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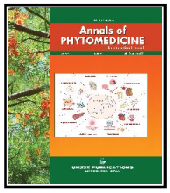

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Phytochemical characterization and antimicrobial properties of *Chukrasia tabularis* A. Juss. leaf extracts towards novel phytomedicinal applications

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Abstract

Chukrasia tabularis A. Juss. predominantly known for its role in traditional Asian folk medicines, marks its distribution across tropical and subtropical regions. Various parts of the *C. tabularis* (leaves, fruits and barks) holds significant ethnobotanical and the ethnomedicinal value and also exhibit biopesticidal properties. The rich presence of phenolic compounds, such as various terpenoids and limonoids, is in charge of the plant's biological processes. Investigating the bioactivities of *C. tabularis* extracts and extracted pure chemicals has gained attention in recent years. This present study aims to investigate phytochemical constituents and the antimicrobial properties of the *C. tabularis* leaf extracts. Fresh leaves were subjected to successive solvent extraction using the petroleum ether, chloroform, ethyl acetate, water, and methanol. Initial screening of phytochemicals indicated the existence of carbohydrates, flavonoids, phenolic compounds, tannins, and alkaloids across different extracts, with the methanol extract showing the highest carbohydrate content (45.10%). Using the disc diffusion method, antimicrobial activity was evaluated, and the minimum inhibitory concentration (MIC) of each extract against different bacterial strains was ascertained. The methanol extract exhibited the most substantial antimicrobial activity, demonstrating significant inhibition zones and low MIC values, underscoring its potential as a natural antimicrobial agent. These findings highlight the medicinal potential of *C. tabularis* and support its traditional use in treating infections, suggesting avenues for future pharmaceutical applications.

1. Introduction

Chukrasia tabularis A. Juss, a tropical tree species has garnered attention for its medicinal properties, particularly in traditional medicine. Phytochemical studies of its leaves have revealed the presence of various bioactive compounds, including alkaloids, flavonoids, and terpenoids, which are known for their therapeutic potential. The antimicrobial properties of *C. tabularis* leaf extracts have been of particular interest, as they exhibit promising activity against a range of pathogenic microorganisms. This makes the plant a valuable candidate for novel phytomedicinal applications, particularly in the development of natural antimicrobial agents to combat infectious diseases.

C. tabularis belongs to family Meliaceae and they are renowned as chickrassy or the Burmese almond wood or as Chittagong wood and also as Lal devdari and marked its distribution as an valuable tree in the Asian region (Anderson, 1980). It can grow up to 40 meters tall, with a branchless trunk extending 25 to 28 meters and large convex buttresses at the base. The bark is smooth in young trees but becomes rusty brown with deep vertical fissures as the tree matures. It was reported that the bark is pinkish or brownish red, while the sapwood is in straw-colored and heartwood ranges from brownish red to yellow. One distinctive feature is the presence of red-colored leaflets at the top. Chukrasia typically begins flowering at 8 to 9 years of age, with abundant blooms occurring every 2 to 3 years between April and June or July. The small, unisexual flowers are light yellow, sweet-scented, and borne on 10 to 30 cm long panicles. Its fruit is capsule, elliptical or ovoidal in shape. The fruits ripen between January and March and contain 180 to 250 anemophilous, winged seeds. The wings are nearly twice the length of the seeds (Ho *et al.,* 1995; Chatterjee and Prakashi, 1997). The species has been traditionally used in various Asian countries for treating skin infections and wounds. Rahman *et al.*(2021) studies have highlighted the importance of plantderived phenolic compounds in combating bacterial infections. These compounds exhibit various mechanisms of action, including membrane disruption and enzyme inhibition (Chen *et al.,* 2023). The bark as well as the leaves had long been utilized in the traditional medicines for treating colds and fevers. Nowadays, this tree is commonly grown for timber and as ornamental greenery (Wang *et al.,* 2019). Phytochemical studies have shown that primary compounds in plants of the Chukrasia genus are phragmalin type limonoids, which possess notable insect antifeedant properties (Guo *et al.,* 2006; Li *et al.,* 2011; Luo *et al.,* 2015). Table 1 represents the various chemical constituents present in different parts of *C. tabularis*.

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Table 1: Chemical constituent present in different parts of *C. tabularis*

Different parts of *C. tabularis*	Chemical constituents
Bark	Sitosterol 7 dimethoxycoumarin Scopoletin Melianone Chuktabularin A, B, C and D
Twigs and Leaves	Quercetin Tannic acid Tabularin Chuktabrin A and B Tabularisin A, B, C, D, E and I
Roots	Cedrelone Tabulalin Tabulalide A, B, C, D and E
Seeds	Chukrasin A, B, C, D and E

