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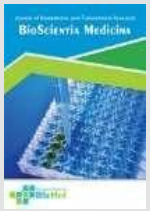

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Phytochemical Screening and In Vitro Antibacterial Activity of *Swietenia mahagoni* Leaf Extract against *Streptococcus mutans*: A Promising Natural Approach for Caries Prevention

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A B S T R A C T

Background: Dental caries, primarily caused by *Streptococcus mutans*, is a prevalent oral health issue. The rise of antibiotic resistance and side effects of synthetic antimicrobials have fueled the search for plant-derived alternatives. *Swietenia mahagoni* (mahogany) leaves, traditionally used for medicinal purposes, exhibit potential antibacterial properties. This study investigated the phytochemical composition and in vitro antibacterial activity of *S. mahagoni* leaf extracts against *S. mutans*. **Methods:** *S. mahagoni* leaves were collected, processed, and extracted using ethanol. Phytochemical screening identified alkaloids, tannins, flavonoids, and saponins. Antibacterial activity was assessed through the agar well diffusion method against *S. mutans*, using various extract concentrations (25%, 50%, 75%) and chlorhexidine as a positive control. Inhibition zone diameters were measured to determine antibacterial efficacy. **Results:** Phytochemical analysis confirmed the presence of alkaloids, tannins, flavonoids, and saponins in the *S. mahagoni* leaf extract. The extract demonstrated significant antibacterial activity against *S. mutans* at all concentrations. The highest concentration (75%) showed the largest inhibition zone (18.07 ± 0.37 mm), significantly larger than those of lower concentrations and the positive control (chlorhexidine, 13.87 ± 0.21 mm). **Conclusion:** *S. mahagoni* leaf extract exhibits substantial antibacterial activity against *S. mutans*, likely due to its diverse phytochemical content. These findings suggest its potential as a natural anti-caries agent. Further research is needed to explore its use in developing novel oral health products.

1. Introduction

Dental caries, commonly known as tooth decay, is a prevalent oral health problem that affects individuals of all ages worldwide. It is a chronic infectious disease characterized by the demineralization of tooth enamel and dentin, leading to the formation of cavities. If left untreated, caries can cause pain, tooth loss, and even systemic infections. The World Health Organization estimates that approximately 2.3 billion people suffer from caries of permanent teeth, while 530 million children experience caries of primary teeth. The global economic burden of dental caries is substantial, with billions of dollars spent annually on treatment and prevention. The primary etiological agent of dental caries is *Streptococcus mutans*, a Gram-positive bacterium that resides in the oral cavity. *S. mutans* metabolizes carbohydrates, producing lactic acid as a byproduct. This lactic acid creates an acidic environment in the mouth, which leads to the

dissolution of tooth minerals and the formation of carious lesions. *S. mutans* possesses several virulence factors that contribute to its cariogenicity, including its ability to adhere to tooth surfaces, form biofilms, and produce acids.[1-3]

The conventional approach to caries management involves the use of synthetic antimicrobials, such as chlorhexidine. However, the widespread use of these agents has led to the emergence of antibiotic resistance, making them less effective. Moreover, some synthetic antimicrobials can cause adverse effects, such as tooth staining and taste alteration, limiting their long-term use. The rise of antibiotic resistance and the side effects of synthetic antimicrobials have fueled the search for alternative approaches to caries prevention and management. In recent years, there has been growing interest in exploring natural products, particularly those derived from plants, as potential alternatives to synthetic antimicrobials. Plants are rich sources of bioactive compounds, including alkaloids, tannins, flavonoids, and saponins, which have demonstrated a wide range of pharmacological activities, including antibacterial effects. These phytochemicals have the potential to inhibit the growth of *S. mutans* and other cariogenic bacteria, thereby preventing the formation of caries.[4-6]

Swietenia mahagoni (L.) Jacq., commonly known as mahogany, is a large tropical tree belonging to the Meliaceae family. It is widely distributed in various regions of the world, including Indonesia, India, and the Americas. Traditionally, different parts of the mahogany tree, including the bark, leaves, and seeds, have been used in folk medicine to treat various ailments, such as hypertension, diabetes, fever, and infections. Scientific investigations have revealed that S. mahagoni leaves contain a diverse array of phytochemicals, including flavonoids, saponins, tannins, and alkaloids, which contribute to their potential therapeutic properties. Flavonoids, in particular, have been shown to possess potent antioxidant and anti-inflammatory activities, which may play a role in protecting against oral diseases. Previous studies have demonstrated the antibacterial activity of S. mahagoni leaf extracts against various bacterial strains, including Staphylococcus aureus, Escherichia coli, and Salmonella typhi. However, there is limited information on the specific effects of S. mahagoni leaf extract on *S. mutans*, the primary cariogenic bacterium.[7-10] Therefore, this study aimed to investigate the phytochemical constituents and evaluate the in vitro antibacterial activity of S. mahagoni leaf extracts against *S. mutans*.

