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Histological and Chemical Studies of Goat Skin Transformation Processing of Raw Skin into Tanned Leather

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ABSTRACT. Fresh goat skin and skins tanned with different tanning agents were prepared for histological, chemical, and physical analyses. Fresh skin samples were fixed in 10% formalin solution, processed using the paraffin embedding technique, sectioned, and stained with hematoxylin and eosin to determine the histological structure. Samples of goat tanned skin, treated with various tanning agents (chrome, aldehyde, chamois, and vegetable), underwent chemical analysis using Fourier Transform Infrared Spectroscopy (FTIR) followed by physical analyses, including tensile strength, tear strength, thickness, and shrinkage temperature. The results showed that the histological structure of fresh skin consisted of two layers: the epidermis and dermis, while tanned leather only exhibited the dermis layer. The epidermis was removed during the tanning process. FTIR analysis of chrome-tanned leather showed bands at 1633 cm^{-1} (amide I), 1554 cm^{-1} (amide II), and 1240 cm^{-1} (amide III). Aldehyde-tanned leather showed bands at 1651 cm^{-1}, 1550 cm^{-1}, and 1271 cm^{-1} (amide I, II, and III), while vegetable-tanned leather displayed bands at 1634 cm^{-1} (amide I), 1552 cm^{-1} (amide II), and 1239 cm^{-1} (amide III). Shifts in peak positions, intensity, and the number of signature peaks were observed across the tanning agents (chrome, aldehyde, oil, and vegetable). The use of different tanning agents—wet blue, wet white, vegetable-tanned, and chamois—resulted in distinct grain-surface structures, significantly influencing the physical characteristics of the leather.

Keywords: epidermis, dermis, FTIR, goat skin, tanned leather

INTRODUCTION

Skin, part of the integumentary system, is the largest organ of the body, serving as a protective barrier between the internal organs and the environment (Mohammed et al., 2022). Mammalian skin consists of three primary layers: the epidermis, dermis, and hypodermis. In goat skin, the dermal papillae and reticular layer are less developed, and it contains fewer hair follicles and sebaceous glands (Mohammed et al., 2022). Goat skin, when tanned, becomes a valuable material in leather production, enhancing its economic value and preventing deterioration (China et al., 2020). Its flexibility (Kade Malam Gadjimi et al., 2022) and distinctive grain pattern (Jawahar et al., 2016) make it a popular choice in the leather industry for both functional and aesthetic applications.

Leather production is a complex process that transforms raw animal hides/skins into durable, flexible materials (Maina et al., 2019). This process has wide-ranging applications across various industries (Sisay, 2021). Tanning induces specific changes in the skin's structure and composition, which significantly affects the histological and chemical properties of the skin (Gun and Syedim, 2022). From a histological perspective, tanning alters structures such as hair follicles, sebaceous glands, collagen fibers, and the epidermal and dermal layers (Mohamed et al., 2016).

Several studies have explored the histology of animal skin, including the histological transformation of sheep skin during parchment production (Fourneau et al., 2020), the preservation quality of skin (Lukas et al., 2022), the histological structure of bovine dermal tissue (Stefano et al., 2015), and the mechanical properties of Dorper sheep skin (Matos et al., 2022). However, few studies have examined the histological and chemical transformations of goat skin, particularly from fresh skin to tanned skin. This study aims to investigate the histological and chemical changes that occur when goat skin undergoes tanning processes such as wet blue, wet white, vegetable tanning, and chamois tanning. This research also compares the changes in the histological structure of fresh and tanned goat skin and explores whether the tanning process affects these changes. Additionally, the study includes chemical analysis using Fourier-transform infrared spectroscopy (FTIR) to identify alterations in the skin's chemical composition and physical analyses to assess the quality of the tanned skin.

MATERIALS AND METHODS

Materials

Fresh goat skin and goat skins tanned through various methods (wet blue, wet white, vegetable-tanned, and chamois) were obtained from the Beamhouse Operation Warehouse,

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Politeknik ATK Yogyakarta. The following materials and equipment were used for the study: histology cassettes, stainless steel embedding molds, rotary microtome (Microm HM 25), water bath (Memmert), rotary shaker (Stuart Mini Orbital Shaker SSM1), laboratory oven (Memmert TV 10u), analytical balance (Ohaus PAJ1003), microscope (Motic-B3), stereo microscope (Motic SFC-11 Series), standard glass microscope slides (75x25mm), glass cover slips (25x60mm), and laboratory glassware (Pyrex). Reagents used included 37% formaldehyde, ethyl alcohol, 96% and 70% ethanol solutions, xylene (clearing agent), 0.1% w/v gelatin, paraffin wax, hematoxylin solution, eosin solution, and xylol.

Methods

Preparation histological slide

The histological slide preparation in this study was based on the procedure outlined by Jusuf (2009) and Isaac et al. (2023), with slight modifications.

Tissue preparation and fixation

Skin specimens were cut into approximately 4×4 mm pieces and fixed in a 10% v/v formaldehyde solution for 24 hours while agitating at 120 rpm on a rotary shaker.

Dehydration and clearing

Dehydration of the tissue was carried out using a series of ethanol solutions (30%, 50%, 70%, 80%, 90%, 96%, and 100%) for 60 minutes at each concentration. The clearing process used toluene as a solvent to replace ethanol in the tissue. Initially, the tissue was immersed in a 1:1 (v/v) ethanol and toluene solution for 30 minutes, followed by immersion in pure toluene for 60 minutes.

Impregnation

The sample was then immersed in liquid paraffin in an oven set at 60°C until the paraffin completely replaced the clearing agent. This process involved immersing the sample in hot liquid paraffin I for 60 minutes, followed by immersion in hot liquid paraffin II for another 60 minutes.