It is a valuable timber tree widely used across industries which are also rich in limonoids, phragmalin derivative, tannins, flavonoids, and various other phenolic compounds exploited for various medicinal properties (Trease and Evans, 2009; Yue *et al.,* 2008) . Its wood is ideal for decorative panelling, musical instruments, cabinet making, furniture, and flooring. It also serves in carving, cooperage, paper pulp production, ship and boat construction, railway sleepers, and also used in general construction (Aggarwal, 1986; Kalinganire and Pinyopusarek, 2000). The bark and leaves are rich in gums and tannins (22%), making them useful in the tanning industry, while its flowers produce red and yellow dyes (Aggarwal, 1986). In Ayurvedic medicine, the bark and leaves of *C. tabularis* are valued for their antipyretic as well as antimalarial effects (Kirtikar and Basu, 1981). Extracts from the twig as well as bark showed antifeedant properties against pests like *Pieris rapae* and *Spodoptera littoralis*, suggesting its potential as a natural insecticide (Kalinganire and Pinyopusarek, 2000). This plant also grown as a shade tree in the coffee plantations, used for agroforestry and green manure (Rai, 1985).

2. Materials and Methods

2.1 Plant material

Fresh green leaves of *C. tabularis* A. Juss. was collected and processed using standard protocols from the trial plantation established at the Forest College and Research Institute, Mettupalayam, Coimbatore. Their scientific authenticity was confirmed by KFRI (Kerala Forest Research Institute), Peechi, Thrissur, Kerala. The specimen is accessed to KFRI herbarium (KFRI Herbarium Accession Number 2413). The plant leaves were thoroughly cleaned with the help of tap water, air dried at the room temperature and also ground into a powder form.

2.2 Microbial organisms

Pathogenic bacterial strains, including *Escherichia coli, Aspergillus fumigatus, Aspergillus niger,* and *Fusarium oxysporum,* were acquired and cultivated on nutrient agar plates that are sterile. Following 18-24 h of broth incubation, during which the microbial cultures reached standard absorbance levels at 625 nm, the samples were prepared for antimicrobial activity testing.

The crude plant extracts were evaluated for their fungicidal properties against various fungi, including plant pathogens as well as industrially significant fungal strains, *viz., Aspergillus flavus, A. niger, A. fumigatus*, *Rhizopus* spp. This was achieved by incorporating the crude extracts into sabouraud dextrose agar (SDA) medium used for fungal culture. This method allowed for the assessment of the antifungal potential of the crude extracts.

Figure 1: *Chukrasia tabularis* A. Juss. plant.

2.2.1 Stock solution

Fresh leaves were properly cleaned with deionized water, allowed to air dry at room temperature, crushed into a fine powder using a blender, and then placed in a sterile glass container to create stock and working solutions of Chukrasia leaf extracts for antimicrobial research (Ajayi *et al*., 2011; Jamuna *et al*., 2011). A Soxhlet apparatus was used to extract 100 grams of leaf powder individually over three days at a temperature between 30 and 40°C in 750 milliliters of various solvents, such as methanol, petroleum ether, and ethyl acetate. The extracts were then concentrated through a distillation process and filtered using Whatman No. 42 filter paper (125 mm). Evaporation using a water bath kept at 100°C allowed for even greater concentration. In order to reach a concentration of 30 mg/ml, the extracts were finally dissolved in 10% dimethyl sulfoxide (DMSO) to create stock solutions.

2.3 Screening for phytochemicals

The study carried out through investigating various phytochemicals present in the leaf extracts through qualitative analysis.

2.4 Protein analysis

2.4.1 Millon's test

2 ml of Millon's reagent were added to the crude extract, resulting in a white precipitate that turned red when heated gently, signifying the presence of proteins.

2.4.2 Ninhydrin test

The presence of proteins and amino acids was indicated by the violet hue that developed when the crude extract was heated with 2 ml of 0.2% Ninhydrin solution.

2.5 Carbohydrate analysis

This method was suggested by Luo (2011) for carbohydrate analysis.

2.5.1 Fehling's test

After mixing equal parts of Fehling A and B reagents, 2 ml of the mixture were added to the crude extract and brought to a gentle boil. Reducing sugars were present because a brick red precipitate formed at the test tube's bottom.

2.5.2 Benedict's test

The presence of carbohydrates was indicated by the formation of a reddishbrown precipitate after boiling the crude extract with 2 ml of Benedict's reagent.

2.6 Flavonoid analysis

2.6.1 Alkaline reagent test

An bright yellow color formed when 2 milliliters of a 2% NaOH solution were mixed with the crude extract. When a few drops of diluted acid were added, this color turned colorless, signifying the presence of flavonoids.

2.7 Glycosides analysis

2.7.1 Liebermann's test

After combining the crude extract with 2 ml of acetic acid and chloroform, the mixture was allowed to cool on ice. A color shift from violet to blue to green upon the cautious addition of concentrated H_2SO_4 signified the presence of a steroidal nucleus, which is equivalent to the glycone component of the glycoside.

2.8 Test for phenols and tannins

The crude extract was mixed with 2 ml of 2% $FeCl_2$ solution to test for phenols and tannins. Phenols and tannins were present when a bluegreen or black coloring appeared (Craig and Stitzel, 2004).

2.9 Test for alkaloids

2 ml of 1% HCl were added to the crude extract, and it was then slowly heated. The mixture was then supplemented with Mayer's and Wagner's reagents. The ensuing precipitate's turbidity was seen as proof that alkaloids were present.