2. Methods

Fresh, mature leaves of *Swietenia mahagoni* (L.) Jacq. were collected from Deli Serdang, North Sumatra, Indonesia, during the dry season (May-September) to ensure optimal phytochemical content. The selection of mature leaves is crucial as they possess higher concentrations of bioactive compounds compared to younger leaves. The leaves were collected from healthy trees exhibiting no signs of disease or damage. The collected plant material was authenticated by a qualified botanist at the Herbarium of the Department of Biology, Faculty of Mathematics and Natural Sciences, Prima Indonesia University, Medan, Indonesia. A voucher specimen (SM-2023-01) was deposited at the herbarium for future reference. The collected leaves were immediately transported to the laboratory in sealed plastic bags to prevent contamination and loss of moisture. Upon arrival, the leaves were subjected to a thorough washing process using running tap water to remove any adhering dust, debris, or microorganisms. This step is essential to ensure the purity of the extract and prevent interference with subsequent analyses. After washing, the leaves were spread out in a single layer on clean trays lined with absorbent paper. The trays were then placed in a well-ventilated, shaded area, away from direct sunlight, to facilitate air-drying. Air-drying in the shade is preferred over sun-drying to prevent the degradation of heat-sensitive phytochemicals. The drying process continued until the leaves reached a constant weight, indicating complete moisture removal. This typically took 7-10 days, depending on

the ambient temperature and humidity. The dried leaves were then carefully inspected to remove any discolored or damaged portions. This ensures that only high-quality plant material is used for extraction. The selected leaves were then ground into a fine powder using a laboratory-grade blender. The fine powder form increases the surface area for efficient extraction of phytochemicals. The powdered leaves were stored in airtight containers, protected from light and moisture, at room temperature until further use. The choice of solvent for extraction is crucial as it influences the type and quantity of phytochemicals extracted. Ethanol (96%) was selected as the extraction solvent in this study due to its several advantages. Ethanol is a relatively polar solvent capable of extracting a wide range of phytochemicals, including alkaloids, tannins, flavonoids, and saponins. It is also less toxic compared to other organic solvents, making it safer for handling and disposal. Additionally, ethanol is readily available and cost-effective. The extraction process was carried out using the maceration method, a simple and widely used technique for extracting phytochemicals from plant materials. Maceration involves soaking the plant material in the solvent for an extended period, allowing the solvent to penetrate the plant cells and dissolve the desired compounds. The powdered leaves were macerated in 96% ethanol at a ratio of 1:10 (w/v), meaning 1 gram of powdered leaves was soaked in 10 milliliters of ethanol. This ratio ensures sufficient solvent volume for efficient extraction. The maceration process was carried out for 72 hours at room temperature (25 ± 2°C) in sealed glass containers. The containers were placed on an orbital shaker and agitated at 100 rpm to facilitate continuous contact between the plant material and the solvent. The agitation enhances the extraction efficiency by promoting the diffusion of phytochemicals from the plant cells into the solvent. After 72 hours, the mixture was filtered through Whatman No. 1 filter paper to separate the liquid extract from the solid residue. The residue was then re-macerated with fresh ethanol for another 24 hours to ensure complete extraction of the phytochemicals. The combined filtrates were then subjected to concentration using a rotary evaporator. The rotary evaporator is a commonly used laboratory equipment for removing solvents from solutions under reduced pressure and controlled temperature. The combined filtrates were concentrated using a rotary evaporator at 40°C under reduced pressure. The reduced pressure lowers the boiling point of the solvent, preventing the degradation of heat-sensitive phytochemicals. The concentrated extract was then lyophilized to obtain a dry powder. Lyophilization, also known as freeze-drying, is a process that removes water from a frozen sample by sublimation under vacuum. This technique preserves the integrity of the phytochemicals and yields a stable, dry powder that is easy to store and handle. The lyophilized extract was stored at -20°C in airtight containers, protected from light and moisture, until further analysis. The low-temperature storage prevents the degradation of phytochemicals and maintains the stability of the extract.

