Recycling of Tannery Fleshing Fat into Functional Crunch Leather

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Abstract

Crunch leather is a special class of leather that exhibits a double-tone effect on the surface due to the migration of oil within the leather surface. In this study, extracted fat has been used in place of oil to get crunch leather. The fat was extracted from cow, buffalo, sheep, and goat and characterised. Due to high fat content, sheep fat was specifically selected for use in the finishing process as an alternative to traditional oils in the making of crunch leather. The experimental leather preparation involved mixing sheep fat with a Beeswax emulsion at 80°C in varying ratios. These experimental leathers were compared with control leathers treated with carnauba wax to assess differences. The physical properties of the experimental leathers were found to be on par with those of the control leathers.

Introduction

The leather industry primarily utilizes hides and skins, which are by-products of the meat and meat processing sector, as its principal raw materials. Despite its economic importance, the leather sector is widely recognized as one of the most polluting industries due to its characteristic odor, generation of large volumes of organic and inorganic wastes, and extensive water consumption in traditional processing operations.[1] Leather is essentially an animal skin that has been chemically stabilized to form a durable, flexible, and decay-resistant material. Leather processing can generally be categorized into three major stages. The first involves the removal of unwanted components such as hair, fats, and connective tissue, leaving behind a fibrous collagen matrix. The second stage—tanning—stabilizes this protein network through chemical crosslinking, thereby enhancing its resistance to heat and microbial degradation. The third stage imparts desirable physical and aesthetic properties such as softness, fullness, color, and surface smoothness through post-tanning, fatliquoring, and finishing operations. These steps together employ a variety of chemical and mechanical processes that transform raw hides or skins into value-added leather products.[2]

The beamhouse and tanning stages, which convert raw hides/skins into wet-blue or wet-white leather, consume substantial amounts of water and chemicals, including lime, sulphides, enzymes, salts, and acids. Consequently, by-products such as fleshing, trimmings, lime sludge, hair, and vegetable barks are produced.[3] The subsequent post-tanning operations that improve the filling, softness, and color of leather employ syntans, fatliquors and dyes, generating additional residues such as dyes, grease, and small quantities of chrome.[4] Finishing operations, which involve binders, pigments, solvents and lacquers to enhance the aesthetic appearance, further release volatile organic compounds, buffing dust, and formaldehyde vapors into the environment.[5]

Pretanning processes, including soaking, unhairing/liming, deliming, and bating, rely heavily on chemicals such as sodium sulphide, lime, and salts to prepare the hides for tanning.[6] Given that hides and skins are protein-based materials, these treatments alter the protein structure, and the waste streams generated often contain significant nitrogenous compounds. Studies have shown that fleshing waste can contain 6–34% protein (as nitrogen), depending on processing conditions.[7] Overall, approximately 80% of the total raw hide weight is lost as solid waste during leather manufacturing, while only about 20% is converted into finished leather.[8] The typical composition of solid wastes includes fleshing (55–65%), chrome shavings and splits (32–40%), trimmings (4.5–7.5%), and hair (2–5%)[9]. The sustainability of the leather sector, therefore, depends on effective management and valorisation of both liquid and solid waste streams.[7,10,11] While effluent treatment plants are widely implemented for wastewater management, the disposal of solid wastes, particularly fleshing, remains a critical environmental concern.

Fleshing waste generated during leather processing typically contains 4–18% fat, 5–7% protein, 1–2% sodium chloride, and 2–4% sodium sulphide, with a moisture content of 62–80%. Previous studies have highlighted the feasibility of recovering valuable constituents such as collagen, proteins, and fats from this residue for applications in adhesives, gelatine production, and biofertilizers.[12, 13] As fleshing alone constitutes nearly 50%

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of the total solid waste produced in tanneries, transforming this nutrient-rich by-product into value-added materials presents an attractive strategy to reduce disposal costs, lower environmental burdens, and promote circularity within the tanning sector.[14,15] Typically, the processing of one tonne of raw hides yields about 240 kg of finished leather, generates approximately 600 kg of solid waste (comprising shaving, trimming, and fleshing), and discharges nearly 20,000 litres of wastewater. Improper disposal of solid wastes—particularly limed fleshing and trimmings—results in rapid putrefaction, offensive odours, and blockage of drainage systems.[6,16] Utilising fleshing waste as a feedstock for the development of chemical intermediates or finishing agents offers a sustainable solution to these challenges, providing both environmental and economic advantages.[17,18] In this context, fat recovered from fleshing waste, once suitably processed and refined, represents a promising renewable raw material for leather finishing formulations, especially for imparting desirable crunch effects in finished leathers.

