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The photostabilizing capacity of collagen peptide and its performance on the properties of white-syntan-vegetable tanned leather

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White-syntan-vegetable tanned leather is a durable product processed from skin/hides using white-syntan and vegetable tanning agents. Despite the product's durability, UV light-induced photodegradation is a major challenge, resulting in discolouration and a loss of physical-mechanical properties. As a photostabilizer, collagen peptide has demonstrated a promising impact due to its natural affinity with protein-based materials and antioxidant properties. The current study assesses the effectiveness of a photostabilizer in improving UV resistance and related properties on white-syntan-vegetable tanned leather. After the treatment with collagen peptide, the photostabilizing capacity and properties of the white-syntan-tanned leather were evaluated through Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR), Xenotest LM, a tensile strength testing machine, a scanning electron microscope (SEM), and a leather shrinkage temperature tester. In comparison to untreated samples, the collagen peptide-treated leather showed a notable rise in UV resistance and improvement in physical-mechanical properties. SEM images revealed well-loosened, separated, and opened fibre bundles, while FTIR analysis confirmed the interactions between collagen peptide and the white-syntan-vegetable tanned leather. These findings confirmed that collagen peptide improved the lightfastness and other related properties of leather. Generally, this study emphasizes the potential of collagen peptides as an eco-friendly additive for improving leather performance in UV-prone environments.

Keywords: Collagen peptide, Leather, Photostabilizer, Vegetable tannin, White-syntan

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Introduction

Leather has been a precious materialfor a very long time[1], and through several processing steps, including soaking, liming, de-liming, bating, and tanning, skin or hide can be converted into leather. When subjected to UV radiation, leather can oxidize to producereactive free radicals because of the unpaired electrons present[2]. This reduces the leather's light fastness and other physical-mechanical properties.
Although vegetable (M)-tanned leather is environmentally friendly, it is reportedto have poor tensile strength, tear strength, light fastness, and shrinkage temperature (Ts)[3,4]. Strong cross-linking agents likewhite syntan (a triazine derivative) can be combined with vegetable-tanned leather, resulting in leather with better properties[5].

White syntan W (a non-toxic to normal cells at the recommended concentrations of anti-proliferative action[6]), is an organic tanning agent derived from sodium p-((4,6-dichloro 1,3,5-triaz-2-yl) amino) benzene sulphonate[5]. The side chains in leather collagen have numerous amine and carboxylic groups, and the mechanism behind white syntan (which contains a reactive chlorinated benzene ring) is that one of the chlorine atoms in white syntan is displaced by the leather collagen or collagen peptide nucleophilic amine group (-NH_2), forming a covalent bond between the white syntan molecule and collagen (Fig. 1a)[7,8]. The hydrolysed chlorine in water forms HCl, which lowers the pH from 8 to 5 and promotes the sulfonate group to interact more withother amine groups[7]. When re-tanned with vegetable tannin (which contains phenolic -OH groups thatform hydrogen bonds), additional crosslinkings are generated between the phenolic group of vegetable tannin and the carboxylic group from leather collagen or collagen peptide (Fig. 1b). Making the leather matrix more stable, other crosslinkings through hydrogen bonding are generated between the amine group of the benzene sulphonate and the phenolic group of the vegetable tannin (Fig. 1c)[7]. Under acidic

