MECHANICAL BEHAVIOR OF BELT LEATHERS PRODUCED WITH DIFFERENT TANNING SYSTEMS

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ABSTRACT. In this study, the effects of different tanning systems on the mechanical behavior of bovine belt leathers were comparatively investigated. Heavy bovine pickled hides were subjected to three commercial tanning systems: System I (Vegetable-based combination: 10% Mimosa + 10% Quebracho), System II (Synthetic-based combination: 10% Phenolic syntan + 15% White syntan), and System III (Chrome-focused combination: 7% Basic chromium sulphate + 10% Phenolic syntan). Following post-tanning, leather samples were evaluated according to TS EN ISO standards. Statistical analysis was performed using one-way ANOVA followed by Tukey's post-hoc test ($p < 0.05$) to determine significant differences among tanning systems. Experimental findings demonstrated that the tanning system plays a definitive role on leather performance. Tanning System III leathers exhibited superior mechanical properties, recording the highest mean thickness (3.80±0.06 mm), tensile strength (25.34±3.64 N/mm²), double edge tear strength (361.57±34.08 N), grain cracking force (65.00±15.00 kgf), grain bursting force (100.00±7.21 kgf), and stitch tear resistance (509.61±80.54 N). Furthermore, they displayed 0.00% extension set, indicating excellent dimensional stability required for premium belt production. Conversely, Tanning System II leathers demonstrated the highest elasticity with an elongation at break of 69.74±16.34% and a comparable single edge tear load (90.42±15.09 N) but displayed an extension set of 1.30±0.42%. Tanning System I leathers overall exhibited lower mechanical strength (tensile strength: 20.75±6.67 N/mm²; highest extension set: 2.22±1.53%), though they offered superior grain crack (12.71±0.57 mm) and bursting distension (15.41±0.34 mm). Under the conditions investigated, System III provided the most favorable overall mechanical performance for heavy-duty belt leather, while the specific synthetic and vegetable formulations used in Systems II and I, respectively, provided greater extensibility and grain distension. These findings are specific to the commercial tanning formulations investigated and should not be generalized to all vegetable, synthetic, or chrome tanning systems.

KEY WORDS: belt leather, chrome tanning, vegetable tanning, synthetic tanning, mechanical properties

COMPORTAMENTUL MECANIC AL PIEILOR PENTRU CURELE OBȚINUTE PRIN DIFERITE SISTEME DE TĂBĂCIRE

REZUMAT. În acest studiu s-au investigat comparativ efectele diferitelor sisteme de tăbăcire asupra comportamentului mecanic al pieilor bovine destinate fabricării curelelor. S-au tăbăcit piei bovine piclate de greutate mare utilizând trei sisteme comerciale de tăbăcire: Sistemul I (combinație pe bază de tananți vegetali: 10% Mimosa + 10% Quebracho), Sistemul II (combinație pe bază de tananți sintetici: 10% sintan fenolic + 15% sintan alb) și Sistemul III (combinație pe bază de crom: 7% sulfat bazic de crom + 10% sintan fenolic). După etapa de retăbăcire, probele de piele au fost evaluate conform standardelor TS EN ISO. Analiza statistică a fost realizată utilizând testul ANOVA unifactorial, urmat de testul post-hoc Tukey ($p < 0,05$), pentru a determina diferențele semnificative între sistemele de tăbăcire. Rezultatele experimentale au demonstrat că sistemul de tăbăcire joacă un rol determinant în performanța pielii. Pieile obținute prin Sistemul III de tăbăcire au prezentat proprietăți mecanice superioare, înregistrând cele mai ridicate valori medii pentru: grosime (3,80±0,06 mm), rezistență la rupere (25,34±3,64 N/mm²), rezistență la sfâșiere pe două margini (361,57±34,08 N), forță de crăpare a feței (65,00±15,00 kgf), forță de plesnire a feței (100,00±7,21 kgf) și rezistență la sfâșiere la cusătură (509,61±80,54 N). De asemenea, acestea au prezentat o deformare remanentă la întindere de 0,00%, indicând o stabilitate dimensională excelentă, necesară pentru producția de curele premium. În schimb, pieile obținute prin Sistemul II de tăbăcire au demonstrat cea mai mare elasticitate, cu o alungire la rupere de 69,74±16,34% și o forță de sfâșiere pe o singură margine comparabilă (90,42±15,09 N), dar au prezentat o deformare remanentă la întindere de 1,30±0,42%. În ansamblu, pieile prelucrate prin Sistemul de tăbăcire I au prezentat o rezistență mecanică mai scăzută (rezistență la rupere: 20,75 ± 6,67 N/mm²; alungire remanentă maximă: 2,22 ± 1,53%), însă au oferit performanțe superioare în ceea ce privește rezistența la crăparea feței (12,71 ± 0,57 mm) și la plesnirea feței (15,41 ± 0,34 mm). În condițiile studiate, Sistemul III a asigurat cea mai favorabilă performanță mecanică generală pentru pielea destinată curelelor cu regim intens de utilizare, în timp ce formulările sintetice și vegetale specifice, utilizate în Sistemele II, respectiv I, au conferit o extensibilitate și o capacitate de distensie a feței mai mari. Aceste rezultate sunt specifice formulelor comerciale de tăbăcire analizate și nu trebuie generalizate la toate sistemele de tăbăcire vegetală, sintetică sau cu săruri de crom.