Crunch leathers are valued for their characteristic "distressed" or "worn" appearance, achieved by using oils or waxes that migrate within the leather matrix. However, conventional oils[19] often penetrate too deeply into the leather structure or leach out over time, diminishing the desired surface effect.[20] Therefore, utilizing extracted fat from fleshing waste offers not only a sustainable source of finishing oil but also the opportunity to improve its retention and performance on the leather surface.[10] In this context, the present study aims to develop a sustainable pull-up finishing agent for leather finishing by utilizing fat recovered from tannery fleshing waste, thereby promoting waste valorisation, cleaner production and environmental sustainability within the leather industry.[4,20,21]

Materials and Methods

Fleshing waste was procured from the CSIR-CLRI tannery and processed immediately upon collection. The material was thoroughly washed, delimed using ammonium chloride, sun-dried, and subsequently cut into small pieces for further treatment. Green fleshing was washed solely with water prior to drying, whereas limed fleshing—containing residual lime and sodium sulfide—underwent both washing and de-liming to remove adhering chemicals. The initial pH of the fleshing samples ranged between 7.5 and 8.0. All prepared samples were stored at 4°C until use.

Analytical-grade reagents including sodium hydroxide, sulfuric acid, castor oil, petroleum ether, and other chemicals required for fat characterization and leather processing were used without further purification. The processed fleshing waste was then subjected to subsequent analyses and experimental procedures to evaluate its suitability as a potential substitute for conventional oils in leather finishing applications.

Fleshing Waste Generated in Cattle Hide Processing

Fleshing is a major solid waste produced during the mechanical fleshing operation, which removes residual flesh, fat, and connective tissue from the inner surface of hides or skins. To quantify the amount of fleshing and trimming waste generated per kilogram of raw hide processed, five pieces of cattle hides that had undergone soaking and liming were randomly selected from two different batches representing both fresh and wet-salted raw materials. Each hide was weighed before and after fleshing and trimming, and the corresponding waste fractions were calculated.