Phytochemical screening is a qualitative analysis that aims to identify the presence of various secondary metabolites in plant extracts. Secondary metabolites are organic compounds produced by plants that are not directly involved in their growth and development but play important roles in their defense mechanisms and interactions with the environment. These compounds often possess diverse pharmacological activities, making them valuable sources of potential therapeutic agents. The phytochemical screening of the *S. mahagoni* leaf extract was performed using standard qualitative methods to identify the presence of alkaloids, tannins, flavonoids, and saponins. These phytochemicals were selected based on their reported antibacterial activities and their potential relevance to caries prevention. Alkaloids are a diverse group of nitrogen-containing compounds that exhibit a wide range of pharmacological activities, including antibacterial, antifungal, and anti-inflammatory effects. The presence of alkaloids in the *S. mahagoni* leaf extract was assessed using three different tests: Dragendorff's, Mayer's, and Wagner's tests;

Dragendorff's Test: This test involves the reaction of alkaloids with Dragendorff's reagent, a solution of potassium bismuth iodide. The formation of an orange-brown precipitate indicates the presence of alkaloids; Mayer's Test: This test involves the reaction of alkaloids with Mayer's reagent, a solution of potassium mercuric iodide. The formation of a white-yellowish precipitate indicates the presence of alkaloids; Wagner's Test: This test involves the reaction of alkaloids with Wagner's reagent, a solution of iodine in potassium iodide. The formation of a reddish-brown precipitate indicates the presence of alkaloids. Tannins are polyphenolic compounds that have astringent properties and are known for their ability to bind and precipitate proteins. They have demonstrated various biological activities, including antibacterial, antiviral, and antioxidant effects. The presence of tannins in the *S. mahagoni* leaf extract was assessed using the ferric chloride test; Ferric Chloride Test: This test involves the reaction of tannins with ferric chloride solution. The formation of a dark blue or greenish-black color indicates the presence of tannins. Flavonoids are a large group of polyphenolic compounds that are widely distributed in plants. They exhibit a variety of biological activities, including antioxidant, anti-inflammatory, and antibacterial effects. The presence of flavonoids in the *S. mahagoni* leaf extract was assessed using the Shinoda test; Shinoda Test: This test involves the reaction of flavonoids with magnesium powder and concentrated hydrochloric acid. The formation of a yellow to orange coloration after adding magnesium powder and concentrated hydrochloric acid, followed by a red coloration after adding sodium hydroxide, indicates the presence of flavonoids. Saponins are glycosides with soap-like properties that are known for their ability to form stable foams in aqueous solutions. They have demonstrated various biological activities, including antibacterial, antifungal, and anti-inflammatory effects. The presence of saponins in the *S. mahagoni* leaf extract was assessed using the foam test; Foam Test: This test involves shaking the extract with water and observing the formation of foam. The formation of persistent foam, which does not disappear easily, indicates the presence of saponins. The foam height can be measured and compared to a standard to estimate the saponin content.

The bacterial strain used in this study was *Streptococcus mutans* ATCC 25175, a standard strain widely used in caries research. This strain was obtained from the American Type Culture Collection (ATCC), a non-profit organization that maintains and distributes a vast collection of microorganisms for research and educational purposes. The use of a standard strain ensures the reproducibility and comparability of the results with other studies. *S. mutans* ATCC 25175 was cultured on Brain Heart Infusion (BHI) agar plates, a rich medium that supports the growth of a wide range of microorganisms. BHI agar contains a blend of peptones, glucose, and other nutrients that provide the necessary components for bacterial growth. The agar is a solidifying agent that provides a solid surface for bacterial growth and colony formation. The inoculated BHI agar plates were incubated at 37°C for 24 hours under aerobic conditions. The incubation temperature of 37°C mimics the oral cavity's temperature, providing optimal conditions for *S. mutans* growth. The aerobic conditions ensure the availability of oxygen, which is required for the growth of *S. mutans*.

The antibacterial activity of the *S. mahagoni* leaf extract was evaluated using the agar well diffusion method, a simple and widely used technique for assessing the antibacterial activity of plant extracts and other substances. This method is based on the diffusion of the test substance through the agar medium, creating a concentration gradient around the well. The test substance inhibits the growth of bacteria in the surrounding area if it has antibacterial activity. BHI agar plates were inoculated with a standardized suspension of *S. mutans* (10^6 CFU/mL) using a sterile cotton swab. The standardized suspension ensures a consistent bacterial concentration across all plates, allowing for reliable comparison of results. The cotton swab is used to evenly spread the bacterial

suspension over the agar surface, creating a uniform lawn of growth. After inoculation, wells of 6 mm diameter were punched into the agar using a sterile cork borer. The wells serve as reservoirs for the test substance. The 6 mm diameter is a standard size used in agar well diffusion assays. Different concentrations of the *S. mahagoni* leaf extract (25%, 50%, and 75%) were prepared by dissolving the lyophilized extract in dimethyl sulfoxide (DMSO). DMSO is a polar aprotic solvent that is commonly used to dissolve plant extracts for antibacterial assays. It is known to have minimal antibacterial activity on its own. The prepared extract solutions were then added to the wells in the agar plates. Each concentration was tested in triplicate to ensure reproducibility. Chlorhexidine (0.2%) was used as a positive control, while DMSO was used as a negative control. Chlorhexidine is a synthetic antimicrobial agent that is widely used in dentistry and has well-established antibacterial activity against *S. mutans*. DMSO serves as a negative control to account for any potential antibacterial activity of the solvent itself.

