Original Research Article

The Impact of Cashew Nut (*Anacardium occidentale*) Testa Tannin Feeding Ratio on the Chemical and Mechanical Characteristics of Leather Tanned from Cowhide, Goatskin and Sheepskin

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ABSTRACT

In recent years, there has been a growing interest in exploring natural alternatives to synthetic tannins, driven by concerns over sustainability and environmental impact. Natural tannins offer several advantages, including biodegradability, renewability, and lower environmental impact compared to synthetic chemicals. Among the natural tannins under investigation, cashew nut testa tannin has emerged as a promising candidate due to its abundance, renewability, and potential benefits in leather tanning applications.

This research investigated the impact of varying feeding ratios of cashew nut testa tannin on the chemical and mechanical characteristics of leather tanned from cowhide, goatskin, and sheepskin. The objective was to determine how different concentrations of cashew nut testa tannin influence the quality and performance of the leather. Leather samples were prepared using different feeding ratios of cashew nut testa tannin and subjected to a series of chemical and mechanical tests.

The results indicated that the absorption of tannin and the resultant chemical stability varied with the type of hide or skin, with each exhibiting unique optimal ratios for tannin uptake. Higher tannin ratios generally improved the tensile and tear strength of the leather across all types, with significant enhancements noted in goatskin and sheepskin. However, an increase in tannin ratio reduced the flexibility of cowhide, while goatskin and sheepskin maintained adequate flexibility.

The study demonstrates that cashew nut testa tannin is an effective and sustainable tanning agent, capable of producing quality leather. The findings suggest that the leather industry can utilize cashew nut testa tannin to enhance leather properties, with potential customization of tannin feeding ratios to meet specific performance requirements. Further research is recommended to explore long-term durability and economic viability on a commercial scale.

This study contributes to the development of eco-friendly tanning practices and provides insights into optimizing the use of cashew nut testa tannin for various types of leather.

Keywords: tannin feeding ratio, cashew nut testa, leather tanning, leather tests, cowhide, goatskin, sheepskin

1. INTRODUCTION

Leather, a material revered for its durability, versatility, and aesthetic appeal, has been an integral part of human civilization for millennia. From ancient times to the present day, leather remains highly valued for its wide range of applications, including footwear, apparel, accessories, furniture, and automotive upholstery. At the core of leather production lies the tanning process, a crucial step that transforms raw animal hides into usable leatherby stabilizing the collagen fibers present in the skin.

The leather industry has long been characterized by its reliance on synthetic chemicals for tanning processes such as chromium salts, which often pose environmental and health risks. The disposal of these chemicals poses significant challenges, including soil and water contamination, as well as adverse effects on human health and ecosystems (Tadesse *et al*., 2017). In recent years, there has been a growing interest in exploring natural alternatives to synthetic tannins, driven by concerns over sustainability and environmental impact. Natural tannins offer several advantages, including biodegradability, renewability, and lower environmental impact compared to synthetic chemicals(Fraga-Corral *et al*., 2020).

Traditionally, tanning agents were derived from natural sources such as tree barks, roots, and leaves, which contain polyphenolic compounds known as tannins. These tannins interact with the amino groups in the collagen fibers present in the animal hide, forming cross-links that stabilize the protein matrix to impart strength, flexibility, and resistance to decay (Yorgancioglu*et al*., 2019). Tannins extracted from plant sources such as oak, chestnut, and mimosa have been used as tanning agents due to their ability to form stable complexes with collagen proteins. However, the extraction of tannins from plant sources can be labor-intensive and environmentally impactful, leading researchers to explore alternative tannins with similar tanning properties as addressed by Rolence, C. (2021).Recent advances in tanning technology have led to the exploration of alternative tannins, such as those derived from cashew nut testa (Mwangi *et al.,* 2024).

Cashew nut testa, the outer seed coat of the cashew nut, is a by-product of the cashew nut processing industry. It contains significant quantities of tannins, primarily catechins and proanthocyanidins, which have been shown to exhibit strong tanning properties (Oliveira *et al*., 2015). Cashew nut testa tannin has garnered interest as a potential alternative tanning agent due to its abundance, low cost, and potential to reduce waste in the cashew processing industry. Additionally, cashew nut testa tannin has been found to possess antioxidant properties, which may contribute to the preservation of leather (Zafeer *et al*., 2023).

Cowhide, goat skin, and sheepskin are among the most commonly used raw materials in the leather industry due to their availability, affordability, and desirable characteristics. Each type of skin presents unique challenges and considerations during the tanning process due to variation on biological properties among species and within the species (Del bino *et al.,* 2018). Cowhide, with its thick and dense structure, requires thorough penetration of the tanning agent to ensure uniform tanning and optimal leather quality. Goat skin, on the other hand, is thinner and more delicate, requiring careful handling to prevent damage during the tanning process. Sheepskin, known for its softness and suppleness, requires tanning agents that can preserve these characteristics while imparting strength and durability to the leather.

