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An Eco-Friendly Approach to Preserve Goatskins Using *Tamarindus Indica* Leaf

Md. Khabir HOSSAIN[1], Md. Mokarom HOSSAIN[1], Kanish FATEMA[1], Shimul CHAKMA[1], Yead MAHMUD[1], Taslima AKTER[1], Shahariar SIDDIQUE[2], Al-TAMANNA[1], Md. Abdur RAZZAQ[1*]

[1]Leather Research Institute, Bangladesh Council of Scientific and Industrial Research, Savar, Dhaka, Bangladesh

[2]Institute of Food Science and Technology, Bangladesh Council of Scientific and Industrial Research, Dhaka, Bangladesh

*arazzaqbcsirlri@gmail.com

Article

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ABSTRACT

Hides and skins, the main raw materials for leather industries, are traditionally preserved with sodium chloride (NaCl). Due to the excessive use of salt (around 40 to 50% w/w) in the curing process, total dissolved solids (TDS), and salinity are produced in large quantities by the soaking effluent during the leather processing. To address the resulting environmental threat from the tanneries and replace traditional curing, plant-based curing is a cutting-edge green technology. In this study, Tamarindus indica leaves were used as a combination of 5% powder + 10% salt and 10% paste + 10% salt to preserve goat skin for 28 days. The organoleptic characteristics, hydrothermal stability, moisture content, nitrogen content, and bacterial load were periodically monitored. After curing, the goatskin was processed into leather, the environmental impact of the wastewater was evaluated, and its physical and fibre *strength was assessed. The TDS value, chloride content, biochemical oxygen demand, and chemical oxygen demand were reduced up to 65.62%, 69.38%, 31.08%, and 27.06% respectively. The prepared shoe-upper leather exhibited equivalent physical properties compared to the control. Scanning electron microscopy (SEM) image ensured the conformity of the* fibre *structure of the experimental leather with control. A significant correlation was seen among the skin preservation efficiency parameters, while the strongest correlation was ($r = -0.996$, $p<0.001$) between moisture content and shrinkage temperature. Therefore, T. indica leaves powder as well as paste could be an effective curing agent by reducing the use of salt in leather industries.*

KEYWORDS

leather, Tamarindus indica, preservation, curing

INTRODUCTION

The leather industry, a centuries-old economic sector in Bangladesh, has generated an extensive variety of leather goods for the society. Bangladesh earns a sizeable export revenue annually as a result of producing a large number of high-quality hides and skins at a low labour cost. Hides and skins are the main raw materials utilized in the tanning process [1]. Bangladeshi leather is highly regarded globally for its consistent fine grain, uniform fibre structure, smooth feel, and natural texture [2]. Flayed hides and skins consist of around 60 - 70% (w/w) water content and almost 25 - 30% (w/w) protein content. The skin begins to deteriorate 5 - 6 hours after the animal's death if it isn't treated.

Within 8 - 12 hours after contact with raw flesh, bacteria on the skin might penetrate the predominant component of the skin corium containing 30% (w/w) protein making the materials vulnerable to bacterial attack [3]. In addition, bacteria can cause major grain peeling and serious gaps in the skin in 15 to 24 hours. The presence of intact protein materials has an impact on the leather's quality. Before the skin is turned into leather, appropriate preservation is essential to prevent the skin's protein from degrading as a result of bacterial attack [4].

To preserve raw skins, salt (sodium chloride, NaCl) is a standard curing agent. Depending on the green weight of the skins, 40% to 50% of salt (NaCl) is widely utilized across the country and has some benefits such as availability, ease of handling, and low cost. The impact of the salt is to dry the skin, generating an environment that is unfavourable to the growth of bacteria, and plasmolysis happens and prevents bacterial development [5]. Approximately 13 - 17% of salt is fixed into the hides and skin [6]. During the soaking operation, this salt is removed from raw hides and skins. As a result, it harms aquatic life significantly by raising salinity, increasing total dissolved solids (TDS), and so on [7]. Unexpectedly, using lots of salt during the preservation stage hurts the aquatic environment [8]. Through the tanneries' drainage system, a vast number of salted waters from the soaking process were discharged into the river. The excessive quantity of salt that is disposed of during the de-salting and soaking process has a serious negative impact on the environment [9]. Salinity issues are common in areas where drought is a significant concern, and they hurt the quality of irrigation water as well as reduce the fertility of the soil. In addition to that sodium chloride has strong solubility and stability characteristics. Because of this, the treatment of wastewater that contains salt is challenging. The ion balance of water exchanges due to salinity, causes rivers' ecosystems to decline. It was discovered that utilizing salty water for irrigation increased surface salinity, which decreased agricultural yield [10]. Moreover, the combined effects of salt and water destroy buildings and infrastructure and the rate of damage is dependent on water management, climate, building age, and construction materials [11]. The primary pollutants in tannery effluents are chlorides, sulfides, and TDS [7]. Owing to the harmful effects of salt on the environment, researchers are currently looking for an effective alternative to the conventional methods of preservation.

A lot of work has been done on alternate preservation techniques such as sun drying, controlled drying, cooling and chilling, cooled air treatment, powder biocide, vacuum, and preservation by irradiation. Several salt-free chemicals have been used including the addition of potassium chloride, benzalkonium chloride, aryl alcohols, silica gel, bacteriocin compounds, sodium silico-fluoride, boric acid, chlorites, hypochlorite, sulfites, and bisulfites in conjunction with acetic acid and MgO in skin preservation [7]. These techniques either have a risk of being hazardous or are not economically or practically viable. For that reason, none of these are accepted and used commercially. Alternative chemical preservation

techniques are either impractical or have significant negative environmental effects, while physical preservation techniques are energy-intensive and economically unviable [5].

Researchers are currently experimenting with various plant formulations. For skin preservation, the leaves of *Clerodendrum viscosum* were tried in both powder and paste form. The results of the study showed that the method of salt-free preservation using 10% leaf paste significantly reduced the levels of chlorides, and TDS in the wastewater from soaking liquor. The reduced salt preservation technique, however, which used 10% leaf paste and 10% salt, could also successfully preserve skin [12]. *Azadirachta indica* (Neem) dried leaf powder 15% was used to preserve skin with less salt because of its antimicrobial properties [13]. *Rumex abyssinicus* (memeko) root powder was explored for use as a potential skin preservative. A combination of 10% memeko and 15% NaCl was able to preserve the skins for 30 days [14]. *Swietenia mahogany* (seed) extract was used to easily preserve raw goat skin for up to 30 days by using only 3% of the weight of the skins [15]. Raw skin preservation was peer-formed using an identical ethanol extract from the *Aegle marmelos* plant. It is a completely salt-free technology that could reduce the number of pollutants produced by soaking liquor. Goat skin was successfully preserved with 10% leaf paste, and 10% salt using the organic preservative *Calotropis gigantea* leaf paste [16]. Studies have shown that *Sesuvium protolocosum* is useful for preserving skin [17]. It was tried to preserve skin using *P. hydropiper* leaf paste. Compared to conventional salt-preserved skins, the experimented skin sample had even better qualities [18]. Besides, a combination of *Cassia fistula* and *Psidium guajava* leaf powder [19]. Neem cake that has been de-oiled was utilized as a plant-based source of skin preservation [19]. Methanolic leaf extract from the *Tamarindus indica* was used as a source for raw skin preservation [5]. Previous research showed the application of various Phyto-based sources with antibacterial properties as a novel source for the preservation of raw skin. The present study investigated only *T. indica* leaves both powder and paste with less salt for skin preservation along similar lines.