Blocking

The specimens were carefully placed in the mold as desired, and liquid paraffin (maintained at 60°C - 65°C) was added to fill the mold. The samples were labeled accordingly, allowed to harden, and then removed from the mold.

Sectioning

The tissue was sectioned from the paraffin block using a microtome. Sections of 4-5 micrometers in thickness were chosen to facilitate staining and subsequent examination under the microscope (Alturkistani et al., 2015; Gurina & Simms, 2024).

Staining

Deparaffinization was performed first with xylene (2 × 2 minutes). Hydration was then carried out using a series of alcohol solutions: 100% ethanol (2 minutes), 95% ethanol (2 minutes), 90% ethanol (2 minutes), 80% ethanol (2 minutes), and 70% ethanol (2 minutes), followed by a second 80% ethanol (2 minutes) and 70% ethanol (2 minutes). The sample was washed with distilled water for 3 minutes. Next, the sample was immersed in hematoxylin for 15 minutes, followed by washing in running water for 15-20 minutes. The sample was then counterstained in eosin solution for 2 minutes. Dehydration proceeded in a series of alcohol solutions, with gradual increases in concentration from 70% to 100%, with each step lasting 2 minutes. Finally, the sample was cleared in xylene (2×2 minutes) (Jusuf, 2009). The final step involved mounting the sample with DPX and placing a cover slip on the sample.

Microscopic Imaging

Crust leather samples were observed using a stereo microscope (Motic SFC-11 Series) to assess the differences in grain structure between wet blue goat, wet white, vegetable-tanned, and chamois goat skins.

Chemical and Physical Analysis

FTIR analysis

The functional groups in fresh goat skin and tanned goat skins (wet blue, wet white, vegetable-tanned, and chamois) were analyzed using a Fourier transform infrared spectrometer (FTIR, Perkin Elmer Frontier) within the scanning range of 4000–700 cm^{-1}. Samples were cut into 5×5 cm pieces and dried at room temperature, ensuring uniform dryness before analysis.

Physical analysis

Physical properties of the tanned leathers were assessed following the international standards (ISO) established by the International Union of Leather Technologists and Chemists Societies (IULTCS) (ISO, 2012). Tensile strength was analyzed according to ISO 3376, with samples for tensile strength cut based on ISO 25889. Tear strength was determined in accordance with ISO 3377-2, with samples cut based on ISO 2419. The thickness of the samples for both tensile and tear strength was measured based on ISO 2589. For each analysis, three samples were used, and average results were reported in this study.

Data Analysis

Goat fresh skin was studied descriptively and illustrated in histological figures. The collected data goat tanned skin were subjected to analysis of variance (ANOVA) utilizing IBM SPSS Statistics 25 software.

RESULTS AND DISCUSSION

Histological Structure

Histologically, the fresh skin of the goat consisted of two main layers: the epidermis and dermis (Figure 1). The epidermis was further divided into five layers: stratum corneum, stratum lucidum, stratum granulosum, stratum spinosum, and stratum basale (Kalangi, 2013). In this study, the stratum granulosum and stratum lucidum were not clearly visible. According to Razvi et al. (2015), these layers are often not clearly visible in thin skin. The stratum granulosum is typically one to ten cells thick, and the stratum lucidum comprises 2–3 cells (Yousef et al., 2024). Figure 2 illustrates the histologically stained tanned leather. With chromium, aldehyde, chamois, and vegetable tanning agents, most collagen fibers in the leather appeared denser and more robust. In contrast, the collagen fibers in fresh skin were loose and disorganized, as they had not yet bonded with tanning agents. According to Wang and Li (2016), tanning improves the dispersion of elemental fibers, the orderly arrangement of fiber bundles, and the formation of a porous fiber network.

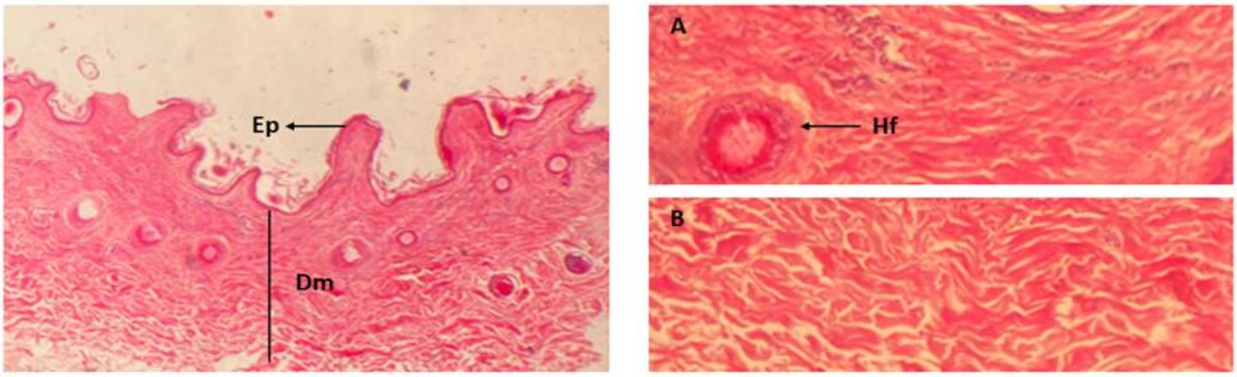

Figure 1. Histological structure of the fresh skin: A) Stratum papilare, B) Stratum reticulare, Ep= epidermis, Dm= dermis, Hf= Hair follicle. HE staining with 400× magnification

