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Identification of Technological Parameters for Vegetable Tanning of Paiche Skin Leather (*Arapaima gigas*) With Quebracho (*Schinopsis balansae*) and Mimosa (*Acacia dealbata*) Extract for Environmentally Sustainable Industrial Use

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ABSTRACT

Paiche farming in the Peruvian Amazon yields sufficient raw material to produce leather; however, these skins pose a pollution problem due to their limited exploitation. This research highlights the importance of employing mechanical and chemical procedures to obtain high-quality leather. Different concentrations of quebracho and mimosa extract were used to process paiche skin. The resulting leather was strong and malleable, exhibiting a flexural strength of over 30,000 flexes without deformation, higher tear strength in treatments T1 (146.23 N) and T5 (143.12 N), and higher tensile strength in T4 (16.62 N/mm^2). The leather also had an ash content of less than 1%, moisture content of less than 9%, and chromium oxide content of less than 1.5%. The effluents from the process were treated and found to have acceptable pH, conductivity, and COD values.

Keywords: skin; paiche; mimosa; quebracho; tanning.

INTRODUCTION

The main contribution of this paper is the identification of the most suitable technological parameters for vegetable tanning of paiche skin using quebracho and mimosa extracts. These parameters include variables such as extract concentration, tanning time, temperature, and other processing conditions.

Tanning is the process of treating animal hides to transform them into leather. Vegetable tanning is presented as an eco-friendly and sustainable alternative to conventional methods that use synthetic chemicals.

This research work makes a highly relevant contribution. On the one hand, paiche (*Arapaima gigas*) is an Amazonian fish species farmed in particular regions and its skin can be used as a valuable source of leather. On the other hand, the use of vegetable tanning methods rather than synthetic chemicals reduces the environmental impact of tanning and promotes sustainability within the leather industry.

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There are significant economic and social benefits to the use of quebracho and mimosa extracts as tanning agents. These extracts are from a natural origin and can be obtained sustainably, benefiting the local communities that depend on them. By identifying the optimal technological parameters, the implementation of vegetable tanning processes in the industry can be facilitated, creating employment opportunities and promoting the conservation of forest ecosystems.

Therefore, this research work is significant because it promotes sustainable practices in the leather industry, making responsible use of natural resources, and creating economic and social opportunities in local communities. The resulting leather from this process proved to be strong and malleable, passing flexural and tear strength tests. Additionally, the effluents from the process were adequately treated, and the values for potential of hydrogen (pH), conductivity, and chemical oxygen demand (COD) were found acceptable.

In today's world, where environmental conservation is a growing concern, the environmentally sustainable approach of this study is particularly relevant. By reducing dependence on harmful chemicals and promoting the use of renewable natural resources, such as plant extracts, the negative environmental impact associated with leather production can be minimized.

Paiche is a popular aquaculture resource found in the Amazon region due to its high protein content and good flavor and is sold in both national and international markets. However, a significant volume of paiche skin, scales, head, and other remains are wasted, accounting for 53% of the fish, as only the meat is commercialized (Alcántara & Guerra, 1992). Fish farmers do not make proper use of these residues, which are then discarded in landfills and bodies of water, causing environmental pollution.

The Peruvian leather industry is shifting towards a more sustainable approach by using resources such as the skins of snakes, lizards, wild animals, and birds, among others. In this context, paiche skin is a key resource, as large quantities are wasted during the processing of meat. Therefore, this research aims to harness paiche skin by identifying the technological parameters for vegetable tanning of paiche skin using quebracho and mimosa extracts, for its environmentally sustainable industrial use.

Different treatment methods using mimosa, quebracho, and a combination of both have been studied to solve the problem of pollution and waste of a great resource. The purpose of this research is to harness paiche skin by transforming it into exotic leather that can open up new opportunities in the leather industry, such as the manufacture of footwear, belts, and wallets, among others.