T. indica is a monotypic genus, and belongs to the subfamily *Caesalpinioideae* of the family *Leguminosae* (*Fabaceae*), commonly known as the tamarind tree is one of the most important multipurpose tropical fruit tree species in the Indian subcontinent, Africa, Bangladesh, Pakistan, Nigeria, and most of the tropical countries. Tamarind plant is a rich source of antioxidant, antidiabetic, antimicrobial, antivenom, antimalarial, cardioprotective, hepatoprotective, antiasthmatic, laxative, and anti-hyperlipidemic, anti-fungal activity [20]. Because of the presence of flavonoid chemicals, the leaves were discovered to have a protective quality. Leaves are a good source of riboflavin, niacin, beta-carotene, protein, vitamins B complex, fat, and polysaccharide.

One of the most essential conditions for sustainable development in industrial processes is environmental sustainability. The extensive environmental contamination caused by the leather industry is well-known. Yet, there might be a paradigm shift in this industry due to green engineering.

The cutting-edge green technique known as "plant-based goatskins curing" is based on the idea of preventing pollution in the upper stream of leather manufacturing [21]. While a key concept of green chemistry is “prevention instead of treatment” [22,23]. Besides, pollution minimization and avoidance are the most preferable approaches for sustainable leather processing by UNIDO [24].

Therefore, the purpose of this study was to develop a reliable, cost-efficient, and environmentally friendly preservation technique for the leather industry using *T. indica* leaves powder and paste as a curing agent.

EXPERIMENTAL

Materials and Methods

Collection of Raw Materials

Two pieces of goatskins were purchased from a meat shop located in Nayarhat, Savar, Dhaka, Bangladesh. Each piece of skin was split into left, and right sides. For the preliminary test, both sides were further divided (each piece of skin) into two parts. The Tamarind leaves were collected from nearby places in Savar, Dhaka, Bangladesh.

Preservation Experiment

Using laboratory mortar, around 1.5 kg of leaves were pasted. On the other hand, 1.5 kg of the green leaves were sun-dried, ground into a fine powder and utilized for preservation (Figure 1). The flesh side of divided goatskins for the preliminary trial was individually covered with eight different combinations (% based on raw skin weight) of leaves powder and paste with less salt (5% –10%) for observation (Table 1).

a b c d

Figure 1. Preparation of *T. indica* Leaf powder and paste for preservation a) Collection of Tamarindus leaf b) Sun Drying c) Leaf paste d) Crushing to get Powder

Table 1. Tamarind leaves to powder and pasted with salt combination chosen for preliminary preservation trial

SL. No.	Sample ID	Combination
1.	Sample A	20% Powder
2.	Sample B	5% Powder + 10% Salt
3.	Sample C	10% Powder + 5% Salt
4.	Sample D	10% Powder + 10% Salt
5.	Sample E	20% Paste
6.	Sample F	5% Paste + 10% Salt
7.	Sample G	10% Paste + 10% Salt
8.	Sample H	10% Paste + 8% Salt

The combinations were 20% Powder (sample A), 5% Powder + 10% Salt (sample B), 10% Powder + 5% Salt (sample C), 10% Powder + 10% salt (sample D), 20% paste (sample E), 5% paste + 10% Salt (sample F), 10% paste + 10 % Salt (sample G), 10% Paste + 8% Salt (sample H) (Figure 2). Various parameters including odour/smell, hair slip, white patches, and physical feel were frequently tested throughout the 1st, 4th, 7th, 14th, 21st, and 28th days to assess organoleptic characteristics. After preliminary observation, the two most effective combinations (5% powder + 10% salt, 10% paste + 10% salt) were chosen for the final preservation experiment (Table 2).