2.10 Test for steroids and triterpenoid glycosides (Salkowski test)

The alcoholic extract was evaporated to dryness and then re-extracted using chloroform ($CHCl_2$). Concentrated sulfuric acid (H_2SO_4) was added along the sidewall of the test tube containing the chloroform extract. A yellow ring at the interface of the two liquids, turning red after about 2 min, indicated a positive result.

2.11 Antimicrobial studies

The disc diffusion method was used to calculate the minimum inhibitory concentration (Bonsignor *et al*., 1990; Barry, 1976; Benson, 1990; Bauer *et al*., 1966). The effectiveness of microorganisms against various plant extracts is demonstrated by the lowest inhibitory concentration, or minimum inhibitory concentration (MIC).

2.12 Preparation of media for bacterial culture

2.12.1 Nutrient agar media

Nutrient agar plates were prepared by dissolving nutrient agar powder (37 g/l, Hi-media) in distilled water. The media was sterilized in an autoclave at 121°C for 15 min, then poured into sterile petri dishes. The plates were dried and kept for 24 h to confirm sterility. Only sterile plates were used for bacterial cultures.

2.12.2 Muller Hinton Agar (MHA)

To prepare MHA, starch was emulsified in a small amount of cold water, followed by the addition of beef infusion, casein hydrolysate, and agar. The total volume was adjusted to 1 l with distilled water. The mixture was heated gently with agitation at 100°C to dissolve all components. After filtering, the pH was adjusted to 7.4. The medium was dispensed into stock bottles and sterilized by autoclaving at 121°C for 20 min. The autoclaved medium was poured into sterile flat-bottomed petri dishes inside a laminar flow hood and allowed to solidify. Plates were stored in a cold room at 4°C for future use. Before experiments, wells of 3 mm, 6 mm, and 8 mm diameter were made in the plates using a sterile borer. A 2 h culture of test bacteria (100 µl) was placed on the nutrient agar plates. The bacterial inoculum was spread uniformly over the entire agar surface using a sterile swab and allowed to dry for 5 min. Wells were loaded with 80 il of various plant extracts dissolved in DMSO. DMSO served as the negative control, and streptomycin (10 µg/80 µl) was used as the positive control. The plates were incubated at 37°C for 24 h. After incubation, the zones of inhibition were measured to evaluate antibacterial activity.

2.12.3 Preparation of media for fungal culture

Sabouraud dextrose agar (SDA) slants were prepared by dissolving SDA powder (Himedia, 67 g/l) in distilled water. The medium was sterilized in an autoclave at 121°C and 1.05 kg/cm². After sterilization, the media were poured into sterile 25 ml culture tubes, with 5 ml dispensed per tube. The tubes were allowed to cool and solidify in a slanted position to form slants. For testing, 0.5 ml of particulate crude extract was added to each tube before the medium solidified, and the contents were thoroughly mixed by shaking. Negative control tubes contained only solvents, without crude extracts, to ensure no external contamination. To test fungal activity, fungal cultures were inoculated onto the SDA slants and incubated at 30-32°C for 5 to 7 days. The results were compared against a standard fungicide (imidazole). SDA slants containing crude extracts were also inoculated with fungal cultures and incubated under the same conditions for 5 to 7 days.

2.13 Disc diffusion assay

All experiments were carried out in the laminar air flow chamber. The Nutrient agar (NA) media were prepared separately for the isolation of microorganisms. 23 g of NA is mixed with 1000 ml of water and kept autoclaved. After the media got cooled down it transferred to the petridishes. After being cultivated, bacterial strains were swabbed onto sterile agar plates. Sterilized Whatman filter paper No. 1 was used to create discs with a diameter of 6 mm. These sterile discs were put on the agar plates after being soaked in various quantities of leaf extracts that had been dissolved in various solvents.

The widths of the inhibitory zones surrounding the discs were determined after a 24 hincubation period at 37°C. Inhibition zone diameters of 11 mm or greater were considered to indicate an effective concentration of the leaf extract, whilst those lower than 10 mm were considered to be mildly effective. The diameter in millimeters of the clean zone encircling each disc was used to measure the suppression of microbial growth.

2.14 Statistical analysis

Three replications of the tests were conducted, and the results were expressed in the tables. Furthermore, comparisons were made in order to assess how well different solvent mediums performed in terms of their antimicrobial activity.

3. Results

3.1 Yield from extracts

Fresh *C. tabularis* leaves weighing 300 g were collected and dried, resulting in approximately 50 g of powdered material. The yields of various extracts are summarized in Tables 2 and 3. The percentage yield of the successive solvent extracts thus obtained will be petroleum ether (2.6%), chloroform (2.4%), ethyl acetate (3.8%), methanol (45.10%) and water (5.72%). The highest yield was obtained from the water extract (7.5%), followed by methanol (4.4%), isopropanol (3.8%), hexane (3.4%), and the lowest yield was from benzene (1.9%). The physical characteristics and nature of the crude extracts of leaves are detailed in Table 4.