The chemical properties of leather encompass various parameters that influence its quality, durability, and performance. Tannin concentration plays a crucial role in determining the degree of collagen cross-linking, which affects leather strength and stability. Moreover, pH levels during tanning influence the efficiency of tannin binding and subsequent leather properties (Pizzi *et al*., 2021). Researches have shown that the feeding ratio of tannins can significantly impact the chemical composition of tanned leather,and different animal skins exhibit varying affinities for tannins, necessitating tailored tanning processes. Cowhide, characterized by its thick and dense structure, may require higher tannin concentrations to achieve adequate penetration and bonding. Conversely, goat and sheep skins, being thinner and more porous, may exhibit optimal tanning results at lower tannin concentrations.

The mechanical properties of leather, including tensile strength, tear resistance, and flexibility, are essential considerations for its suitability in various applications. Tannins contribute to the mechanical properties of leather by reinforcing the collagen matrix and increasing its overall strength and resilience (Mazotto*et al*., 2022). Studies have demonstrated that the feeding ratio of tannins can influence the mechanical properties of

tanned leather. Higher tannin concentrations may result in leather with greater tensile strength and tear resistance, making it suitable for applications requiring durability and longevity. However, excessively high tannin concentrations may also render the leather stiff and less pliable, limiting its flexibility and usability (Shakil *et al.,* 2023).
While the potential of cashew nut testa tannin in leather tanning was recognized, there was still a need for systematic studies to evaluate its efficacy and impact on leather properties. This study sought to address this gap by investigating the effect of varying feeding ratios (concentrations) of cashew nut testa tannin on the chemical and mechanical properties of leather derived from cow, goat, and sheep skin.

2. METHODOLOGY

The tanning study was carried out at Kiwango Leather Cluster Company, located in Mwanga District, Kilimanjaro region (Coordinates 3.70341^{o} S, 37.66593^{o} E). Leather chemical analysis and mechanical tests were done at Tanzania Bureau of Standards (TBS)'s laboratory.

2.1 Materials Used

Cashew nut testa was collected randomly from different cashew nut processors in Mtwara region, Southern Tanzania. Cows, Goats and Sheep skins were purchased from Mwanga abattoir in Kilimanjaro region, where environmental factors for growth were taken into consideration. Water as a solvent, and all reagents with analytical grade were used.

The equipment used were rotary drum (Cap: Max 50pcs, 4rpm), thermometer, weigh balance, pH meter, heated agitator reactor (Cap: Max 80 Litres, 5000rpm), hammer mill, and muslin cloth.

2.2 Tanning Trial

The study employed a controlled experimental design, where leather samples from cow, goat, and sheep skin were subjected to tanning processes using varying feeding ratios of cashew nut testa tannin solution. The extracted cashew nut testa tannin solutions were prepared using ratio 1:9 of cashew nut testa powder and water on weight basis (Mwangi *et al.,* 2024). Pelts were prepared according to convectional procedures that involved soaking, liming, deliming, bating and pickling.The tanning process was involved immersing the pelts in aqueous solutions of cashew nut testa tannin at varying feeding ratios followed by drying and finishing treatments (*appendix 1*). Trials were conducted using the extracted tannin solutions whereby the weight of the pickled cow, goat and sheepskins was applied independently in various ratios (1:3, 1:4, and 1:5) to that of the tannin solution.All skin trials received the same preparation treatment except in tanning where various feeding ratios of tannin solution were applied independently. The retanningwas done using equal weight of extracted tannin solution and tanned leather.The tanning trials were carried out using convectional mimosatanning as a matched control as comparison for experimental leathers.Chemical analyses and mechanical testing were conducted to assess the properties of the resulting leather.

2.3 Chemical Analysis

2.3.1 Determination of hide substance

Leather samples were prepared for chemical tests in accordance with ISO 4044:2017.3 g of the test portion were weighed and placed in a Kjeldahl flask. Thirty mls of concentrated sulphuric acid, 5 g of Copper Sulphate, and 10 gm of Sodium Sulphate as a catalyst mixture were added to the flask. The mixture was heated to boiling, starting with a low flame and then using a high flameat 400^{0}C, until 1 hour after all carbon had been oxidized. A small funnel was placed in the neck of the flask to prevent acid loss during digestion. The mixture was cooled and diluted with 50 ml of distilled water, then transferred to the distilling flask. The Kjeldahl flask was rinsed twice with 20 ml of distilled water each time. The solution was made alkaline with an excess of 35% caustic soda solution of 60 ml. The mixture was then steam distilled. The flask was connected to a vertical condenser via a tube bent twice. Ammonia was distilled with water vapor into a 300 ml receiver containing 100 ml of saturated boric acid (1%) and indicator solution. The distilled ammonia turned the indicator green. Distillation continued until 150 ml of distillate was collected. Before ending the distillation, the receiver was lowered so the cooling tube no longer dipped in, and distillation proceeded for an additional 3 minutes. The end of the condenser was rinsed with distilled water. The ammonia was titrated with 0.1M standard hydrochloric acid to pH 4.6. Using the methyl red as indicator, titration continued until the first constant pale pink color was achieved.