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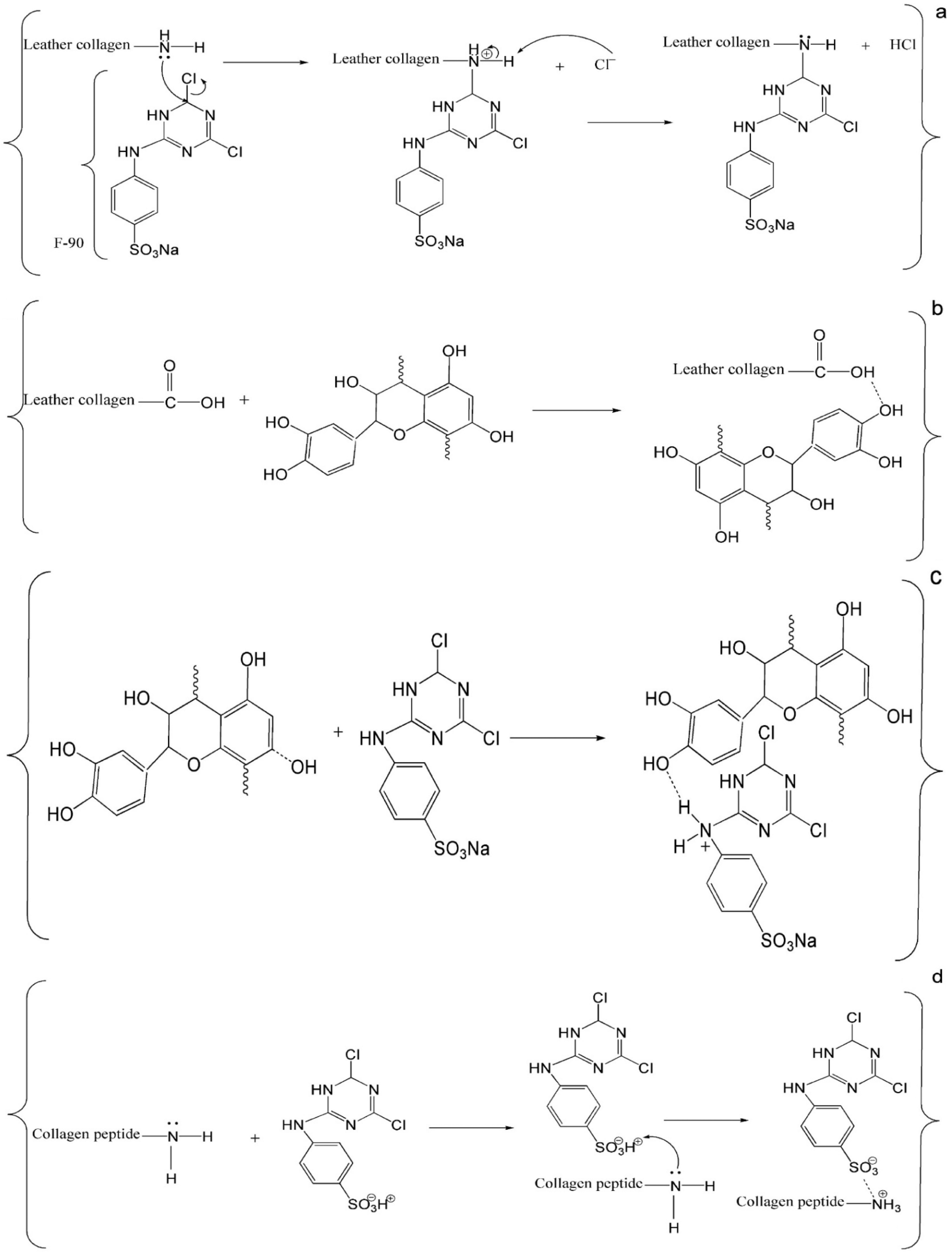

Fig. 1 — Interaction mechanisms of a) Leather collagen and white-syntan, b) Leather collagen and vegetable tannin, c) Vegetable tannin and F-90, and d) Collagen peptide and F-90.

medium, application of collagen peptides and the leather collagen having free -NH_2 groups generates more cross-linking connections through electrostatic and hydrogen bonds with the sulphonate group in the white syntan (Fig. 1d). These interactions altogether create more cross-linking connections, resulting in an increase in physical-mechanical strength, shrinkage temperature, and lightfastness of the leather material.

As reported by Xiao *et al.*[8] and Liang[9], despite the development of integrative cross-linking between vegetable and white-syntan, which results in improved physical characteristics, the leather is still considered to have poor light fastness. Low light fastness causes the produced leather to fade easily, which lowers the leather's strength and lifespan[10]. Therefore, it is suggested that materials with photostabilizing properties that can improve the lightfastness and physical-mechanical properties of leather be used to extend the durability of the finished product while preserving the environment.

Photostabilizers are active radical scavengers that provide a protective environment to products in textiles, leather, and other industries that are prone to the fading process[11]. It is accepted that collagen peptide (C), a low molecular weight protein (1–30 kDa) with good biocompatibility and low antigenicity, can be used as a photostabilizer[12,13]. Collagen peptide is a water-soluble and partly hydrophobic, and/or polybasic peptideat physiological pH. The main feature of C is that it can penetrate the cell membrane at low micromolar concentrations without using any chiral receptors and without causing significant membrane damage. For biomedical or environmental safety of collagen peptides, two evaluations, cytotoxicity and cell uptake, are conducted. As reported by Ma[14], when different samples of various densities of collagen peptides were added to cells, no significant inhibition of cell growth was noticed at a concentration of up to 5.0 mg/mL. As the cell membrane structure protects living cells from the surrounding environment, the peptide compounds with small molecular size are allowed to cross the membrane into the cell through endocytosis and a direct penetration uptake mechanism[15]. The availability of the aromatic amino acids and histidine in the collagen peptide, which are hydrophobic amino acids, gives the collagen peptide properties of working as a photostabilizer[13].