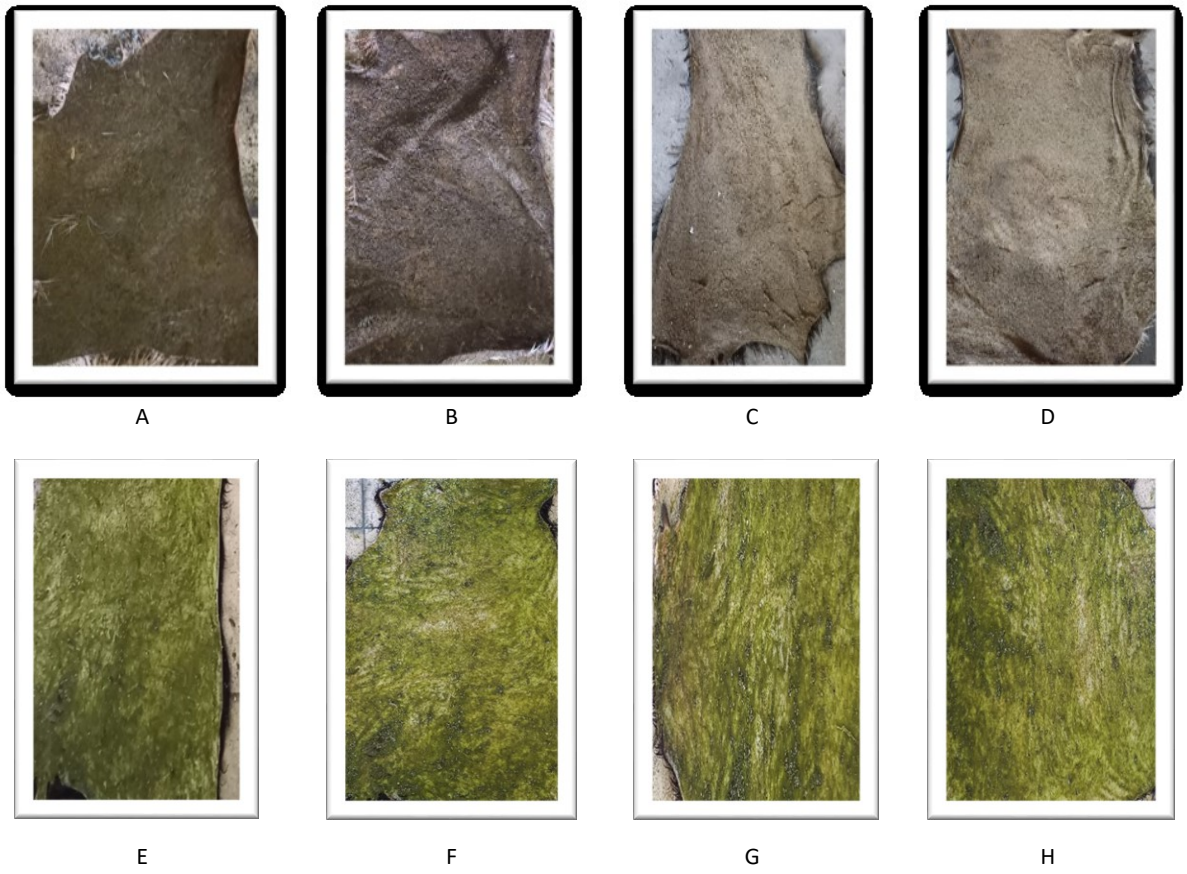
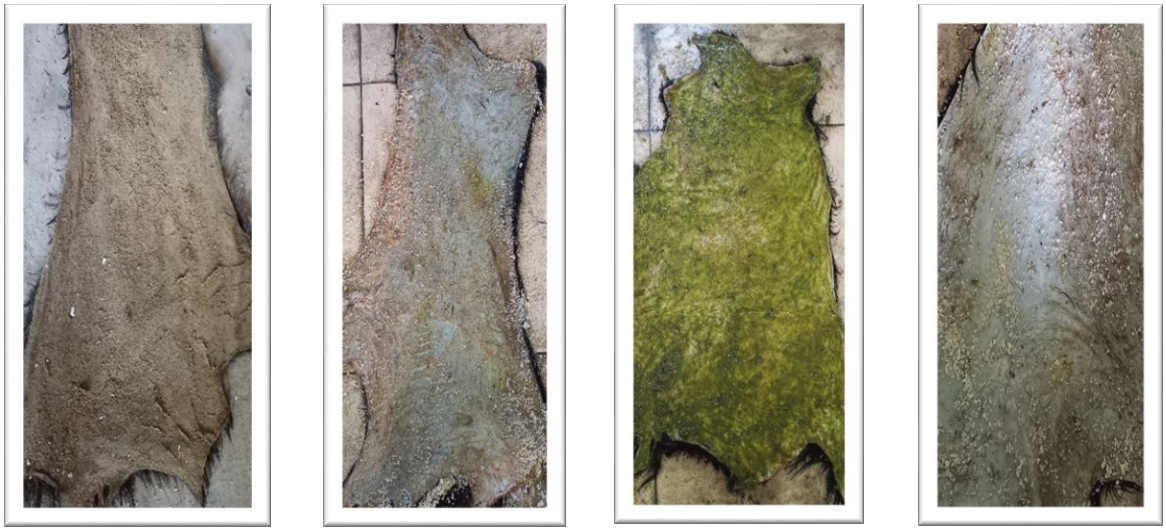


Figure 2. Goat skin was treated with different combinations of plant-based preservatives during 30 days of preliminary trial (see details in Table 1)

Table 2. Combination chosen for final preservation trial

Combination	Designation
5% Powder + 10% Salt	Exp. 1
40% Salt	Cont. 1
10% Paste + 10% Salt	Exp. 2
40% Salt	Cont. 2

The physical feel of the skins and other factors were taken into consideration for optimization. Six of the other combinations that were used in the preliminary trials resulted in the skins becoming hard, and medium hard after storage. As a result, it will be difficult to wet back the skins in beam house operations, and other chemical consumption will be higher for them. Two left-side and right-side split goatskins were treated with the two optimized combinations for 28-day preservation with corresponding controls (40% salt) on the other side (Figure 3) and the preserved goatskins were subsequently brought into the final leather processing.



Exp. 1 Cont. 1 Exp. 2 Cont. 2

Figure 3. Application of preservative for the final preservation experiment

During the final preservation period the shrinkage temperature, nitrogen content, bacterial count, and moisture content were evaluated at regular intervals to measure the efficiency of the optimized preservatives. However, the preservation experiments were carried out from June to August, during the wet season. The environment was difficult and adverse for preservation because it was much more humid than it was in other months of the year.

FTIR Analysis

An FTIR spectrophotometer from Perkin-Elmer with UATR was used to determine the functional group of the Tamarindus leaf. The samples' FTIR Spectra were recorded. First, a control sample of pure KBr was used to calibrate the FT-IR for the background scanning signal.

Evaluation of Preservation Experiment

The preservation efficiency measuring parameters like shrinkage temperature, nitrogen content, bacterial count, and moisture content were determined on the 1st, 4th, 7th, 14th, 21st, and 28th days of preservation.

Moisture content

Small pieces (1-2 g) of skin samples were cut. Moisture content was determined by using the High-performance Moisture Analyzer (model WBA-110M).

Nitrogen content

To assess the nitrogen concentration a known weight was taken out of the preserved samples and treated with ten times (w/v) its weight in distilled water in a conical flask. The flask was kept in a shaker and shaken at 200 rpm for 30 minutes. After being filtered with filter paper, the liquor was then transported to an automated Kjeldahl chamber's digestion unit. Nitrogen content was determined by following the procedure outlined in the literature according to the Kjeldahl Method [8].

Bacterial Count

At various stages of preservation skin samples of known weight were cut and followed the process for determining the nitrogen content up to filtration. 1 ml of the filtrate was taken and 10 ml of sterile water was used to dilute it. A serial dilution was done. To achieve the identical bacterial suspension, the solution was thoroughly shaken and 0.1 ml was spread for uniform bacterial dissemination on a previously prepared sterile nutritional agar plate. The petri plates were incubated at 37 °C for 48 hours. A bacterial colony counter was used to count the number of bacteria.

Hydrothermal Property

The shrinkage temperature of hides and skins represents their hydrothermal properties. The shrinkage temperature tester SATRA STD 114 was used to determine according to ISO 3380:2015 [25]. Test samples (20 × 3 mm) were divided into pieces and fixed to the shrinkage temperature instrument holder. After that, the apparatus was placed in a bath of 70:30 glycerin/water solution. The rate of heat

growth occurred simultaneously with a gradual temperature rise. The shrinkage temperature for that specific skin was recorded as the shrinkage starting temperature.

Leather Processing

The skins that had been preserved for 28 days were turned into crust leather by using the conventional leather processing method.