2.3.2 Determination of water content

Leather samples were prepared for chemical tests in accordance with ISO 4044:2017. Ten g of the test portion was weighed and placed in the distillation flask, followed by adding 10 ml of toluene and swirling to mix. The apparatus was assembled, and the receiver was filled with the solvent by pouring it through the condenser until it began to overflow into the distillation flask. A loose cotton plug was inserted in the top of the condenser to prevent condensation of atmospheric moisture within the tube. The flux and tube leading to the receiver were wrapped with asbestos cloth to control refluxing. The flask was heated to achieve a distillation rate of about 100 drops per minute. Once the greater part of the water had distilled over, the distillation rate was increased to about 200 drops per minute and continued until no more water was collected. During distillation, the reflux condenser was occasionally purged with 6-ml portions of toluene to wash down moisture adhering to the wall of the condenser. The water in the receiver was made to separate from the toluene by moving the spiral copper wire up and down in the condenser and receiver occasionally, causing the water to settle at the bottom of the receiver. Refluxing continued until the water level in the receiver remained unchanged for 30 minutes, after which the source of heat was shut off. The condenser was flushed with toluene as required, using the spiral copper wire to discharge any moisture droplets. The receiver was then immersed in water at about 27°C for at least 15 minutes or until the toluene layer was clear, and the volume of water was read.

2.3.3 Determination of oil content

Leather was sampled and a test portion was prepared for chemical testing in accordance with ISO 4044:2017. Ten g sample material was digested for an hour in a flask fitted with a reflux condenser containing 50 ml of alcoholic potassium hydroxide solution (8% w/v) on a boiling water-bath. The alcohol was evaporated, and the residue was diluted with 50 ml of water. Then, 15 ml of concentrated hydrochloric acid was slowly added, and the flask was placed again on the boiling water-bath for an hour. The flask was cooled, and its contents were completely transferred into a separating funnel. It was shaken with ether, and the layers were allowed to separate. The ether layer was collected in a conical flask. The water layer was shaken again with ether, and the ether layer was collected as before in the same conical flask. This extraction with ether was continued until the fatty acids were completely removed. The combined ether extracts containing the fatty acids were transferred to a clean separating funnel and washed with water to remove mineral acids. The extracts were subsequently dried over anhydrous sodium sulphate to remove dissolved water. The solution was filtered into a weighed conical flask, and the ether was evaporated on the boiling water-bath. The sample was dried in the air-oven at 100±2°C for one hour and weighed.

2.3.4 Determination of water-soluble content

Leather samples were prepared for chemical testing in accordance with ISO 4044:2017.A test portion of 10.00 g of leather was accurately weighed. The extracted leather was freed from solvent by spreading it on a clean surface and allowing it to air dry. The sample leather was transferred to a vacuum thermos flask. Five hundred ml of water was added, and the mixture was shaken in a mechanical shaker at 26±2°C for 2 hours. The liquid was separated from the residual leather by filtration using Whatman No. 11, and the first 50 ml of the filtrate was discarded. Fifty ml of the filtrate was evaporated to dryness in an evaporating basin, previously heated to 800±25°C, cooled, and weighed. The residue was dried at 100±10°C in an oven for 2 hours. The dried residue was cooled in a desiccator for 20 minutes and quickly weighed. Only one dish was placed in a small desiccator, with at most two dishes in a large desiccator. The dish was returned to the oven for an additional hour, then cooled in the desiccator for 20 minutes and reweighed.

2.3.5 Determination of ash content

Leather was sampled and a test portion was prepared for chemical testing in accordance with ISO 4044:2017. Five g of the test portion was weighed and carbonized over a low flame in a crucible, previously heated to 800 °C, cooled, and weighed. The ash was thoroughly moistened with 2 N sulphuric acid and heated over a low flame until sulphuric acid fumes were no longer visible. The sample was then ignited in a muffle furnace at 800 °C. The residue was moistened with ammonium nitrate (10% v/w) solution and reheated until carbon-free. The carbon residue along with the filter paper was ashed, and the filtrate was added back to the crucible contents. The mixture was evaporated on a water-bath and heated again at 800 °C until all visible carbon traces were removed. The sample was cooled in a desiccator and weighed. Heating, cooling, and weighing were repeated until the residue weight was constant. This was followed by calculation of the total ash.