Photostabilizers like UV absorbers (e.g., benzotriazoles, benzophenones) and HALS (Hindered Amine Light Stabilizers) act through direct UV absorption or radical scavenging cycles and are reported to perform better than natural photostabilizers[16] (reference). A study by Ding[17] reported a scavenging activity of collagen peptides ranging between 29.78 and 43.10%, which is a bit lower than that of UV absorbers and HALS, which possess a scavenging activity of 30-50% and 40-60% respectively[16]. Due to the eco-friendliness and biodegradability of collagen peptides, this was chosen to be used in the current study in preference to other UV absorbers and HALS.Studies have worked on the photostabilizing impact of collagen peptides on human skin[5,13,18]. However, no research has been done on the effect of applying collagen peptide, either by itself or in combination with other tanning agents, on lightfastness and related leather qualities. Therefore, it is interesting to find out whether adding collagen peptide (C) to the white-syntan-vegetable (WM)-tanned leather could increase its lightfastness.

Materials and Methods

Materials

In the leather tanning process, bovine hides were used as raw materials, and all samples were taken from the butt side of the same bovine. The tanning agents used were commercially available. These consist of collagen peptide, white syntan (F-90) from Stahl, Burtral 30 WB from Buckman, Merpin 8020 from Carpetex, Lipoderm Licker A1, Decaltal ES FL, Borron A, Borron T, Preventol ZL, Oropon, Erhavit MB from TFL, and vegetable (Mimosa) from Silvachimica S.r.l. Other chemicals and reagents used were provided by various suppliers and were of analytical standard.

Preparation of materials and the tanning process

The raw fresh hide from bovine was processed following the necessary steps used prior to the leather tanning process. The weight of the chemicals used in the main tanning was determined based on the weight of the limed pelt. With some modifications, fresh hides were prepared and processed as per Yu *et al.*[19] and the steps are tabulated in Tables 1 and 2.

Analysis of WM and WMC leather samples' physical and mechanical properties

According to the accepted procedures (ASTM D6076-18 (2013)), a shrinkage tester (Heidolph MR 3001 K, SKU: RBN 22734) was used to measure the shrinkage temperature (Ts). A thin 50 by 10 mm strip was taken from the leather sample and hung in the water. The temperature of the first noticeable shrinking was noted, and the bath's temperature was increased by 2 degrees Celsius every minute. The tensile strength and elongation at break were performed using the tensile strength testing machine as per standard methods (DIN EN ISO 3376:2002(E) IULTCS/IUP6) using a LLOYD instrument (Erichsen Prüftechnik Wuppertal). Single-edge tear strength measurements were performed following DIN EN ISO 3377-1:2002 (E) IULTCS/IUP 40. Three trials were carried out per sample, and the average value was calculated.

Fourier Transform Infrared (FTIR) analysis of WM and WMC leather samples

The ATR-FTIR spectroscopy technique was used to investigate the molecular alterations of samples

Table 1 — Soaking, liming, de-liming, and bating

Process	%	Product	Temp	Runtime	pH	Comment
Dirt soak	150	Water, drain	25	20'		
	150	Water	25	20'		
	0.1	Borron A, drain				Wetting, dispersing and emulsifying agent
Main soak	400	Water				
	0.2	Sodium Dimethyl 68 Dithiocarbamate (Preventol Z-L)				Bactericidal
	0.5	MgO (Merpin 8020 90)				Basifying agent
	0.2	Borron T			9.5	Degreasing agent
Liming	80	Water	20			
	1	Erhavit MB				sulphide-free liming agent
	0.1	$Ca(OH)_2$ (Lime)		20'	12	
	1	NaHS		30'		
	1	Na_2S		60'		2'/1'/run/stop
	1	Na_2S		60'		To complete hair removal
	0.5	Na_2S				
	1	$Ca(OH)_2$ (Lime)		45'		
	30	Water				
	1	$Ca(OH)_2$ (Lime)	20			
	0.1	Borron A		90'		
		Drain				
	150	Water, Flesh, split, weigh	25	15'		Wash 2 times
Delime	100	Water	25			
	2	Decaltal ES-N liquid (carboxylic acid esters)				
	0.05	Borron A				
	0.05	Borron T		60'	8	
Bating	0.6	Protease enzyme (Oropon ∞), wash		45'	8	