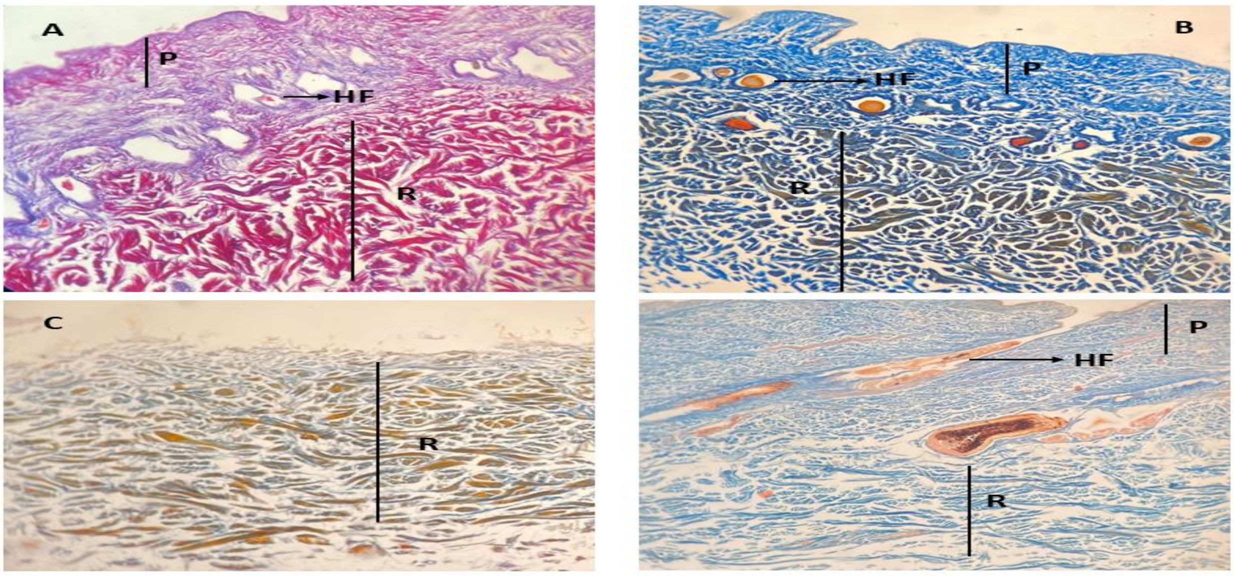

Figure 2. Histological structure of tanned leather: A) Wet blue goatskin, B) Wet white goatskin, C) Chamois goat skin, D) Vegetable goat skin, P= Stratum papilare, R= Stratum reticulare, Hf= Hair follicle. HE staining with 400× magnification

Grain Surface Pattern

The grain structure of goat leather tanned with various agents was analyzed using a stereo microscope at 10× magnification. Figure 3(A) shows the grain structure of wet blue crust leather, which appears prominent and wavy. In contrast, the grain structure of wet white goat leather (Figure 3(B)) was less pronounced, resembling that of vegetable-tanned leather (Figure 3(C)). Vegetable-tanned leather exhibited a stitch-like grain pattern and a brown color, which is characteristic of plant-based tanning agents. Chamois leather, on the other hand, displayed a fibrous structure, resulting from the buffing treatment applied to smooth the leather surface. The results suggest that different tanning agents (wet blue, wet white, vegetable-tanned, and chamois) produce distinct grain surface structures.

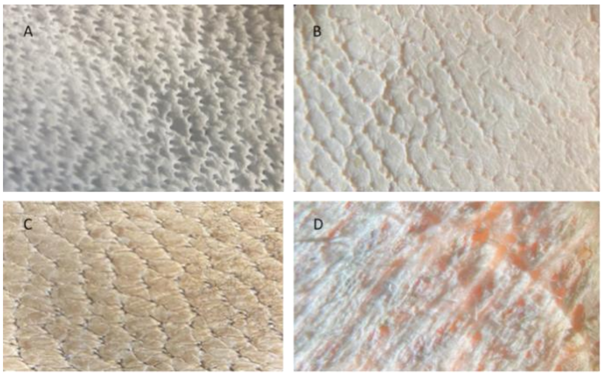

Figure 3. Stereo micrograph of the grain surface with 10x magnification: A) Wet blue goat skin, B) Wet white goat skin, C) Vegetable tanned goat skin, D) Chamois goat skin

Chemical Analysis

Band assignments and their interpretation are based on IR studies of collagen tissue (Kumar et al., 2016). Visual inspection revealed variations in the collagen region (1081-1651 cm^{-1}). A careful examination of the spectra showed shifts in a few peaks, which can be attributed to the complexity of the biochemical components in leather. The observed peak positions of the OR bands and their assignments for several tanned agents are presented in Table 1.

FTIR results of leather tanned with chrome material show a band at 1633 cm^{-1}, corresponding to the amide I vibration (Fig 4), which is dominated by peptide carbonyl stretching, with some contribution from C-N stretching and N-H in-plane bending (Chen et al., 2013). Special emphasis was placed on the spectral features at 1455 cm^{-1}, which is assigned to the CH_2 bending of phospholipids (Qin et al., 2016). Therefore, collagen analysis was performed using the peak area ratio of the CH_2 wag band at 1455 cm^{-1} (Mehta et al., 2020). The NH_2 bending coupled with CN stretching vibration in the amide group, assigned as amide II, gives rise to a band at 1554 cm^{-1}. The NH bending of amide III occurs at 1240 cm^{-1}.