Pollution Load Analysis

Both the control trial's and the experimental trial's wastewater produced by the soaking operation during leather processing were collected and analyzed for biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and chloride concentration. Analysis was conducted using APHA standards, and each experiment was performed three times [26].

Physical Property Analysis

The aged crust leathers' physical strength was assessed after conditioning for 48 hours at a temperature of 23 ± 2 °C, and a relative humidity of 65 ± 2%. Then, the samples were collected from the designated sampling location of crust leather. Tensile strength and elongation at break, stitch tear strength, and bursting strength were all evaluated by IUP-06 [27], DIN-5331 [28], and IUP-09 [29] methods.

FESEM Analysis

A JEOL Field Emission Scanning Electron Microscope (FESEM, JSM-7610F, Japan) was used to evaluate the proposed preservation method's impact on leather's fibre structure and compare it to the control. The leather samples were collected from the same area to determine the SEM analysis. Examining the cross-section of prepared leather samples. The fibre images were assessed at a 100X magnification with an accelerating voltage of 5.0 kV for examining the cross-section of prepared leather samples.

Statistical analysis

Using Origin software version 2018 (Origin Lab Corp., USA), the Pearson Correlation matrix was performed to determine the correlation of nitrogen content, bacterial count, moisture content, and hydrothermal stability.

RESULTS AND DISCUSSION

Preservation Experiment

Organoleptic features of the preserved skins were regularly assessed from day one (1) to day twenty-eight (28) of preservation. Common organoleptic properties of skin preservation contain physical feel, odour, smell, and hair slip. These characteristics allow to notice and assess the sensory properties of a material, which can be helpful for several tasks, such as judging a product's quality, safety, or suitability for a particular usage. Table 3. shows preliminary goatskin study results maintained with tamarind leaves both powder and paste as a source for Phyto-based preservation. There was no hair slip, putrid odour, and white patches throughout the whole period of preservation. But different combinations of the samples revealed different physical feel. Only soft and flexible samples were chosen for the final trial to minimize water and chemical usage, proper handling, probable fibre breakage, and time consumption during leather processing. Therefore, samples B and sample G were the optimized samples for the final preservation experiment. This combination was exhibited as soft and flexible during a full preliminary period.

Table 3. Assessment of Organoleptic Properties after 30 days of preliminary trial

SL. No	Combination	Hair Slip	Putrid Order	Relative Physical Feel	White Patches
1	Sample A	No	No	Very Hard	No
2	Sample B	No	No	Soft and flexible	No
3	Sample C	No	No	Hard	No
4	Sample D	No	No	Medium Hard	No
5	Sample E	No	No	Medium Hard	No
6	Sample F	No	No	Flexible	No
7	Sample G	No	No	Soft and Flexible	No
8	Sample H	No	No	Flexible	No

FTIR Spectroscopy of *T. indica* Leaves

FTIR investigation is a valuable tool in many research and industrial fields because it reveals insightful information about the chemical composition and structure of materials. The FTIR Spectroscopy of *T. indica Leaves* is presented in Figure 4.

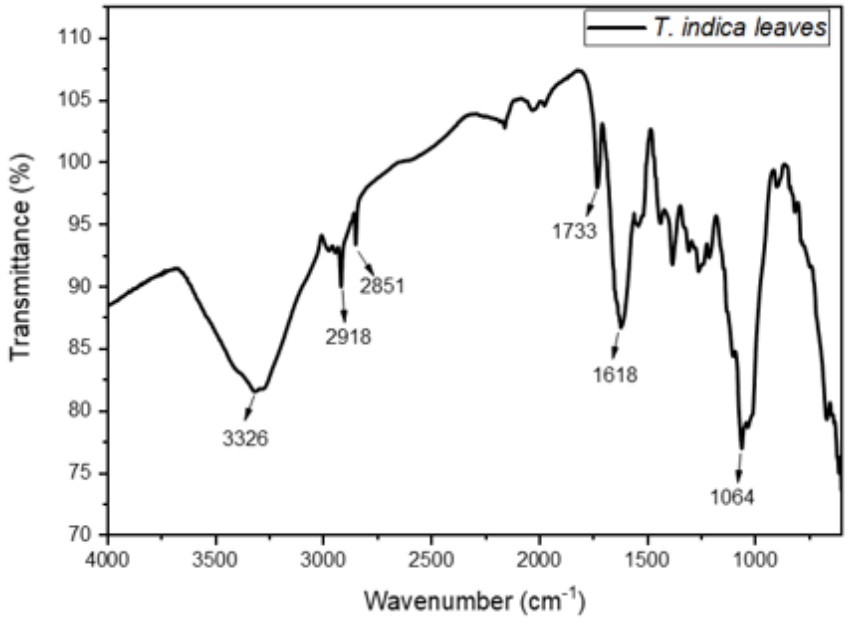


Figure 4. FTIR Spectrum of the *Tamarindus indica* Leaves powder

The presence of -OH in the phenolic compound is shown by a high peak at 3326 cm^{-1} in the IR peak of Tamarind leaves powder, followed by -CH stretching at 2918 cm^{-1} and -C–H ($-CH_3$, $-CH_2$) stretching at 2851 cm^{-1}. The peak for -HC=CH- bending is located at 1064 cm^{-1} [30] Furthermore, the peak at 1618 suggests aromatic C=C stretching [31], whereas peaks at 1733 cm^{-1} and 1708 cm^{-1} are caused by C=O stretching vibrations [30]. These functional groups estimate the presence of different bioactive groups.

Evaluating the Efficiency of Preservation

Moisture Content

The moisture content is one of the most crucial factors to evaluate the effectiveness of a curing agent [7]. Moisture content is also an important parameter for the preservation process as the bacteria need moisture content for their survival. A preservation agent can effectively work through three techniques of skin preservation: dehydration, bacteriostatic activity, and antibacterial action. When hypertonic preservatives are introduced to bacterial cells, the water content of the bacterial cell is released to the semipermeable cell membrane, resulting in dehydration. Causing the decrease in moisture content, bacterial growth can be inhibited by dehydration from preserved skin fibres. Conventional salt takes out water from both skin fibres and bacterial cells. Thus, the curing operation occurs. The salt curing method is regarded as one of the better techniques for cure due to the salt's dual role in skin preservation: dehydrating and bacteriostatic effect [32].