The plates were incubated at 37°C for 24 hours to allow bacterial growth and the diffusion of the test substances. After incubation, the diameter of the inhibition zones around the wells was measured using a digital caliper. The inhibition zone is the clear area around the well where bacterial growth is inhibited. The diameter of the inhibition zone is a measure of the antibacterial activity of the test substance.

The data collected from the antibacterial activity assay were entered into a spreadsheet and analyzed using SPSS software (version 25). The data consisted of the diameter of the inhibition zones for each concentration of the *S. mahagoni* leaf extract, chlorhexidine, and DMSO. The normality of the data was assessed using the Shapiro-Wilk test, a statistical test that assesses whether a dataset follows a normal distribution. The normal distribution is a bell-shaped curve that is commonly used in statistical analysis. The Shapiro-Wilk test compares the observed distribution of the data to a normal distribution and calculates a p-value. A p-value greater than 0.05 indicates that the data is normally distributed. One-way analysis of variance (ANOVA) was used to compare the mean inhibition zone diameters among the different groups. ANOVA is a statistical test that compares the means of two or more groups to determine if there is a significant difference between them. It calculates an F-statistic, which is a measure of the variance between the groups relative to the variance within the groups. A p-value less than 0.05 indicates that there is a significant difference between the means of the groups. Post hoc comparisons were performed using Tukey's test to determine which specific groups were significantly different from each other. Tukey's test is a multiple comparison test that compares all possible pairs of means. It calculates a p-value for each pair of means, indicating whether the difference between them is statistically significant. A p-value less than 0.05 indicates a significant difference between the two means.

3. Results

Table 1 summarizes the results of the phytochemical screening of the *Swietenia mahagoni* leaf extract. The screening aimed to identify the presence of various secondary metabolites, namely alkaloids, tannins, flavonoids, and saponins, using specific qualitative tests. The table presents the phytochemical tested, the test employed, the result (positive or negative), and the observation associated with each test; Alkaloids: The extract was tested for alkaloids using three different reagents: Dragendorff's, Mayer's, and Wagner's. Positive results were observed for all three tests, indicating the presence of alkaloids in the extract. The observations include the formation of orange-brown precipitate with Dragendorff's reagent, white-yellowish precipitate with Mayer's reagent, and reddish-brown precipitate with Wagner's reagent. These precipitates are characteristic reactions of alkaloids with the respective reagents; Tannins: The presence of tannins was assessed using the ferric chloride test. The extract showed a positive result, indicated by the development of a dark blue or greenish-black color upon reaction with ferric chloride

solution. This color change is attributed to the complexation of tannins with ferric ions; Flavonoids: The Shinoda test was employed to detect flavonoids in the extract. A positive result was observed, characterized by a yellow to orange coloration after the addition of magnesium powder and concentrated hydrochloric acid. Further addition of sodium hydroxide resulted in a red coloration. These color changes are indicative of the presence of flavonoids, which undergo structural changes in response to the reagents; Saponins: The foam test was used to determine the presence of saponins. The extract produced persistent foam upon shaking with water, suggesting the presence of saponins. The foam height was measured and compared to a standard, providing a qualitative estimate of the saponin content.

Table 1. Phytochemical constituents of *Swietenia mahagoni* leaf extract.

Phytochemical	**Test**	**Result**	**Observation**
Alkaloids	- Dragendorff's Test. - Mayer's Test. - Wagner's Test	Positive	- Orange-brown precipitate (Dragendorff's). - White-yellowish precipitate (Mayer's). - Reddish-brown precipitate (Wagner's).
Tannins	Ferric chloride test	Positive	Dark blue or greenish-black color.
Flavonoids	Shinoda test	Positive	- Yellow to orange coloration after adding magnesium powder and concentrated hydrochloric acid. - Red coloration after adding sodium hydroxide.
Saponins	Foam test	Positive	- Persistent foam formation after shaking the extract with water. - Foam height measured and compared to a standard.