Table 2 — Tanning, re-tanning and dyeing

Process	%	Dilution	Product	Temp	Time	pH	Comment
Tanning	80		Water				
	10		sodium p-((4,6-dichloro 1,3,5-triaz-2-yl) amino) benzene sulphonate (Granofin Easy F-90)	55	o. n	6	
	0.1	1:10	Burtol 30 WB				Fungicide, in hot water
	150		Water, drain, Samm, shave				Wash 2 times
Re-tanning	100		Water	40	40'		
	15		Mimosa			3.6-3.8	
	1		Tamol (naphthalene sulfonic acid)		60'		% based on mimosa weight
	50		Water		o. n	5.7	o.n (overnight)
	5		Collagen hydrolysate		o. n	5.7	
fat liquoring	4		Lipoderm liquor A1 (sulphited esters)		o. n	4.0-4.5	
	2		Ensul AM 90				
	100		Water, drain	25			Wash
Dying	100		Water	25			
	1		Dye (avacor brown mrz)				Leave till penetration
Fixation	1.5	1:5	formic acid, drain		60'	3.5-3.6	3x @ 10+ 30
	200		Water		20'		
Top dying	1		Dye (avacor braun mrz)				
Fixation	1.5	1:5	Formic acid, drain, wash, toggle		60'		3x @ 10+ 30

WM and WMC. This was done to detect the interaction between leather collagen, collagen peptide, and other tanning agents. The spectra were acquired using 16 scans, a resolution of 4 cm^{-1}, and a wave number between 400 and 4500 cm^{-1}. A Nicolet iZ10, an expansion of the Nicolet iN10 infrared microscope, was utilized to record spectra.

Scanning Electron Microscopy (SEM) analysis of WM and WMC leather samples

FE-SEM Thermo Fisher FEI Quanta 250 FEG, a field emission scanning electron microscope, was used to analyze the surface morphology of the leather samples. The experimental leather samples were developed from samples taken at official sampling positions. Samples were cut into specimens of uniform thickness and covered with gold before being placed into a sample holder. The surface micrographs were created with the SEM set to 800× magnification levels and an accelerating voltage of 10 kV.

Colourfastness to artificial light by Xenon arc fading lamp test

The leather samples were subjected to reflectance measurements using Xenotest Alpha and Beta LM to test their lightfastness for UV light and hot light, respectively. This was done using the standard testing methods DIN EN ISO 105-B06:2020 and ISO 105-B02:2014. During measurement, leather samples were exposed to controlled artificial light from a Xenon arc fading lamp along with a set of reference materials. To determine the colour's fastness to light, the colour change of the test specimen was compared with the reference materials. The results of the light fastness test were assessed using DIN EN 20105-A02 standards. The reference material for ISO 105-B02 and its associated test procedures was the ISO blue wool scale, which has a range of 1 to 8, including an intermediate. In blue wool, 1 denotes the least amount of colour fastness and 8 the most. The greyscale was created using nine levels, each of which appeared in two grey fields with a matching contrast. Nine alternative values are taken into consideration, including 5, 4-5, 4, 3-4, 3, 2-3, 2, 1-2, and 1, by DIN EN ISO 20105-A02: A grey scale for evaluating the colour variations. The highest grading, Grade 5, denotes no visual colour shift, whereas Grade 1 denotes a major visual change. The visual inspections included comparing the exposed part of a sample to an unexposed reference sample.

Colour index measurements for leathers tanned with white syntan-vegetable (WM) and white syntan-vegetable-collagen peptide (WMC)

The Digi Eye colour imaging system (Digi Eye, VeriVide Ltd, Great Britain), which includes a digital camera and an illumination box with diffuse illuminant D65, was used to quantify colour. Digitizer calibration charts were used to calibrate the system. The colour difference between the reference and tested leather samples was calculated using the computed CIELab values with digital imaging techniques. The DIN EN ISO 105-A05 standard was used to calculate the colourfastness grade. The colour of the leather was represented by ΔL (Luminosity) in the colour space coordinates of the CIE Lab.

The sample's lightness (high L) or darkness (low L) is determined by this. It merely indicates how light or dark the sample is, and it doesn't display any colour information. The coordinates Δa and Δb indicate whether the sample is red or green and whether it is yellow or blue. The colour change or chromatic aberration (ΔE) between the light-subjected and un-subjected samples was measured to determine the specimen's luminosity. ΔE was calculated using Equation 1[20]. The letter L represents light and dark, the difference between red (+a) and green (-a) is denoted by a, and the difference between blue (-b) and yellow (+b) by b. After exposure to light, a positive ΔL means that the leather's colour is lighter, whereas a negative ΔL means that the colour is darker.

$$\Delta E = \sqrt{\Delta a^2 + \Delta b^2 + \Delta L^2} \quad \ldots (1)$$

Results and Discussion

Physical and mechanical properties for WM and WMC tanned leather

A schematic comparison of the physical properties of WM and WMC-tanned leather is shown in Fig. 2. According to the findings, the collagen peptide-treated sample had greater tensile and tear strength than the untreated sample. The rise was brought on by the stabilizing role of collagen peptide functional groups, leather matrix, white syntan, and vegetable crosslinkers[21]. As per the findings, the physical specifications for shoe-upper leather were met[22].