Conventional salt curing results in better-quality leather because of the method of salt dispersion by the osmotic diffusion mechanism. The water-absorbing ability of both leaves powder and paste is very

significant. However, collagen matrix fibrils can stack together because there is an imbalance between the leaf sample and skin fibres, resulting in extremely hard skin that breaks down before tanning. Having the ability to generate osmosis, NaCl effectively preserves the collagen structure by converting it from hypertonic to isotonic solutions, during the curing process. Therefore, leaf powders and pastes are an effective way to preserve and reduce moisture content during skin preservation if they have antimicrobial properties [32]. In this study, the moisture content of experimental skin and control skin is shown in Figure 5 throughout 28 days of the preservation period. The reduction of moisture contents was 59.3% -to 30.26% for Exp. 1, 58.55% -to 31.55% for cont. 1, 57.35% -to 31.1% for Exp. 2, and 56.96% -to 32.19% for cont. 2. Therefore, the Exp. 1 sample showed the highest moisture reduction than other experimental and control samples after 28 days of preservation. It was also observed that moisture content gradually decreased in the case of all the samples. The experimental samples' moisture content reduction differed from the control samples by only 2%. The effects of dehydration were similar in the control samples (containing 40% salt) and experimental samples (containing 10% paste and 5% powder). So, this illustrates how *T. indica* leaves both powders and paste effectively preserve skin by showing the dehydrating properties.

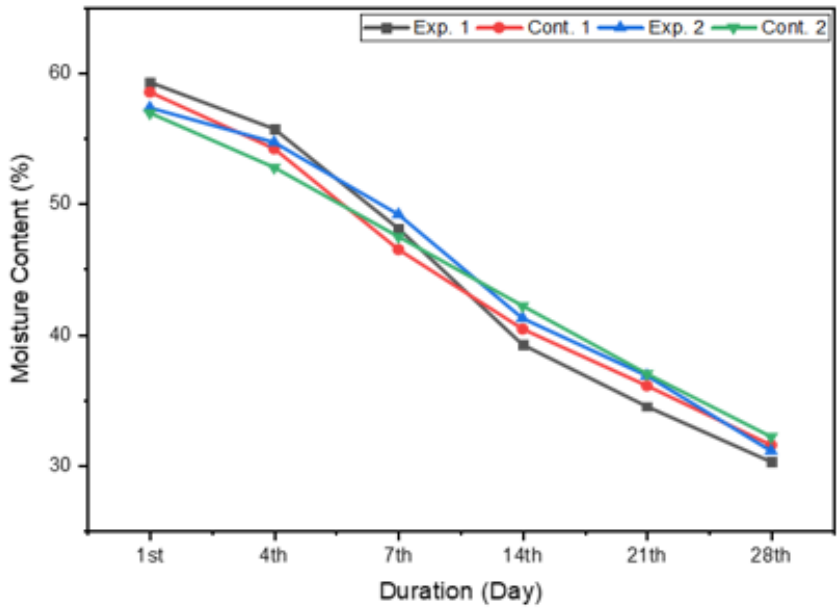


Figure 5. The moisture content of the experimental and control samples during 28 days of goatskin preservation

Hydrothermal stability

The shrinkage temperature (Ts) or hydrothermal stability can be used to indirectly measure any deterioration in the skin's collagen structure. By detecting structural integrity by wet heat shrinkage, this test can initiate the denaturation transition of collagen. As skin collagen triple helix comprises 12% of -Gly-Pro-Hypro-, 44% of -Gly-Pro-Y- or -Gly-X-Hypro-, and 44% of -Gly-X-Y-, where X and Y are not defined. Therefore, any breakdown of the collagen triple helix's amino acid chains will lower the

temperature at which it shrinks. It indicates the breaking of various connections and links as a sign of current interactions in collagen shrinks [3].

In this study, the T_s of experimental and control goatskins in the various intervals of 28 days of preservation were presented in Figure 6. After 28 days of preservation, the results showed a brief extension in T_s. On 1st day of preservation, T_s was 60.2 °C for Exp. 1, 61.1 °C for Cont. 1, 61.3 °C for Exp. 2, 61.9 °C for Cont. 2. After 28 days of preservation, this value turned into 63.1 °C for Exp. 1, 64.4 °C for Cont. 1, 63.3 °C for Exp. 2, 64.4 °C for Cont. 2. It was also observed that T_s gradually increased in the case of all the samples. There was no noticeable distinction in T_s during the preservation of any of the experimental skins. Probably due to the decrease in moisture content, this T_s has been increased [12]. From these findings, it can be concluded that preservation using Tamarind leaves both powder and paste had no impact on the collagen matrix.

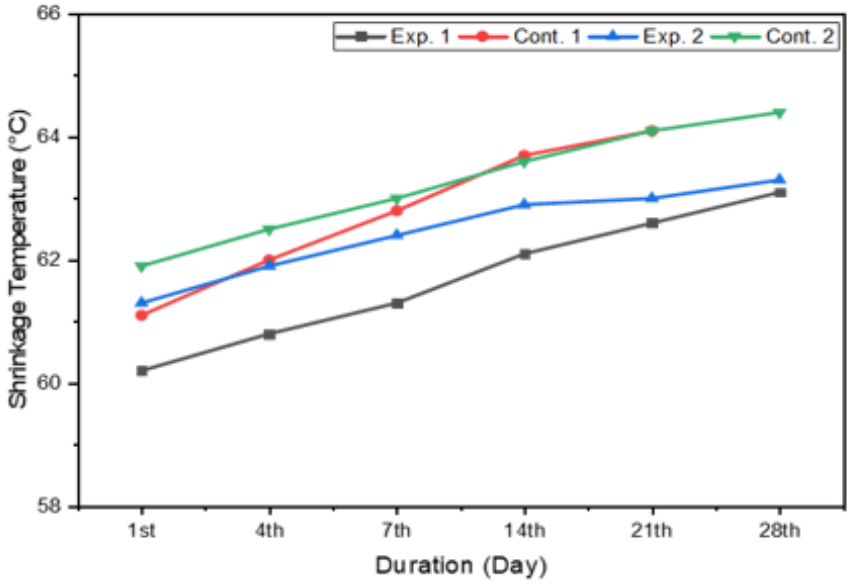


Figure 6. Shrinkage temperature of the experimental and control samples during 28 days of goatskin preservation

Bacterial load

The bacterial load is one of the most important factors in understanding the rate of denaturation of hides and skins throughout the curing process [12]. The bacterial load of experimental and control goatskin samples with different time intervals of 28 days of preservation was presented in Figure 7.