The production of leather from paiche skin has allowed us to learn the technological aspects of vegetable tanning in detail, from the reception of the raw material to the finishing process, all in accordance with Peruvian Technical Standards (NTP, by its Spanish acronym). This demonstrates that it is possible to make proper use of paiche skin waste, transform it into a valuable resource for the leather industry, and reduce environmental pollution.

This study is structured in three stages. In the first stage, we manufactured leather from paiche skin using five different concentrations of quebracho and mimosa, with three replicates for each treatment. In the second stage, we evaluated the physicochemical and mechanical characteristics of the leather samples obtained from each treatment. This allowed us to determine the differences and qualities for the manufacture of footwear and clothing. In the third stage, we treated the wastewater to ensure that it met the maximum permissible limits established by the Ministry of Environment.

Fish leather is a resource with great potential due to its adaptable texture as well as its impervious and lightweight properties, which make it a more convenient resource compared to other types of leather in high demand on the markets (Álvarez et al., 2020). There are also several investment opportunities in the production of leather from paiche skins aiming to make inroads into the fashion industry and trade with countries such as the United States, China, and the European Union, all of which have a high demand for this type of product (Gonzales, 2019).

Once the fish skin has been completely processed, one can begin with the design and manufacture of garments. Leather appliqués of different textures, colors, and shapes can be added to create unique and authentic collections and make the most of fish skins.

THEORETICAL FRAMEWORK

National Research

In her quantitative research for her master's degree entitled *Evaluación comparativa de los métodos de curtido con tara y glutaraldehído aplicados en piel*

de pollo, Lizárraga (2015) concluded that the method that yields the most leather is determined as a result of a comparison of methods. She also found that the level of chemical pollution of wastewater (BOD_5) for the studied tanning methods was 10,400 and 4,600 g/L.

In their study entitled *Determinación del tiempo y temperatura óptima en la operación de teñido de cuero de piel de pescado perico (*Coryphaena hippurus*) utilizando el colorante natural carmín de cochinilla (*Dactilopius coccus costa*) Chiclayo - Lambayeque, 2013,* Barrera and Símpalo (2014) discovered that the optimal time and temperature for dying fish leather are 60 minutes and 44.33°C, respectively, to produce a color with significant characteristics of strength, robustness, and durability.

International Research

In his research entitled *Estudio técnico-económico para la creación de una empresa que elabore zapatos de cuero a base de la piel de pescado en la ciudad de Esmeraldas*, Valdez (2015) found that fixed and variable costs represent a significant value since fish leather footwear is a high-value product.

In her research entitled *Obtención de cuero a partir de piel de tilapia (*Oreochromis niloticus*), utilizando como curtiente extracto de quebracho, en el laboratorio de química de la UNAN-MANAGUA. Segundo semestre del año 2014*, Ramírez (2015) concluded the optimal operational results for leather processing can be achieved after 16 days of tanning using quebracho extract at 40% by weight of the leather, resulting in greater brightness, flexibility, and color, and, consequently, greater acceptance.

In their scientific paper entitled *Estudio comparativo de taninos de tara, mimosa y pino como re curtientes*, Hourdebaigt et al. (2007) reported that all the leathers retanned in the study (using tara, mimosa, and radiata pine), on the basis of wet blue bovine leather for making uppers, complied with the preset specifications, except for those pertaining to tensile strength in the performed tests.

In their research entitled *Industrialización y comercialización de la piel de pescado (merluza, berrugate y tiburón)*, Duran and Lopez (1993) concluded that fish skins can be used for exotic applications in exclusive markets, where they can be marketed at high prices and generate high-profit margins.

Paiche

The paiche is a type of freshwater scaly fish species that belongs to the family Arapaimidae (*Osteoglossidae*) and the superorder Osteoglossomorpha. This superorder includes primitive tropical fish, except for the family Hiodontidae (Figure 1). The paiche is a large fish that can grow up to 3 m long and has an average weight of 200 kg. Its body is covered in scales and it has a proportionally small head. It is usually dark ash-colored, but it may have a yellow or annatto reddish scale border. Its fins are small and point backward. Additionally, it has a bony tongue that is approximately 25 cm long and 5 cm wide, as well as filiform teeth (Campos, 2001).