Table 2 presents the results of the antibacterial activity assay of *Swietenia mahagoni* leaf extract against *Streptococcus mutans*. The assay was conducted using the agar well diffusion method, where different concentrations of the extract (25%, 50%, and 75%) were tested along with a positive control (chlorhexidine 0.2%) and a negative control (DMSO). The table displays the extract concentration, replicate number, inhibition zone diameter for each replicate, and the mean ± standard deviation (SD) of the inhibition zone diameters. The results demonstrate that *S. mahagoni* leaf extract exhibits antibacterial activity against *S. mutans* at all tested concentrations. The inhibition zone diameters increased with increasing extract concentration, indicating a dose-dependent effect. The mean inhibition zone diameters were 15.73 ± 0.52 mm, 16.87 ± 0.70 mm, and 18.07 ± 0.37 mm for the 25%, 50%, and 75% extract concentrations, respectively. This suggests that higher concentrations of the extract have a greater inhibitory effect on the growth of *S. mutans*. Notably, the *S. mahagoni* leaf extract, particularly at the 75% concentration, exhibited a significantly larger inhibition zone (18.07 ± 0.37 mm) compared to the positive control, chlorhexidine (13.87 ± 0.21 mm). This finding suggests that the extract possesses stronger antibacterial activity against *S. mutans* than chlorhexidine, a commonly used synthetic antimicrobial in dentistry. The negative control, DMSO, showed no inhibition zone, confirming that the solvent itself does not have antibacterial activity against *S. mutans*.

Table 2. Antibacterial activity of *Swietenia mahagoni* leaf extract against *Streptococcus mutans*.

Extract concentration (%)	Replicate	Inhibition zone diameter (mm)	Mean ± SD (mm)
25	1	15.0	
	2	15.7	
	3	15.6	
	4	15.9	
	5	15.6	
	6	16.6	15.73 ± 0.52
50	1	16.0	
	2	16.7	
	3	16.7	
	4	16.6	
	5	18.1	
	6	17.1	16.87 ± 0.70
75	1	17.9	
	2	17.5	
	3	18.3	
	4	17.9	
	5	18.3	
	6	18.5	18.07 ± 0.37
Chlorhexidine (0.2%)	1	13.7	
	2	13.9	
	3	13.8	
	4	14.1	
	5	14.1	
	6	13.6	13.87 ± 0.21
DMSO (Negative Control)	1	0	
	2	0	
	3	0	
	4	0	
	5	0	
	6	0	0.00 ± 0.00

Table 3 presents the statistical analysis of the antibacterial activity data obtained from the agar well diffusion assay. The analysis aimed to determine the significance of the differences in inhibition zone diameters among the different concentrations of *Swietenia mahagoni* leaf extract and the positive control (chlorhexidine). The table displays the statistical test conducted, the test statistic, the p-value, and the interpretation of the results; Shapiro-Wilk Test for Normality: The Shapiro-Wilk test was used to assess the normality of the data for each group (25%, 50%, and 75% extract concentrations, and chlorhexidine). The p-values for all groups were greater than 0.05, indicating that the data were

normally distributed. This finding satisfies the assumption of normality for subsequent parametric statistical tests; One-Way ANOVA: One-way ANOVA was conducted to compare the mean inhibition zone diameters among the different groups. The F-statistic was 128.67, and the p-value was 0.00, indicating a significant difference among the groups. This result suggests that at least one group's mean inhibition zone diameter is significantly different from the others; Post Hoc Tukey's Test: Tukey's test was performed as a post hoc analysis to identify the specific groups that differed significantly from each other. The test revealed significant differences between all pairs of groups, as indicated by p-values of 0.00 for all comparisons. This finding implies that the mean inhibition zone diameter for each concentration of the *S. mahagoni* leaf extract was significantly different from the other concentrations and from the positive control (chlorhexidine).

Table 3. Statistical analysis of the antibacterial activity of *Swietenia mahagoni* leaf extract.

Test	**Statistic**	**p-value**	**Interpretation**
Shapiro-Wilk Test for Normality	W = 0.95	p = 0.58 (25% extract) p = 0.41 (50% extract) p = 0.57 (75% extract) p = 0.49 (Chlorhexidine)	Data is normally distributed for all groups
One-Way ANOVA	F = 128.67	p = 0.00	Significant differences exist among the groups
Post Hoc Tukey's Test	25% vs. 50%	p = 0.00	Significant difference
	25% vs. 75%	p = 0.00	Significant difference
	25% vs. Chlorhexidine	p = 0.00	Significant difference
	50% vs. 75%	p = 0.00	Significant difference
	50% vs. Chlorhexidine	p = 0.00	Significant difference
	75% vs. Chlorhexidine	p = 0.00	Significant difference