2.3.6 Determination of degree of tannage:

Degree of tannage was calculated as the percentage of tannins retained in the leather relative to the total amount used in the leather tanning process. This can be expressed using the formula in eq 1;

$$Degree\ of\ tannage = 100 \times \frac{\text{bound organic substance}}{\text{hide substance}} \quad \text{(eq 1)}$$

Bound organic substance = 100% - [water content + oil content + water soluble matter+ insoluble ash content+ hide substance] % ....(eqn 2)

2.4 Physical Analysis

2.4.1 Tensile strength and elongation at break

Tensile strength and percentage of elongation of leather samples were measured by using Instron, Series IX AMTS 8.25.00 and Bluehill 3 version 3.41 software according to the official method (ISO 3376/TZS 212). Leather samples were cut parallel and perpendicular to the backbone using a dumbbell shaped press knife, set with jaws arranged 50 mm apart for standard testing and jaws separating at a rate of 100 mm/min. The greatest force recorded was taken as the breaking force (N) and the distance between the jaws at break relative to the original distance was taken as the percentage extension at break. The tensile strength (MPa) was calculated as the breaking force per area (width by thickness) of the strip. Each sample(crust) was measured ten times.

2.4.2 Tear strength

The sample was cut into the specified dimensions of 50 mm x 25 mm with a notch/slit as per the ISO 3377-2/TZS 208-2 standard. The sample was marked for identification and orientation. The tear strength fixture was attached to the Instron, Series IX AMTS 8.25.00. The leather sample was placed in the fixture, ensuring proper alignment of the notched/slit edge. The Instron, Series IX AMTS 8.25.00applied a force at a rate of 100±20mm/min until the sample tore completely. The maximum force applied before the sample tore (tear force) was recorded.

3. RESULTS AND DISCUSSION

3.1. Chemical Properties

The chemical properties of tanned leather of cow, goat and sheepskin are given in Table 1. The chemical measurements for water content, oil content, water soluble matter content, insoluble ash content and hide substance are shown on the table. The tannins bound organic content and degrees of tannage are shown in *Plot 1* and *2*, respectively.

Table 1; The chemical properties of experimental tanned leathers

Leather type	Ratio	Test parameters				
		Water content, %	Oil content, %	Water soluble content, %	Insoluble ash content, %	Hide substance content, %
Cow	1:5	13.59	13.8	2.7	3.23	46.37
	1:4	15.43	21.5	0.1	3.38	47.82
	1:3	15.26	4.5	0.8	3.15	52.42
	Control	15.50	17.3	0.8	2.26	49.11
Goat	1:5	11.67	7.9	2.9	3.09	46.13
	1:4	9.64	10.2	1.4	1.94	48.64
	1:3	12.12	7.9	2.4	2.53	44.56
	Control	11.87	20.3	0.3	3.73	40.82
Sheep	1:5	9.89	10.8	0.4	3.28	46.37
	1:4	7.79	16.4	0.2	3.09	50.12
	1:3	8.72	11.6	1.7	3.30	52.14
	Control	10.30	17.2	0.3	2.35	48.12

****Percent by weight***

The test results from these parameters were used to calculate the degree of tannage. The degree of tannage is a measure of how thoroughly the tanning agents have chemically bonded with the collagen fibers in an animal hide/skin during the tanning process. This parameter is crucial in determining the quality, durability, and properties of the finished leather product, hence it is of practical value to the tanner in determining the quality of leather. The calculation of the degree of tannage is to determine tannins which are bound by the skin compared with skin proteins that are not bounded with tannins (raw skin). Therefore, the degree of tannage in leather is affected by a combination of chemical properties including water content, oil content, water soluble matter content, insoluble ash content and hide substance.