Table 2: Yield of major extracts from *C. tabularis* leaf

S.No.	Sample	Percentage
1.	Petroleum ether	2.6%
2.	Chloroform	2.4%
3.	Methyl acetate	3.8%
4.	Methanol	45.4%
5.	Water	5.52%

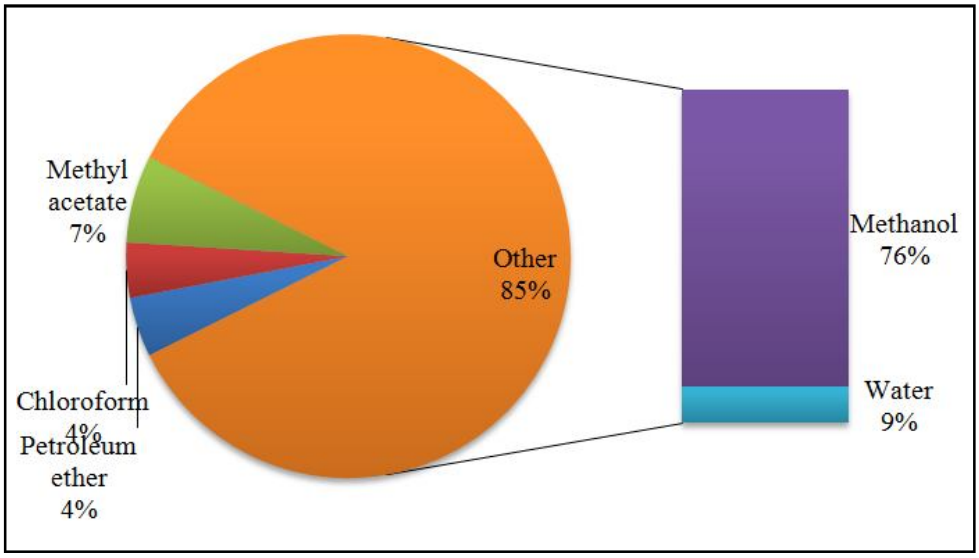

Figure 2: Percentage yield of the major successive solvent extracts.

Table 3: Yield of minor extracts from *C. tabularis* leaf

S.No.	Sample	Percentage
1.	Hexane	3.4%
2.	Benzene	1.9%
3.	Isopropanol	3.8%
4.	Methanol	4.4%
5.	Water	7.5%

Table 4: Nature of the crude extract of *C. tabularis* leaf

S.No.	Sample	Colour	Odour	Consistency
1	Hexane	Rusty Brown	Tingling	Sticky
2	Benzene	Black	Sharp tingling	Sticky
3	Isopropanol	Dark Brown	Pungent	Sticky
4	Methanol	Brown	Alcoholic	Powder
5	Water	Brown	Pungent	Powder

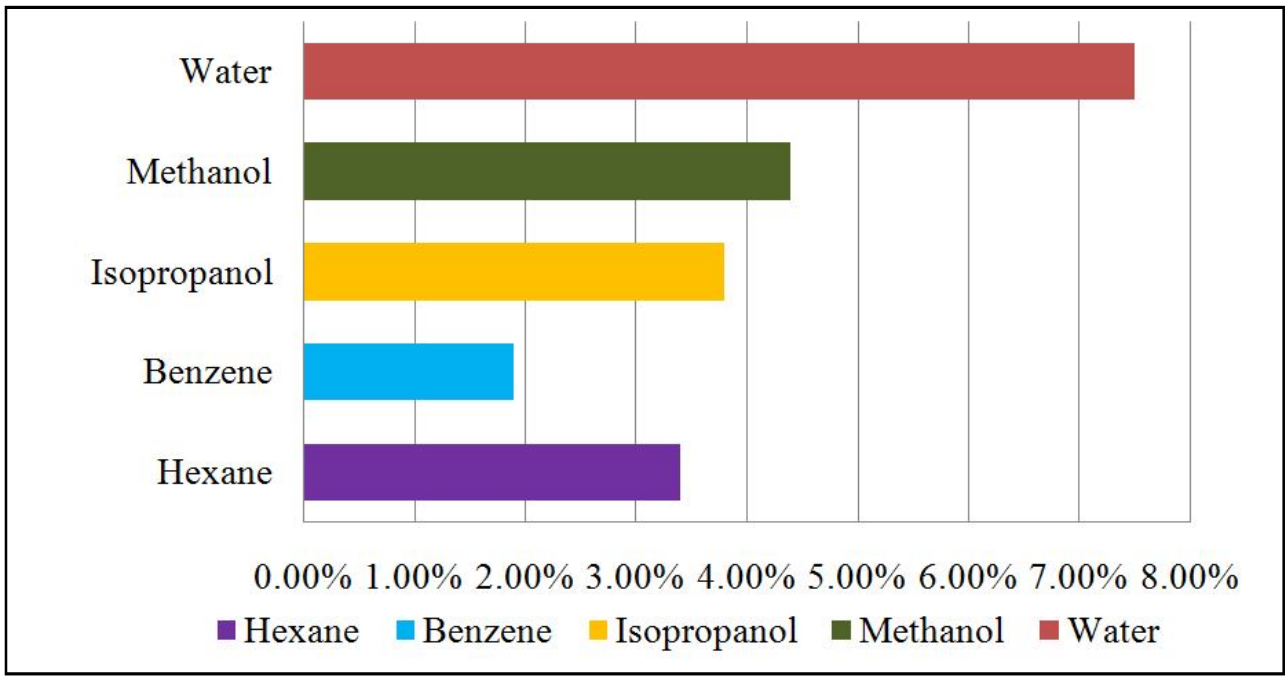

Figure 3: Percentage yield of minor successive solvent extracts.