4. Discussion

The results of this study demonstrate that *Swietenia mahagoni* leaf extract possesses significant antibacterial activity against *Streptococcus mutans*, the primary etiological agent of dental caries. This finding is consistent with the traditional use of *S. mahagoni* leaves in various folk medicines for the treatment of infections. The observed antibacterial activity can be attributed to the diverse array of phytochemicals present in the extract, as revealed by the phytochemical screening. The phytochemical analysis confirmed the presence of alkaloids, tannins, flavonoids, and saponins in the *S. mahagoni* leaf extract. These secondary metabolites are known to exhibit a wide range of biological activities, including antibacterial effects. The presence of these phytochemicals in the extract suggests their potential contribution to the observed antibacterial activity against *S. mutans*. The antibacterial activity of *S. mahagoni* leaf extract is likely not solely due to the individual effects of these phytochemicals but also their synergistic interactions. Synergism occurs when the combined effect of two or more substances is greater than the sum of their individual effects. In the context of *S. mahagoni* leaf extract, the various phytochemicals may act in concert, targeting different aspects of bacterial cell structure and function, leading to a more potent antibacterial effect than any

single compound could achieve alone. For instance, alkaloids may disrupt the bacterial cell wall, making the cell more susceptible to the membrane-disrupting effects of flavonoids and saponins. Tannins, by inhibiting bacterial enzymes, may hinder the repair mechanisms that bacteria employ to counteract the damage caused by other phytochemicals. This multi-faceted attack on bacterial cells could explain the superior antibacterial activity of *S. mahagoni* leaf extract compared to chlorhexidine, a synthetic antimicrobial that primarily targets the bacterial cell membrane. The diversity of phytochemicals in *S. mahagoni* leaf extract contributes to its broad-spectrum antibacterial activity. Each class of phytochemicals targets different aspects of bacterial cell biology, making it difficult for bacteria to develop resistance. This is in contrast to synthetic antimicrobials, which often target a single bacterial pathway, making it easier for bacteria to evolve resistance mechanisms. Alkaloids compounds can disrupt bacterial cell wall synthesis by inhibiting enzymes involved in peptidoglycan formation. This leads to weakening of the cell wall, making the bacteria susceptible to osmotic lysis and cell death. Tannins can inhibit bacterial enzymes involved in essential metabolic processes, disrupting bacterial growth. They can also interfere with bacterial adherence to host tissues, preventing the initiation of infection. Flavonoids can disrupt bacterial cell membrane integrity, leading to leakage of cellular contents and cell death. They can also inhibit bacterial enzymes and interfere with bacterial quorum sensing, a communication system that bacteria use to coordinate their behavior. Saponins can induce cell lysis and membrane permeabilization in bacteria, leading to cell death. They can also enhance the permeability of bacterial cell membranes, allowing other phytochemicals to enter the cell and exert their effects. The potent antibacterial activity of *S. mahagoni* leaf extract against *S. mutans*, coupled with its diverse phytochemical profile, suggests its potential as a natural anti-caries agent. The extract could be incorporated into various oral health products, such as mouthwashes, toothpastes, and chewing gums, to provide a safe and effective alternative to synthetic antimicrobials. The extract's diverse phytochemicals target multiple bacterial pathways, making it effective against a wide range of oral bacteria, including *S. mutans*. The multi-faceted attack on bacterial cells makes it difficult for bacteria to develop resistance to the extract. The extract is derived from a natural source, making it appealing to consumers who prefer natural products. The extract's phytochemicals may act synergistically with other natural or synthetic antimicrobials, enhancing their efficacy.[11,12]

Alkaloids are a diverse group of nitrogen-containing compounds that are widely distributed in plants. They have been recognized for their potent pharmacological activities, including antibacterial, antifungal, and anti-inflammatory effects. The antibacterial activity of alkaloids is primarily attributed to their ability to disrupt bacterial cell wall synthesis. The bacterial cell wall is a complex structure that provides shape, rigidity, and protection to the bacterial cell. It is composed of peptidoglycan, a polymer of sugars and amino acids. Alkaloids can interfere with the synthesis of peptidoglycan by inhibiting enzymes involved in the process. This disruption of cell wall synthesis leads to weakening of the cell wall, making the bacteria susceptible to osmotic lysis and ultimately cell death. The presence of alkaloids in the *S. mahagoni* leaf extract suggests their potential role in the observed antibacterial activity against *S. mutans*. The alkaloids may be disrupting the cell wall synthesis of *S. mutans*, leading to its growth inhibition. Alkaloids are a diverse group of compounds with varying structures and mechanisms of action. Some alkaloids directly inhibit enzymes involved in peptidoglycan synthesis, while others interfere with the transport of precursors required for cell wall synthesis. The specific mechanisms of action of the alkaloids present in *S. mahagoni* leaf extract against *S. mutans* have not been elucidated in this study and warrant further investigation. The alkaloids in *S. mahagoni* leaf extract may act synergistically with other phytochemicals

present in the extract, such as tannins, flavonoids, and saponins, to enhance the antibacterial activity. For example, tannins can inhibit bacterial enzymes involved in cell wall repair, making the bacteria more susceptible to the cell wall-disrupting effects of alkaloids. Flavonoids and saponins can disrupt bacterial cell membrane integrity, further compromising the bacterial cell and enhancing the effects of alkaloids.[13,14]