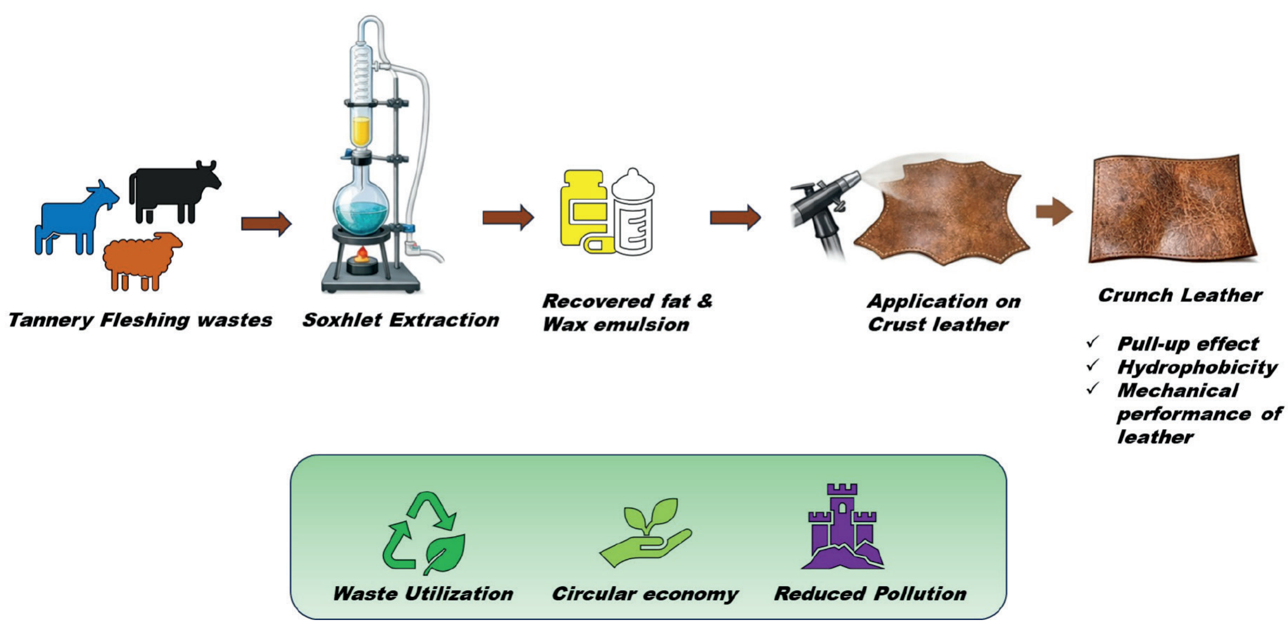


Figure 1. Recycling of tannery fleshing waste

Fleshing Waste Generated in Sheep and Goat Skins
To quantify the amount of fleshing waste generated per kilogram of wet-salted sheep skins, five pieces of goat and un-haired sheep skins were randomly selected from five different batches prepared for the fleshing operation. Each skin was weighed before and after the fleshing process, and the corresponding waste fraction was calculated.

Characterization

Fleshing wastes from tanneries are characterized by a very high water and protein content. Hydrolysis with alkaline proteinase results in 4-12% fat, 5-10% collagen hydrolysate and 1-3% protein concentrate. Purification of the collagen hydrolysate fraction into edible gelatine has been reported.

Extraction of Fat
Fat was extracted from the fleshing waste using the Soxhlet extraction method. Prior to extraction, the fleshing material was de-limed, thoroughly washed, and dried under sunlight. A measured quantity of the dried sample was placed in a thimble or filter-paper bag and loaded into the glass Soxhlet chamber. For the experiment, 10g of dried fleshing powder and 40g of wet fleshing were used, and extraction was conducted for approximately 5 hours.

Chemical Characterization of Fat Extraction
The extracted fat was subjected to comprehensive physicochemical characterization to determine its suitability for application in leather finishing. Fat content was quantified gravimetrically following the standard method SLC 319 (ISO 2/14).

Acid value
The acid value (AV), which expresses the milligrams of potassium hydroxide required to neutralize the free fatty acids in 1g of oil, was determined following standard analytical procedures. This parameter indicates the extent of hydrolytic degradation of triacylglycerols, with higher values reflecting greater free fatty acid content and reduced lipid quality. The acid value was calculated using the standard method ISO 660.

Saponification value
Saponification value, defined as the milligrams of potassium hydroxide needed to neutralize free acids and saponify the esters present in 1g of fat, was determined to evaluate the average molecular weight of triacylglycerols. Lower saponification values correspond to higher molecular weight fatty acids using the standard method ISO 3657.

Ester Value
The ester value (EV), representing the amount of alkali required to saponify the ester fraction alone, was obtained from the relation using the standard method ISO 709.

Iodine Value
The iodine value (IV), a measure of the degree of unsaturation in the extracted oil, was determined to assess susceptibility to oxidative rancidity. Higher iodine values indicate higher numbers of carbon–carbon double bonds and increased oxidative sensitivity using standard Hanus methods.

Un-saponification value
Unsaponifiable matter—components that do not form soap upon alkaline hydrolysis and are not readily volatile—was also quantified according to established procedures. The percentage of unsaponifiable content was calculated using the standard method ISO 18609

Finishing process
Crust leather was prepared following a standard upper-leather processing recipe.[22] For the production of crunch leather, a conventional finishing sequence was employed in which a staining coat was first sprayed to achieve color uniformity, followed by a season coat consisting of fat blended with a wax emulsion in a 1:1 ratio. Industrial practice typically uses synthetic oils in combination with paraffin wax or wax emulsions to develop the characteristic pull-up effect. In this study, goat skins were processed into crust leather using established operations—soaking, liming, tanning, and post-tanning—and the finishing stage was subsequently modified by incorporating the fat extracted from fleshing waste (via Soxhlet extraction) as a substitute for conventional oils in the pull-up formulation.

Crunch leather recipe
The crust leather was prepared based on the upper leather recipe. Crunch leather is the finishing technique, staining coat is sprayed for color correction, then in-season coat oil mixed with wax emulsion dissolved in water in the ratio of 1:1. Conventionally, in the industry, oil used is synthetic oil and the wax used is paraffin wax or wax emulsion to make a crunch effect.