CUVINTE CHEIE: piele pentru curele, tăbăcire în crom, tăbăcire vegetală, tăbăcire sintetică, proprietăți mecanice

LE COMPORTEMENT MÉCANIQUE DES CUIRS DE CEINTURE PRODUITS AVEC DIFFÉRENTS SYSTÈMES DE TANNAGE

RÉSUMÉ. Cette étude compare les effets de différents systèmes de tannage sur le comportement mécanique des cuirs de ceinture bovins. Des peaux de bovins épaisses, préalablement picklées, ont été soumises à trois systèmes de tannage commerciaux : le Système I (combinaison végétale : 10 % de mimosa et 10 % de quebracho), le Système II (combinaison synthétique : 10 % de tanin phénolique synthétique et 15 % de tanin blanc synthétique) et le Système III (combinaison à base de chrome : 7 % de sulfate de chrome basique et 10 % de tanin phénolique synthétique). Après tannage, les échantillons de cuir ont été évalués selon la norme TS EN ISO. Une analyse statistique a été réalisée par l'ANOVA à un facteur, suivie du test post-hoc de Tukey ($p < 0,05$) afin de déterminer les différences significatives entre les systèmes de tannage. Les résultats expérimentaux ont démontré que le système de tannage influence fortement les

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performances du cuir. Les cuirs tannés selon le Système III ont présenté des propriétés mécaniques supérieures, avec une épaisseur moyenne (3,80 ± 0,06 mm), une résistance à la traction (25,34 ± 3,64 N/mm²), une résistance au déchirement des deux bords (361,57 ± 34,08 N), une force de fissuration de la fleur (65,00 ± 15,00 kgf), une force d'éclatement de la fleur (100,00 ± 7,21 kgf) et une résistance à l'arrachement au point de couture (509,61 ± 80,54 N) plus élevées. De plus, ils ont affiché un allongement à la rupture de 0,00 %, ce qui indique une excellente stabilité dimensionnelle, essentielle à la fabrication de ceintures haut de gamme. À l'inverse, les cuirs tannés selon le Système II ont démontré la plus grande élasticité, avec un allongement à la rupture de 69,74 ± 16,34 % et une résistance au déchirement d'un seul bord comparable (90,42 ± 15,09 N), mais un allongement à la rupture de 1,30 ± 0,42 %. Les cuirs tannés selon le Système I ont globalement présenté une résistance mécanique inférieure (résistance à la traction : 20,75 ± 6,67 N/mm² ; allongement maximal : 2,22 ± 1,53 %), malgré une meilleure résistance à la gerçure (12,71 ± 0,57 mm) et à l'éclatement (15,41 ± 0,34 mm) de la fleur. Dans les conditions étudiées, le Système III a offert les meilleures performances mécaniques globales pour les cuirs de ceintures robustes, tandis que les formulations synthétiques et végétales spécifiques utilisées respectivement dans les Systèmes II et I ont permis une extensibilité et un allongement de la fleur supérieurs. Ces résultats sont spécifiques aux formulations de tannage commerciales étudiées et ne doivent pas être généralisés à tous les systèmes de tannage végétaux, synthétiques ou au chrome.
MOTS-CLÉS : cuir de ceinture, tannage au chrome, tannage végétal, tannage synthétique, propriétés mécaniques

INTRODUCTION

Leather is a natural polymeric material characterized by a complex, three-dimensionally interwoven network of collagen fibers. Its mechanical properties are affected by many factors and used in evaluating the quality and suitability of leather [1]. In the leather industry, products designated for manufacturing bags, belts, wallets, and industrial accessories are broadly classified as leather goods. Depending on specific consumer demands, these leathers require structural adaptations ranging from a flexible, soft touch to an extremely compact, firm, and rigid character [2]. Historically, the evolutionary steps of tanning began when early humans discovered that certain plant woods, barks, roots, and seeds rich in natural polyphenolic tannins could systematically transform raw hides into non-putrescible, durable materials [3]. In the modern manufacturing of heavy-duty leather goods, the choice of the tanning system remains the most crucial chemical factor establishing macromolecular architecture and ultimate performance limits of the leather matrix.