3.2 Screening for phytochemicals

Qualitative phytochemical analysis of *C. tabularis* leaf extracts (hexane, benzene, isopropanol, methanol, and water) revealed the presence of several bioactive compounds. These included alkaloids, tannins, phenolic compounds, terpenoids, carbohydrates, amino acids, oils, and fats. The results are presented in Table 5.

The extracted compounds were then analyzed through preliminary phytochemical evaluation to identify the substances present in the extracts, with the results displayed in Table 4 revealed that the extracts varied in their chemical composition. The methanol extract yielded the highest concentrations of carbohydrates (45.10%), followed by the water extract (5.72%). Carbohydrates were detected predominantly in the methanol and water extracts, which can serve as an energy source for microorganisms. Flavonoids were found mainly in the ethyl acetate and methanol extracts. The result indicates that the *C. tabularis* may serve as a natural source of flavonoids that can be utilized for therapeutic purposes. The study also identified the ethyl acetate and methanol extracts phenolic constituents and tannin content. Phenolic compounds have been recognized for their antioxidant properties, which help mitigate oxidative stress in cells and provide protection against various diseases. The results confirm the rich diversity of bioactive compounds in *C. tabularis.*

Table 5: Phytochemical screening of major successive solvent extracts

Compounds	Petroleum ether	Chloroform	Ethyl acetate	Methanol	Water
Protein	-	-	-	-	-
Carbohydrates	-	+	+	++	+++
Flavonoids	-	-	++	++	-
Glycosides	-	++	+	+	+
Phenol and tannins	-	+	+	++	+
Alkaloids	+	+	+	+	+

(**Note:** +* indicates presence of phytochemical , -* indicates absence of phytochemical, ++* shows moderate concentration, +++* shows high concentration.)

The phytochemical analysis of *C. tabularis* leaf extracts (hexane, benzene, isopropanol, methanol, and water) revealed a rich diversity of bioactive compounds, as displayed in Table 6. The extracts varied in their chemical composition, with certain compounds detected in specific solvents, highlighting the influence of solvent polarity on compound solubility and extraction efficiency. Methanol, water, and isopropanol extracts showed strong presence of tannins and phenolic compounds, suggesting that polar solvents are efficient at extracting these bioactive compounds. These compounds are known for their antioxidant properties, which are essential in protecting cells from oxidative stress and have potential therapeutic uses in preventing or treating diseases related to oxidative damage. Hexane and benzene extracts showed no presence of phenolic compounds, indicating that non-polar solvents are ineffective in extracting these compounds.

Benzene exhibited the strongest presence of cardiac glycosides, followed by hexane, with weak presence in water, and no presence in methanol and isopropanol. This suggests that cardiac glycosides are more soluble in less polar solvents like benzene and hexane. Cardiac glycosides have important pharmacological properties, particularly in treating heart conditions by influencing heart rate and force of contraction. Benzene and hexane extracts showed strong positive results, indicating that non-polar solvents effectively extract oils and fats from the leaves.

Oils and fats are rich in lipids, which have applications in industries like cosmetics, and as natural carriers for lipophilic drugs. Benzene exhibited the strongest presence of terpenoids followed by moderate presence in methanol and water, and no presence in hexane. Terpenoids are a diverse class of compounds known for their antimicrobial, anti-inflammatory, and anticancer properties, making them valuable in pharmaceutical applications. As with the **$FeCl_2$** test, methanol extracts showed the highest concentration of phenolic compounds, followed by water extracts. The presence of phenolic compounds, particularly in these extracts, indicates their significant role in the plant's antimicrobial and antioxidant activities

3.3 Antimicrobial activity

Table 7 and Figure 4 shows the antimicrobial efficacy of *C. tabularis* leaf extracts against various microorganisms using different solvents: petroleum ether, ethyl acetate, chloroform, and the methanol using disc diffusion method. The activity is represented by inhibition zones in millimeters, with a standard reference given for comparison. The *C. tabularis* methanol extract exhibited the highest activity against *E. coli* with a zone of inhibition of 22.6 mm, surpassing the standard reference (19.5 mm). Ethyl acetate also showed notable activity (17.5 mm). Petroleum ether and the chloroform extracts, however, does not display any activity. The methanolic extract showed the highest inhibition against *A. fumigatus* (19.1 mm), again surpassing the standard (16 mm). Petroleum ether (14.3 mm) and ethyl acetate (13.5 mm) also exhibited mild activity, while chloroform displayed no inhibition. Only petroleum ether exhibited activity against *A. niger* with a large inhibition zone (25.5 mm), notably higher than the standard (13 mm). Other extracts showed no inhibition. Petroleum ether's effectiveness in this case might suggest that non-polar compounds within *C. tabularis* leaves, potentially including essential oils and other terpenoids, possess significant antifungal properties. None of the extracts showed activity against *F. oxysporum*.