Physical Testing of Leather Samples
After the leather samples were produced, standardized performance testing was carried out to evaluate their suitability for end-use applications. Because leather properties are influenced by environmental factors such as temperature and relative humidity—which fluctuate with seasons and time of day—it was essential to condition all samples before testing under controlled laboratory conditions. Conditioning was performed in accordance with ISO 2419 and the Indian Standard specifications, i.e., at 20±2°C and 60 ±2% relative humidity for a period of 48 hours. Following conditioning, the samples were analysed for key mechanical properties, including tensile strength, elongation at break and tear load. All tests were conducted following the respective official standard methods, and the principles underlying each measurement are outlined below. Tensile strength, tear strength, and elongation at break were measured using standard ISO 3376:2011.

Contact Angle Measurement

When a droplet of water is deposited on a solid surface, its spreading behaviour depends on the intermolecular interactions between the liquid and the surface. The water contact angle provides a direct measure of the surface wettability. A contact angle greater than 90° indicates poor wetting and denotes a hydrophobic surface, whereas angles below 90° correspond to hydrophilic behaviour. In extreme cases, the droplet may spread completely (complete wetting) or remain nearly spherical (super hydrophobicity), reflecting the surface's interfacial properties.

Results and Discussion

The assessment revealed that approximately 0.26 kg of combined fleshing and trimming waste is generated per kilogram of wet-salted hide processed, while about 0.25 kg of fleshing waste is produced per kilogram of green hide. These values indicate that leather processing typically generates about 250–260 kg of fleshing waste per tonne of fresh or wet-salted hides.

As the estimated fleshing waste from goat and sheep skins showed no significant difference, the results were consolidated and presented collectively as "skin fleshing waste."

Identifying maximum yield of fat extraction from specific fleshing wastes

Results from the table indicated that fat yield increased with extraction time up to an optimum level, and the application of agitation produced a positive enhancement in extraction efficiency. These observations were used to establish the optimized conditions for maximum fat recovery from fleshing waste.

Determination of Fat Content and Yield

The fat content of green and limed fleshing obtained from different raw materials was evaluated using petroleum ether as the extraction solvent. Among the samples tested, green sheep-skin fleshing exhibited the highest fat content at approximately 70%, whereas limed fleshing samples showed comparatively lower values. This reduction in fat content following liming is attributed to partial saponification of fats during the alkaline treatment. Notably, limed sheep fleshing (LSF) retained a relatively high fat content of 59.2%, while limed goat and cow hide fleshing contained 45.6% and 39%, respectively These results indicate that green fleshing, being free from process chemicals, is inherently more suitable for producing high-quality fat-derived products. However, as most tanneries generate only limed fleshing,

Table I

Flesh waste generated by hides

S.No.	Weight of wet salted hide (kg)	Weight hide after fleshing (kg)	Weight of a fleshing waste generated (kg)
1	32.0	27	0.28
2	29.0	26	0.24
3	30.5	27	0.25
4	33.7	30	0.23
5	30.6	26	0.29
Average	31.16	27.2	0.26

Table II

Flesh waste generated by skins

S.No.	Weight of wet salted skin (kg)	Weight skin after fleshing (kg)	Weight of a fleshing waste generated (kg/kg of raw skin
1	1.22	1.77	0.016
2	1.23	1.76	0.081
3	1.25	1.75	0.024
4	1.26	1.73	0.048
5	1.35	1.79	0.022
Average	1.26	1.76	0.038