The elongation at break is reduced after theapplication ofcollagen peptide;though, this valuewas still greater than the minimal value for leather shoe uppers[21]. By preventing over-elongation, the collagen peptide treatment improved the leather's fullness. Compared with the existing studies, a study by Afşar *et al.*[23] examined the effects of collagen peptide on the physical characteristics of leather during the re-tanning process, and the results were in line with the current study.

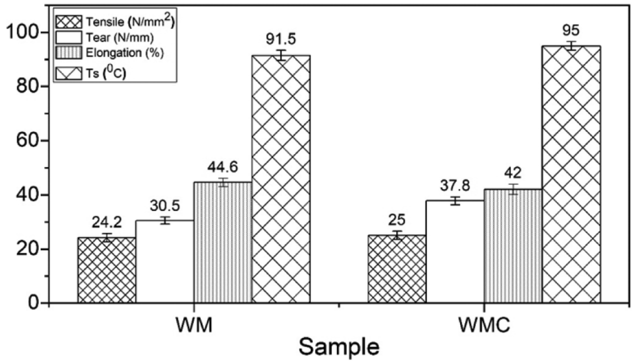

Fig. 2 — Properties of leather tanned with WM and WMC.

Sample WMC had a higher shrinkage temperature than sample WM (Fig. 2). The increased shrinkage temperature was caused by the electrostatic interaction of collagen peptide, leather matrix, and other tanning agents,as well as the formation of a hydrogen bonding network[21]. Based on previous studies, it is reported thatthere is a direct connection between the collagen peptide, photostabilizing ability, and the physical characteristics of the leather[21]. The ability of collagen peptides to photostabilize is controlled by their functional groups, such as hydrophobic amino acids, which can stabilize free radicals by either donating electrons or absorbing them to lessen their reactivity[13]. Hence, collagen peptide has a double impact as a photostabilizer in improving light fastness and mechanical/physical properties of leather.

In the leather industry, the durability and quality of the material ensure the lastingness of products; however, upon UV light exposure/artificial ageing and repeated flexing, leather properties are reported to diminish, hence affecting the material's longevity[24]. As reported by Thomasset[24], when comparing the longevity of chrome, triazine, and vegetable tanned leather, both were affected under artificial ageing, heat, humidity, and UV exposure; however, the finished leathers remained suitable for applications. In this study, artificial ageing and repeated flexing were not done; however, we recommend the inclusion of artificial ageing protocols in future studies, which are suitable for determining the stability and lifespan of peptide-incorporated leather products.

To evaluate the statistical significance of variations in the properties of WM and WMC-tanned leather, a Welch Two Sample t-test on two variables was applied. Four pairs of variables were involved in the dataset for the selected properties. The t-test results demonstrate a p-value of 0.9207 and a t-value of -0.10379 with a degree of freedom of six(df = 5.9986). The conduct of the test was facilitated by the other hypothesis that the true deviation in means is not equal to zero. The 95% confidence interval for the variations in means is between -55.29598 and 50.79598. Furthermore, the estimations of the sample indicate that WM's mean is 49.95 and WMC's is 47.70. Given the large p-value, the divergence between the means of WMC and WM is statistically insignificant.

Fourier Transform Infra Red (FTIR) of WM and WMC leather samples

FTIR measurement confirmed that collagen peptide was successfully incorporated into the WM, and the findings are displayed in Fig. 3. The FTIR spectra of WM and WMC showed distinctive absorption bands at 3003, 2923, 1630, 1541, and 1234 cm^{-1}. The Amide A band detected at 3003 cm^{-1} shows the hydrogen bonding that occurs when N-H is attached to a peptide chain ofthe carbonyl group[25]. At 2923 cm^{-1}, the amide band B was detected due to CH_2 stretching. At 1630 cm^{-1}, the protein's secondary structure, represented by the amide band I, was visible. This is caused by hydrogen bonding due to the stretching of N-H and C=O. Amide II and III, due to N-H bending vibration coupled with C-N and C-H stretching vibrations, were found at 1541 and 1234 cm^{-1}, respectively. The absorption ratio between amide I and II, or 1451 cm$^{-1,}$ and amide III, which is equivalent to 1, confirms the existence of the triple helical structure of collagen[3]. The band observed at wavenumber 2853 cm^{-1} was influenced by the lipids from the fat liquors used during the tanning process.