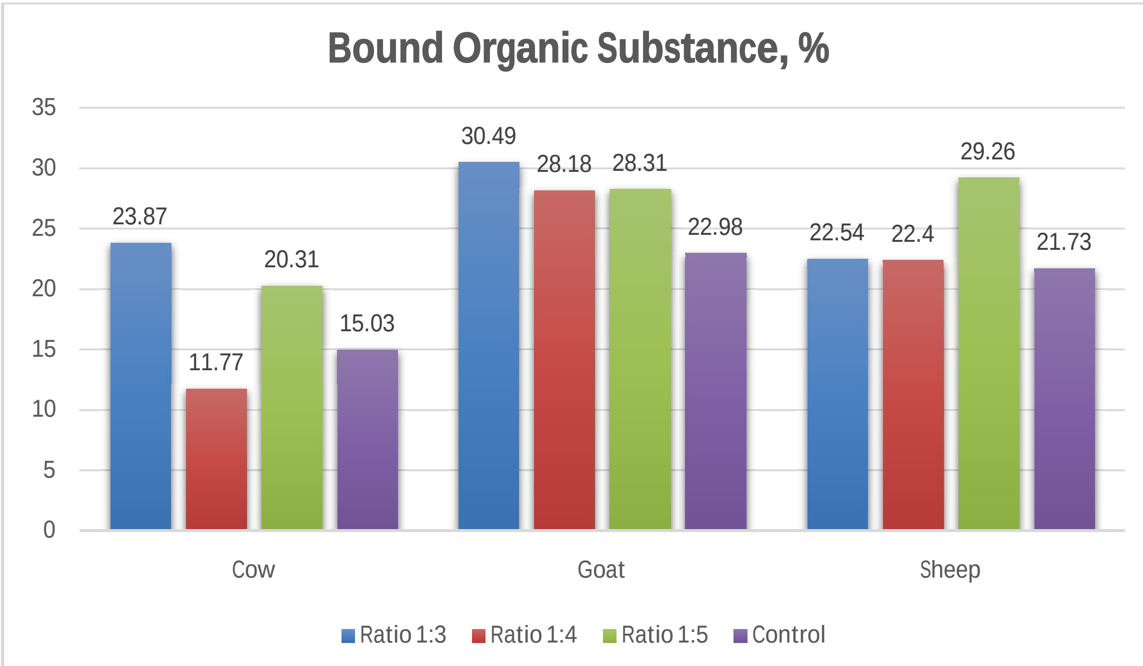

Figure 1: Bound organic substance for various feeding ratio on cow, goat, and sheep leather

Plot 1 shows how tannin was absorbed and bound tightly by collagen of the raw skin during tanning. The tannin bound in the skin is affected by the number of tannins that can diffuse into the skin tissue. High concentration of tanning material outside the skin may increase the diffusion of tanning material. Therefore, the amount of tanning by collagen increases with higher concentration. The higher the concentration of Cashew nut testa tanninused, the greater the tannin bound to the skin tissue, although variation among species can significantly affect the tannin bound content of leather. The highest tannin bound content for cow was 23.86% observed on the skin tanned by *ratio 1:3,* for goat was 30.49% observed on the skin tanned by *ratio 1:3*, and for sheep was 29.26% observed on the skin tanned by *ratio 1:5* (*Plot 1*). Expressing the term "Hide substance" as a protein that has not bounded with tannin, the increase of tannin bound implies the number of hide substance in the skin will decrease, hence the number of comparisons of tannins bound and hide substance will be even greater. On the contrary, the highest hide substance on cow was 52.32% observed on the skin tanned by ratio 1:3, on goat was 48.64% observed on the skin tanned by ratio 1:4, and on sheep was 52.14% observed on the skin tanned by ratio 1:3 *(Table 1).*

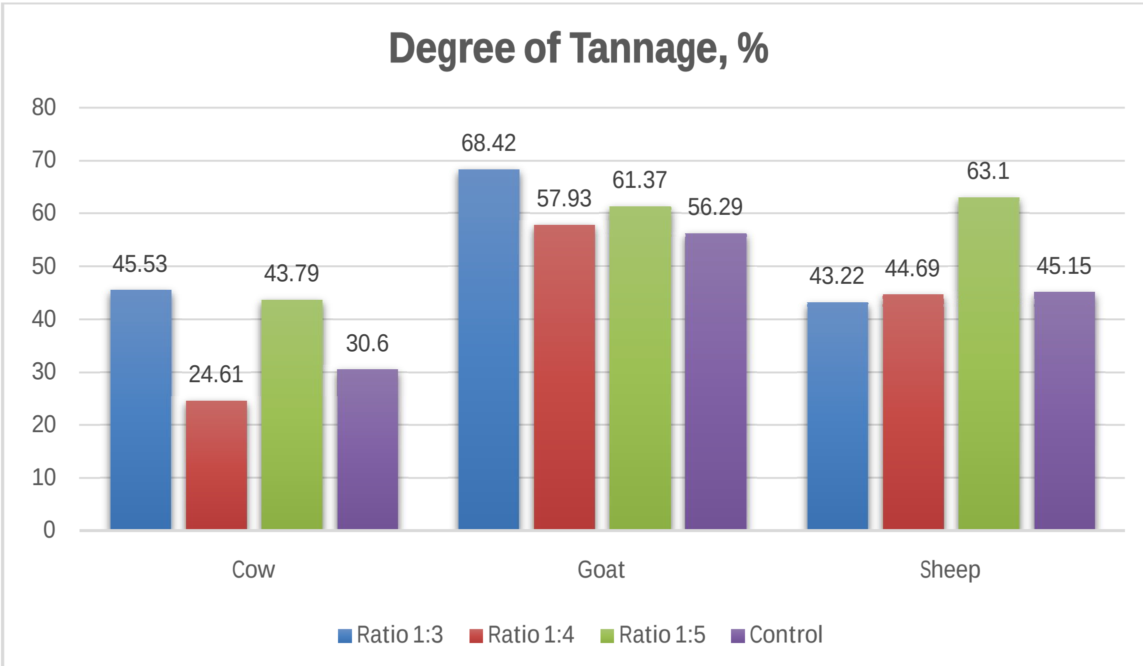

Figure 2: Degree of tannage for various feeding ratio on cow, goat, and sheep leather