Fish Skin

According to the Food and Agriculture Organization (Naciones Unidas para la Agricultura y la Alimentación, 2010), the scaly skin of the paiche has a light brown tone on the upper part and a whitish tone on the lower part, which can turn reddish during breeding periods. Although the paiche does not exhibit sexual dimorphism, differences in coloration during breeding periods help identify the sex of the

Figure 1. *Arapaima Gigas* (Paiche).

Source: Prepared by the authors.

specimens. Males have an intense reddish coloration, while females have a less intense coloration.

Structure of Fish Skin

Based on the research by Duran and Lopez (1993), fish skin has a keratinous structure shaped like plates called scales that derive from the dermal skeleton and do not have sebaceous glands. The skin fibers are arranged in horizontal layers and/or bundles, with columns of fibers running from the flesh side to the grain side.

In terms of composition, fish collagen is very similar to mammalian collagen, as they have similar molecular weight and dimensions, although they differ in terms of amino acids, hydroxyproline, serine, threonine, and methionine content.

Fish skin is susceptible to injury and damage due to exposure to environmental conditions, such as time and temperature, which can favor the proliferation of microorganisms and cause pollution.

Skin Utilization

According to Prado (n.d.), fish skin has a smooth, moderately pigmented surface with oval-shaped scales firmly attached to it. Nevertheless, it must meet three important requirements to be used as raw material for leather production:

- It must not have flesh.
- There must be no tears or damage from poor filleting or scaling.
- It must be as long and intact as possible.

Tanning

The primary aim of the tanning process is to make leather irreversible, rendering it more resistant to enzymatic degradation, chemicals, and heat. The process is carried out in an artisanal and clean manner, creating new business opportunities. Jones (2002) outlines several stages involved in the process, including deliming, bating, pickling, and tanning. During the deliming and bating stages, not all of the lime absorbed by the hide is entirely eliminated, leaving a residue combined with collagen, and the final pH is approximately 8.3. The delimed and bated hides are then treated with acidic inputs during pickling, which reduces the pH to between 1.8 and 3.5, depending on the type of item to be produced.

Vegetable Tanning

According to Jones (2002), some innovative designers are now looking for sustainable alternatives to traditional leather tanning methods. According to them, leathers tanned using chrome or vegetable extracts obtained naturally from cultivated and harvested trees, which are widely used by tanneries today, do not meet sustainability standards. Vegetable tanning is used for the manufacture of various items such as soles, saddlery leathers, belts, industrial applications, and embossed leather. The most common sources of tannins used in vegetable tanning are obtained mainly from quebracho extract, black wattle bark, and mimosa. In the past, the tanning process used to take several weeks in pits. However, modern tanneries today use rotating drums, and the process takes about 12 hours in a 12% tannin solution. Some tanning companies still use pits but monitor the concentration of the tannin solution.

Types of Tanning Agents with Plant Extracts

According to a study by Alfonso et al. (2015), companies all over the world are looking to diversify their business areas and add value to their products. This is also true for the aquaculture and fisheries industry, which has found a new market in fish skins for human consumption. Every year, thousands of tons of fish waste are either discarded or used to make fishmeal. Therefore, processing fish skin processing has become an attractive business opportunity for the industry.

Soler (2004) explains that plant extracts derived from plants that have undergone different treatments to give them specific properties are the main products used. Based on their hydrolysis when boiled in water acidified with hot hydrochloric acid, tannins are classified into two types: hydrolysable and condensed. The former tannins decompose into gallic or ellagic acid during hydrolysis, while the latter yield insoluble products. Vegetal extracts of plants with high tannin content are easily available in the market or can be imported into the country.