The assignment of specific peaks to hydrogen bonding or cross-linking interactions was validated using FTIR. No change in the wave number of the amide bands; however, a shift in the absorbance's peak intensity was observed between the treated and untreated samples. When comparing the two samples, an increase in peak intensity for the treated sample WMC was noticed as compared to the untreated sample WM. The positive change in peak intensity for the treated sample confirms the existence of stronger hydrogen bonding and the cross-linking effect after the addition of collagen peptide to sample WM[12]. The broader absorption band observed between 3000–3400 cm^{-1} corresponds to the N–H stretching vibrations, which are commonly linked to amide A bands in collagen-based materials[12]. In the spectrum of WMC, this band appears broader/wider and slightly more powerful than in WM, indicating an increase in intermolecular hydrogen bonding. Again,

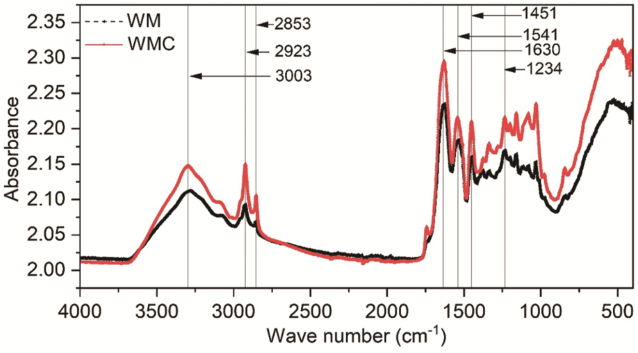

Fig. 3 — The FTIR spectra of WM and WMC.

a higher peak intensity in FTIR always signifies a higher concentration of the molecular bond's functional groups per unit volume[26]. According to the dispersion theory, the intensity of the absorption band is related to the square effective charge of the moving atom and the number of oscillators per unit volume[27]. Hence, any changes in the peaks of the absorbance intensity indeed indicate structural changes.

The amide A's intensity change was associated with both intramolecular and intermolecular hydrogen bonds, indicating that a peptide's NH group should form the hydrogen bond[12]. The study's findings showed that the leather treated with collagen peptide did not change its chemical characteristics, and the stronger hydrogen bond detected is thought to be caused by the increase in concentration of the functional groups.

Regarding the impact of the functional groups on colour fastness to light, collagen peptide can penetrate inside the collagen fibres of leather due to its lower molecular weight[21]. Since it contains reactive amino, carboxyl, and hydroxyl groups, it can interact with leather collagen and other tanning chemicals through hydrophobic, hydrogen, Van der Waals, and electrovalent bonds[28]. The peptides present in collagen function as electron donors to break down chain reactions in the leather matrix by reacting with free radicals to create more stable products[29]. When exposed to light, the stable product will not be significantly affected by light, hence pronouncing the improved lightfastness.

Scanning Electron Microscopy (SEM) for WM and WMC-tanned leather samples

In this study, the fibre structure of the tanned leather was examined using scanning electron microscopy (SEM). The results are shown in Fig. 4. The WM fibre bundles were tightly and densely packed before the addition of collagen peptide (Fig. 4a). These results are similar to what was reported by Wang[30], where, after the addition of collagen peptide, the fiber bundles of the tanned leather (WMC) were loosened, well separated, and opened (Fig. 4b) as a result of the collagen peptide's inner penetration, which was also advantageous for the additional sites and dye infiltration. Visual and morphological analysis through SEM were the methods used to observe the opened fibre bundles after adding collagen peptide to the sample. Though the direct quantification of fibre diameter distribution or porosity was necessary, it was not performed in this study. The existing literature correlates the increased porosity and fibre loosening with improved chemical uptake in the leather matrix[31]. Through the employment of the SEM analysis process, the image in this study demonstrated a better, more open, separated, loosened, and uniformly distributed leather fibre matrix in the collagen peptide-treated sample than the untreated sample. The loosened fibre bundles are important indicators of enhanced reactivity and accessibility, which impact dye uptake and finish adhesion.

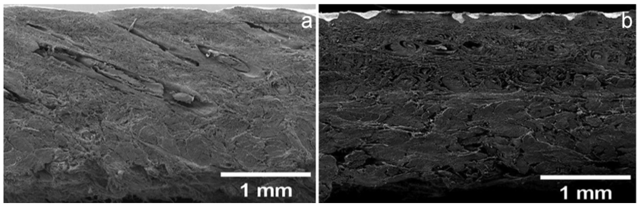

Fig. 4 — SEM images of a) WM, and b) WMC tanned leather.

The collagen peptides' interaction with white-syntan, vegetable, and leather collagen caused the fibre bundles to open[28] and, as a photostabilizer, the fibre bundles' opening enhanced the electron transfer, stabilizing the leather matrix's structure.