A higher degree of tannage typically correlates with improved leather properties such as enhanced durability, flexibility, and resistance to environmental factors. The higher tannage percentages achieved with certain ratios indicate the potential for producing higher quality leather. The data reveals a clear trend where concentration ratios of tanning agents affect degree of tannage. On Cow hide, the 1:3 ratio achieved the highest degree of tannage, followed by the 1:5 ratio, while the 1:4 ratio was the least effective. The 1:3 ratio proved to be the most effective, suggesting this concentration maximized the binding of tanning agents to the cow hide. The 1:5 ratio has also shown significant effectiveness, making it a viable alternative to the 1:3 ratio, whereas the 1:4 ratio is less efficient. Therefore, the 1:3 and 1:5 ratios are likely to produce cow hide of superior quality compared to the control and the 1:4 ratio.

On goat skin, the 1:3 ratio achieved the highest degree of tannage, followed by the 1:5 ratio, indicating that these higher concentrations are more effective than the 1:4 ratio and the control. The 1:3 ratio emerged as the most effective, suggesting that this concentration maximizes the binding of tanning agents to the goat skin. The 1:5 ratio also showed significant effectiveness, indicating that it is a viable alternative to the 1:3 ratio, while the 1:4 ratio is less efficient.

On Sheepskin, the data shows that the 1:5 ratio achieved the highest degree of tannage, suggesting that a higher concentration of tanning agents significantly enhances the tanning process. The 1:4 and 1:3 ratios showed lower degrees of tannage than the control, indicating that these concentrations are less effective for sheep skin tanning. The 1:5 ratio is clearly the most effective, suggesting that this concentration maximizes the binding of tanning agents to the sheep skin. The lower effectiveness of the 1:4 and 1:3 ratios compared to the control suggests that these concentrations may not be optimal for sheep skin tanning.

The optimal tanning concentration varied among the skins. For cow hides, the 1:3 ratio showed the highest effectiveness, while for goat skin, it was the 1:3 ratio, and for sheep skin, it was also the 1:5 ratio. This suggests that the optimal tanning concentration depends on the type of skin being processed.

3.2 Physical Properties

The research conducted physical test on the selected parameters of leather from cow, goat, and sheep treated with different tanning ratios (1:5, 1:4, 1:3) of cashew nut testa tannin compared to a conventional mimosa tanning (control sample) shown in table 2.

Table 2: The physical properties of experimental tanned leathers

Leather type	**Ratio**	**Physical parameters**		
		Tear strength, (N)	**Tensile Strength, (Mpa)**	**Elongation at Break, (%)**
Cow	1:5	326.06	28.42	37.72
	1:4	389.64	27.85	58.79
	1:3	182.40	24.85	50.28
	Control	451.94	25.13	48.97
Goat	1:5	92.87	24.82	44.94
	1:4	53.37	22.62	52.54
	1:3	70.59	19.36	57.24
	Control	49.30	15.76	40.47
Sheep	1:5	58.04	19.81	53.44
	1:4	53.10	18.59	53.41
	1:3	36.71	17.41	40.24
	Control	38.68	17.33	43.31
Recommended value (ISO 14931-2021)		≥ 15	≥ 12	40 – 90

Tensile strength is a critical property that measures the leather's ability to withstand tension without breaking, which is essential for various applications(Oliveira *et al*., 2022). The data confirms that all tanning processes used in this study produced leather that exceeded the minimum tensile strength requirement of 12 MPa, making them suitable for various applications. For all types of leather (cow, goat, sheep), the 1:5 ratio yielded the highest tensile strength, suggesting that a higher concentration of tanning agents enhances the structural integrity and durability of the leather. The 1:4 ratio also resulted in strong tensile strength across all samples, indicating it as an effective tanning concentration. The 1:3 ratio resulted in a noticeable decrease in tensile strength compared to 1:5 and 1:4 ratios but still produced leather that met the required standards.The 1:5 ratio was consistently the most effective, suggesting it should be the preferred choice for maximizing tensile strength and durability. The control samples displayed that the standard tanning processes were effective, but optimizing the ratio could have enhanced leather quality.