Among various commercial leather applications, belt leathers occupy a highly demanding technical category. Unlike garment leathers, which are primarily designed to provide softness, drape, and wearer comfort, belt leathers are subjected to continuous mechanical stresses throughout their service life. During daily use, belts must maintain dimensional stability while resisting repeated tensile, bending, and torsional forces generated by fastening and body movements. In addition to these mechanical requirements, belt leathers are commonly used in direct contact with garments and are frequently exposed to perspiration. Therefore, adequate resistance to colour migration, perspiration fastness, and rubbing fastness are important quality attributes that directly affect user satisfaction and product durability. Owing to these requirements, belt leathers exhibit a structural character more closely related to sole and heavy leather products than to garment leathers, requiring a compact fiber structure, high firmness, and superior resistance to deformation [4, 5].

Traditionally, mineral tanning based on basic chromium (III) salts has been the universal standard due to its outstanding cross-linking efficiency, producing leather with exceptional hydrothermal stability and superior strength parameters [6]. However, the strict global environmental regulations and potential ecological footprints of chromium-bearing waste streams have accelerated the engineering of alternative chrome-free matrices.

To address these challenges, continuous efforts have been directed toward optimizing synthetic and vegetable tanning systems capable of providing mechanical properties comparable to conventional chrome tanning. Srinivasan *et al*. (2021) developed a pickle-free tanning approach combining vegetable tannins and aluminum salts and reported a compact fiber structure with high physical strength values [7]. Furthermore, current market trends favor leather products exhibiting enhanced natural appearance and

sustainable production characteristics, leading to renewed interest in vegetable tanning systems. Nevertheless, vegetable-tanned leathers often display higher hydrophilicity and different deformation behavior than chrome-tanned counterparts, requiring careful process optimization and retanning strategies to achieve the desired balance between firmness and flexibility [2].

Recent micro-mechanical characterizations —utilizing advanced methods such as instrumental indentation, zeta potential and surface topography—have confirmed that modern alternative tanning matrices induce highly specific structural profiles within the collagen network that differ fundamentally from traditional chrome baselines [8]. The structural variations induced by these chemical cross-links have direct statistical consequences for commercial performance. As demonstrated by Ork *et al*. (2014) through rigorous statistical modeling on identical bovine raw material, the type of tanning matrix dictates significant differences across physical strength, fastness, and elongation properties, directly determining the leather's suitability for specific high-performance leather goods applications [9].

Although extensive literature focuses on the chemistry or ecological aspects of alternative tanning systems, comparative studies evaluating the comprehensive mechanical performance of bovine belt leathers—including tensile strength, trouser tear strength, double-edge tear strength, grain distension, stitch tear resistance, and dimensional stability—remain remarkably scarce.

Therefore, this study systematically evaluates and contrasts the mechanical behavior of bovine belt leathers produced using three specific commercial tanning formulations: a vegetable combination of mimosa and quebracho, a synthetic combination of phenolic and white syntans, and a chrome-focused combination of basic chromium sulphate and phenolic syntan. By maintaining uniform mechanical operations and identical bovine raw materials across all trials, this paper establishes a precise quantitative baseline. All mechanical results were statistically analyzed using one-way ANOVA followed by Tukey's post-hoc test to ensure robust inter-group comparison and reliable differentiation of tanning effects ($p < 0.05$). The numerical trends and performance differentials observed herein not only elucidate the structural effects of different cross-linking mechanisms but also serve as a guide for selecting optimal tanning matrices based on the mechanical requirements of industrial belt manufacturing.

EXPERIMENTAL

Materials and Methods

In this study, heavy pickled bovine hides sourced from a commercial supplier operating in Bolu, Türkiye, were used as the primary research material. These hides were systematically divided into three experimental groups and processed using the three commercial tanning formulations described below under controlled conditions.

