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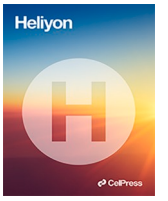

Research article

# Fatliquor for fungus resistant leather-a sustainable ecofriendly approach

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ABSTRACT

Surface-active softening agents, such as Fatliquors, have a significant impact on the leather industry as they enhance the physicochemical properties of leather. This study focuses on analyzing the synthesis, properties, characterization, and sulfonation of *Swietenia mahagoni* seed oil to determine its potential as a fatliquoring agent for leather. An investigation was conducted to verify the alteration of *Swietenia mahagoni* oil through the analysis of its properties before and after the sulfonation process. A scientific analysis was carried on the oil using GC-FID, revealing the presence of various unsaturated fatty acids such as linoleic, linolenic, oleic, palmitic, and arachidic acids. This demonstrates the sulfonating capability of this sky fruit seed oil. A fatliquor was created by sulfonating the oil, and the sulfonation was verified through Fourier Transform Infrared Spectroscopy (FTIR) and $^{1}$H Nuclear Magnetic Resonance (NMR) spectra. The prominent peak observed at 1209 cm-1 in the FTIR spectra indicated the stretching of S=O in both sulfate and sulfonate groups. The newly formed protons (H–C–S or H–C–O) showed signals between δ 4.09 and 4.29 ppm in the $^{1}$H NMR spectra, confirming the sulfonation of the fatliquor that was prepared. Moreover, the change in the melting point of sulfonated Mahogany oil from 40.8 °C to 48.1 °C suggests increased saturation levels. The fatliquor's emulsion stability was found to be at a satisfactory level. After conducting tests on the treated leather, the physical strength and morphological structure was analyzed using Field Emission Scanning Electron Microscopy (FE-SEM), the fatliquor improved the lubrication and strengthened the fibrous network structure of the leather, composed of thin and tight collagen fibers. The BOD5/COD ratio of the effluent from the experimental trial was determined to be 0.52, suggesting that the fatliquor developed is a biodegradable product. Finally, the antifungal capabilities of the fatliquor-treated leather were tested against four different fungus species: *Aspergillus niger, Aspergillus flavus, Penicillium notatum, and Candida albicans,* and the treated leather sample shown favorable antifungal activity.

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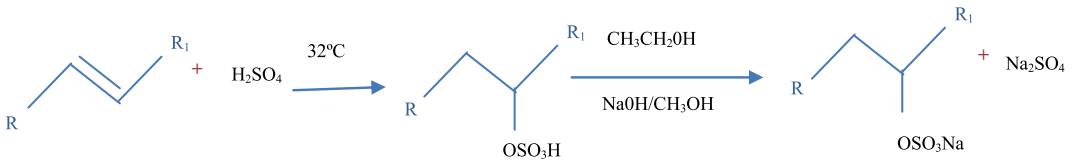
## 1. Introduction

Raw hides and skins require a process to create the valuable and comfortable material called leather [1]. Pre-tanning, tanning, post-tanning, and finishing are the essential stages that constitute the complete leather processing cycle [2]. Applying fats to wet blue leather is a critical step in a series of processes that aims to improve its physico-chemical properties [3]. As the leather dries, the inter-fibrillary water is removed, allowing the components of the fine structure to come closer together and potentially interact [4]. To avoid this issue, fatliquors are utilized as surface active softening agents for chrome-tanned leather fibers [5]. This study discusses how certain agents improve the mechanical characteristics of leather, making it softer, more flexible, and stronger, while also enhancing its dispersion and tactile feel. The hydrophilic group in the fatliquors helps stabilize them and incorporates sulfite or sulfated oils, which act as surface-active substances [6]. Biological origins like vegetable oils, animal fats, oils, and waxes are found in fatliquors. Nonbiological substances like mineral oils, fatty alcohols, and processed hydrocarbons can also be present [7]. For optimal penetration and reaction between fatliquors and leather fiber, it is necessary to use fatliquors in excess, leading to elevated pollution levels in the float [8]. Around 85–91 % of applied fatliquors are utilized by leather, with the remaining percentage being discharged into wastewater [9]. Most of the oils utilized for fatliquor production are synthetic and non-sustainable, leading to significant environmental harm when compared to natural alternatives [10]. Biological fatliquors offer superior surface activity, affordability, safety, and production convenience compared to nonbiological alternatives [11]. In addition, they reduce the use of chemical substances and environmental pollution in leather processing [12]. Therefore, it is imperative to create natural/biodegradable fatliquors for leather processing [13] (see Schemes 1 and 2).

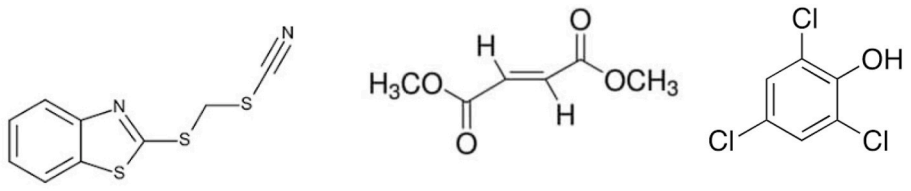
*Swietenia mahagoni*, commonly referred to as Mahogany, is a significant deciduous hardwood tree belonging to the Meliaceae family [14]. Mahogany trees are commonly found in tropical and subtropical regions. They can also be found in various regions around the globe where they have been introduced or grown, including Africa, Asia, and the Caribbean [15]. This species has a broad distribution across Bangladesh, India, China, Africa, as well as different areas of North and South America [16]. The fruit yield of the Mahogany tree is significantly influenced by its diameter, with larger trees capable of producing over 700 fruits per year [17]. According to a study, harvesting 50–75 fruit capsules containing 40 seeds each results in 1 kg of cleaned seeds [18]. Typically, Mahogany trees may begin bearing fruit around 10–15 years old and continue producing fruit as they mature. Each tree's ability to produce fruit can differ, affected by factors such as environmental conditions, tree maintenance, and genetic traits [17].