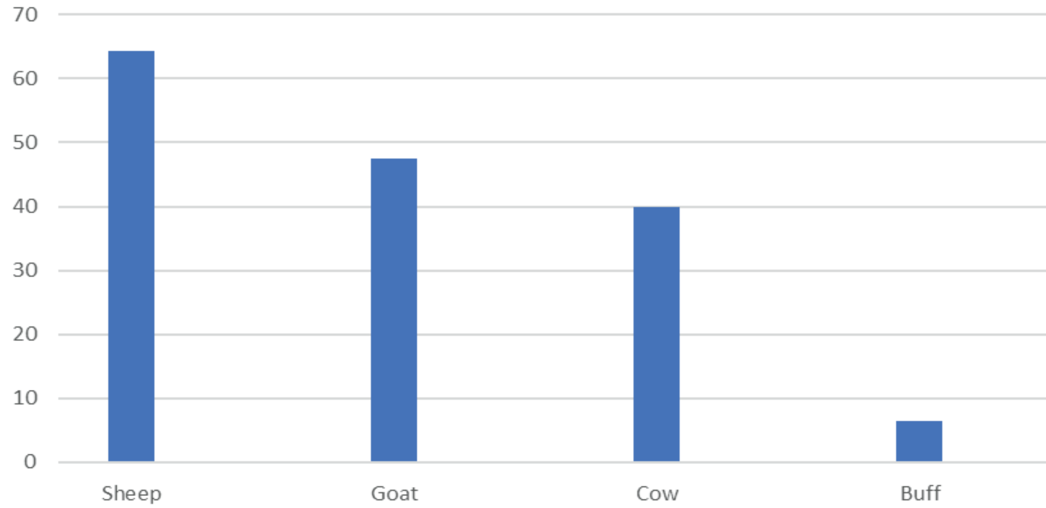


Figure 2. Fat extraction efficiency

Table III
Fat extraction efficiency

Flesh	Weight of sample (g)	Fat extracted (g)	Efficiency (%)
GGF	10	4.97	49.7
GSF	5	3.51	70.0
GCF	10	4.20	42.0
GBF	10	0.80	8.0
LGF	10	4.56	45.6
LSF	10	5.92	59.2
LCF	40	15.6	39.0

it becomes necessary to thoroughly wash and delime the material to remove residual chemicals and ensure the quality of the extracted fat and protein hydrolysate. In the present study, limed fleshing was therefore subjected to washing and deliming before Soxhlet extraction. The color of the extracted products from both green and limed fleshing appeared comparable, supporting the use of cleaned limed fleshing for subsequent experiments.

From the above Table III, GSF and LSF (green and limed fleshing of the sheep) showed higher efficiency when compared to the green and limed fleshing of the goat and cow.

Extraction and characterization of fleshing fat wastes

Saponification value

The saponification value is a key characteristic of oils derived from fleshing waste, particularly for their application in preparing fatliquor–cum–filler agents. It provides an estimate of the average molecular weight of triacylglycerols present in the sample; lower saponification values correspond to higher molecular weight fatty acids, as the parameter is inversely proportional to the mean molecular weight. The saponification values of oils extracted from both green and limed fleshing across different species were

Table IV
Determination of Saponification Value

Sample	Saponification value in mg KOH/g of fat
GGF	187.0
GSF	198.9
GCF	206.8
LGF	214.1
LSF	193.0
LCF	228.8

determined and are presented in Table IV. The sheep green fleshing oil exhibited a saponification value of 198.9, while sheep limed fleshing showed 193. Goat limed fleshing recorded a value of 214.1, and hide limed fleshing showed the highest value of 228.8. These results indicate that hide fleshing oil contains triacylglycerols of relatively higher molecular weight compared to the other samples. All measured values fall within the standard acceptable range of 180–233.

The acid value provides an indication of the extent of rancidity in fats and oils; higher values correspond to greater degradation. For fats or oils intended for fatliquor preparation, the acceptable limit is typically below 8.6 mg KOH/g of fat. As shown in Table V, the acid value of fat extracted from sheep green fleshing was 8.38 mg KOH/g of fat, while that from LSF fleshing was 8 mg KOH/g of fat. Goat limed fleshing and cowhide limed fleshing exhibited acid values of 7.5 and 4.5 mg KOH/g of fat, respectively. These results confirm that all extracted fats fall within the permissible limit for fatliquor application. The percentage of free fatty acids (FFA) was also calculated from the acid value. The calculated values are presented in Table VI.

Table V
Determination of Acid Value

Sample	Acid value in mg KOH/g of fat
GGF	7.38
GSF	8.38
GCF	5.04
LGF	7.5
LSF	8.0
LCF	4.5

Table VI
Determination of free fatty acid

Sample	Free fatty acid
GGF	3.71
GSF	4.17
GCF	2.56
LGF	3.78
LSF	4.00
LCF	2.28

A low iodine value indicates a low level of unsaturated fatty acids in a fat or oil. All extracted samples exhibited relatively low iodine numbers, confirming that the fats possess limited unsaturation and are therefore well suited for fatliquor production, where lower unsaturation contributes to improved lubrication performance. A reduced iodine value is also associated with a higher melting point and enhanced soft-lubricating characteristics. Iodine value is commonly used to assess the degree of unsaturation in fatty acids, and fats or oils are often classified accordingly. In the present study, the highest iodine values were observed in GGF (73.7) and LGF (56.91), with all samples falling within the typical range of 55–75. Based on these values, the extracted fleshing fats can be categorized as non-drying oils, indicating their suitability for use in the formulation of fatliquor-cum-filler products. A summary of their chemical properties is provided in Table VII.