The chemical formulations utilized throughout the processing of the experimental leathers consisted of conventional tannery chemicals. Rather than evaluating theoretical pure single-agent baselines, this study specifically focused on practical recipes commercialized and utilized in current industrial belt leather production. Consequently, the experimental formulations were designed to reflect real-world tanneries' combination systems—such as integrating syntans into chrome matrices to achieve the required structural firmness and density—thereby offering direct insights for industrial applications. These processing chemicals were procured from local commercial suppliers based in Bolu, Türkiye. The specific cross-linking matrix agents utilized for each independent tanning system were determined as follows:

- System I (Vegetable-Based Combination): Commercial natural polyphenolic extracts of mimosa (10%) and quebracho (10%) were utilized as the primary tanning agents to crosslink and stabilize the collagen matrix.
- System II (Synthetic-Based Combination): A formulation of phenolic syntan (10%) and white syntan (15%) was employed to execute the synthetic organic tanning trials.

- System III (Chrome-Focused Combination): A combination of standard basic chromium sulphate (7%) and phenolic syntan (10%) was applied to establish the mineral-synthetic tanning matrix.

All other auxiliary post-tanning chemicals—including sodium format and sodium bicarbonate for basification/ neutralization, specialized fatliquoring agents (neat's-foot oil, lecithin, sulfated oil, sulfosuccinate, and combined oil matrices) and formic acid (HCOOH) for fixation—were of commercial grade and applied directly according to standard industrial leather manufacturing protocols.

Tanning Protocols and Mechanical Operations

The processed bovine hides were split into sides and transferred into experimental tanning drums. The samples were separate-batched and subjected to three independent tanning formulations: System I (vegetable combination), System II (synthetic combination), and System III (chrome-focused combination) (Figure 1). Following the completion of the respective tanning and fixation processes, all experimental leathers were drained, aged on horses, hooked for air-drying, and subjected to identical mechanical softening (setting out and staking) operations.

	TANNING SYSTEM 1	TANNING SYSTEM 2	TANNING SYSTEM 3
DE-PICKLING	• %80 Wator (7-8 Be°) • %1 Sodium Formate, 15' • %1 Sodium Bicarbonate, 60'	• %80 Water (7-8 Be°)	• %80 Water (7-8 Be°)
TANNING	• %10 Mimosa • %10 Quebracho • %2 Penetrating agent, 60' • %1 Sulfite oil, 360', **pH: 4**	• %10 Phenolic Syntan • %5 White Syntan, 60' • %1 Sulfite oil, 30' • %10 White Syntan, 180'	• %10 Phenolic Syntan • %3 Chromium Sulfate, 60' • %1 Sulfite oil, 30' • %4 Chromium Sulfate, 240'
BASIFICATION	-	• %150 Water • %1 Sodium Formate • %1 Sodium Bicarbonate, 180', **pH: 4**	• %100 Water • %1 Sodium Formate • %1 Sodium Bicarbonate, 180', **pH: 4**
WASHING	• %200 Water, 15'	• %200 Water, 15'	• %200 Water, 15'
NOTRALIZATION	• %100 Water • %1.5 Sodium Formiate, 20' • %1 Sodium Bicarbonate, 60', **pH: 5**	• %100 Water • %1.5 Sodium Formiate, 20' • %1 Sodium Bicarbonate, 60', **pH: 5**	• %100 Water • %1.5 Sodium Formiate, 20' • %1 Sodium Bicarbonate, 60', **pH: 5**
FATLIQUORING	• %2 Tallow oil • %2 Lesitin oil • %2 Sulfite oil • %2 Sulfosuccinate • %2 Combine oil, 60' • %1.5 HCOOH, 20'	• %2 Tallow oil • %2 Lesitin oil • %2 Sulfite oil • %2 Sulfosuccinate • %2 Combine oil, 60' • %1.5 HCOOH, 20'	• %2 Tallow oil • %2 Lesitin oil • %2 Suifite oil • %2 Sulfosuccinate • %2 Combine oil, 60' • %1.5 HCOOH, 20'
WASHING	• %300 Water, 15'	• %300 Water, 15'	• %300 Water, 15'

Figure 1. Leather tanning recipes

Sampling and Conditioning

To execute the physical and mechanical characterizations, test specimens were sampled systematically from the designated structural locations of the processed sides in strict compliance with the TS EN ISO 2418 standard. Prior to any mechanical testing, all specimens were kept in a standard controlled atmosphere at 20 ± 2°C and 65 ± 2% relative humidity for at least 48 hours to ensure complete moisture equilibrium according to TS EN ISO 2419.

Mechanical Characterization

The mechanical behavior of the belt leathers was quantified using multi-axial physical tests performed via standardized equipment and specialized templates:

Determination of Thickness: The thickness of the conditioned leather samples

was measured in accordance with the TS EN ISO 2589 standard using a specialized thickness gauge (SATRA, model STD 483). The measurements were executed across designated structural locations to establish the structural baseline for subsequent mechanical evaluations.