The therapeutic uses of Mahogany's root, bark, seed, and other parts include abortifacient, antiseptic, astringent, depurative, and tonic properties. It is also used to treat amoebiasis, high blood pressure, diabetes, malaria, coughs, chest pain, and tuberculosis [16]. Moreover, the seed extract is used in agricultural applications for controlling pesticides and preserving unprocessed hides and skins [19,20]. Several scientific articles have discussed the antimicrobial properties of *Swietenia mahagoni* seed extracts [14,16]. A scientific study reveals that Mahogany seed extract is rich in antimicrobial fatty acids such as linoleic, oleic, stearic, and palmitic acids [21]. *Swietenia mahagoni* is known for containing limonoids, many of which have a wide range of biological effects [22]. These activities include insect antifeedant activity [23], antifungal [24], cytotoxic [25], antimalarial [26], and antibacterial properties [27]. The Meliaceae family is known for producing limonoids, which are triterpenes with a unique steroid skeleton [28] and substances found in the Mahogany family known as triterpenoids play a crucial role in microbial defense [29].

Various types of bacteria and fungi are commonly found in different environments and can quickly establish themselves on various surfaces, including food, clothing, and footwear [30,31]. When leather interacts with the human body or garments, it can serve as a carrier and create a conducive environment for microbial growth [32,33]. While vegetable-tanned leathers are susceptible to microbial attacks particularly from fungus, chrome-tanned leathers also can cause biodeterioration by fungus [34]. During the leather processing in the leather industry, a variety of synthetic fungicides are commonly employed alongside fatliquoring techniques. 2-thiocyanomethylthio benzothiazole (TCMTB), dimethylfumarate (DMF), N-OITZ (N-Octylisothiazolinone), OPP (Ortho phenyl phenol), PCMC (*p*-Chlorom-cresol), Carbendazim, Merkaptobenzothiazole, TCP (tri-chloro phenol), p-Nitro phenol, BMC, DIMTS, etc. are commonly used fungicides in leather industries [35]. Few fungicides like TCMTB also show antibacterial properties [36]. These substances can be damaging to both the environment and human health, leading to symptoms like itchiness, irritation, redness, and burns [31].




**Scheme 1.** Sulfonation of *S. mahagoni* seed oil to produce sulfonated oil.




TCMTB DMF TCP

Commonly used fungicides in leather Industry.

*Swietenia mahagoni* fatliquor, which possesses antifungal properties and serves the dual purpose of fatliquoring and exerting antifungal activities during leather processing. Some innovative sources of antifungal fatliquors include *Citrullus colocynthis* [1], *Calophyllun Inophyllum,* etc [35]. The study focused on creating fatliquors with antifungal properties from Mahogany seed oil, which is easily available in the local areas. The research delved into the possible application of these fatliquors as leather lubricants/fatliquors in the leather industry.

## 2. Materials and methods

### 2.1. Material collection and preparation

The seed samples were sourced from Noyarhat, Savar Botanical Garden in Dhaka, Bangladesh. A Taxonomist from the Bangladesh National Herbarium in Dhaka identified the plant with voucher no (DACB 94783). The seeds were meticulously peeled and left to dry under the sun for several days. They were then crushed into powder using an analytical grinder. The powder was stored at 4 °C in a refrigerator. Wet blue goat skin was acquired from a local market in Dhaka near Savar. We acquired commercial grade chemicals and auxiliaries from local chemical suppliers. We acquired high-quality chemicals to analyze biochemical and pollution indicators.

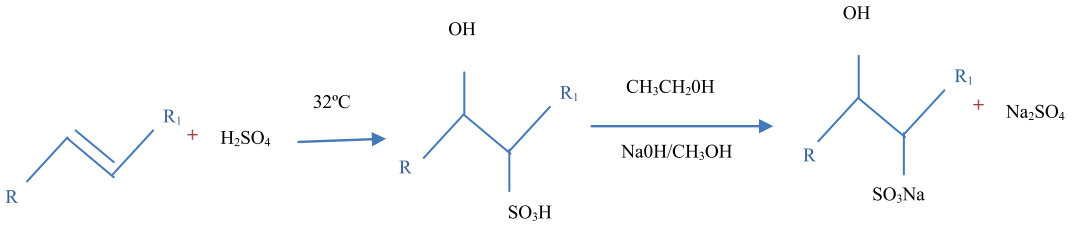
### 2.2. Oil extraction

Using a Soxhlet apparatus, 100 gm of crushed Mahogany seed powder was soaked in n-hexane solvent for 3 h to extract oil. Yield percentage was calculated following the formula mentioned below:

Yield (%) = (Weight of extracted oil/sample weight) × 100%

### 2.3. Physico-chemical characterization of the extracted oil

The oil's physicochemical properties, iodine value, and saponification value, were investigated based on existing research [37]. Degree of sulfonation was determined by Elemental analyzer (Elementar Vario Micro Cube, Germany). The fatty acid composition of the oil was analyzed using a Shimadzu GC-2010 plus gas chromatograph with a fatty acid methyl ester mixture (FAME) standard [38, 39]. A small portion of the sample was added to a test tube and stirred for 10 min with an MTB solution (Boron Tri Fluoride Methanol) in a Soxhlet at a precise temperature. The samples underwent cooling at room temperature with Heptane in the solution. Afterward, unsaturated sodium chloride was introduced and mixed vigorously for 1 min to aid in the separation of heavier molecules like ketones and water. The upper layer contains fatty acid methyl esters that are extracted into mini vials for analysis using GC-FID. A sample volume of 1 μL was injected using nitrogen as the carrier gas at a flow rate of 60 ml/min. The injector temperature was set at 230 °C, while the flame ionization detector temperature was maintained at 250 °C. The injection mode was split with a split ratio of 1:5. The oven temperature varied from 100 °C to 250 °C following a stepwise temperature programmed during the 15-min total runtime. We utilized a Restek RT Famewax column for the fatty acid profiling, with a diameter of 0.25 μm and a thickness of 0.20 μm.