Leather tanned with aldehyde showed bands at 1651 cm−1 as amide I, 1550 cm−1 as amide II, and 1271 cm−1 as amide III (Fig 5). Meanwhile, leather tanned with vegetable showed bands at 1634 cm^{-1}, 1552 cm^{-1}, and 1239 cm^{-1} as amide I, II, and III (Fig 6). This result is in agreement with previously reported by Stani *et al* (2020) that characteristic FTIR spectrum with absorption bands of amide I around 1650 cm^{-1} and amide II around 1560 cm^{-1}. There is a shift observed in peak position, intensity and number of signature peaks between chrome, aldehyde, oil and vegetable tanned agents. Some structural changes in collagen may occur due to alterations in secondary structure –α helix, β sheet, random coils or immature cross links.

Table 1. The FTIR band assignments for several tanned agents

No	Assignments	Peak position (cm^{-1})			
		Chrome	Aldehyde	Oil	Vegetable
1	-OH hydroxyl	3302	3322		3307
2	NH stretching	2926	2925	2922	2925
3	CH vibration	1455 and 1339	-	1323	1400 and 1455
4	C-H vibration	-	-	-	1032
5	C-O symmetric	-	-	-	1323
6	C-O asymmetric	-	-	-	1032
7	Amide I band of leather protein	1633	1651	1628	1634
8	Amide II band of leather protein	1554	1550	-	1552
9	Amide III band of leather protein	1240	1271	-	1239
10	C-C skeletal stretching	1081	1086	1032	1082

In Figure 7, a new absorption is observed at the wave number 1032 cm^{-1}, which is thought to indicate the presence of C-H vibrations from the aromatic group. Symmetrical and asymmetric vibrations of C−O occur at a wave number of 1323 cm^{-1} (Falcão and Araújo, 2014). According to

Falcão and Araújo (2018), a characteristic absorption of aromatic groups originating from tannins in vegetable tanning materials is observed in the wave number range of 1350-1000 cm^{-1}. In this study, the symmetric and asymmetric vibrations of C−O and the presence of aromatic groups in tannin were demonstrated at wave numbers 1323 cm^{-1} and 1032 cm^{-1}.