Tensile Strength and Elongation (%): The ultimate tensile strength (N/mm^2) and percentage elongation at break of the leather samples were determined using a universal testing machine (Shimadzu, model AG-IS) equipped with a 5 kN load cell and managed via Trapezium-2 software in accordance with the TS EN ISO 3376 standard. The testing machine was operated under continuous structural loading to evaluate the directional resistance of the collagen matrices.

Single Edge Tear Load: The single-edge tear load of the samples was evaluated in accordance with the TS EN ISO 3377-1 standard. The trouser-shaped leather specimens were cut using specialized dies and positioned firmly between the jaws of the Shimadzu AG-IS testing machine with a 5 kN load cell to record the maximum force (N) required to propagate the tear line.

Double Edge Tear Load: The evaluation of multi-directional tear strength was carried out in accordance with the TS EN ISO 3377-2 standard. The rectangular leather samples featuring standard internal slots were positioned between the jaws of the Shimadzu AG-IS testing machine equipped with a 5 kN load cell. The machine was operated until complete structural rupture occurred, and the peak force exerted during the tearing process was recorded in Newtons (N).

Determination of Extension Set: The evaluation of permanent linear deformation profiles was carried out in accordance with the TS EN ISO 17236 standard. Flawless leather specimens were cut to dimensions of 250 x 10 mm using specialized cutting dies. The samples were mounted between the jaws of the universal testing machine (Shimadzu, model AG-IS) with a 5 kN load cell. The testing machine was operated via Trapezium-2 software to subject each specimen to a cyclical mechanical loading up to a force of 20 N for a total of 5 consecutive times. Following the completion of the loading cycles, the leather specimens were removed from the device grips and placed flat on a smooth, horizontal surface, where the final linear dimensions were precisely measured to calculate the percentage of structural extension set.

Determination of Distension and Strength of Surface (Ball Burst Method): The conditioned leather samples were tested according to the principles described in the TS EN ISO 3379 standard using a lastometer. Each leather sample was secured under a standardized compression ring ensuring the central grain area remained clear. While the lastometer advanced a steel ball towards the sample at a constant velocity of 12 mm/min, the force (kgf) and linear distension (mm) at the exact moment of grain cracking were recorded. The device continued to operate until absolute structural bursting occurred, where the ultimate burst force (kgf) and corresponding burst distension (mm) were systematically noted.

Stitch Tear Resistance: Performed using flawless rectangular specimens measuring 50 x 20 mm in accordance with the TS EN ISO 23910 standard. Structural slits were formed on the samples using specialized cutting dies. The test setup was initiated by clamping the upper end of a metal specimen holder into the top grip of a universal tensile testing machine (Shimadzu AG-IS). The perforated end of the leather specimen was positioned between the arms of the holder, and a specialized steel mandrel was locked through both the holder hole and the leather slit. The free lower end of the leather sample was clamped firmly by the bottom grip of the machine. The tensile device was operated at a constant speed of 100 ± 20 mm/min until complete structural rupture occurred. The maximum force at the exact moment of tearing was recorded in Newtons (N) via specialized computer software (Trapezium-2), and comparative analyses were evaluated alongside the pre-measured leather thickness (mm) values.

Statistical Analysis

The experimental data obtained from the physical and mechanical tests were statistically evaluated using one-way analysis

of variance (ANOVA) to determine the effect of tanning system on the measured properties. Prior to the analysis, the data were checked for normal distribution and homogeneity of variances. When significant differences were detected among the tanning systems, Tukey's multiple comparison test was applied to identify differences between group means. Statistical significance was considered at a confidence level of 95% ($p < 0.05$). All results are presented as mean ± standard deviation.

RESULTS AND DISCUSSIONS

The mechanical properties of belt leathers produced using different tanning systems are presented in Table 1. Statistical analysis revealed that the tanning system significantly affected most of the investigated properties ($p < 0.05$).

Table 1: Dependence of physical and mechanical properties of belt leathers on tanning system