**Scheme 2.** Side reaction of the sulfonation of *S. mahagoni* seed oil.

### 2.4. Sulfonation of extracted oil

Utilizing sulfonation is a common technique for creating fatliquors, particularly those made from natural oils and fats [6]. When fatty acids in oils or fats undergo sulfonation, they react with sulfuric acid or sulfur trioxide to create sulfonated fat that is emulsified. A beaker containing 100 ml of seed oil was placed in a controlled chamber with a temperature range of 15-20 °C. Concentrated sulfuric acid (95–97 %) was slowly added in drops over a period of approximately 2 h. Using an electric stirrer from BOECO in Germany set at 100 rpm to mix the contents in the beaker during sulfonation. The crude mixture was dissolved in 300 ml of methanol. Next, a solution of 15 % NaOH in methanol was added to neutralize the prepared sulfonated oil. After the solvent was recovered, the final product was ready to be used as a fatliquor [5].

### 2.5. Evaluation of fatliquor

#### 2.5.1. DSC analysis

An analysis was conducted on the oil using a Simultaneous Thermal Analyzer (STA) model 449F3 from NETZSCH in Germany through the process of Differential scanning calorimetry (DSC). The nitrogen gas was flowing at a rate of approximately 50 ml/min. The sample weighed 6.43 mg and was placed into low pressure aluminum crucibles, which were then sealed with a lid. Prior to analysis, the crucibles were sealed and inserted [40]. An empty, aluminum crucible was utilized as a reference point. The temperature range was set between 25 °C and 100 °C following a specific temperature program: Temperature held at 25 °C for 3 min; gradual increase to 100 °C at a rate of 10 °C per minute, followed by holding at 100 °C for 3 min; then held at 30 °C for 2 min. Analyzed the resulting data from DSC for peak temperature, onset temperature, and melting temperature to make comparisons [41].

#### 2.5.2. FT-IR analysis

Utilizing a PerkinElmer FTIR spectrophotometer with UATR, the functional group of the Mahogany seed oil and the prepared fatliquor (600-4000 cm-1) was identified. The absorbance and FT-IR spectra of the samples were documented.

#### 2.5.3. NMR analysis

The unsulfonated and sulfonated oil underwent $^{1}$H NMR spectroscopy using a 400 MHz NMR Spectrometer (400TM ASCEND, Bruker, Switzerland).

### 2.6. Application of Fatliquor

Two halves of a goat skin were used for different fatliquoring treatments: one with a newly developed fatliquor and the other with a vegetable fatliquor. Weighing was conducted on each half to determine the quantities of chemicals present. Both experiments were carried out using the same procedure, with the only variation being the fatliquoring agent [12]. The methodology and necessary chemicals for fatliquoring leather are detailed in **Table-1**. While washing, wet blue leather was placed in a trial drum with 200 % water and 1 % washing agent for 30 min. In a study, a specific combination of ingredients was used for neutralization for a set period of time. The pH of neutralization was determined to be 5. During the fatliquoring process, 10 % fatliquor was added to the drum containing 100 % water and run for an additional 60 min. Ultimately, a solution of 1 % formic acid was used to fix the dye on the fabric.

### 2.7. Analysis of fatliquored leather

An evaluation of the physical strength of the leather samples was conducted in an ISO/IEC accredited laboratory. The samples were conditioned for 48 hours in a sample conditioning chamber before being sent to the specified sampling location. An evaluation was conducted on various properties including tensile strength, percentage of elongation, tear strength, bursting strength, and softness using specific testing methods such as SATRA TM 43, TM 162, TM 24, and IUP36 with appropriate instruments. Throughout the entire process, the temperature and humidity were kept at 23 ± 2 °C and 65 ± 2 % respectively.

Examining the morphological features of crust leathers from preserved control and experimental goat skins involved using a JEOL

**Table 1**
Methodology/Practical recipe to prepare leather using developed fatliquoring and control trial.

| Process name | Used Chemicals | Percentage (%) | Temperature (°C) | Time (min) | Drum Speed (rpm) | Remarks |
|---|---|---|---|---|---|---|
| **Washing/Wet back** | water | 200 | 30 | 30 | 60 | Drained |
| | Wetting agent | 1 | | | | |
| **Neutralization** | water | 100 | 30 | 60 | | pH = 5 |
| | sodium bicarbonate sodium format | 0.5 | | | | |
| | Syntan | 0.5 | | | | |
| | | 0.5 | | | | |
| **Fatliquoring** | water | 90 | 55 | 60 | | Drained |
| | fatliquor | 10 | | | | |
| **Fixation** | formic acid | 1 | 30 | 30 | | Drained |
| **Washing** | water | 150 | 30 | 20 | | Drained |

Field Emission Scanning Electron Microscope (JSM-7610F, Japan). Examining the fiber images involved using an accelerating voltage of 5.0 kV and a magnification of 1000×.

For the analysis of the leather's fat content, the Soxhlet extraction method was employed, using diethyl ether as the solvent, following the official procedure outlined in SATRA TM 346. The leather sample was first grind into a powder. Using a solvent like dichloromethane, the leather powder was incorporated into cylindrical filtration paper placed inside an extraction flask. For a duration of 4 h, the fat from leather was extracted at a temperature of 60 °C. Afterward, the solvent was extracted, dried in an oven at 102 °C, and its weight was measured. The following formula was utilized to calculate the quantity of fat in leather.

$$\text{Fat content} = \frac{\textit{Flask weight with extract} - \textit{empty flask weight}}{\textit{Sample weight}} \times 100\%$$

The remaining bath from the fatliquoring process underwent analysis for the biochemical oxygen demand ($BOD_5$) and chemical oxygen demand (COD) parameters using the method outlined in the literature [42].