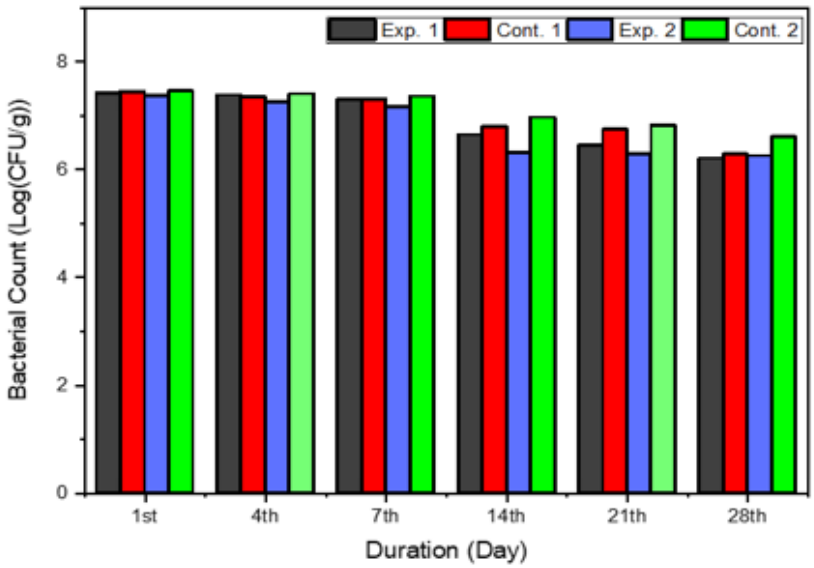


Figure 7. Bacterial count of the experimental and control samples during 28 days of goatskin preservation

Following the first day of storage, the number of bacteria was determined to be 2.57x10^7 CFU/g for Exp. 1, 8.8x10^6 CFU/g for Cont. 1, 2.28x10^7 CFU/g for Exp. 2, 2.85 x10^7 CFU/g for Cont. 2. On the 1th to 7th day of curing, the total bacterial load decreased to 2.01x10^7 CFU/g for Exp. 1, 1.98x10^7 CFU/g for Cont. 1, 1.45 x10^7 CFU/g for Exp. 2, 2.27 x10^7 CFU/g for Cont. 2. In the 1st to 7th days of preservation, the bacterial load decreased at a slower rate similar to the control samples. During this period Tamarind leaves inhibit the bacteria from attacking the available protein content of collagen matrix like salt. Therefore, the bacteriostatic action of that plant leaves powder and paste was effective from the beginning of preservation. In addition, during the 7th to 28th days of preservation, the bacterial load for all the mentioned skin samples decreased significantly and became stable. After 28 days of preservation, total bacterial load was recorded as 5.5x10^6 CFU/g for Exp. 1, 1.6 x10^6 CFU/g for cont. 1, 4.0 x10^6 CFU/g for Exp. 2, 1.78 x10^6 CFU/g for Cont. 2. Where the experimental sample revealed the similarity of Phyto-based curing agents to conventional practice. In addition, the bacterial load was decreased for all samples in comparing the 1st to 28th day of curing. So, the two samples have bacteriostatic effect in the 1st to 7th days and bactericidal activities in the 7th to 28th days of curing. In conclusion, the leaves of *T. indica* leaves possess an antibacterial activity.

Nitrogen Content

Total extractable nitrogen is the best indicator of whether bacteria have degraded the animal skin or not [31]. Nitrogenous components are generated when goatskin proteins are putrefied. Therefore, bad odours are emitted, and hair slips. The degree of putrefaction caused by microbes can be determined by testing the hide or skin for extractable nitrogenous compounds. It is determined by measuring how

much nitrogen was removed in the aqueous phase. By determining total Kjeldahl nitrogen (TKN), it is possible to detect bacterial degradation in preserved goatskin. In this study, the values of the nitrogen content are shown in Figure 8. The extractable nitrogen contents on the first day were 2.39 mg/L for Exp. 1, 2.46 mg/L for Cont. 1, 2.20 mg/L for Exp. 2, and 2.29 mg/L for Cont. 2. After 28 days, the amount of extractable nitrogen was 3.12 mg/L for Exp. 1, 3.20 mg/L for Cont. 1, 3.22 mg/L for Exp. 2, 3.29 mg/L for Cont. 2. The amount of nitrogen content was gradually raised (0.73 - 1.02 mg/L) in all samples with time but became nearly stable after 14 days. Besides, the experimental samples' values were therefore lower than the equivalent control. The amount of extractable nitrogen in the respective control and experimental skins appears to have been almost similar after the 14th day. However, despite having a slight incremental nitrogen content, the experimental sample had no hair peeling or bad odour. Therefore, the increment of the nitrogen content was negligible as the bacterial load was decreased gradually over the preservation period. In conclusion, the proposed curing agent can control the bacterial action on the preserved goatskins.

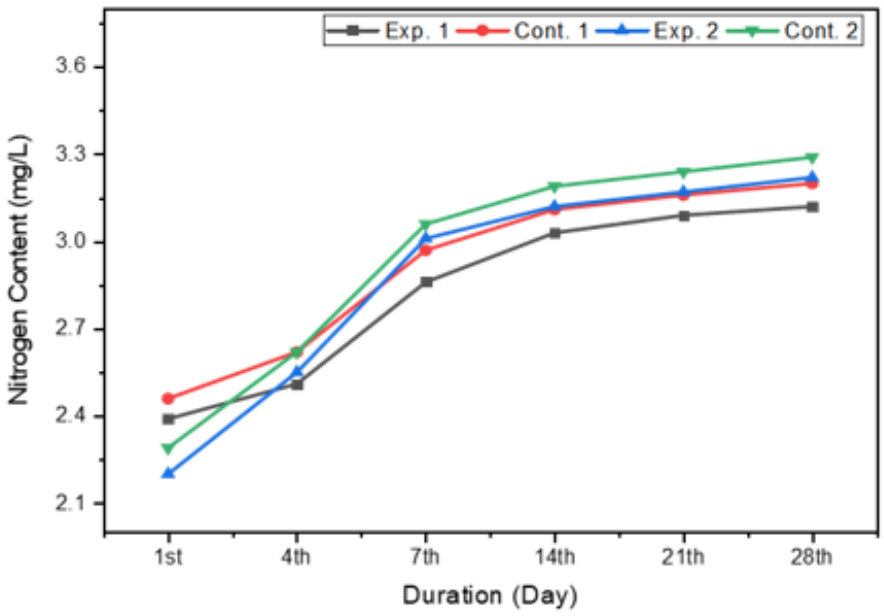


Figure 8. Nitrogen content of the experimental and control samples during 28 days of goatskin preservation

Correlation Analysis

Table 4 displays the correlation study between the control samples and experimental samples' shrinkage temperature, moisture content, bacterial count, and nitrogen content throughout the 28-day curing period. A substantial association is found between the preservation efficacy metrics. The results indicate a very significant ($P<0.001$) negative correlation between the moisture content and shrinkage temperature (Exp. 1, r = -0.996; Cont. 1, r = -0.994; Exp. 2, r = -0.963; and Cont. 2, r = -0.995).