Quebracho

According to Ramírez (2015), the name quebracho is derived from its exceptional hardness. The tree contains a complex combination of natural polyphenols that gives it particular characteristics. It belongs to the condensed tannin family and is of catechin origin. Its molecular weight ranges from 200 and 15,000 u, and its composition can be separated according to its intended use. It has trimers and tetramers of C15 polymers with numerous hydroxyl groups (OH-), which makes it highly reactive. Moreover, it has very low levels of acids and sugars,

is highly stable against hydrolysis, and is potentially resistant to microorganisms.

Mimosa

According to the Instituto Forestal de Chile (2005), Acacia melanoxylon is a broadleaf tree species that exhibits different phenotypic characteristics depending on the environment in which it grows. Its size can range from a compact shrub to one of the most formidable acacias in Australia. It belongs to the Leguminosae family, subfamily Mimosoidae, and to the order Rosales, which also includes Acacia dealbata. These species are known for their ability to fix nitrogen and their fast and efficient colonization.

Tanning Process

Puente (2018) states that after the animal is slaughtered, the skin is separated from the rest of the body and undergoes various treatments to temporarily preserve it before it is delivered to the tanner. These treatments can vary depending on the country of origin, climatic conditions, and type of animal. The two most common treatments are drying and salting, both aimed at preventing bacteria growth in the skin, which contains proteins and fats. The purpose of drying and salting is to dehydrate the skin and use bactericides for its preservation. The purpose of these treatments is to prevent the leather from rotting before it reaches the hands of the tanner.

METHODOLOGY

In their book entitled *Metodología de la investigación*, Hernández et al. (2014) describe the experimental approach that allows the researcher to manipulate and control independent variables to observe their effects on dependent variables. They also describe the quantitative approach that focuses on collecting and analyzing numerical and statistical data to draw conclusions. In this research, different concentrations of two plant inputs, quebracho, and mimosa, were evaluated in the process of obtaining paiche leather, making it an experimental study. Moreover, values were obtained for each treatment under study, which were analyzed statistically, making it quantitative as well. Furthermore, this particular study aims to investigate the degree of association between the use of quebracho and mimosa extract in the paiche leather production process, giving it a correlational nature.

Unit of Analysis

Fifteen paiche skins with the same characteristics (species, weight, age, and size), selected at the aquaculture center, were used as units of analysis in this experimental study.

- Species: *Arapaima gigas*
- Weight: 9 - 11 kg
- Age: 13 months
- Average total size: 1.05 m

Data Collection Techniques

In experimental research, the primary data is collected directly from the object of analysis, which, in this case, is leather that has undergone the tanning process using quebracho and mimosa extracts.

To begin the process, each paiche skin is weighed individually to determine the concentration of quebracho and mimosa to be used after conditioning. The required amount of inputs and materials is then recorded. Once the tanning process is complete, the paiche skins are sent to the CITE Call Lima laboratory of the Ministry of Production. Here, the skins undergo physical, mechanical, and chemical analysis.

Tools, Equipment, Materials and Supplies

In this stage, the following was used: wooden board, knife, 15 L tubs, 500 ml test tubes, 8 L bucket, sandpaper for iron (200 grit), sandpaper for iron (100 grit), pH tape, weighing scale, Baumé scale, thermometer, table salt, degreasing agent, bactericide, humectant, organic acid, fungicide, organic acid, fungicide, quebracho extract, mimosa extract, dispersant, oxalic acid, sodium bicarbonate, aniline, dye dispersant, water softener, vegetable leather oil, matte cream, gloss cream, soaking indicator, bromocresol green, coagulants, and flocculants.