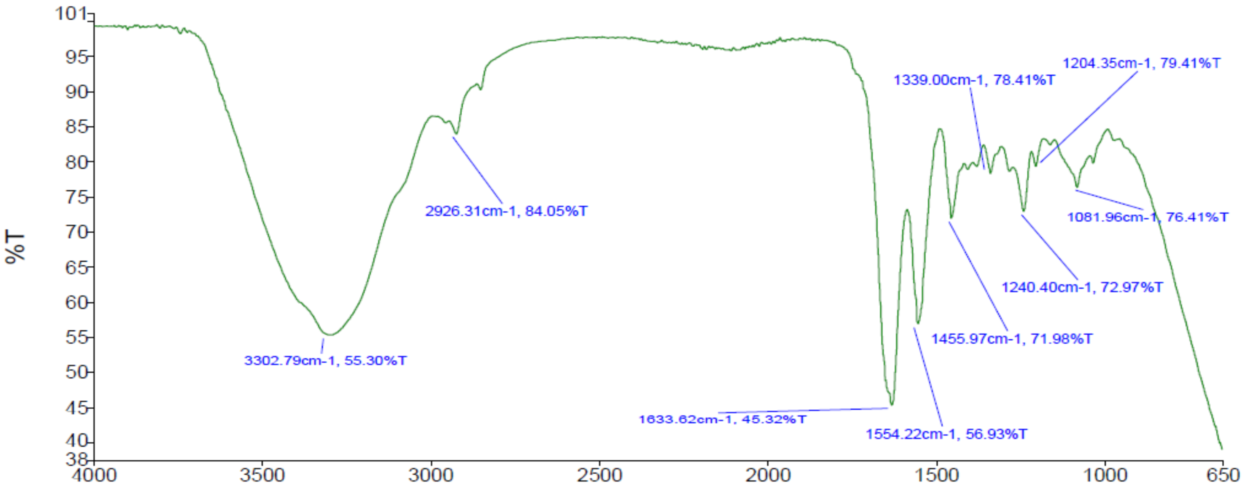

Figure 4. Infrared spectrum pattern of wet blue tanned

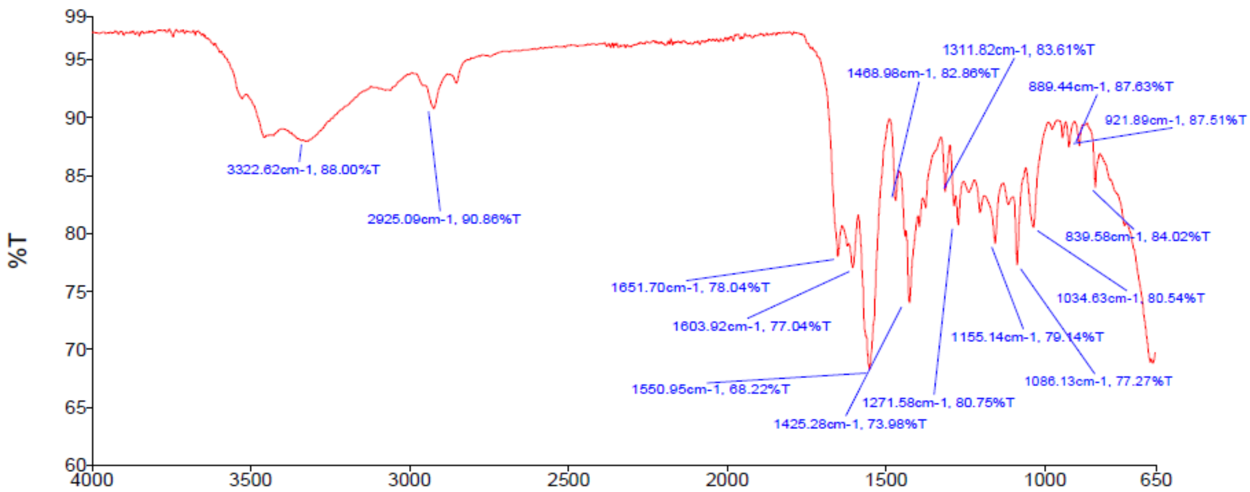

Figure 5. Infrared spectrum pattern of wet white tanned

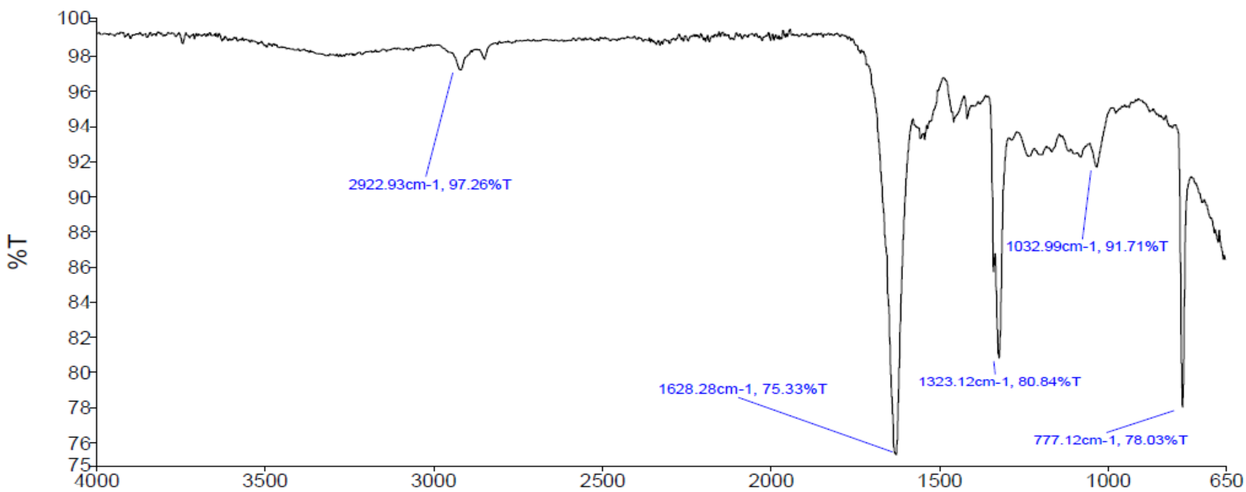

Figure 6. Infrared spectrum pattern of chamois tanned

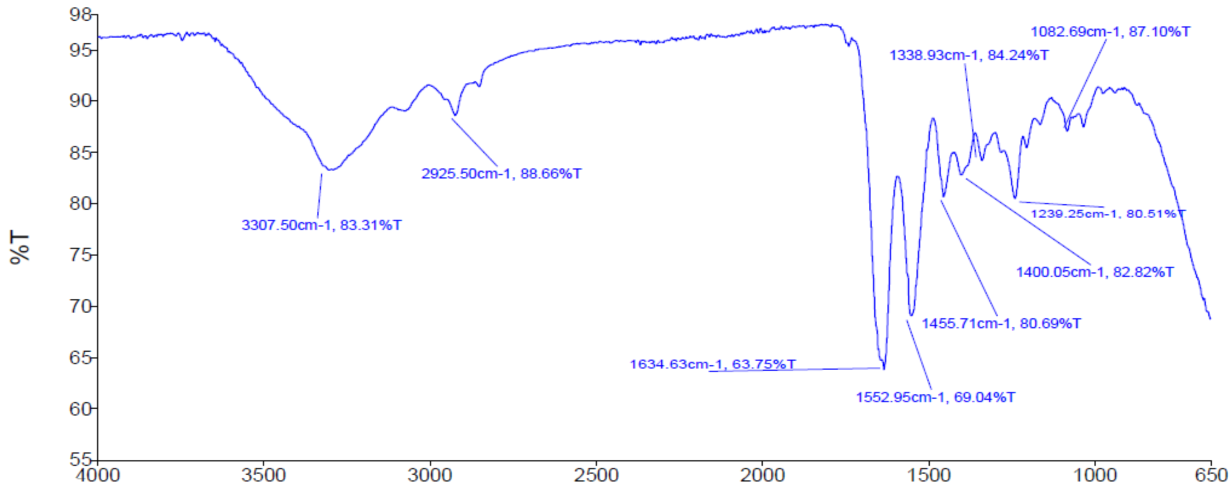

Figure 7. Infrared spectrum pattern of vegetable-tanned

Chrome tanning

The leather tanning process using chromium is one of the most common causes of environmental problems. According to the Occupational Safety and Health Administration (OSHA) (2019), permissible exposure limits (PELs) for Cr (III) are set at 0.5 mg/m³. Trivalent chromium salts are preferred due to their superiority over other tanning materials, with nearly 90% of tanned leather using this material (Chen et al., 2023). Trivalent Cr (III) is insoluble and cannot penetrate cell membranes, which makes it less toxic compared to Cr (VI) (Plestenjak et al., 2022). However, both forms of chromium can inhibit biological processes in humans (Vaiopoulou and Gikas, 2012). Therefore, it is crucial that the leather tanning process prevents the oxidation of Cr (III) to Cr (VI) to ensure the leather remains safe (China et al., 2020).