Property	Tanning Systems		
	System I	System II	System III
Thickness (mm)	2.32 ±0.07	2.34 ±0.14	3.80 ±0.06
Tensile strength (N/mm²)	20.75 ± 6.67^{b}	20.69 ± 6.77^{b}	25.34 ± 3.64^{a}
Elongation at break (%)	57.33 ± 16.73^{a}	69.74 ± 16.34^{a}	36.92 ± 5.13^{b}
Double-edge tear strength (N)	168.39 ± 21.89^{b}	153.87 ± 33.09^{b}	361.57 ± 34.08^{a}
Single-edge tear strength (N)	89.39 ± 13.41^{b}	90.42 ± 15.09^{b}	156.27 ± 27.94^{a}
Stitch tear strength (N)	242.47 ± 31.70^{b}	243.74 ± 31.80^{b}	509.61 ± 80.54^{a}
Extension set (%)	2.22 ± 1.53^{a}	1.30 ± 0.42^{b}	0.00 ± 0.00^{c}
Crack length (mm)	12.71 ± 0.57^{a}	12.58 ± 0.54^{a}	8.69 ± 0.65^{b}
Crack force (kgf)	45.67 ± 5.51^{b}	43.00 ± 5.57^{b}	65.00 ± 15.00^{a}
Burst length (mm)	15.41 ± 0.34^{a}	14.65 ± 0.19^{a}	11.96 ± 1.31^{b}
Burst force (kgf)	61.33 ± 3.51^{b}	50.67 ± 2.89^{b}	100.00 ± 7.21^{a}

^{a,b,c} Different superscript letters within the same row indicate statistically significant differences according to Tukey's multiple comparison test ($p < 0.05$).

The tensile strength and elongation at break of the leathers are presented in Figure 2. Leathers tanned with System III exhibited the highest tensile strength (25.34 N/mm^2), followed by System I (20.75 N/mm^2) and System II leathers (20.69 N/mm^2). While the difference between System III and System II leathers was statistically significant, System I leathers demonstrated a tensile strength profile that was statistically similar to the synthetic-tanned group. In contrast, the highest elongation at break was observed for synthetic-tanned leathers (69.74%), followed by System I (57.33%) and System II leathers (36.92%). System II and System I leathers demonstrated statistically similar elongation behavior, whereas System III leathers exhibited a significantly lower ultimate elongation capacity.

The results obtained in terms of force-based mechanical properties were generally similar to the findings reported in the literature for upper leathers [2, 10–12]. However, a distinctly different trend was observed particularly regarding the extension set values. While certain levels of permanent elongation are commonly reported for shoe upper leathers, dimensional stability—a critical performance criterion for belt leathers—was revealed more prominently in this study. Notably, the absence of any permanent deformation in System III leathers indicates that this specific tanning system provides a vital technical advantage for high-performance belt applications.

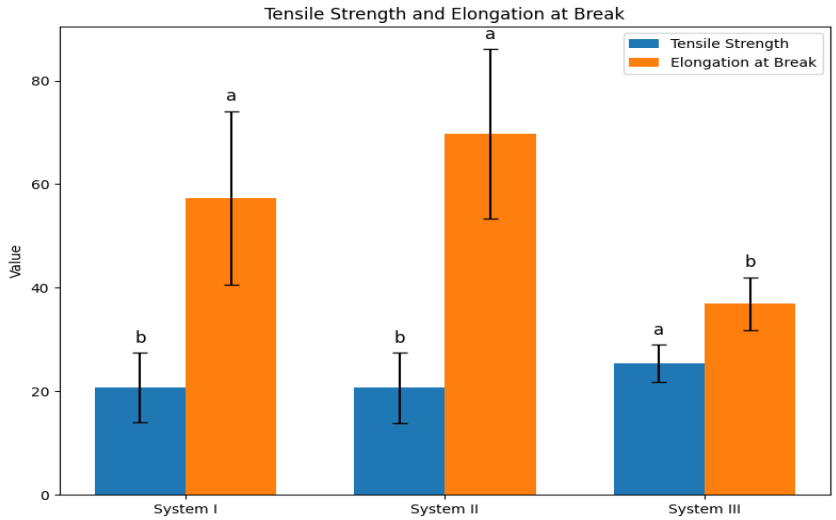


Figure 2. Tanning system influence on tensile strength and elongation of belt leathers

The tear resistance behavior is illustrated in Figure 3, including single-edge, double-edge, and stitch tear strength. A similar trend was observed for tear resistance. System III leathers demonstrated significantly higher double-edge tear strength (361.57 N) than System I (168.39 N) and System II leathers (153.87 N) ($p < 0.05$). For single-edge tear strength, System III leathers also exhibited the highest value (156.27 N), whereas System I and System II leathers showed statistically similar results, averaging 89.39 N and 90.42 N, respectively. The tanning system had a pronounced effect on stitch tear resistance. System III leathers yielded the highest stitch tear strength (509.61 N) and differed significantly from System I (242.47 N) and synthetic tanned focused leathers (243.74 N), which were statistically similar ($p < 0.05$). The superior tear and stitch resistance observed for System III may be associated with the combined effects of chromium complexes and phenolic syntan within the applied tanning formulation.