Furthermore, there is a significant positive association between moisture content and bacterial load (Exp. 1, r = 0.969; Cont. 1, r = 0.944; Exp. 2, r = 0.947; and Cont. 2, r = 0.971); however, Exp. 1 and Cont. 2 exhibit a very strong correlation ($P<0.01$). Moreover, for Exp. 1 and Cont. 2, there is a substantial negative association ($P<0.01$) between the bacterial load and the shrinkage temperature. Furthermore, given the negligible increment of nitrogen content (<1 mg/L) over the preservation period, the significant ($P<0.01$) strong positive correlation between nitrogen content and shrinkage temperature is nonsensical. A similar conclusion can be drawn regarding the correlation of nitrogen content with bacterial count and moisture content over the preservation period.

Pollution load generated during the soaking process

The soaking process can emit a variety of contaminants into the environment when leather is processed. Soaking is a critical stage in the leather-making process to remove impurities, salts, and other contaminants from raw animal skins. The pollution load was determined after the soaking operation. Soaking can generate significant pollution which is determined by checking BOD, COD, TDS, and chloride content (Cl^-) [34]. The quantity of produced pollution load is displayed in Table 5. When comparing the results to conventional practice, it is evident that all the signs of water contamination have significantly decreased. The removal capacity for Cl^- and COD were found to be 54.39% and 35.22% in Exp. 1 while 68.89% and 27.06% in Exp. 2, respectively.

Table 4. Correlation matrix between bacterial count, shrinkage temperature (T_s), Nitrogen Content, and moisture content of experimental samples (Exp. 1 and Exp. 2) and control samples (Cont. 1 and Cont. 2) in 30 days of curing

Exp. 1				
	Moisture Content	Nitrogen Content	Bacterial Count	T_s
Moisture Content	1			
Nitrogen Content	-0.969**	1		
Bacterial Count	0.969**	-0.887*	1	
T_s	-0.996**	0.955*	-0.966**	1
Exp. 2				
Moisture Content	1			
Nitrogen Content	-0.893*	1		
Bacterial Count	0.947*	-0.846	1	
T_s	-0.963**	0.974**	-0.923*	1
Cont. 1				
Moisture Content	1			
Nitrogen Content	-0.969**	1		
Bacterial Count	0.944*	-0.848	1	
T_s	-0.994**	0.982*	-0.932	1

Cont. 2

	Moisture Content	Nitrogen Content	Bacterial Count	T_s
Moisture Content	1			
Nitrogen Content	-0.920*	1		
Bacterial Count	0.971**	-0.824	1	
T_s	-0.995**	0.946*	-0.957**	1

*Correlation is significant at the 0.01 level (2-tailed). **Correlation is significant at the 0.001 level (2-tailed)

Furthermore, TDS readings for the controls are greater than those for the experiments. According to reports, the TDS reduction was 65.62% and 64.92% respectively for Exp. 1 and Exp. 2. It is highly suggested that *T. indica* leaf-based curing agents be used instead of conventional methods due to their notable reduction in water pollution. Selvi Alagumuthu et al., 2015, showed that a methanolic leaf extract of *T. indica* was used to reduce TDS and Cl^-, but the current work has solely used *T. indica* leaf powder and paste as a curing agent. It could be declared that the environmental pollution caused by conventionally soaking liquor may be easily reduced by using our optimal combinations for skin preservation. Therefore, alternative curing agents from *T. indica* not only contribute to effective preservation but also can reduce the pollution load in the leather industry.

Table 5. Pollution loads generated in the preserved skin samples

Parameters	Exp. 1	Cont. 1	Removal (%)	Exp. 2	Cont. 2	Removal (%)
Cl^- mg/L	7864	22880	65.62%	8387	23944	64.97%
BOD mg/L	541	785	31.08%	594	825	28%
COD mg/L	4336	5768	24.82%	5088	6976	27.06%
TDS mg/L	5895.9	19260.92	69.38%	6601.76	20150.76	67.23%

All the values are presented as the mean of triplicate data

Processed Leather Quality Assessment

Table 6 shows the Physical strength properties of processed leather. Tensile strength, stitch tear strength, load at grain break, and distention tests on shoe upper crust leather samples from the experimental and controls were reported. Every experimental leather sample is compared to both the standard value and the control sample. The physical test results showed that curing agents based on Tamarindus leaves did not affect the final qualities of leather, including fibre strength.

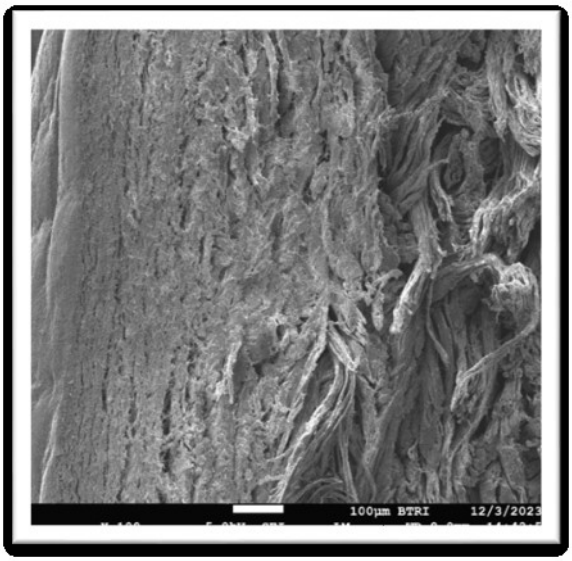
Table 6. Physical strength properties of processed leather

Test name	Exp. 1	Cont. 1	Exp. 2	Cont. 2	Requirements of shoe upper leather [33]
Tensile Strength, (N/mm²)	19.6±0.4	21.4±0.1	23.1±0.6	24.3±0.2	19.61
% of Elongation at Break	61.5±1.2	58.5±1.4	65.2±1.5	59.4±1.1	60-65
Load at grain crack	25.0±3.8	30.0±2.1	30.0±3.7	28.0±2.8	20±2
Distension (mm)	8.96±0.7	7.87±0.4	9.01±0.9	8.90±0.6	8
Stitch tear strength (kg/cm)	88.0±4.8	92.0±5.1	83.0±3.9	87.0±4.1	80-100

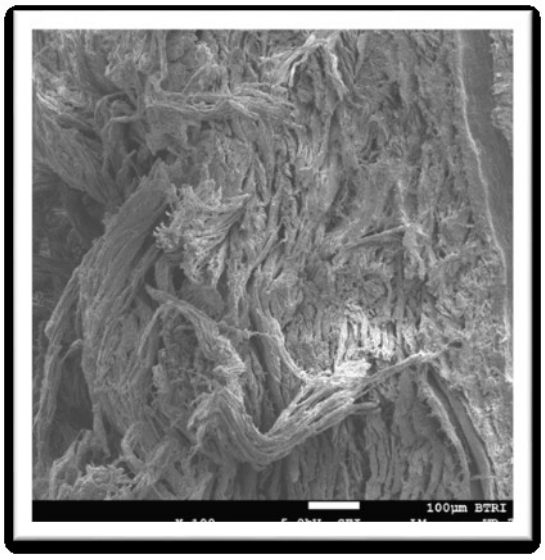
All the values are presented as Mean ± SD (n=3)