Aldehyde tanning

One alternative tanning agent to replace formaldehyde is glutaraldehyde, which is considered safer and more environmentally friendly. Although not commonly used, this method can be combined with other materials in the tanning process (Shirmohammadli et al., 2018). Aldehyde tanning agents are employed to produce chrome-free leather. Aldehyde tanning is often referred to as "wet white" due to the pale cream color it imparts to the skins. Formaldehyde, however, is highly toxic to animals, and the ingestion of even small amounts of a solution containing 37% formaldehyde has been reported to cause death in humans. It is also classified as a carcinogen (List et al., 2016). At concentrations below 2 ppm, formaldehyde is an irritant to the eyes and can have respiratory effects; repeated contact with solutions may cause eczematoid dermatitis. The permissible exposure limits (PELs) for formaldehyde are 0.75 ppm (OSHA, 2019).

Chamois tanning

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Oil has potential as a leather tanning agent for chamois leather. Chamois leather is a well-known product with specific uses, such as in high-quality gasoline filtration, cleaning and drying optical equipment, spectacles, mirrors, and vehicles. This is due to its softness and high water absorbance. The material needs to remain soft to avoid scratching the surface being cleaned (Suparno, 2010).

Vegetable tanning

Vegetable tannins are considered less polluting compared to chromium and are the oldest known leather tanning agents. Vegetable tanning involves treating hides and skins with leaves and barks that contain tannins. Vegetable-tanned leather is used in the production of heavy leather goods such as furniture leather, garment leather, and shoe upper leather.

Physical Analysis

Physical analysis such as thickness, tear strength, tensile strength, and shrinkage temperature were carried out to determine the properties of each tanning agent. Table 2 describes the physical properties of several tanning agents. Based on the results of the ANOVA test, tanning materials (chrome, aldehyde, chamois, vegetable) significantly affect tear strength.

The tear strength of the leather is indicated by the quality standard relating to the tearing load. Leather with high tear strength means that the tanning agent is well absorbed during the tanning process. The highest observed tear strength was 28.128±0.02 N/mm for the chamois agent. In general, the tear strength of the chamois leather fulfilled the SNI 06-1752-1990 standard, which requires the tear strength to be at least 15 N/mm.

Table 2. Physical properties of leather by several tanning agents

Tanning agents	Tear strength (N/mm)	Tensile strength (N/mm^2)	Shrinkage temperature (^{0}C)	Thickness (mm)
Chrome	14.1745±0.823 ^{b}	13.5±2.54 ^{a}	102.5±0.70 ^{d}	0.752±0.029 ^{a}
Formaldehyde	17.26±0.165 ^{c}	19.74±3.27 ^{b}	59±0 ^{a}	1.071±0.002 ^{c}
Chamois	28.128±0.02 ^{d}	20.64±0.46 ^{b}	63±0 ^{b}	0.801±0.002 ^{a}
Vegetable tanned	12.262±0.14 ^{a}	29.39±0.59 ^{c}	72±0 ^{c}	0.878±0.019 ^{b}

Note: $^{a, b, c}$ different lowercase superscript letters indicate significant differences ($p<0.05$)

From Table 2 above, the tensile strength of the goat skin treated with various tanning agents was 13.5±2.54 N/mm² for chrome, 19.74±3.27 N/mm² for formaldehyde, 20.64±0.46 N/mm² for chamois, and 29.39±0.59 N/mm² for vegetable agents. Based on the results of the ANOVA test, chrome and vegetable tanning materials showed significant differences, while aldehyde and chamois materials did not differ significantly in terms of tensile strength. The variation in tensile strength can be attributed to the presence of structural resistance in leather to tensile forces, thus affecting its state and usability. This is explained by Tournier (2020), who states that tensile strength is influenced by the type of tanning material, tanning time, and the type of leather used (species and age). The 4% chrome tanning agent yielded the best results, with a tensile strength value of 15.40 N/mm² (Anggraeny et al., 2022). Additionally, tannins used in vegetable leather tanning agents produced a tensile strength above the expected minimum of 10 N/mm² (Cheloti et al., 2023).

The shrinkage temperature of the chrome-tanned leather was 102.5±0.70 °C, formaldehyde was 59±0 °C, vegetable-tanned was 72±0 °C, and chamois was 63±0 °C. Based on the results of the ANOVA test, tanning materials (chrome, aldehyde, chamois, vegetable) significantly affect shrinkage temperature. The variability in shrinkage temperature is influenced by the specific tanning agents used. Shrinkage temperature is a critical indicator of the hydrothermal stability of leather, reflecting the chemical changes in collagen. Modifications in tanning agents can significantly impact shrinkage temperature. The stabilization of the reaction between tanning agents and collagen fibers increases the shrinkage temperature, whereas destabilization of collagen bonds leads to its reduction (Covington and Wise, 2020). Similarly, Zhang et al. (2021) state that shrinkage temperature is indirectly related to the degree of cross-linking within collagen. A higher shrinkage temperature denotes good thermal stability of leather and a greater degree of cross-linking between collagen fibers and tanning agents.

The goat skins presented a thickness of 0.752±0.029 mm for chrome agent, 1.071±0.002 mm for formaldehyde agent, 0.801±0.002 mm for chamois agent, and 0.878±0.019 mm for vegetable agent (leather samples cut across/perpendicular to the backbone and leather samples cut along/parallel to the backbone). Based on the results of the ANOVA test, chrome and chamois tanning materials did not have a significant effect, while aldehyde and vegetable tanning materials had a significant effect on thickness.

CONCLUSION

In conclusion, histologically, the fresh skin of a goat consists of both the epidermis and dermis, whereas tanned leather retains only the dermis due to the degradation of the epidermis during processing. The tanning process significantly alters the structure of collagen fibers, increasing their density and making them more robust. Different tanning agents, such as wet blue, wet white, vegetable-tanned, and chamois, produce distinct grain surface structures. Wet blue exhibits a wavy pattern, while chamois has a fibrous texture.