Elongation at break measures the extent to which the leather can be stretched before breaking, an important property for flexibility and durability(Tomljenović *et al*., 2020). The standard elongation at break for high-quality leather ranges between 40% and 90%. On cow leather, the 1:4 ratio provided the best flexibility within the standard range, followed by the 1:3 and the control samples. The 1:5 ratio fell below the standard range, indicating insufficient flexibility. On goat leather, all ratios and the control fell within the standard range. The 1:3 ratio exhibited the highest elongation at break, indicating excellent flexibility. The 1:4 and 1:5 ratios also indicated good flexibility, while the control was at the lower end of the standard range. On sheep leather, all ratios and the control fell within the standard range. The 1:5 and 1:4 ratios exhibited the highest elongation at break, indicating a very good flexibility. The 1:3 ratio and the control indicated acceptable flexibility, although the 1:3 ratio was just at the lower limit of the standard. These results indicate that adjusting the tanning ratio can significantly impact the flexibility of leather. For cow leather, the 1:4 ratio appears optimal for achieving good flexibility. Goat leather shows good flexibility across all tested ratios, suggesting a broader range of suitable tanning conditions. Sheep leather benefits most from the 1:5 and 1:4 ratios for optimal flexibility.

Tear strength is a critical parameter for indicating the resistance of leather to tearing, which is essential for durability and quality (Tournier *et al.,* 2022). The standard tear strength forquality leather is specified to be greater than 15 N. On cow leather, all tested ratios and the control exhibited tear strengths well above the standard, with the control sample showing the highest tear strength. This suggests that all tanning processes used were effective in enhancing tear resistance. The 1:4 ratio performed exceptionally well, nearly matching the control, indicating an optimal balance of chemical treatment for maximum tear strength. On goat leather, all samples met and exceeded the standard tear strength, with the 1:5 ratio showing the highest tear resistance. The lower ratios (1:4 and 1:3) still performed well but were slightly lower than the 1:5 ratio, suggesting that higher ratios might contribute to better tear strength. On sheep leather, all ratios and the control exceeded the standard tear strength, with the 1:5 ratio providing the best tear resistance. The lower ratios (1:4 and 1:3) still offered good tear resistance but were somewhat lower than the 1:5 ratio, indicating that the 1:5 ratio could be more effective for sheep leather. The data indicates that all tested leather samples (cow, goat, and sheep) possessed tear strengths well above the standard, confirming their suitability for quality leather products.

4. CONCLUSION

The study assessed how different ratios affect the quality and performance of the resulting leather. The study found that the absorption of cashew nut testa tannin varied across cowhide, goatskin, and sheepskin. The optimal feeding ratio differed for each type of hide/skin, indicating that each material had a unique capacity for tannin uptake. The leathers tanned with higher ratios of cashew nut testa tannin exhibited improved chemical stability, suggesting enhanced resistance to hydrolytic and oxidative degradation.

The tensile strength of leather increased with higher feeding ratios of cashew nut testa tannin, particularly in goatskin and sheepskin. Cowhide showed a significant improvement at moderate ratios but plateaued at higher concentrations. Tear strength was enhanced across all types of leather with increased tannin ratios, indicating better durability and resistance to mechanical stress. Higher tannin ratios resulted in reduced flexibility in cowhide, while goatskin and sheepskin maintained adequate flexibility even at higher concentrations.

Cashew nut testa tannin can be an effective tanning agent for cowhide, goatskin, and sheepskin, with varying optimal feeding ratios for each type of leather. The chemical stability and mechanical properties such as tensile and tear strength improved with increased tannin ratios, demonstrating the potential for producing high-quality leather. However, careful consideration must be given to the balance between strength and flexibility, especially in cowhide, to ensure the leather meets specific application requirements.

The study assessed how different ratios affect the quality and performance of the resulting leather. The research successfully demonstrated that cashew nut testa tannin is a viable tanning agent that can positively influence the chemical and mechanical characteristics of leather made from cowhide, goatskin, and sheepskin. The optimal feeding ratios need to be carefully determined for each type of leather to achieve the desired balance of properties, paving the way for innovative and sustainable tanning practices in the leather industry.

Cashew nut testa a by-product of the cashew industry, offers a sustainable and eco-friendly alternative to traditional tanning agents. The leather industry can adopt cashew nut testa tannin to enhance the quality of leather products, especially where high strength and durability are required. Leather manufacturers can tailor the tannin feeding ratios to optimize the properties of leather for specific end uses, ensuring better product performance and customer satisfaction.

Additional studies should be conducted to explore the long-term effects of cashew nut testa tannin on leather durability and aging. Pilot-scale studies should be implemented to evaluate the economic feasibility and scalability of using cashew nut testa tannin in commercial leather tanning processes.

REFERENCES

Del Bino, S., Duval, C., & Bernerd, F. (2018). Clinical and biological characterization of skin pigmentation diversity and its consequences on UV impact. International journal of molecular sciences, 19(9), 2668.