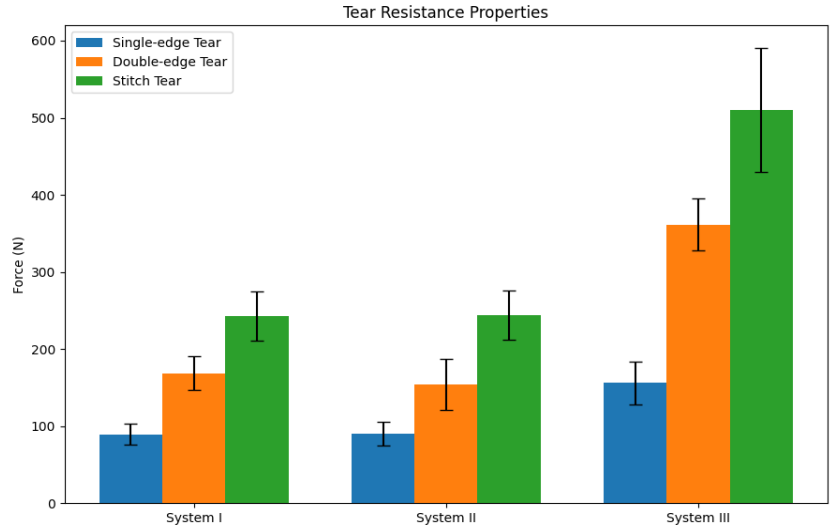


Figure 3. Effect of different tanning systems on tear resistance (single edge, double edge, and stitch tear) of belt leathers

Extension set values are presented in Figure 4, representing permanent deformation behavior. Extension set values showed the opposite tendency. System III leathers exhibited no measurable permanent elongation (0.00%), whereas System II and System I leathers showed values of 1.30% and 2.22%, respectively. Statistical analysis

indicated significant differences among all tanning systems ($p < 0.05$), suggesting that System III provides superior dimensional stability for belt applications where permanent deformation is undesirable.

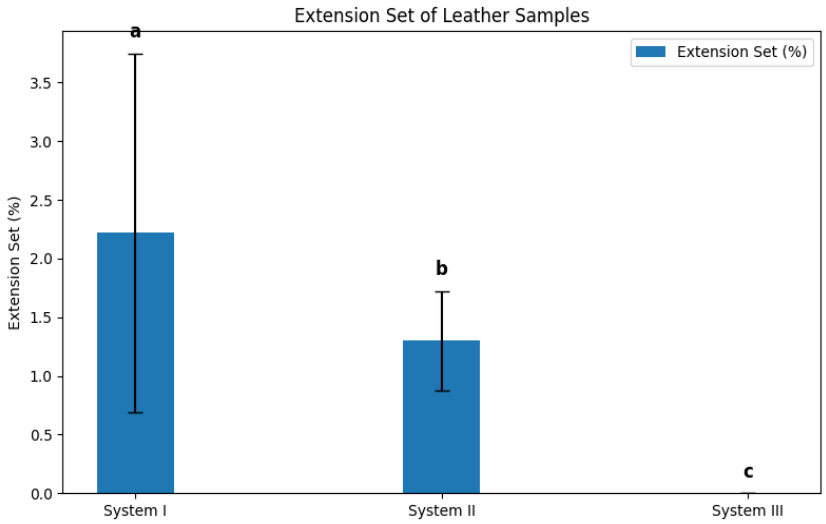


Figure 4. Extension set (permanent structural deformation) profile of belt leathers according to tanning system

Grain surface resistance properties are presented in Figure 5. Grain crack and grain burst properties were also significantly influenced by tanning type. The highest crack length values were obtained for System I (12.71 mm) and System II leathers (12.58 mm), whereas System III leathers showed significantly lower values (8.69 mm). Similarly, burst length values were significantly higher for System I leathers (15.41 mm) and System II leathers (14.65 mm) than for System III leathers (11.96 mm). These results indicate greater extensibility of vegetable- and synthetic-tanned focused leathers. However, System III leathers required significantly higher forces for both grain crack (65.00 kgf) and grain burst (100.00 kgf), demonstrating superior resistance against grain damage.