Colorfastness test to artificial light by Xenon arc fading lamp test

The leathers tanned with WM and WMC show greater differences in their light fastness when exposed to UV light and hot light, as shown in Table 3. WMC had better lightfastness than WM. This is due to the impact of collagen peptide, which has a photostabilizing capacity on tanned leather.

Many studies indicate that most ofthe polymer's photodegradation routes are oxidative[3], where auto-oxidation in leather is a process that is primarily triggered by UV radiations that are high in energy. Environmental pollutants or chemicals that function as radical initiators catalyze this process by splitting into free radicals when exposed to high-energyradiation. Since free radicals are so reactive, they react with oxygen in the air to generate peroxide radicals. These peroxide radicals react with organic components of leather such as fat liquor, colourants, dyes, tanning agents, and collagen, leading to the deterioration/fading of the material[32]. As a photostabilizer, collagen peptide neutralizes the propagation action, preventing the photodegradation process.

Table 3 — Lightfastness for leathers tanned with WM and WMC

Sample	Blue scale	Greyscale
WM	3-4	1-2
WMC	4	3

The radical scavenging mechanisms of collagen peptides come from their bioactive peptides, which are rich in amino acids such as glycine, proline, hydroxyproline, glutamine, arginine, and lysine. The antioxidant activity exhibited by the peptides includes the donation of the hydrogen atom and/or electron (e^-) to neutralize species (ROS) like hydroxyl radicals, superoxide anions, and peroxyl radicals[33]. When the reactive oxygen species (ROS) attack the leather collagen, collagen peptides donate hydrogen atoms or electrons, neutralizing the ROS, resulting in harmless byproducts. The antioxidant activity of collagen peptides inhibits oxidative stress, which is reported as the main cause of fading in leather products[33].

Colour index measurements for leathers tanned with WM and WMC

Fig. 5 shows images of leathers treated with (WMC) and without collagen peptide (WM) for visual evaluation. Avacor Brown MRZ dye was utilized for both samples. Compared to the colour processed with WM alone, the colour for WMC is noticeably more intense. The availability of collagen peptide affected the sample WMC's intensity due to the increased dye uptake. Collagen peptide creates additional sites or functional groups where the dye reacts through hydrogen bonding or electrostatic interaction, which is the reason for the strong absorption ofthe dye[21]. Both interactions enhance the penetration and fixation of the dye into the leather. As a result, the more the dye penetrates and fixes, the more the colour change is observed in the material.

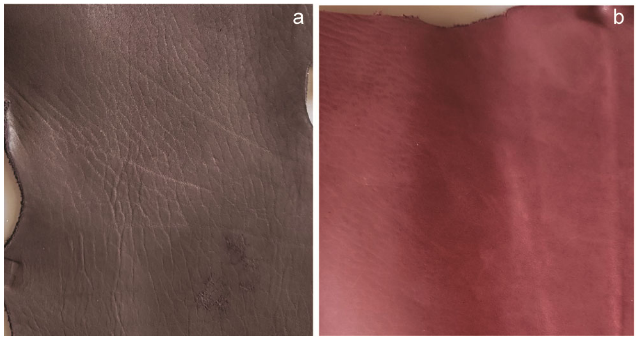

Fig. 5 — Image of leather tanned with a) WMC, and b) WM.

For measuring the colour index, Fig. 6 displays the colour variations or chromatic aberration (ΔE) of leather samples. Good colour resistance to fade in hot or normal light is necessary for all types of leather[34], and the change in chromatic aberration (ΔE) can be used to examine resistance to yellowing[35].

When WM and WMC were exposed to normal and hotlight, respectively, their ΔE values (2.19/7.8 and 1.55/3.38) were slightly lower for the collagen peptide-treated sample, indicating that WMC is more resistant to yellowing[9,36]. This also suggests that WM will be more impacted (prone to yellowing) than WMC when exposed to light. The addition of collagen peptide contributed to the WMC sample's increased resistance to yellowing, confirming that the light fastnesses of WM and WMC differed. From this, we can conclude that WMC-tanned leather is more light-fast than WM.