Fraga-Corral, M., García-Oliveira, P., Pereira, A. G., Lourenço-Lopes, C., Jimenez-Lopez, C., Prieto, M. A., & Simal-Gandara, J. (2020). Technological application of tannin-based extracts. Molecules, 25(3), 614.

ISO 14931:2021

Leather - Chemical tests - Preparation of chemical test samples (ISO 4044:2017)

Oliveira, G. G., Gasparino, E., Castilha, L. D., Marengoni, N. G., Souza dos Reis Goes, E., Alves de Almeida, F. L., ... & Rodrigues de Souza, M. L. (2022). Characterization and Strength Quality of the Oryctolagus cuniculus Leather Compared to Oreochromis niloticus Leather. *The Scientific World Journal*, *2022*(1), 4561404.

Oliveira, N. F., Leal, R. S., & Dantas, T. N. C. (2015). The importance of the cashew nut (Anacardium occidentale L.) coat: a review. American International Journal of Contemporary Scientific Research, 2(8), 09-41.

Mazotto, A. M. (2022). Biopolymers in the leather industry. In Biopolymers: Recent Updates, Challenges and Opportunities (pp. 245-270). Cham: Springer International Publishing.

Mwangi, S. Z., Silayo, V. C., & Chaula, D. N. (2024). Optimization of Tannin's Extraction from Cashew (Anacardium occidentale L.) Nut Testa for Use in Leather Tanning. Asian Journal of Applied Chemistry Research, 15(2), 7-16.

Pizzi, A. (2021). Covalent and Ionic Bonding between Tannin and Collagen in Leather making and shrinking: A MALDI-ToF study. Journal of Renewable Materials, 9(8), 1345-1364.

Rolence, C. (2021). An eco-friendly tanning method using plant barks and their combination with aluminium sulphate from kaolin for leather industry (Doctoral dissertation, NM-AIST).

Shakil, M. S. R., Aktar, M. S., Rahman, S., & Ahmed, S. (2023). A novel vegetable tannin for eco-leather production: separation, characterization and application of facile valorized indigenous Acacia nilotica bark extract. Bioresource Technology Reports, 23, 101591.

Tadesse, G. L., Guya, T. K., &Walabu, M. (2017). Impacts of tannery effluent on environments and human health: a review article. Advances in Life Science and Technology, 54(10).

Tomljenović, A., Akalović, J., Živičnjak, J., & Barišić, A. (2020). Influence of sampling location on physical and mechanical properties of full grain leather. *ČasopisKoža& Obuća*, *69*(2), 4-11.

Tournier, R., & Lado, F. (2022). Improving Tearing Resistance of Leather-Part 2 Prevention and Treatment of Low Tearing Strength in the Tannery. *Journal of the American Leather Chemists Association*, *117*(1).

Yorgancioglu, A., Başaran, B., &Sancakli, A. (2020). Value addition to leather industry wastes and by-products: hydrolyzed collagen and collagen peptides. Waste in textile and leather sectors, 1(2).

Zafeer, M. K., & Bhat, K. S. (2023). Valorisation of agro-waste cashew nut husk (Testa) for different value-added products. Sustainable Chemistry for Climate Action, 2, 100014.

APPENDIX

Formulation of tanning process

Process	**Product used**	**Percent**	**Duration (mins)**	**Remarks**
Washing	Water	300	15	Drain
Soaking	Water	300	60	Drain
	Wetting agent	1		
Washing	Water	300	15	Drain
Liming	Water	300	285	Run 30' stop 30' (3X)
	Sodium sulphide	2		
	Lime	6	150	
Fleshing				Done mechanically
Washing	Water	300	15	Drain
Deliming, Bating and Degreasing	Water	200	90	Drain
	Ammonium chloride	2		
	Bating agent	0.5		
	Degreasing agent	2		
Washing	Water	300	15	Drain
Pickling	Water	100		Overnight
	Salt (sodium chloride)	10	15	
	Formic acid	1	(3 x 15)	
Tanning	1:3 tannin solution	300	(3 x 120) + 360	Solution divided in three equal portion and fed for every 120mins
	1:4 tannin solution			
	1:5 tannin solution			
	1:3 Mimosa (Control)			
Fixation	Formic acid	2	30	pH 3.5
Neutralization	Sodium bicarbonate	1	(3 x 15) + 60	pH 5
Washing	Water	300	15	Drain
Retanning	With respectively	100	120	Drain

	tannin solution			
Fatliquoring	Water 45 ^{o}C	100	60	
	Lipoderm liquor	2		
Fixing	Formic acid	0.5	30	pH 3.5
	Anti-mold	0.02	15	
Washing	Water	300	15	Drain
Drying	Shade-dry	-	Two days	Drain
Staking	Hands-on (pulling)	-	-	Soften