### 2.8. Antifungal activity

Cultures of ATCC strains of *Aspergillus niger, Aspergillus flavus, Penicillium notatum and Candida albicans* were used for antimicrobial evaluation. Nutrient agar medium was prepared and autoclaved at 121 °C for 20 min. Sterilized petri plates were prepared with an equal thickness of nutrient agar. Test organisms were grown overnight at 37 °C, 120 rpm in 10 ml nutrient broth. This broth was used for seeding the agar plates. Piece of disc (diameter 11.0 mm) from the leather treated with 10 % *Swietenia mahagoni* fatliquor (SMF) placed on top of the seeded medium. Then, the plates were incubated at 37 °C for 24 h. Antimicrobial activity was detected by measuring the zone of inhibition (including the disc diameter) appeared after the incubation period. All the experiments were performed in duplicate and repeated at least in two independent assays. The antifungal activity of sulfonated *Swietenia mahagoni* oil was compared to that of Commercial vegetable fatliquor (CVF) [35,43].

### 2.9. Statistical analysis

We utilized Microsoft Excel software for statistical analysis. Calculations were made to determine the linear growth of antifungal activities by measuring the diameter of inhibition zones in millimeters. The data was displayed as Mean ± SD.

## 3. Results and discussion

### 3.1. Physico-chemical properties of mahogany oil

Through the extraction process, we were able to obtain 60 % oil from crushed Mahogany seeds. Once more, during the sulfonation process, the yield percentage was reduced by half. Therefore, through our calculations, we determined that 30 ml of fatliquor can be obtained from crushing 100 gm of seeds using n-hexane. Despite its practical applications, n-hexane can also pose risks to human health and the environment. It is essential to handle and use N-hexane responsibly to reduce its negative effects. This involves following proper ventilation, containment, and disposal protocols [44]. For the sake of environmental safety, n-hexane was recovered through a distillation process utilizing a rotary evaporator from Witeg in Germany. The physicochemical properties of the unsulfonated Mahogany seed oil are presented in **Table-2**. The yield percentage was determined to be approximately 52 percent, demonstrating its potential for commercial applications. The iodine value of the unsulfonated oil, measured at 71.45, suggests a significant level of unsaturation available for the sulfonation reaction [45]. According to research, the sulfonated oil's SO3 percentage (1.074 %) reflects the typical penetration of sulfonated *Swietenia mahagoni* oil in leather fatliquoring. **Table-3** presents the fatty acid types and percentage composition profile of Mahogany seed oil. The Mahogany seed oil was discovered to contain a higher percentage of unsaturated fatty acids, indicating the presence of numerous double bonds that are readily available for the sulfonation reaction.

**Table 2**
Physiochemical properties of raw and sulfonated Mahogany oil.

| Name of the Parameter | Raw Mahogany oil | Sulfonated Mahogany oil |
|---|---|---|
| **Color/Appearance** | Brownish | Yellowish |
| **Melting point** | 32.0 | 40.6 |
| **Yield** | 52 % | 48 %[a] |
| **Iodine Value** | 71.45 g/100g | 12.75 |
| **Saponification value** | 141.2 mg NaOH | 128.5 |
| **Stability of 10 % emulsion** | – | Stable |
| **Appearance of 10 % emulsion** | – | Translucent |
| **Color of 10 % emulsion** | – | Yellowish |
| **Sulfur content** | – | 1.074 |

Mean ± SD triplicate analysis.
[a] Sulfonated mahogany oil was obtained from 100 % raw mahogany oil.

**Table 3**
Fatty acid composition of Mahogany oil.

| Fatty acid | Retention time min | Area pAmin | Rel. Area[a] % |
|---|---|---|---|
| Palmitic acid ($C_{16:0}$) | 7.140 | 5.101 | 12.73 |
| Palmitoleic acid ($C_{16:0}$) | 7.707 | 0.098 | 0.24 |
| Stearic acid ($C_{18:0}$) | 10.078 | 6.516 | 16.26 |
| Oleic acid ($C_{18:1}$) | 10.572 | 9.627 | 24.75 |
| Linoleic acid ($C_{18:2}$) | 11.463 | 13.154 | 32.83 |
| Linolenic acid ($C_{18:3}$) | 12.465 | 3.800 | 9.48 |
| Arachidic acid ($C_{20:0}$) | 12.805 | 0.652 | 1.63 |
| Ecosenoic acid ($C_{20:1}$) | 13.252 | 0.054 | 0.13 |
| Behenic acid ($C_{22:0}$) | 15.343 | 0.119 | 0.30 |
| Lignoceric acid ($C_{24:0}$) | 18.373 | 0.059 | 0.15 |

[a] Concentration = peak area percentage. Higher percentage of Oleic, Palmitic, Linoleic and stearic acid indicates the identification for use as a fatliquor.

### 3.2. DSC analysis

The main emphasis is on the physical properties of oils and fats, particularly their melting and crystallization behaviors [46]. The crystallization pattern significantly affects the oil or fat's performance. The process of fat crystal formation starts with the rearrangement of molecules caused by high saturation and concludes with the aggregation and compaction of molecules. We analyzed the physical characteristics of oil and fatliquor by studying their crystallization and melting behaviors with Differential Scanning Calorimetry (DSC). In comparison to saturated fatty acids, unsaturated fatty acids have lower melting points [5]. The melting point of the unsulfonated and sulfonated oil shows a noticeable increase, as illustrated in **Figure- 1(a, b).** A study revealed that the unsulfonated Mahogany oil had a melting point of 40.8 °C in **Figure-1(a)**, while the sulfonated Mahogany oil had a melting point of 48.1 °C **Figure-1 (b)**. Therefore, it is evident that most of the oil's unsaturated fatty acids were used up in the sulfonation process, resulting in saturated fatty acids with a higher melting point compared to unsaturated fatty acids.