SEM Analysis

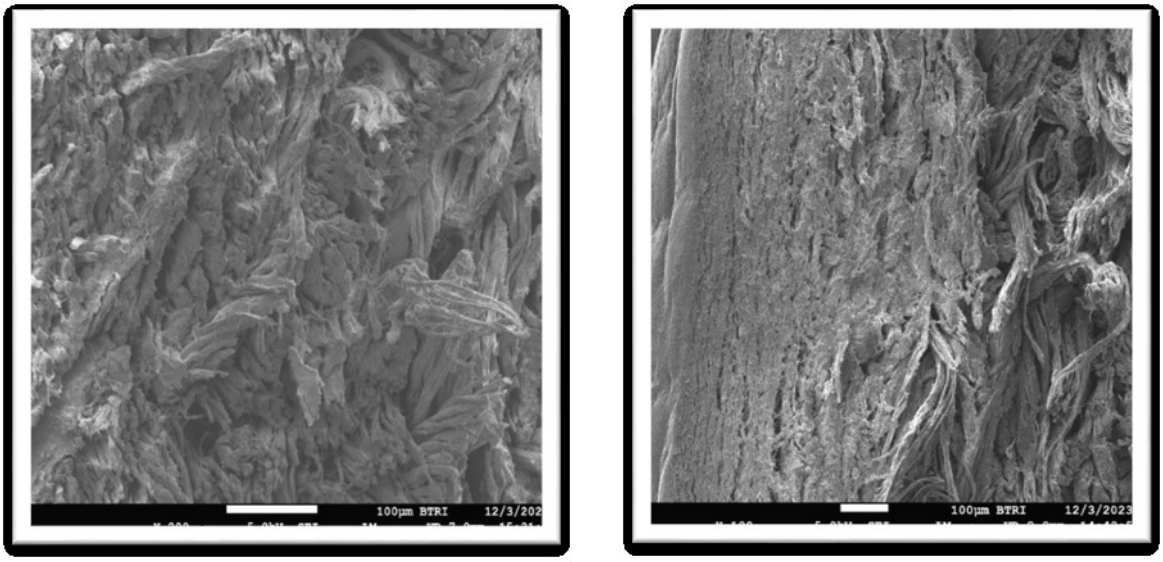
SEM images illustrate the impact of preservation substances on the structure, strength, and fibre orientation of the leather specimen. The samples of leather were examined under an SEM to assess their fibre structure. In Figure 9, the fibre orientation of the experimental and control samples is displayed. The results indicate that there were no noteworthy variations found in the samples from the corresponding trials and controls. The fibre orientation was nearly identical, and there was no fibre breakage. It so proves that the goat skin's texture and quality won't be compromised by the use of this cutting-edge preservation method.



Exp. 1



Cont. 1



Exp. 2 Cont. 2

Figure 9. SEM Analysis of the prepared leather of experimental and control samples

Cost Benefit Analysis

Cost-benefit analysis's primary objective is to determine whether potential benefits outweigh potential costs so that decision-makers may allocate resources wisely and make informed decisions. An economic benefit analysis utilising an organic preservation agent derived from *T. indica* leaves was carried out, accounting for the procedure's significance, with a few basic computations. Traditionally, 1000 kg of raw hide or skin must be preserved with 500 - 600 kg of table salt (sodium chloride). In Bangladesh, the price of a kilogram of commercial sodium chloride is approximately 20 BDT (0.23 USD). Consequently, 10,000 - 12,000 BDT (116–139.45 USD) is required to preserve 1000 kg of hide or skin. Bangladesh produces about 34.5 thousand tonnes of cowhide and 19.7 thousand tonnes of goat and sheepskin annually (Food and Agriculture Organisation, 2016). This indicates that an annual budget of 542-650.4 million BDT (6.3-7.54 million USD) is needed to preserve the hide or skin before any leather production procedures. This huge amount of money is often distributed in Bangladesh during the Muslim festival of Eid Ul Azha when the supply of hide and skin is at its peak. Preserving so many hides and skins so rapidly not only makes them more expensive but also reduces the amount of salt available for Eid Ul Azha. As a result, skin and hides valued at millions of dollars degrade annually. For the preservation of rawhides and skin, the current study suggests 5% leaf powder combined with 10% salt and 10% leaf paste combined with 10% salt. During the lab experiment, the

T. indica leaf was collected and removed at a very low cost. The powder and paste were processed in a fusion blade blender for a mere two minutes. About 75% of the material cost is saved when the amount of salt needed is reduced to about 08 BDT (0.073 USD) per kilogramme of hides and skin preservation.

The writers concur that when the preservation process is commercialised, it will be expensive to gather and prepare leaf powder and paste.

It will still save a significant amount of money annually, though. Furthermore, by employing this technique, the soaking liquors chloride and TDS concentrations are decreased by 69.38% and 65.62%, respectively. This suggests that the pollution load at the ETP (Effluent Treatment Plant) will also be reduced. The ETP will require fewer membrane filters to remove chloride from wastewater because of decreased levels of TDS and chloride contamination. This will have significant financial benefits for the sector as well.

CONCLUSION

Lower amounts of salt combined with *T. indica* leaves powder and paste have been demonstrated efficacy at preserving goat skins, resulting in cleaner approaches to skin preservation. The 5%-10% leaves powder and paste with 10% salt was found to be effective as a curative agent at least for 28 days. Since *T. indica* leaves contain a variety of bioactive compounds, they exhibited a moderate level of sensitivity to different bacteria. This approach significantly decreased the number of pollutants in various parameters like chloride content, TDS, COD, and BOD. Compared to control samples, the fibre strength characteristics and scanning electron microscopy (SEM) images showed equivalent values and textures. Therefore, *T. indica* leaves powder and paste could be an alternative agent to reduce salt curing for sustainable leather production.

Author Contributions

Conceptualization – Hossain MK, Chakma S; methodology – Hossain MK, Akter T, Siddique S, and Al-Tamanna; formal analysis – Hossain MK and Hossain MM; investigation – Hossain MK, Fatema K, Chakma S, Mahmud Y, Akter T, Siddique S, and Al-Tamanna; resources – Hossain MK, Akter T, Siddique S, and Al-Tamanna; writing-original draft preparation – Hossain MK; writing-review and editing – Hossain MM and Razzaq MA; visualization – Hossain MK and Hossain MM; supervision – Razzaq MA. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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