Producing Paiche Skin Leather

a. Reception of raw material

Fifteen fresh, filleted paiche skins, complete with scales and flesh remains still adhered to it, were received after primary processing and stored at a suitable temperature of no more than 4.4°C, as recommended by the National Fishery Health Agency (SANIPES, by its acronym in Spanish). A physical-sensory analysis of the fish was conducted to evaluate the freshness of the fish, including texture, odor, color, and general appearance. No physical or chemical contaminants were detected.

b. Scaling and Fleshing

At this stage, the scales were removed manually using a knife to remove them one at a time and taking care not to damage the skin surface. During this process, the meat attached to the skin was also removed.

c. Conditioning

To protect them from external factors such as bacteria and fungi, the paiche skins were treated with domestic salt at 35% of their weight. They were then left in the shade for 24 hours.

d. Soaking

The following steps were taken to restore the leather to its natural state and eliminate dirt or impurities:

- First soaking: The skins were immersed in room temperature water (26 ºC) three times, changing the water each time.
- Second soaking: A bactericide and degreaser agent were added to moisturize the skin and eliminate any fats, natural oils, or other residues that might be present in the skin. The skins were stirred continuously and left to soak for 24 hours.

e. Degreasing

To eliminate grease from the skin, the degreaser and moisturizer were diluted by shaking them for 30 minutes and repeating the procedure seven times. The skin was then rubbed by hand to remove any residual grease. At the end of the process, the skin should not have a greasy appearance.

f. Pickling

To achieve an acid pH in the leather before the tanning process, it is important to ensure that the tanning agent adheres correctly to the leather.

g. Tanning

A variety of vegetable tanning agents were used to avoid leather degradation while fixing the tanning agent. Additionally, these tannins help leather settle against heat and humidity. The selection of the vegetable tannin extracts has an impact on the quality of the resulting leather. The origin of each extract gives the leather certain characteristics such as tone, tension, and firmness of the resulting leather.

Parametric Analysis

Mathematical Model

According to Gutiérrez and De la Vara (2008), the mathematical model used in ANOVA is based on dividing the total data variability into two components: the variability between groups and the variability within groups. Our research satisfies the necessary conditions to use this model as the study involves evaluating five (5) treatments, each with three replicates.

$$Yij=\mu+\tau i+\varepsilon ij$$

- Yij is the result obtained from the group subjected to treatment “i”.
- μ is the mean of all the data of the experiment.
- τi is the effect of treatment “i”.
- εij is the experimental error that refers to the random sampling effect in an experiment.

The relationship of the five treatments under study with the tanning agent and/or combination between quebracho and mimosa is displayed in Table 1.

As shown in Table 2, five treatments were randomly assigned in the study, and each was

Table 1. *Treatments Under Study.*

Treatments	Quebracho (*Schinopsis Balansae*)	Mimosa (*Acacia Dealbata*)
T1	0%	20%
T2	20%	0%
T3	10%	10%
T4	5%	15%
T5	15%	5%

Source: Prepared by the authors.

repeated three times (T1: quebracho 0% - mimosa 20%), (T2: quebracho 20% - mimosa 0%), (T3: quebracho 10 % - mimosa 10%), (T4: quebracho 5% - mimosa 15%), (T5: quebracho 15% - mimosa 5%).

h. Neutralization

Neutralization is a process carried out to eliminate free acids that may be generated during the tanning process. For this purpose, moisture is removed from the leather fibers using a gentle adjuvant.

i. Dying

The dyeing process involves adding color to the leather by immersing it in a bath of acid dyes and impregnating or fixing the color in the leather. This is achieved by diluting aniline in water until a homogeneous paste is obtained, adding a dispersant and a softener, and then mixing slowly. Finally, a fungicide is added with gentle agitation and organic acid is used as a dye fixative. The skins are then removed from the bath and dried in the shade for 24 hours. To stabilize the dye, organic acids are added later.

j. Fatliquoring

Fatliquoring involves applying a uniform layer of animal fat on the surface of the leather using a sponge. The entire surface of the leather is covered, and the fat is allowed to be absorbed for 24 hours in a cool, shaded environment. This helps restore the natural softness and suppleness of leather, which in turn improves its strength and elasticity under mechanical stress. It also helps to protect the leather from humidity and external agents.

k. Finishing

The finishing process involves techniques that enhance the physical characteristics of the leather (color, shine, and texture) while protecting it from factors like humidity. To achieve this, gloss and matte creams are applied to the surface of the leather, gently rubbing the outer layer of the leather. The leather is then left to dry in the shade for four hours before being polished with a cloth to achieve a shiny finish.

l. Wastewater collection and treatment

To analyze the pH, conductivity, and COD in wastewater generated during the soaking, degreasing, pickling, and tanning processes, 15 liters of samples were collected and subjected to homogenization treatment by coagulation and flocculation. To achieve a clear hue and pH close to 6 as recommended by Abdón (2018), flocculant and coagulant substances were added, followed by oxygenated water.