### 3.3. FTIR analysis

FTIR spectroscopy is capable of identifying unfamiliar substances, examining chemical composition, researching molecular structure, tracking chemical reactions, and exploring physical properties of materials. It is utilized in pharmaceuticals, polymers, forensics, environmental science, and various other fields [47]. In **Figure-2(a, b)** as well as **Table-4**, FTIR images depicted the unsulfonated (a) and sulfonated (b) Mahogany seed oil with different intensity levels. The peak at 3009 cm-1 is indicative of the C–H stretching frequency, suggesting unsaturation in the unsulfonated oil. Interestingly, this peak disappeared entirely following sulfonation. This could be a result of the reaction of $H_2SO_4$ with the carbon double bond (-C=C-) in Mahogany oil. The presence of trace alcohol used during the sulfonation process is indicated by the peak at 3413cm-1. The presence of the peak at 2923-2854cm-1 in **Figure-2(a)** is likely due to the stretching frequency of alkane. The presence of the peak at 1744 cm-1 is attributed to the ester's C=O stretching frequency. This specific peak is likely due to the bending vibrations of the aliphatic groups $CH_2$ and $CH_3$. In the Figure, the appearance of a peak at 1209 cm-1 can be attributed to the stretching of S=O in both sulfate and sulfonate groups. The absence of the peak at 1161cm-1 in **figure-2(b)** further confirms the incorporation of the sulfonate group in the oil. The bending frequency of saturated oil can be used to explain the observed peak at 721 $cm^{-1}$.

### 3.4. NMR analysis

The illustration depicts the $^1H$ NMR spectra of *Swietenia mahagoni* oil before and during sulfonation **Figure-3(a, b).** Seven to ten

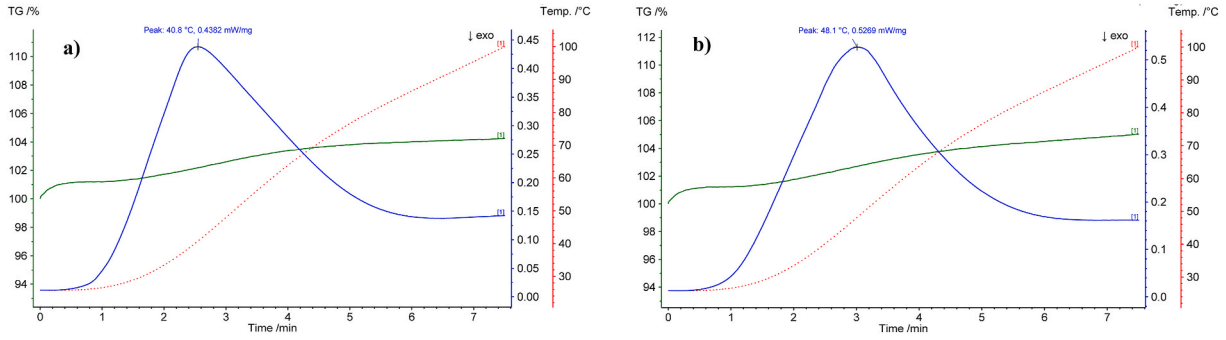



**Fig. 1.** DSC curve (a) unsulfonated of Mahogany oil and (b) sulfonated of Mahogany oil.

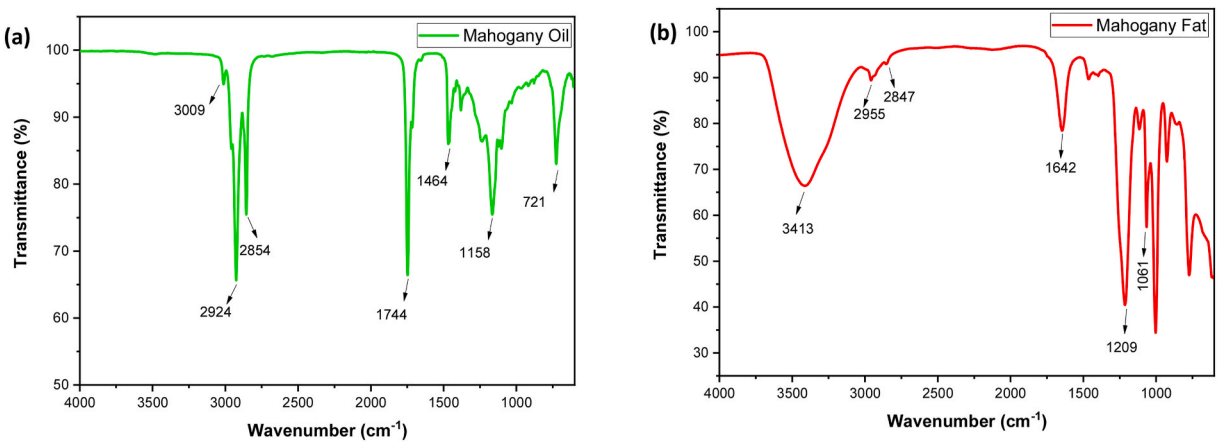



**Fig. 2.** FTIR Spectra of (a) unsulfonated oil and (b) sulfonated Mahogany seed oil.

**Table 4**
The main IR peaks and their corresponding functional groups.

| Unsulfonated oil | Sulfonated oil | Function | Description |
|---|---|---|---|
| **Frequency ($cm^{-1}$)** | | | |
| - | 3413 | -OH | Presence of hydroxyl group |
| **3009** | – | -CH=CH- | Non-conjugated unsaturation |
| **2923** | 2956 | $-CH_2$ | Alkane stretching frequency |
| **2854** | 2854 | $-CH_3$ | Alkane stretching frequency |
| **1744** | 1643 | C–O | Ester stretching frequency |
| **1464** | 1459 | C–H | Unsaturated alkene bending |
| - | 1209 | S=O | Stretching of sulfate and sulfonated group |
| - | 1061 | S=O | Asymmetric stretching frequency of sulfate and sulfonated group |
| **722** | 768 | C–C | Unsaturated carbon bending frequency |