Table VII
Determination of Iodine Value

Sample	Iodine value
GGF	73.7
GSF	61.9
GCF	59.3
LGF	57.35
LSF	59.9
LCF	56.91

Optimization

From the below Table VIII the optimized trial was trial 5 with the ratio 1:5:1with respect to wax emulsion, fat and water respectively. The characterized fats obtained from sheep was blended with wax emulsion in various ratios and subsequently diluted with water. The resulting emulsions were applied to the leather either by spraying or hand application. To assess emulsion stability, the fat–wax mixtures were maintained at temperatures between 15°C and 50°C, during which phase separation was monitored as a function of temperature. Multiple fat-to-wax emulsion ratios were evaluated. Initial observations indicated that the applied mixtures appeared light in color; however, the color progressively darkened upon ageing. A mild crunch effect was observed immediately after application, but this effect diminished and eventually disappeared as the color deepened over time.

Microscopic analysis was conducted to evaluate the influence of different oils on the fiber morphology of crust leather. Figures 3 and 4 illustrate the surface characteristics of leather treated with commercial and experimental products, respectively. Clear differences in fiber opening, surface lubrication, and structural uniformity were observed, demonstrating that the chemistry and viscosity of each oil strongly influence its fatliquoring behaviour. In contrast, Figure 3 (Commercial wax applied leather) exhibits a compact and denser fiber arrangement. The surface appears smoother but with limited fiber opening, suggesting that the commercial oil forms a superficial lubricating film rather than penetrating deeply. This behaviour is consistent with typical mineral/synthetic oil–based fatliquors, which tend to produce surface smoothness without significantly modifying internal fiber structure. Finally, Figure 4 shows a relatively uniform and smooth fiber network, with moderate opening and good coating. The balanced morphology suggests that the antifungal oil—likely formulated with both lubricating and protective components—provides controlled penetration and consistent fiber coverage. The enhanced uniformity supports its dual functional role in lubrication and microbial protection. Overall, the microscopic evaluation confirms that fish oil provides the best internal lubrication, while commercial oil mainly improves surface feel, castor oil exhibits limited penetration, and the antifungal oil offers balanced performance. These structural observations strongly correlate with the expected chemical characteristics of each oil and support their performance trends in fatliquoring applications.

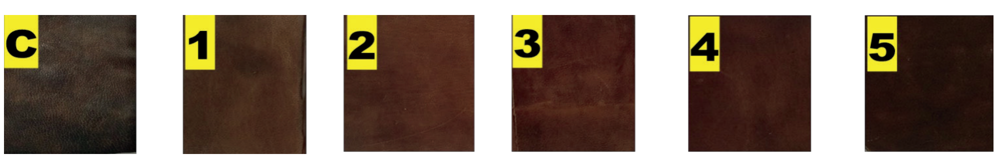
Contact Angle measurements

Based on the observed results as indicated by the Table VIII, the finished leathers treated with optimized trail 5 with the ratio 1:5:1 with respect to wax emulsion, sheep fat and water respectively exhibited higher hydrophobicity (98.45°) compared to the control leather (89.99°). The sheep derived fat showed the highest water contact angle indicating superior hydrophobic behaviour. This clearly demonstrates that the application of extracted fats enhances the hydrophobic nature of the finished leather surfaces.