Table 6: Phytochemical screening of minor successive solvent extracts

Compounds	Hexane	Benzene	Isoproponal	Methanol	Water
Tanin and phenolic compounds	-	-	+++	+++	+++
Cardiac glycosides	++	+++	-	-	+
Oil and fat	++	+++	-	-	-
Terpenoids	-	++	+	+	+
Phenol and tannins	-	-	-	++	+

(**Note:** +* indicates presence of phytochemical , -* indicates absence of phytochemical, ++* shows moderate concentration, +++* shows high concentration).

Table 7: Antimicrobial activity of *C.tabularis* leaf extracts

Micro organisms	Petroleum ether	Chloroform	Ethyl acetate	Methanol	Standards
Escherichia coli	-	-	17.5	22.6	19.5
Aspergillus fumigatus	14.3	-	13.5	19.1	16
Aspergillus niger	25.5	-	-	-	13
Fusarium oxysporum	-	-	-	-	n.t

The mean of three replicates is used to calculate the zone of inhibition, and when the minimal inhibitory doses are found, they are presented in parenthesis. -* no inhibition; n.t., not tested; all tested at 25 mg/ml.

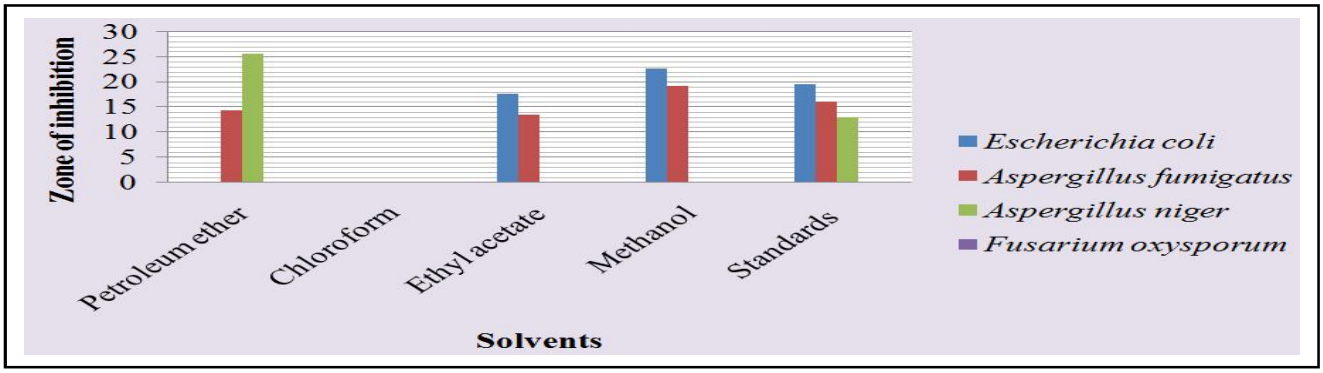

Figure 4: Antimicrobial activity of *C. tabularis* leaf extracts.

The antimicrobial efficacy of *C. tabularis* leaf extracts against various microorganisms was evaluated using different solvents: hexane, benzene, isopropanol, methanol, and water. The results presented in table 8 were based on the disc diffusion method, where the activity is represented by the inhibition zones in millimeters, with a standard reference for comparison. The methanol extract exhibited the highest antimicrobial activity with a zone of inhibition of 23.6 mm, surpassing the standard reference (19.5 mm). Water extract also showed notable activity with a zone of 19.5 mm, while ethyl acetate (17.5 mm) demonstrated moderate inhibition. Hexane and benzene extracts did not display any significant antimicrobial activity, suggesting the absence of effective antifungal compounds in these non-polar extracts. The water extract demonstrated the strongest activity against *A. niger*, with a zone of inhibition of 16.3 mm, followed by methanol (14.3 mm). Ethyl acetate showed moderate activity with a zone of 13.5 mm. Hexane and benzene did not exhibit any activity against *A. niger*.

The methanol extract showed the highest inhibition against *A. fumigatus*, with a zone of inhibition of 25.5 mm, surpassing the standard reference (16 mm). The water extract exhibited moderate inhibition (13.4 mm), while the ethyl acetate extract demonstrated mild activity (14.8 mm). Hexane and benzene showed no inhibition, indicating the absence of active compounds in these non-polar solvents for *A. fumigatus*. The methanol extract showed minimal activity with a zone of 12.7 mm against *Rhizopus* spp., while other extracts did not display any significant inhibition.