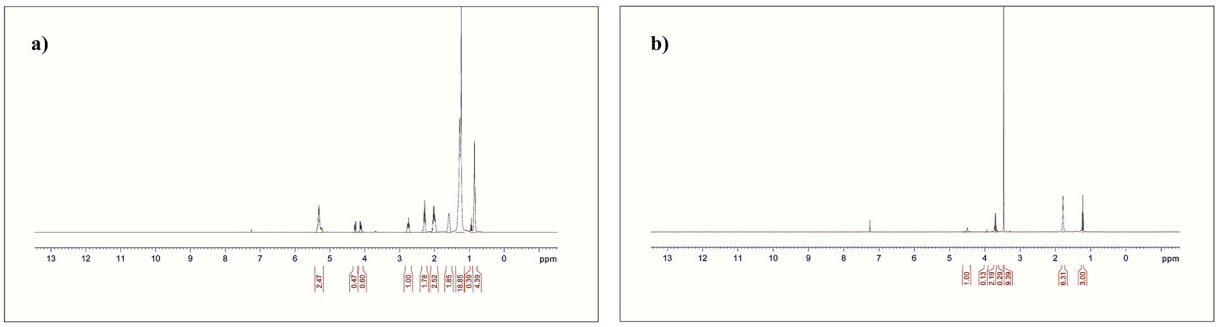



**Fig. 3.** NMR image of (a) Unsulfonated Mahogany oil (b) Sulfonated Mahogany oil.

notable signals were also found in the spectra of both oil samples. A value of δ around 0.85 ppm was derived from the terminal methyl group. The chemical shift between δ 1.1 and 2.3 ppm suggests the existence of methylene proton signals at different positions along the acyl chain in the triglycerol structure. The protons of two methylene groups attached to the oxygen of fatty acid ester functionality were identified by a triplet at δ 4.20. The additional methylene and methane protons are highlighted by the multiple peaks in the range of δ 1.20–1.8 in the $^{1}$H NMR spectrum of the compound [47]. The peak at δ 4.09–4.29 ppm is attributed to protons from the glyceride moiety, while the peak at 5.22–5.38 ppm is attributed to protons from the –CH = CH- moiety. Multiple research papers have documented comparable findings. The molecular protons with –CH = CH- structure are sp2 hybridized, leading to their NMR signals being unshielded by the diamagnetic anisotropy of the π system. When sulfonation occurs, it often leads to the saturation of double bonds. Given this scenario, the sp3 hybridized protons are expected to be shielded in comparison to the sp2 olefinic protons. The newly formed protons (H–C–S or H–C–O) in sulfonated *Swietenia mahagoni* oil figure-3(a) showed signals ranging from δ 4.09–4.29 ppm. In addition, the slight deshielding observed for these protons compared to the other protons in the sulfonated oil could be attributed to the electron-withdrawing impact of sulfur and oxygen atoms. Despite the fact that the inductive effect leads to lower shielding compared

to diamagnetic anisotropy. In the unsulfonated *Swietenia mahagoni* oil **figure-3(b),** the proton signals at δ 4.09 and 4.29 ppm are completely absent. The proton at δ 2.76 ppm from CH=CHCH2–CH=CH in the sulfonated oil was almost non-existent.

### 3.5. Emulsion stability of the prepared fatliquor

The stability of a fatliquoring agent matters for ensuring optimal penetration and absorption. Here, it is crucial to examine the stability of the fatliquoring agent [48]. An investigation was conducted on the emulsion stability of the fatliquor prepared, testing its resistance to various substances such as water, acid, alkali, salt, vegetable, and synthetic tanning agents in **Table-5** [49]. Therefore, the stability of the fatliquor emulsions was assessed and determined to be stable with a 1:4 dilution after 8 h and a 1:9 dilution after 24 h. Ensuring stability in acid, salt, and tanning agents is crucial for their application in leather fatliquoring [50]. Stability in acidic, salty media was found uniform rapidly and fantastic quality. Since, most of the leathers are tanned either by vegetable tannins or Basic Chromium Sulfate [51], emulsion stability against these was carefully evaluated. The fatliquor that was created emulsified easily and the resulting emulsion was highly stable (see Fig. 4).

### 3.6. Mechanical properties of treated leather

After fatliquoring, the leather underwent testing for mechanical properties such as shrinkage temperature, tensile strength, tear strength, percentage of elongation, and lastometer tests. After the fatliquoring process, the leather was subjected to several physical tests, and the data obtained is presented in **Table-6.** Based on the research findings, leather treated with sulfonated Mahogany seed oil has a similar fat content to leather treated with conventional vegetable oil. An evaluation was conducted on the leather's hydrothermal stability by determining its shrinkage temperature to be 105 °C. This value closely corresponds to that of the sulfonated vegetable oil. A test was carried out following established protocols, where a leather specimen treated with fatliquor was securely fastened between circular rings before testing. Our findings meet the standard requirements for physical testing in the leather industry regarding tensile strength and tear strength. Based on the physical parameter values, it is evident that the properties of the leather treated with sulfonated Mahogany seed oil are similar to those of the leather treated with sulfated vegetable oil.