Table 3 indicates the percentage of coagulant, flocculant, and hydrogen peroxide used in relation to the total effluent collected.

Table 2. *Designation of Treatments*.

Treatments	Repetitions		
	1	2	3
T1	R_1	R_2	R_3
T2	R_1	R_2	R_3
T3	R_1	R_2	R_3
T4	R_1	R_2	R_3
T5	R_1	R_2	R_3

Source: Prepared by the authors.

Table 3. *Wastewater Treatment.*

No.	Chemical Inputs	Percentage	Input
1	Coagulant	5%	Ferric Sulfate at 10%
2	Flocculant (anionic polymer)	0.1%	Arifloc C606 at 0.1%
3	Hydrogen Peroxide 20°	0.5%	Hydrogen Peroxide

% Ratio of wastewater to input water.

Source: Prepared by the authors.

RESULTS

Physical and Mechanical Properties of Paiche Skin Leather

a. Determination of Flexural Strength

The results of the flexural strength properties are presented in Table 4. All five treatments meet the parameters established in the Peruvian Technical Standards NTP 241.021:2022, NTP 241.022:2022 and NTP 241.023:2022 for the manufacture of casual footwear, men's footwear, and women's footwear. According to these standards, leather must have a minimum dry flexural strength ≥ 30,000 and must be free of defects in the material.

b. Determination of Tear Strength

As shown in Table 5, the average result for tear strength is 112.75 N. This means that the values obtained by each treatment fall within the ranges established in the Peruvian Technical Standards NTP 241.021:2022, NTP 241.021:2022, and NTP 241.023:2022 for the manufacture of leather casual footwear, men's footwear, and women's footwear. According to these standards, leather must have a minimum tear strength ≥ 40 N.

Method for Comparison of Treatments

Null hypothesis: All mean values are identical.

Alternate hypothesis: At least one mean value differs from the others.

Significance level: $\alpha = 0.05$

All variances were assumed to be equal for the analysis (see Table 6).

Decision Criteria

If $\alpha > p$, H_0 is rejected.

If $\alpha \leq p$, H_0 is accepted.

Based on the analysis of variance, the *p*-value is 0.004. Since alpha (0.05) is greater than the *p*-value (0.004), H_0 is rejected, indicating that

Table 4. *Results for Leather Flexural Strength.*

Treatment	Number of Test Tubes Tested	30,000 Flexions on Average
T1	Six	No defects are observed.
T2	Six	No defects are observed.
T3	Six	No defects are observed.
T4	Six	No defects are observed.
T5	Six	No defects are observed.

Source: Prepared by the authors.

Table 5. *Results for Leather Tear Strength.*

Treatment	Direction	Average Tear Strength
T1	A – B	146.23
T2	A – B	93.31
T3	A – B	88.70
T4	A – B	92.39
T5	A – B	143.12
Average		**112.75**

Source: Prepared by the authors.

Table 6. *Variance for the Determination of Tear Strength.*

Source	df	Adjusted SS	Adjusted MS	F	P
Factor	4	10 152	2537.9	7.78	0.004
Error	10	3264	326.4		
Total	14	13 416			

Source: Prepared by the authors.

the type of treatment used does influence the results obtained.

Comparison Testing

Since at least one mean is found to be different from the others, it is necessary to perform Tukey comparison tests.