Table 8: Antifungal activity of *C.tabularis* leaf extracts

Micro organisms	Hexane	Benzene	Isoproponal	Methanol	Water
Aspergillus flavus	-	-	17.5	23.6	19.5
Aspergillus niger	-	-	13.5	14.3	16.3
Aspergillus fumigatus	-	-	14.8	25.5	13.4
Rhizopus spp.	-	-	-	12.7	-

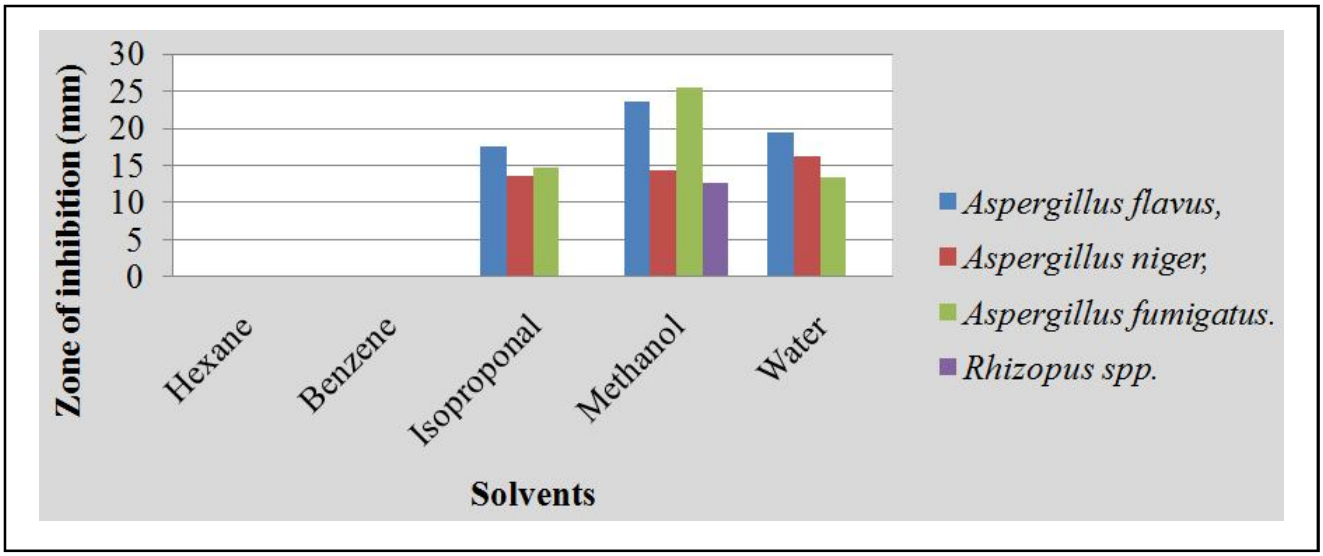

Figure 5: Antifungal activity of *C.tabularis* leaf extracts.

4. Discussion

4.1 Phytochemical studies

Methanol's high extraction efficiency highlights the effectiveness of polar solvents in isolating bioactive molecules. The importance of phenolic compounds in combating bacterial infections through mechanisms such as membrane disruption and enzyme inhibition (Wang *et al.,* 2019). The presence of carbohydrates in plant extracts has been associated with various biological activities, including antioxidant and antimicrobial properties (Rahman *et al.,* 2021). Flavonoids are important for pharmaceutical uses because of their well documented capacity to scavenge free radicals and have anti-inflammatory properties (Chen *et al.,* 2023). The abundant presence of phenolic compounds in methanol and ethyl acetate correlates with their role in bacterial membrane disruption and enzyme inhibition (Guo *et al.,* 2006). The presence of tannins, particularly in the chloroform and methanol extracts, suggests potential applications in the tanning industry and for medicinal purposes, as tannins possess antimicrobial properties (Li *et al.,* 2011). Alkaloids were present in all solvent extracts, which coincides with previous findings where some Chukrasia species demonstrated alkaloid content (Nakatani *et al.,* 2004).

The presence of tannins and phenolic compounds in isopropanol, methanol, and water highlights their polarity. These compounds have hydroxyl groups capable of forming hydrogen bonds, making them more soluble in polar solvents. Phenolic compounds are known for their antioxidant, anti-inflammatory, and antimicrobial properties. Their prevalence in polar extracts suggests that methanol and water extracts could be promising for pharmaceutical applications targeting oxidative stress or microbial infections.Strong presence in benzene

and moderate presence in hexane suggests their semipolar nature. Their solubility in nonpolar solvents like benzene and hexane aligns with the lipophilic nature of these compounds. Oils and fats include triglycerides, sterols, and other hydrophobic molecules. Oils and fats derived from Chukrasia leaves may have industrial applications in cosmetics or as carriers for hydrophobic drugs. Terpenoids were present across a range of solvents, suggesting diverse polarity within this class. Benzene showed the strongest result indicating that some terpenoids are semipolar. Terpenoids exhibit a wide range of bioactivities, including antimicrobial, anticancer, and antiinflammatory effects. Their extraction in both polar and nonpolar solvents makes them versatile candidates for drug development. Their stronger presence in methanol compared to water demonstrates methanol's superior solvating ability for polar compounds. This may be due to its dual nature as a hydrogen bond donor and acceptor. This data confirms that methanol extracts are optimal for isolating bioactive tannins and phenolics, essential for therapeutic antioxidant application.