### 3.7. SEM analysis

Leather is made up of collagen fibers with a very complicated structure, a network of interwoven fiber bundles with vast voids unevenly distributed amongst them, which can be better understood via SEM pictures. Using SEM is critical for assessing leather shape since it allows for detailed imaging, surface analysis, fiber structure study, cross-section analysis, defect detection, and comparison experiments. A scanning electron microscope image shows the cross section of tanned leather that has been treated with a blend of commercial vegetable oil and sulfonated Mahogany seed oil **Figure-5(a, b)** is a typical cross-sectional view of leather treated with 10 % fatliquor, clearly shows that there was no fat spew or unequal penetration, revealing a particularly fibrous structure. Leather fiber bundles (20–200 μm) are made up of very tiny element fibers (10 μm) and much finer fibrils (0.01–0.5 μm) [52]. Compared to commercial vegetable fatliquor **Figure-5(a)**, *Swietenia mahagoni* fatliquor improved the lubrication and strengthened the fibrous network structure of the leather, composed of thin and tight collagen fibers **Figure-5(b)**, [53]**.**

### 3.8. Environmental analysis

Following the fatliquoring step, the bath was evaluated for $BOD_5$ and COD parameters. Based on this observation, the $BOD_5$ and COD measurements of the bath after the fatliquoring process closely resemble those of the bath treated with a commercially available vegetable fatliquoring agent. Variations in results may occur due to factors such as reaction speed, time, and the ratio of different chemicals in the leather processing reaction tank [54]. Understanding the $BOD_5$/COD ratio is essential for evaluating water quality, controlling organic pollutants, and monitoring microbial degradation. When the $BOD_5$/COD ratio in water samples is above 0.5, it indicates that microorganisms can efficiently degrade organic pollutants, leading to self-purification of the water. When the $BOD_5$/COD ratio is low (usually less than 0.5), it suggests that a large portion of organic pollutants in water cannot be easily broken down by microbes. In order to decrease the amount of organic pollutants in water, further treatment may be necessary [55]. **In Table-7**, you can see the results for $BOD_5$ and COD. This study revealed that the $BOD_5$ values of the bath after the fatliquoring process

**Table 5**
Dissolve status and Emulsion stability status of sulfonated Mahogany oil.

| S. N | Emulsifying agent | Dissolve Status | Stability |
|---|---|---|---|
| 1. | 1:9 Water | Dissolved uniformly | Stable |
| 2. | 1:4 Water | Dissolved uniformly | Stable |
| 3. | 10 % NaCl | Dissolved uniformly | Stable |
| 4. | 10 % HCl | Dissolved uniformly | Stable |
| 5. | 10 % Mimosa Powder (veg. tanning agent) | Dissolved uniformly | Stable |
| 6. | 10 % Quebracho (veg. tanning agent) | Dissolved uniformly | Stable |
| 7. | 10 % Basic Chromium Sulfate | Dissolved uniformly | Stable |

All experiments were performed triplicate and the data was expressed as Mean ± SD.


**Fig. 4.** Emulsion stability of developed fatliquor against various Tanning agents and water

**Table 6**
Mechanical properties of processed leathers.

| Parameters | Experimental | Control |
|---|---|---|
| **Shrinkage temperature (°C)** | 105.00 ± 0.50 | 108.00 ± 0.50 |
| **Tensile strength (N/mˆ2)** | 18.17 ± 2.50 | 16.68 ± 2.50 |
| **% of elongation** | 44.61 ± 3.50 | 52.03 ± 3.50 |
| **Tear strength (mm)** | 36.00 ± 2.00 | 42 ± 2.00 |
| **Bursting strength (mm)** | 35.69 ± 0.50 | 38.32 ± 0.50 |
| **Softness property (mm)** | 3.17 ± 0.40 | 3.68 ± 0.40 |
| **Fat content (%)** | 11.04 ± 0.25 | 13.16 ± 0.25 |

Mean values ± SD, n = 3.

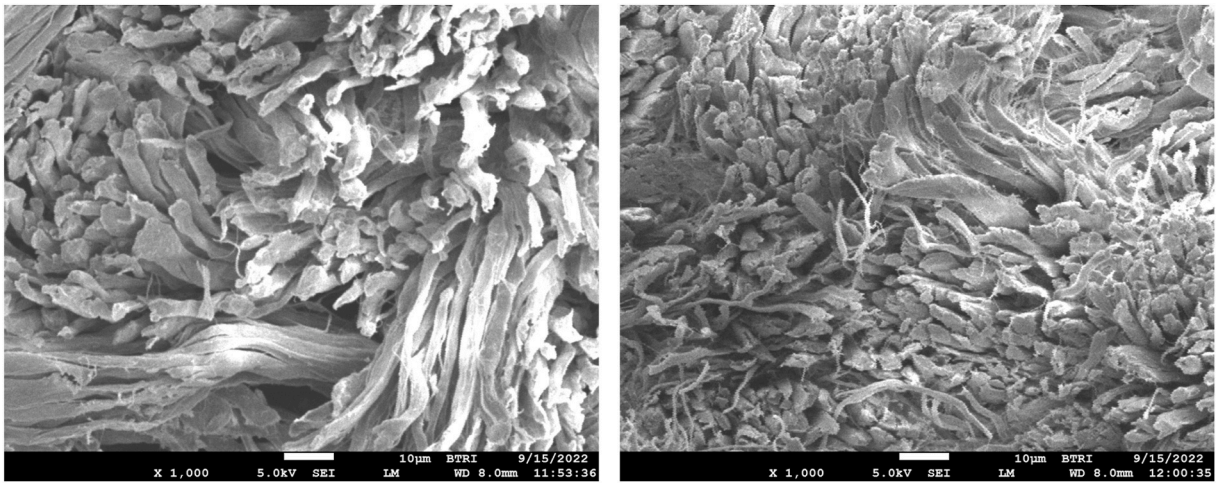



**Fig. 5.** Cross-sectional image of Leather treated with (a) 10 % synthetic fat (b) 10 % developed fat.

exhibited minimal variation. Similarly, the value of the COD for the Mahogany fatliquor and commercial vegetable fatliquor showed close similarity. The ratio of $BOD_5$/COD for the experimental and control trial was determined to be 0.52 and 0.51 respectively. Therefore, it can be noted that the newly created fatliquor demonstrated its effectiveness as an environmentally friendly product.