Table VIII

Optimization Trials

Materials	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Wax emulsion	5	4	3	2	1
Fat	1	2	3	4	5
Water	0	0	0	0	1



Microscopic images of leather with different oil applications

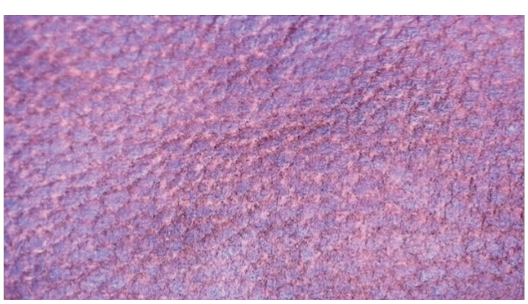


Figure 3. Microscopic image of a commercial product in leather

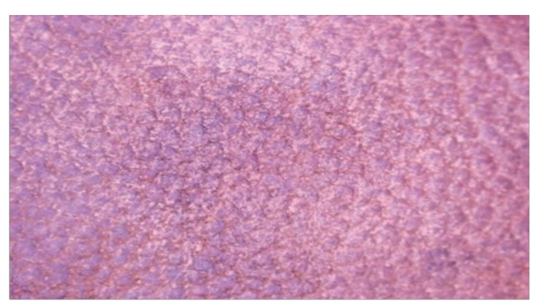


Figure 4. Microscopic image of the experimental product applied to leather

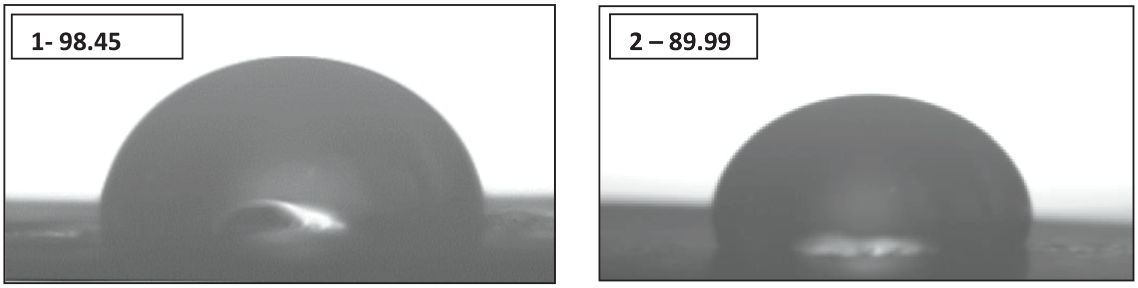


Figure 5. **1** – Experimental leather and **2** – Control leather

Table IX
Physical strength characterisation

S. No.	Tensile strength (MPa)	Extension at maximum load (mm)	Elongation at break (%)
Control	16.0	21.2	43.2
Trial -1	16.5	31.7	64.0
Trial -2	21.5	26.5	53.7
Trial -3	13.0	25.0	50.7
Trial -4	18.7	25.5	51.7
Trial -5	23.0	27.0	54.0

Physical characterisation of experimental leathers

The trials provided in Table VIII, showed that the experimental leather treated with Trial -5 where ratio 1:5:1with respect to wax emulsion, fat and water respectively taken showed better tensile strength than other trials and control. The best results of Extension at maximum load (mm) and Elongation at break (%) were shown by the trial 1 where ratio 5:1:0 with respect to wax emulsion, fat and water respectively followed by the trial 5. Therefore, it can be concluded that the trial 5 can be consider for the making of crunch leather.

Conclusion

This study demonstrates the potential for valorizing fleshing wastes from sheep, goat, buffalo, and cow hides into valuable products for leather processing through appropriate chemical and thermal treatments. The extracted fat from fleshing waste was successfully utilized in the preparation of pull-up leather, where it contributed effectively to the characteristic distressed appearance and lubrication properties. The findings clearly highlight that fleshing waste, traditionally regarded as a disposal burden, can be transformed into a functional input for leather finishing. The adoption of this approach offers multiple advantages for the tanning sector. Converting fleshing waste into a usable chemical product can reduce waste-management costs, generate an additional revenue stream, and promote the development of indigenous chemical alternatives. This valorization strategy also supports environmental compliance by minimizing the volume of solid waste requiring disposal, while simultaneously creating new employment opportunities within the leather-processing value chain. Overall, the outcomes of this study indicate that the reutilization of fleshing waste is both technically feasible and economically beneficial. Future work should focus on scaling up the process, assessing long-term feasibility, and engaging industry stakeholders to foster positive attitudes toward waste-to-resource technologies. By adopting such sustainable practices, tanneries can significantly reduce their environmental footprint while enhancing operational efficiency and contributing to circular-economy initiatives in the leather industry.

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Conflict of Interest statement in the revision

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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