Physical analyses reveal that tanning agents have a significant impact on key properties like tensile strength, tear strength, and shrinkage temperature. Among the agents tested, vegetable tanning yields the highest tensile strength, while chrome tanning provides superior thermal stability.

REFERENCE

Animal Science Commodity Outlook Book, "Goat and sheep meat". In Data Center and Agricultural Information System, Secretariat General of the Ministry of Agriculture; Pusat Data dan Sistem Informasi Pertanian, Sekretariat Jenderal—Kementerian Pertanian: Jakarta, Indonesia, 2022. Available online: https://satudata.pertanian.go.id/assets/docs/publikasi/Outlook_DgKambing_2022 .pdf (Accessed on 26 Juni 2024)

Alturkistani, H. A., Tashkandi, F. M., and Mohammedsaleh, Z. M. 2015. Histological Stains: A Literature Review and Case Study. Global Journal of Health Science, 8(3), 72–79. https://doi.org/10.5539/gjhs.v8n3p72

Anggraeny, D. T., Awwaly, K. U. Al, and Manab, A. 2022. Physicochemical Characteristics of Leather Goat Quality from less Tanning Process. Journal of Environmental and Agricultural Studies, 3(3), 39–49. https://doi.org/10.32996/jeas.2022.3.3.5

Awwaly, K. U. A. 2017. Protein Pangan Hasil Ternak dan Aplikasinya (1st ed.). Universitas Brawijaya Press. Malang.

California Division of Occupational Safety and Health (Cal/OSHA). 2019. Permissible exposure limits (PELs), in California code regulations (CCR) Title 8 Section 5155.

Cheloti, M., Wangila, P., Kiprop, A., Onyuka, A., Sasia, A., Mutuku, M., Induli, M., Kundu, B., and Masenge, E. 2023. Evaluation of Mechanical Properties of Goat Leather Tanned using Acacia xanthophloea. Textile & Leather Review, 6, 333–342. https://doi.org/10.31881/TLR.2023.053

Chen, J., Ma, J., Fan, Q., Zhang, W., and Guo, R. 2023. A sustainable chrome-free tanning approach based on Zr-MOFs functionalized with different metals through post-synthetic modification. Chemical Engineering Journal, 474, 145453. https://doi.org/10.1016/j.cej.2023.145453.

Chen, Z., Butke, R., Miller, B., Hitchcock, C.L., Allen, H.C., Povoski, S.P. 2013. Infrared metrics for fixation-free liver tumor detection. J Phys Chem B. 2013;117(41): 12442–50.

China, C. R., Maguta, M. M., Nyandoro, S. S., Hilonga, A., Kanth, S. V., and Njau, K. N. 2020. Alternative tanning technologies and their suitability in curbing environmental pollution from the leather industry: A comprehensive review. Chemosphere, 254, 126804. https://doi.org/10.1016/j.chemosphere.2020.126804

Covington, A., and Wise, W. 2020. Tanning Chemistry the Science of Leather (2nd ed.). Royal Society of Chemistry.

Falcão, L., and Araújo, M. E. M. 2014. Application of ATR-FTIR spectroscopy to the analysis of tannins in historic leathers: The case study of the upholstery from the 19th century Portuguese Royal Train. Vibrational Spectroscopy, 74, 98–103. https://doi.org/10.1016/j.vibspec.2014.08.001

Falcão, L., and Araújo, M. E. M. 2018. Vegetable tannins used in the manufacture of historic leathers. Molecules, 23(5). https://doi.org/10.3390/molecules23051081

Fourneau, M., Canon, C., Van Vlaender, D., Collins, M. J., Fiddyment, S., Poumay, Y., and Deparis, O. 2020. Histological study of sheep skin transformation during the recreation of historical parchment manufacture. Heritage Science, 8(1). https://doi.org/10.1186/s40494-020-00421-z

Gun, İ., and Syedim, Z. 2022. The Characteristics of Goat Skin used in The Production of Tulum Cheese and Changes in Ripening Environments. Gıda Journal of Food, 47(5), 729–743. https://doi.org/10.15237/gida.gd22015

Gurina, T. S., and Simms, L. 2024. Histology, Staining.

Hamdi, I., Benaissa, A., Babelhadja, B., Bedda, H., Aboub, S., and Loubakic, R. 2022. Composition and structure of the skin of dromedary (Camelus dromedarius, L. 1758) young adult from two Algerian populations. Journal of Animal Behavior and

Biometeorology, 10(2). https://doi.org/10.31893/jabb.22017

Heth, C. L. 2015. The skin they were in: Leather and tanning in antiquity. In ACS Symposium Series (Vol. 1211, pp. 181–196). American Chemical Society. https://doi.org/10.1021/bk-2015-1211.ch006

Jawahar, M., Vani, and Babu, N. K. C. 2016. Leather Species Identification Based on Surface Morphological Characteristics using Image Analysis Technique. Journal of the American Leather Chemists Association, 111, 308–314.

Jusuf, A. A. 2009. Histoteknik Dasar (1st ed.). Universitas Indonesia press.

Kade Malam Gadjimi, A., Mamman, M., Guiguigbaza-Kossigan, C.-D., Kountou Marliya, G., Adamou, A., and Hamani, M. 2022. Comparative zootechnic characteristics of Maradi Red goat and her Black variant in Niger. International Journal of Innovation and Applied Studies, 36(2), 564–576. http://www.ijias.issr-journals.org/

Kalangi, S. J. R. (2013). Histofisiologi Kulit. Jurnal Biomedi, 5(3), 12–20.