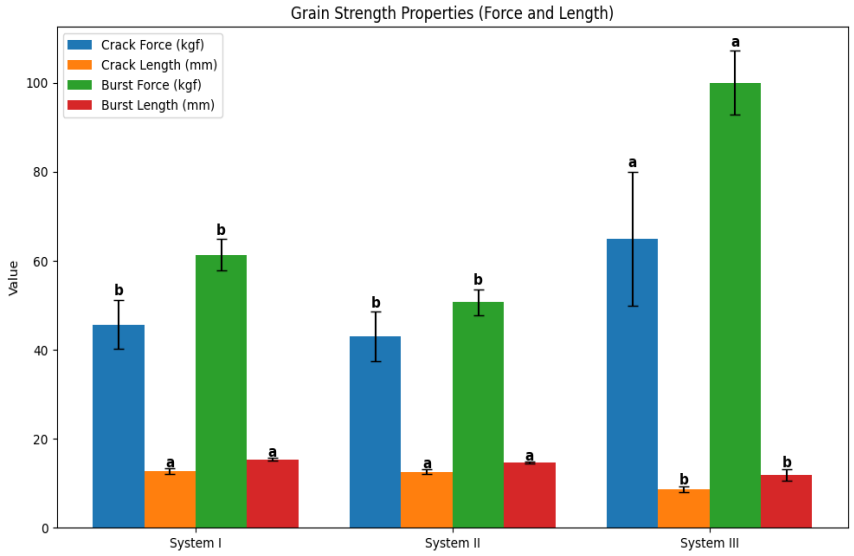


Figure 5. Influence of tanning system on grain crack and burst strength/distension of belt leathers

From a mechanical performance perspective, System III, which combined 7% basic chromium sulphate with 10% phenolic syntan, exhibited higher tensile strength, tear resistance, stitch tear strength, grain strength, and dimensional stability than Systems I and II

under the conditions investigated. These findings should be attributed to the specific tanning formulation used in System III rather than to chrome tanning in general. Similar trends have been reported in previous studies comparing chrome-tanned and alternative-tanned leathers, where chrome tanning was associated with higher tensile and tear strength values [13–15]. However, the present findings concern the specific combined formulation used in System III and should not be interpreted as evidence for pure chrome tanning. For belt applications, mechanical strength alone is not sufficient; dimensional stability and resistance to permanent deformation are also important performance criteria. The extension set results obtained in the present study demonstrated that System III leathers exhibited the highest dimensional stability, indicating their suitability for heavy-duty belt production. System II leathers showed the highest elongation at break, suggesting a more extensible and flexible collagen structure. Although their tensile and tear strength values were lower than those of System III leathers, their increased flexibility may be advantageous for applications requiring greater adaptability and comfort. In contrast, System I leathers exhibited the highest grain crack and grain burst distension values, indicating a greater capacity for deformation before structural failure. This behavior may be associated with the structural characteristics induced by the specific vegetable tanning formulation used in System I [13].

Overall, System III provided the highest mechanical resistance, particularly in terms of tensile strength, tear strength, stitch tear resistance, and grain strength. Conversely, System II enhanced extensibility and elongation properties, while System I generally exhibited intermediate behavior with lower mechanical performance but higher deformability.

CONCLUSIONS

In this study, three commercial tanning systems were comparatively evaluated using bovine hides. System I consisted of 10% mimosa and 10% quebracho, System II consisted of 10% phenolic syntan and 15% white syntan, and System III consisted of 7% basic chromium sulphate and 10% phenolic syntan. Therefore, the results obtained in this study should be interpreted specifically in relation to these formulations rather than as general characteristics of vegetable, synthetic, or chrome tanning systems.

Among the tanning methods investigated, System III leathers exhibited superior tensile strength, tear resistance, stitch tear strength, grain strength and dimensional stability. In particular, the absence of measurable extension set in System III indicates that this specific formulation may be well suited to belt applications where shape retention and resistance to deformation are critical requirements.

System II leathers showed the highest elongation at break, indicating a more elastic structure compared to the other tanning systems. Although their strength properties were lower than those of System III, they exhibited comparable performance in several mechanical tests and may be considered as an alternative for applications requiring greater flexibility.

System I leathers generally displayed lower mechanical strength values but provided the highest grain crack and burst distension values, reflecting their greater deformability. In addition, the use of plant-derived tannins in System I may also be of interest for applications where renewable tanning materials are prioritized.

Overall, the findings indicate that the selection of the tanning system should be based on the intended end-use requirements of the leather product. Under the conditions investigated, System III—the combination of 7% basic chromium sulphate and 10% phenolic syntan—provided the most favorable overall mechanical performance for belt leather production, particularly in terms of strength and dimensional stability. However, synthetic and vegetable tanning focused systems may offer viable alternatives when flexibility, sustainability or specific aesthetic characteristics are prioritized. Future studies may focus on the environmental performance and long-term durability of these tanning

systems to provide a more comprehensive evaluation of their suitability for leather goods production.

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