From the data presented in Table 7, treatments T1 and T5 exhibit the most favorable average values compared to treatments T2, T3, and T4.

c. Determination of Tensile Strength

The results of the tensile strength properties are presented in Table 8. This means that the values obtained by each treatment fall within the ranges established in the Peruvian Technical Standards NTP 241.021:2022, NTP 241.021:2022, and NTP 241.023:2022 for the manufacture of leather casual footwear, men's footwear, and women's footwear. According to these standards, leather must have a tensile strength ≥ 10,000 N/mm^2. Only treatment 2 (T2) exhibits lower values.

Method for the Comparison of Treatments

Null hypothesis: All mean values are identical.

Alternate hypothesis: At least one mean value differs from the others.

Significance level: $\alpha = 0.05$

All variances were assumed to be equal for the analysis (see Table 9).

Decision Criteria

If $\alpha > p$, H_0 is rejected.

If $\alpha \leq p$, H_0 is accepted.

From the analysis of variance, there are significant differences between the groups, given that the *p*-value (0.004) is less than 0.05. Therefore, it is necessary to perform Tukey's multiple comparison test.

Table 7. *Tukey Test to Evaluate the Tear Strength with a Confidence Level of 95%.*

Treatments	N	Mean	Groups	
1	3	146.2	A	
5	3	141.96	A	
4	3	92.39		B
2	3	92.32		B
3	3	88.70		B

Means of different groups that do not share a letter are significantly different.

Source: Prepared by the authors.

Table 8. *Results for Leather Tensile Strength.*

Treatments	Direction	Average Tensile Strength (N/mm^2)
T1	A – B	13.05
T2	A – B	8.17
T3	A – B	14.94
T4	A – B	16.62
T5	A – B	10.43

Source: Prepared by the authors.

Table 9. *Variance for the Determination of Tensile Strength.*

Source	df	SS	MS	F	P
Factor	4	138.48	34.620	7.86	0.004
Error	10	44.02	4.402		
Total	14	182.50			

Source: Prepared by the authors.

Comparison Testing

From the data presented in Table 10, treatments T1 and T5 exhibit the most favorable average values compared to treatments T2, T3, and T4.

Physicochemical Properties of Paiche Skin Leather After Processing

Table 11 lists the values obtained for ash content, moisture percentage, and chromium oxide percentage. The data for each treatment falls within the permissible ranges set by the Peruvian Technical Norms for leather.

Recovery of Effluents from the Tanning Process

The Ministerial Resolution No. 071-2022-MINAM establishes the maximum allowable limits for effluents produced by leather tanning and dressing activities, along with leather dressing and dyeing. These regulations ensure compliance with the requirements for the release of effluents with a pH of 5 to 8.5 and a COD of 50 mg/L into the environment. Table 12 shows the average maximum allowable limits for effluents generated during the tanning processes for treatments T1, T2, T3, T4, and T5.

DISCUSSION

Physical and Mechanical Properties of Paiche Skin Leather

- This scientific paper highlights the critical importance of flexural strength in leather products, as stated in several studies including those by Vilca (2019) and Ramírez (2015). The treatments studied have successfully surpassed 30,000 flexes, significantly improving the durability and appearance of leather products like shoes and handbags. Furthermore, the potential to introduce fish skin leather in elite markets is being explored (Ramírez, 2015), which would generate high profit margins. However, it is

Table 10. *Tukey Test to Evaluate the Tear Strength with a Confidence Level of 95%.*

Treatments	N	Mean	Groups		
4	3	16.62	A		
3	3	14.940	A	B	
1	3	13.05	A	B	C
5	3	10.44		B	C
2	3	8.170			C

Means of different groups that do not share a letter are significantly different.

Source: Prepared by the authors.

Table 11. *Content of Ash, Moisture, and Chromium Oxide.*

Treatments	Code	Ash Content	Moisture %	Chromium Oxide %
T1	129-(1,2,3)	0.40	8.79	0.0116
T2	129-(4,5,6)	0.40	8.39	0.0132
T3	129-(7,8,9)	0.36	8.36	0.0128
T4	129-(10,11,12)	0.34	8.12	0.0135
T5	129-(13,14,15)	0.36	8.51	0.0132

Source: Prepared by the authors.