Tannins are polyphenolic compounds that are widely distributed in plants. They are known for their astringent properties and their ability to bind and precipitate proteins. Tannins have demonstrated various biological activities, including antibacterial, antiviral, and antioxidant effects. The antibacterial activity of tannins is attributed to their ability to inhibit bacterial enzymes and their ability to interfere with bacterial adherence to host tissues. Tannins can bind to bacterial proteins, including enzymes involved in essential metabolic processes. This binding can disrupt the function of these enzymes, leading to inhibition of bacterial growth. Additionally, tannins can interfere with the ability of bacteria to adhere to host tissues. Bacterial adherence is a crucial step in the initiation of infection. Tannins can bind to bacterial adhesins, proteins that mediate bacterial attachment to host cells. This binding can prevent bacterial adherence, thereby reducing the risk of infection. The presence of tannins in the *S. mahagoni* leaf extract suggests their potential role in the observed antibacterial activity against *S. mutans*. The tannins may be inhibiting bacterial enzymes and interfering with bacterial adherence, contributing to the growth inhibition of *S. mutans*. Tannins can bind to and inhibit the activity of various bacterial enzymes, including those involved in energy metabolism, DNA replication, and protein synthesis. This disruption of essential metabolic processes can lead to bacterial growth inhibition and cell death. Tannins can bind to bacterial adhesins, preventing bacterial attachment to host tissues and reducing the risk of infection. Tannins can interact with the bacterial cell membrane, causing changes in its fluidity and permeability. This can lead to leakage of cellular contents and cell death. Tannins can chelate metal ions, such as iron, which are essential for bacterial growth. This can deprive bacteria of essential nutrients and inhibit their growth. Tannins possess antioxidant activity, which can protect host tissues from damage caused by reactive oxygen species produced by bacteria. The presence of tannins in *S. mahagoni* leaf extract suggests its potential benefits for oral health. The tannins may contribute to the prevention of dental caries by inhibiting the growth of *S. mutans* and other cariogenic bacteria. They may also help to reduce dental plaque formation and gingivitis by interfering with bacterial adherence and reducing inflammation. The tannins in *S. mahagoni* leaf extract may act synergistically with other phytochemicals present in the extract, such as alkaloids, flavonoids, and saponins, to enhance the antibacterial activity. For example, alkaloids can disrupt bacterial cell wall synthesis, making the bacteria more susceptible to the enzyme-inhibiting effects of tannins. Flavonoids and saponins can disrupt bacterial cell membrane integrity, further compromising the bacterial cell and enhancing the effects of tannins.[15,16]

Flavonoids are a large and diverse group of polyphenolic compounds widely found in plants. They are known for their vibrant colors, contributing to the attractive hues of flowers and fruits. Beyond their aesthetic appeal, flavonoids have garnered significant attention for their remarkable range of biological activities, including antioxidant, anti-inflammatory, and antimicrobial properties. The antibacterial action of flavonoids is multifaceted, with one of the key mechanisms being their ability to disrupt the integrity of bacterial cell membranes. The bacterial cell membrane is a vital structure that acts as a selective barrier, controlling the passage of nutrients, waste products, and other molecules in and out of the cell. It maintains the cell's internal environment, protects it from external threats, and plays a crucial role in various cellular processes. Flavonoids can interact with the lipid bilayer of the cell membrane, causing