Looking at the ΔL, Δa, and Δb values for samples WM and WMC, it is objectively determined that the two samples do not match in colour. Considering the ΔL, it is evident that sample WM is lighter than sample WMC, which was dark in colour. The greater lightness of sample WM was influenced by serious photodegradation and photooxidation[35], leading to the disorientation of the structural network of the leather. Chroma values (Δa and Δb) in WM were higher than in WMC, suggesting that WM underwent a considerable yellowing upon exposure to light.These differences between WM and WMC might have resulted from including collagen peptides. The overall colour difference between the sample and the standard is represented by the ΔE value. When it comes to ΔE, WM has a greater value than WMC. The lower a sample's ΔE value, the closer

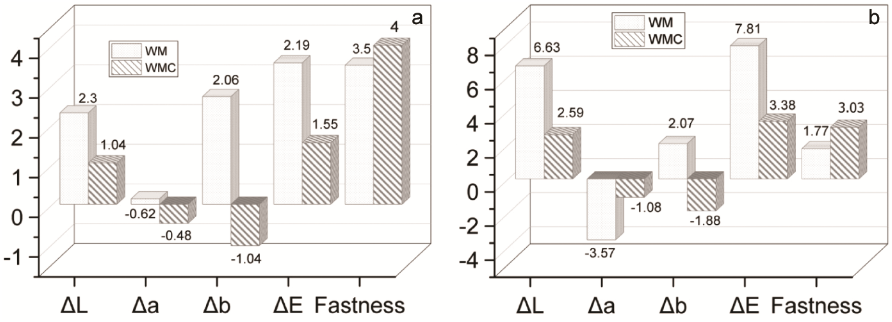

Fig. 6 — Colour index measurements of a) normal light, and b) hot light for leathers tanned with WM and WMC.

it is to the standard and the less it changes colour when exposed to UV light[35].

Possible Photostabilizers with similar or superior performance to collagen peptide

While collagen peptide in this study demonstrated an encouraging photostabilizing potential, there is a necessity to compare its performance with other available Photostabilizers, such as inorganic ones like TiO_2, ZnO, SiO_2, and synthetic organic stabilizers like benzophenones, salicylates, benzimidazole derivatives, phenolic benzotriazoles, dibenzoylmethane derivatives, and cinnamates[37]. For the organic UV absorbers, benzotriazole is considered the most effective option available. Comparing the performance between inorganic, synthetic organic, and bio-organic photostabilizers,[37] were reported in descending order, starting with inorganic materials under 10 nm, followed by inorganic materials over 10 nm, then synthetic organic, and lastly bio-organic UV absorbers. A study by Ramalingam[38] reported an improvement in lightfastness from 4 to 5 on the grey scale when SiO_2 it was used in leather dyeing. Comparatively, biodegradable cross-linkers like chitosan and ascorbic acid offer an alternative and degradable antioxidant that has a moderate capability of scavenging free radicals but align nearly with sustainable leather manufacturing goals.

Implications of using collagen peptides in terms of cost, sourcing, and potential scalability

The use of collagen peptides in leather processing offers a promising economic and environmental advantage, particularly in leather-producing countries that generate huge amounts of trimming wastes and low-quality hides/skin[39]. The generated wastes can be recycled intocollagen peptide, which becomes a useful material in leather processing industries and other potential areas. While synthesizing collagen peptides through the recommended methods consumes much energy and time, the cost can be minimized by excluding the freeze-drying process and employing the use of collagen peptides in their solution state. The perspective view of collagen peptide as a sourcing material and its potentiality in scaling up the production for industrial use is directed towards developing countries like Tanzania and Ethiopia, which are currently facing challenges of low quality and rejected hides/skins, which mostly are disposed of in landfills, leading to the generation of wastes in the environment[40]. Hence, the availability of livestock and unused hides/skins will lead to scaling upwhen faced with increased production.

Conclusion

The importance of collagen peptide for white syntan–vegetable tanned leather is illustrated in this study. The incorporation of collagen peptide improved the UV resistance the physical-mechanical properties of leather. The lightfastness was improved from 3/4 (Blue scale) 1/2 and (Greyscale) for the untreated sample to 4 (Blue scale) and 3 (Grey scale) for the treated sample. Aditionally, the tensile strength increased from 24.2 $N/mm^2$to 25 N/mm^2. Also, tear strength increased from 30.5 N/mm to 37.8 N/mm. Again, there was a rise in shrinkage temperature (Ts) from 91.5°C to 95°C.

Its successful performance of collagen peptide at the lab scale suggests strong potential for commercial re-tanning applications.

Using white syntans offers an improved cross-linking network in the leather matrix, however the presence of chlorine raises environmental and safety issues. During the tanning process, the hydrolysis of chlorine may lead to HCl production, which contributes to the acid load in the effluents. Although the generation of HCl in this study was not quantified, the pH conditions were kept under control, and the neutralization of the acid in the effluent/wastewater was also carried out. Furthermore, the present study recommends evaluating the lasting environmental fate of chlorine-containing residues in effluent.

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Conflict of interest

The authors declare that they have no competing interests.

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