**Table 7**
Environmental analysis of developed and commercial vegetable fatliquor.

| Fatliquor | BOD5(mg/l) | COD (mg/l) | ($BOD_5$: COD) Ratio |
|---|---|---|---|
| *S. mahagoni* Fatliquor (SMF) | 592 ± 15.4 | 1120 ± 18.0 | 0.52 |
| Commercial vegetable fatliquor (CVF) | 570 ± 13.1 | 1105 ± 12.2 | 0.51 |

Mean values ± SD, n = 3.

### 3.9. Antifungal activity

The current study focused on exploring the antifungal properties of *Swietenia mahagoni* fatliquor against four human pathogenic fungal strains: *Aspergillus niger, Aspergillus flavus, Penicillium notatum, and Candida albicans,* as previous research has shown the seed oils antifungal activity [29,56]. Leather has been treated with *Swietenia mahagoni* fatliquor (SMF) to assess its antifungal properties. The findings are detailed in **Table-8** and **Figure-6**. Based on the information provided in the table, it was noted that the leather disc measuring 11 mm in diameter exhibited zone of inhibition against the selected four fungal species [1,57], indicating satisfactory antifungal activity compared to the control (leather specimens treated with commercial vegetable fatliquor, CVF). From the table, it was observed that *S. mahagoni* fatliquor exhibited the highest zone of inhibition, an 18.04 mm, 18.02 mm zone of inhibition against *Aspergillus niger and Candida albicans.*

On the other hand, the synthetic fatliquor locally named Commercial Vegetable Fatliquor (CVF) used in this experiment is widely known for leather processing and is easily accessible in the market in Bangladesh. It exhibited limited antifungal activity against *Aspergillus niger* showing a 12 mm zone of inhibition. The leather disc treated with CVF did not create an inhibition zone against the other three chosen fungal strains. The complete findings showed that the zone of inhibition caused by *S. mahagoni* fatliquor was acceptable for SMF in comparison to CVF. Overall, the remarkable antifungal properties of this *S. mahagoni* fatliquor showed promise as a substance for combating fungi after leather treatment as well as enhancing leather processing, which can establish fungus-resistant leather as beneficial and health-protective for consumers.

## 4. Conclusion

The Mahogany seed is readily accessible locally, yet it lacks any commercial importance. The oil from the harvested Mahogany seeds was utilized for fatliquor production. During the evaluation process, the fatliquor demonstrated significant effectiveness against the majority of emulsifiers commonly utilized in leather processing. The fiber opening and other mechanical properties of the resulting leather were found to be different to leather treated with a commercial vegetable fatliquor. Therefore, using the newly created fatliquor would provide resistance to fungus and not be hazardous to the environment compared to commercial vegetable fat liquors. Moreover, a significant quantity of fatliquors and synthetic fungicides are imported each year to fulfill the needs of the leather industry. This product has the potential to serve as a dual-purpose solution, acting as a natural eco-friendly leather processing fatliquor while also providing antifungal properties.

## Data availability statement

The data that supports the findings of this study are available on request from the corresponding author.

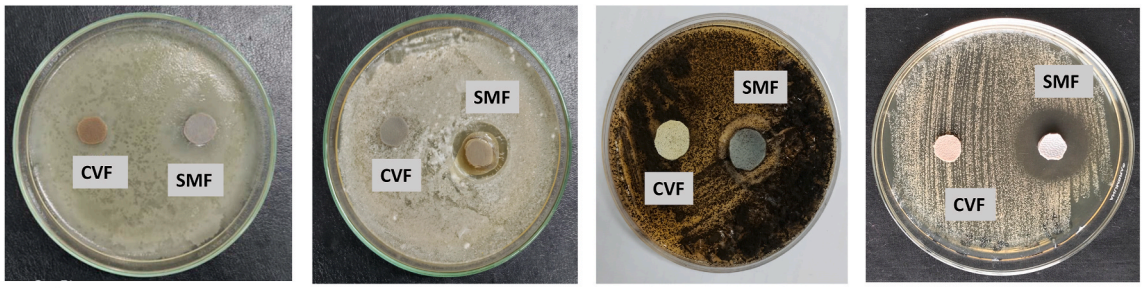
## CRediT authorship contribution statement

**Md. Abdur Razzaq:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Conceptualization. **Chadni Lyzu:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Conceptualization. **Sahana Parveen:** Writing – review & editing, Writing – original draft, Methodology. **Md. Tushar Uddin:** Writing – review & editing, Writing – original draft. **Md. Aftab Ali Shaikh:** Writing – review & editing, Writing – original draft. **Murshid Jaman Chowdhury:** Writing – review & editing, Writing – original draft. **A.H.M. Shafiul Islam Molla Jamal:** Writing – review & editing, Writing – original draft. **Muhammad Abdullah Al-Mansur:** Writing – review & editing, Writing – original draft.

**Table 8**
Zone of inhibition for *Swietenia mahagoni* fatliquor against selected fungal strain.

| Fungal species | Zone of Inhibition (diameter in mm) | |
|---|---|---|
| | SMF applied leather disc (11 mm) | CVF applied leather disc (11 mm) |
| *A. niger* | 18.04 ± 0.02 | 12 ± 0.04 |
| *A. flavus* | 15.03 ± 0.03 | – |
| *P. notatum* | 15.54 ± 0.04 | – |
| *C. albicans* | 18.02 ± 0.02 | – |

SMF= *Swietenia mahagoni* fatliquor, CVF = Commercial vegetable fatliquor. Mean values ± SD, n = 3.




(a) *Aspergillus niger* (b) *Aspergillus flavus* (c) *Penicillium notatum* (d) *Candida albicans*

**Fig. 6.** Zone of inhibition against (a) *Aspergillus niger, (b) Aspergillus flavus, (c) Penicillium notatum* and *(d) Candida albicans respectively* by commercial vegetable fatliquor and developed fatliquor by disc diffusion method. Here CVFL= Commercial Vegetable Fatliquor, SMFL= *Swietenia mahagoni* Fatliquor.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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