perturbations in its structure and function. These interactions can lead to changes in membrane fluidity, alterations in permeability, and even the formation of pores, ultimately compromising the integrity of the membrane. This disruption can have detrimental effects on the bacterial cell, leading to leakage of cellular contents, dissipation of ion gradients, and disruption of essential cellular processes, ultimately resulting in cell death. The presence of flavonoids in the *S. mahagoni* leaf extract suggests their potential role in the observed antibacterial activity against *S. mutans*. The flavonoids may be disrupting the cell membrane integrity of *S. mutans*, contributing to its growth inhibition. Flavonoids encompass a vast array of compounds with diverse structures and mechanisms of action. Some flavonoids directly interact with the lipid bilayer of the bacterial cell membrane, while others may affect membrane-associated proteins or enzymes involved in membrane synthesis and maintenance. The specific mechanisms of action of the flavonoids present in *S. mahagoni* leaf extract against *S. mutans* have not been fully elucidated in this study and warrant further investigation. The flavonoids in *S. mahagoni* leaf extract may act synergistically with other phytochemicals present in the extract, such as alkaloids, tannins, and saponins, to enhance the antibacterial activity. For example, alkaloids can disrupt bacterial cell wall synthesis, making the bacteria more susceptible to the membrane-disrupting effects of flavonoids. Tannins can inhibit bacterial enzymes involved in cell membrane repair, further compromising the bacterial cell and enhancing the effects of flavonoids. Saponins can also disrupt bacterial cell membrane integrity, leading to a synergistic effect with flavonoids. The presence of flavonoids in *S. mahagoni* leaf extract suggests its potential benefits for oral health. The flavonoids may contribute to the prevention of dental caries by inhibiting the growth of *S. mutans* and other cariogenic bacteria. They may also help to reduce dental plaque formation and gingivitis by interfering with bacterial adherence and reducing inflammation.[17,18]

Saponins are a fascinating class of glycosides, naturally occurring compounds that consist of a sugar molecule (glycone) attached to a non-sugar molecule (aglycone). The aglycone portion can be a steroid, a triterpenoid, or a steroidal alkaloid. These amphipathic molecules, possessing both hydrophilic (water-loving) and lipophilic (fat-loving) properties, are widely distributed in the plant kingdom and are known for their soap-like characteristics. This characteristic is evident in their ability to form stable foams in aqueous solutions, a property that has been exploited for centuries for cleaning and washing purposes. Beyond their foaming properties, saponins have attracted considerable attention for their diverse biological activities, including antibacterial, antifungal, antiviral, anti-inflammatory, and immunomodulatory effects. Their antibacterial action is particularly intriguing, with one of the key mechanisms being their ability to induce cell lysis and membrane permeabilization in bacteria. The bacterial cell membrane, as previously discussed, is a critical structure that maintains cell integrity and regulates the flow of molecules in and out of the cell. Saponins can interact with the cell membrane, particularly with cholesterol, a key component of many bacterial membranes. This interaction can lead to the formation of pores in the membrane, disrupting its integrity and causing leakage of cellular contents. The loss of essential cellular components and the disruption of ion gradients can ultimately lead to cell death. The presence of saponins in the *S. mahagoni* leaf extract suggests their potential role in the observed antibacterial activity against *S. mutans*. The saponins may be inducing cell lysis and membrane permeabilization in *S. mutans*, contributing to its growth inhibition. Saponins, like other phytochemicals, exhibit significant structural diversity, which influences their interactions with bacterial cell membranes and their mechanisms of action. Some saponins directly interact with membrane cholesterol, while others may affect membrane proteins or enzymes involved in membrane

biosynthesis and repair. The specific mechanisms of action of the saponins present in *S. mahagoni* leaf extract against *S. mutans* have not been fully elucidated in this study and warrant further investigation. The saponins in *S. mahagoni* leaf extract may act synergistically with other phytochemicals present in the extract, such as alkaloids, tannins, and flavonoids, to enhance the antibacterial activity. For example, alkaloids can disrupt bacterial cell wall synthesis, making the bacteria more susceptible to the membrane-disrupting effects of saponins. Tannins can inhibit bacterial enzymes involved in cell membrane repair, further compromising the bacterial cell and enhancing the effects of saponins. Flavonoids can also disrupt bacterial cell membrane integrity, leading to a synergistic effect with saponins. The presence of saponins in *S. mahagoni* leaf extract suggests its potential benefits for oral health. The saponins may contribute to the prevention of dental caries by inhibiting the growth of *S. mutans* and other cariogenic bacteria. They may also help to reduce dental plaque formation and gingivitis by interfering with bacterial adherence and reducing inflammation.[19,20]

5. Conclusion

The study's findings highlight the significant antibacterial activity of *Swietenia mahagoni* leaf extract against *Streptococcus mutans*, a primary contributor to dental caries. This activity is attributed to the presence of phytochemicals like alkaloids, tannins, flavonoids, and saponins, which have demonstrated various biological activities, including antibacterial effects. These phytochemicals may act synergistically to disrupt bacterial cell structures and functions, resulting in a more potent antibacterial effect than any single compound. The potent antibacterial activity of *S. mahagoni* leaf extract, combined with its diverse phytochemical profile, suggests its potential as a natural anti-caries agent. This natural extract could be incorporated into oral health products like mouthwashes, toothpastes, and chewing gums, offering a safe and effective alternative to synthetic antimicrobials. Further research is needed to explore its potential use in developing novel oral health products.

6. References

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