4.2 Antimicrobial activity

The superior performance of methanol extracts suggests the solubility of active antimicrobial compounds like alkaloids and terpenoids in polar solvents. Findings indicate that the methanolic extracts might contain active phytochemicals, such as alkaloids, terpenoids, and glycosides, effective against Gram-negative bacteria (Khan *et al.,* 2022). Earlier research highlighting the effectiveness of methanolic extracts in suppressing bacterial growth. This observation is in line with prior studies that demonstrate methanolic extractsability to isolate phenolic compounds, flavonoids, and other polar substances with strong antibacterial effects, particularly against Gram-negative bacteria such as *E. coli* (Singh *et al.,* 2021). The solubility of active ingredients like saponins and tannins in polar solvents may be the cause of the antifungal effects seen, particularly in methanol extracts (Zhang *et al.,* 2020). Recent studies indicate that these compounds disrupt fungal cell walls, resulting in cellular leakage and growth inhibition (Chaudhary *et al.,* 2023). Additionally, petroleum ether's moderate effect suggests the presence of non polar antifungal compounds that could inhibit certain fungal strains (Rahman *et al.,* 2021). Terpenes are known to interact with fungal cell membranes, disrupting membrane integrity (Singh *et al.,* 2022). Previous studies have documented the strong antifungal properties of terpenoids, which could explain the high inhibition observed with petroleum ether extracts (Bajpai *et al.,* 2023). The lack of activity against *F. oxysporum* indicates that *C. tabularis* extracts may lack compounds effective against certain fungal cell wall structures or metabolic processes specific to *F. oxysporum*.

Similar findings were reported by Patel *et al.* (2021), where certain plant extracts showed selective activity based on fungal cell wall composition and permeability. Traditional medicine has long utilized *C. tabularis* to treat wounds and skin problems(Rahman *et al.,* 2021). The identified phytochemicals in this study, particularly phenolic compounds and flavonoids, likely contribute to the antimicrobial properties observed and also have been historically associated with bacterial inhibition. These findings underscore the importance of *C. tabularis* as a potential source for developing new antimicrobial agents derived from natural products. The findings validate traditional medicinal uses of *C. tabularis* for treating infections. High efficacy against *E. coli* and *A. fumigatus* suggests applications in pharmaceutical formulations (Rahman *et al.,* 2021). The potential use of tannins in the tanning industry and alkaloids in therapeutic applications reinforces the multifunctional nature of the plant's extracts (Li *et al.,* 2011).

Methanol consistently displayed the strongest antimicrobial activity, especially against *Aspergillus fumigatus* (25.5 mm) and *Aspergillus flavus* (23.6 mm). The high concentration of phenolic compounds and flavonoids in methanol extracts likely disrupt microbial cell walls and interfere with intracellular processes such as enzyme activity. These compounds have been shown to permeabilize membranes and chelate essential metal ions, leading to microbial inhibition (Chaudhary *et al.,* 2023). Moderate antimicrobial activity was observed, with inhibition zones ranging from 13.4 mm (*A. fumigatus*) to 19.5 mm (*A. flavus*). The water extract's lower efficacy compared to methanol can be attributed to its relatively lower capacity to dissolve flavonoids and certain tannins. Despite its lower activity, the water extract offers an eco-friendly alternative for applications in food preservation and topical treatments. The absence of activity with hexane and benzene extracts suggests that lipophilic compounds in Chukrasia do not significantly contribute to antimicrobial effects (Bajpai *et al.,* 2023). This aligns with previous studies where polar solvents outperformed non-polar ones in isolating bioactive phytochemicals. Methanol exhibited superior inhibition across all tested fungi, including *A. flavus*, *A. niger*, and *A. fumigatus*, highlighting its effectiveness against a broad spectrum of fungal pathogens. The ability of methanol extracts to inhibit plant pathogens like *A. flavus* suggests potential uses in biofungicides, reducing dependence on synthetic chemicals. In medicine, these extracts could serve as natural antifungal agents, particularly against drugresistant strains. Minimal inhibition by methanol (12.7 mm) and the lack of activity by other extracts suggest that Rhizopus may possess unique resistance mechanisms, such as cell wall composition or efflux systems, that reduce susceptibility to Chukrasiaderived compounds (Li *et al.,* 2011).

5. Conclusion

This study establishes that *C. tabularis* extracts contain a diverse array of phytochemicals with significant antimicrobial properties. The methanol extract, in particular, demonstrated remarkable antibacterial activity, suggesting its potential use in pharmaceutical applications as a natural alternative to synthetic antimicrobials. The presence of flavonoids, phenolic compounds, and tannins highlights the medicinal value of the plant, while its alkaloid content reinforces its role in traditional medicine. Future studies should focus on isolating specific active compounds and exploring their mechanisms of action against bacterial pathogens to further substantiate the medicinal value of *C. tabularis*.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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