile, the therapeutic benefits of liquid smoke include antioxidant, anti-inflammatory, anti-nociceptive, antibacterial, antifungal, and antiviral activities [12].

3.4 Evaluation of bioactive compounds and aphrodisiac potential

Lignin plays an important role in the mangrove ecosystem and has potential applications in renewable energy, bioactive compounds, and material development. *Avicenna marina* contains 7.34% lignin [24,25]. Likewise, it consists of significant levels of bioactive compounds, with flavonoid concentrations ranging from 21.79% to 45.45% (relative to quercetin) and phenol content between 6.22% and 9.51% [26]. These phenolic compounds exhibit antioxidant properties that combat oxidative stress, a factor linked to sexual dysfunction, such as erectile dysfunction and reduced libido. Phenolic and flavonoid content can modulate blood flow through vasodilation, influence testosterone levels, and reduce stress, which are critical for enhancing sexual performance. Examples include the polyphenols in pomegranate juice and *Campsiandra angustifolia* bark, which have shown aphrodisiac potential in animal and human studies [19].

The bioactive phenolic compounds found in mangrove leaves act through multiple mechanisms. Their antioxidant activity helps reduce oxidative damage and improve vascular function, while hormonal modulation influences testosterone production, essential for male libido [18,23]. Additionally, phenolic aids in managing cognitive stress and fatigue, further supporting sexual health. Studies on other medicinal plants, like *Tribulus terrestris* and *Rhodiola rosea*, reveal similar bioactivities, with phenolic and steroidal saponins enhancing testosterone levels and sexual performance in animal models. Furthermore, the neuroprotective and anti-inflammatory properties of polyphenols contribute to managing conditions like diabetes mellitus, which often coexists with sexual dysfunction [27–29].

Utilizing mangrove leaves for bioactive liquid smoke production provides a sustainable and eco-friendly solution to coastal organic waste management while adding economic value to local communities. The diversification of mangrove-based products aligns with conservation strategies to protect mangrove ecosystems. This approach supports the dual goals of reducing environmental impact and generating high-value products, such as bioactive liquid smoke with potential health applications, including aphrodisiac effects [30,31]. Further studies are needed to confirm these biological effects for broader applications in health and wellness.

4 Conclusion

Liquid smoke originating from mangrove leaves, which is produced at 100-200°C, contains bioactive compounds such as 42.39% organic acids and 6.22% total phenol. In the meantime, pyrolysis at 200-300°C yields liquid smoke that consists of 42.56% organic acids and 9.51% total phenol. Both conditions have the potential to have an aphrodisiac effect. From this study, the use of mangrove leaves as raw material encourages the sustainability of coastal ecosystems by reducing organic waste and providing economic value. Nevertheless, further studies are needed to ensure and confirm its health compliance, particularly for managing diabetes-related sexual dysfunction, as phenolic compounds offer anti-inflammatory, antidiabetic, neuroprotective, and aphrodisiac benefits.

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