Kumar, S., Verma, T., Mukherjee, R., Ariese, F., Somasundaram, K., Umapathy, S., Raman. (2016). Infra-red micro spectroscopy: towards quantitative evaluation for clinical research by ratio metric analysis. Chem Soc Rev. 45(7):1879–90

List, M., Puchinger, H., Gabriel, H., Monkowius, U., & Schwarzinger, C. (2016). N-Methylmelamines: Synthesis, Characterization, and Physical Properties. Journal of Organic Chemistry, 81(10), 4066–4075. https://doi.org/10.1021/acs.joc.6b00355

Lukas, R., Satrio, M., Wibowo, A., Maryati, T., & Yuliatmo, R. (2022). Skin-Preserved Quality In Terms Of Histological Structure During The Covid-19 Pandemic. Journal of Industrial Innovation, 1(1), 66–75.

Maina, P., Ollengo, M. A., and Nthiga, E. W. 2019. Trends in leather processing: A Review. International Journal of Scientific and Research Publications (IJSRP), 9(12), 9626. https://doi.org/10.29322/ijsrp.9.12.2019.p9626

Matos, J. C., Menezes, V. G., Gois, G. C., de Araújo, G. G. L., de Carvalho Barcellos, B. S., Soares, M. G., de Matos, M. H. T., Moraes, E. A., Menezes, D. R., and Queiroz, M. A. Á. 2022. Histological and physical–mechanical characteristics of the skin of Dorper sheep related to residual feed intake and the confinement environment. Tropical Animal Health and Production, 54(5). https://doi.org/10.1007/s11250-022-03320-6

Mehta, M., Naffa, R., Maidment, C., Holmes, G., Waterland, M. 2020. Raman and ATR-FTIR spectroscopy towards classification of wet blue bovine leather using ratio metric and chemometric analysis. Journal of leather science and engineering, 2(3),1-15.

Mohamed, H., Van Klink, E., Mohamed, H. A. A., Van Klink, E. G. M., and Elhassan, S. M. 2016. Damage caused by spoilage bacteria to the structure of cattle hides and sheep skins. International Journal of Animal Health and Livestock Production Research, 2(1), 39–56. https://www.researchgate.net/publication/299850965

Monteiro, A., Costa, J. M., and Lima, M. J. 2018. Goat System Productions: Advantages and Disadvantages to the Animal, Environment and Farmer. In Goat Science. InTech. https://doi.org/10.5772/intechopen.70002

Plestenjak, E., Kraigher, B., Leskovec, S., Mandic Mulec, I., Marković, S., Ščančar, J., and Milačič, R. 2022. Reduction of hexavalent chromium using bacterial isolates and a microbial community enriched from tannery effluent. Scientific Reports, 12(1), 20197. https://doi.org/10.1038/s41598-022-24797-z

Qin, L., Bi, J. R., Li, D. M., Dong, M., Zhao, Z.Y., and Dong, X.P. 2016. Unfolding/ refolding study on collagen from sea cucumber based on 2D fourier transform infrared spectroscopy. Molecules. 21(11):1546.

Razvi, R., Suri, S., Sarma, K., and Sharma, R. 2015. Histomorphological and histochemical studies on the different layers of skin of Bakerwali goat. Journal of Applied Animal Research, 43(2), 208–213. https://doi.org/10.1080/09712119.2014.963089

Shirmohammadli, Y., Efhamisisi, D., and Pizzi, A. 2018. Tannins as a sustainable raw material for green chemistry: A review. Industrial

Crops and Products, 126, 316–332. https://doi.org/10.1016/j.indcrop.2018.10.034

Stani, C., Vaccari, L., Mitri, E., Birarda, G. (2020). FTIR investigation of the secondary structure of type I collagen: New insight into the amide III band. Spectrochemical Acta Part A, 229, 1-7. https://doi.org/10.1016/j.saa.2019.118006.

Stefano, M., Corain, L., & Peruffo, A. (2015). Histological analysis of the skin dermal components in bovine hides stored under different conditions. Article in Journal of the American Leather Chemists Association, 110. https://www.researchgate.net/publication/279315225

Suparno, O. 2010. Optimizing of chamois leather tanning using rubber seed oil. JALCA, 105.

Taotao, Q., Xuechuan, W., and Longfang, R. 2009. Recovery of Collagen from Phosphonium tanned leather shavings and application as formaldehyde scavenger. Phosphonium Scavenger JALCA, 104, 316–322.

Tournier, R. 2020. Tanning Chemicals' Influence in Leather Tensile and Tear Strength Review. Journal of the American Leather Chemists Association, 115(11), 409–412. https://doi.org/10.34314/jalca.v115i11.4185

Vaiopoulou, E., and Gikas, P. 2012. Effects of chromium on activated sludge and on the performance of wastewater treatment plants: A review. Water Research, 46(3), 549–570. https://doi.org/10.1016/j.watres.2011.11.024

Wang, Y. N., and Li, J. 2016. Effect of Sodium Chloride on Structure of Collagen Fiber Network in Pickling and Tanning. In JALCA (Vol. 111). https://www.researchgate.net/publication/303840560

Yousef, H., Alhajj, M., Fakoya, A.O., Sharma, S. Anatomy, Skin (Integument), Epidermis. [Updated 2024 Jun 8]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK470464/

Zhang, Y., Liu, H., Tang, K., Liu, J., and Li, X. 2021. Effect of different ions in assisting protease to open the collagen fiber bundles in leather making. Journal of Cleaner Production, 293. https://doi.org/10.1016/j.jclepro.2021.126017