Table 12. *Recovery of Effluents from the Tanning Process.*

Treatments	pH	COD (mg/L)
T1	6.3	45
T2	6.1	46
T3	6	45.5
T4	6.3	46.1
T5	6.3	45.6

Source: Prepared by the authors.

important to consider ethical and sustainable aspects to ensure responsible practices in the procurement of these leathers. The cultural perception of using fish skins should also be evaluated, as it could influence their acceptance in the market. This study provides a valuable foundation for future research in the field of leather and material innovation.

- Tear strength is a crucial factor in determining the quality and durability of leather products. Treatments T1 and T5 have been found to exhibit a higher capacity to resist rupture under tensile or tear strength, highlighting their significance. The study also highlights the structural integrity of the material when stretched or subjected to tension. Research by Puente (2018) demonstrates the effectiveness of certain tanning methods in achieving high tear strength values, making it essential for items such as bags and belts subjected to heavy loads. However, the study by Hourdebaigt et al. (2007) indicates that some retanned leathers may not meet the required tensile specifications. Therefore, it is crucial to address these limitations to improve the quality and durability of leather products.
- Our research findings indicate that treatment T4 demonstrates outstanding tensile strength results (16.62 N/mm^2), followed by treatments T3 (14.940 N/mm^2) and T1 (13.05 N/mm^2). This highlights the material's capacity to withstand loads without breaking, which reflects its resistance to rupture. Authors such as Melgar (2000) and Valdez (2015) have emphasized the importance of tensile strength in leather to ensure product durability and its value to consumers. These findings highlight the importance of optimizing tensile strength in leather production.

Chemical Properties of Paiche Skin Leather

- The assessment of the ash and moisture content in leather is crucial to determine its quality and safety. The results revealed a low average ash content (0.37) in all samples, in compliance with NTP 241.023.2022, which specifies a maximum limit of 2. A high ash content could indicate excessive use of chemicals or poor quality, which could negatively impact health and the environment. On the other hand, the average moisture content (8.43%) is in line with previous references (Melgar, 2000) and is considered optimal for leather durability. Excess moisture makes it susceptible to mildew, while dryness makes it brittle. As for the dyeing process, the study conducted by Barrera and Símpalo (2014) recommends carrying it out in 60 minutes at 33°C with cochineal carmine to obtain optimal colors with adequate chemical characteristics for moisture and ash.

Reclaimed Water Obtained from the Tanning Process

- This scientific article provides a comprehensive analysis of the maximum allowable limits for effluents generated during the tanning process. The limits have been compared extensively with the values established in Ministerial Resolution No. 071-2022-MINAM (R. M. N.° 071-2022-MINAM, 2022) to ensure that tanning operations strictly comply with environmental standards. It is crucial to adhere to these standards to prevent negative impacts on natural resources and public health caused by industrial activities.
- The methodology used in this research is consistent with that of Lizárraga (2015). To produce high-quality leather from paiche, it is important to identify the most efficient and sustainable tanning method. Lizárraga (2015) proposes that a comprehensive evaluation of available tanning techniques should be conducted, considering both efficiency and sustainability. The author emphasizes the need for a detailed and exhaustive assessment of different tanning methods to determine the most appropriate methodology for producing high-quality leather.
- The pH and COD test results obtained are in line with the standards set by Ministerial Resolution No. 071-2022-MINAM. This reinforces the fact that the method used for production is environmentally friendly, thereby validating the adoption of more sustainable practices in leather manufacturing (R. M. N.º 071-2022-MINAM, 2022).

Economic and Environmental Impacts

- The research conducted on flexural strength, tear strength, and tensile strength demonstrates that the leather produced from the paiche vegetable tanning process is of high quality. These positive results have the potential to have a significant impact on multiple levels. At the local and regional level, the establishment of tanning and leather product manufacturing industries can boost the economy, generate employment,

and improve infrastructure in the production areas (De los Ríos et al., 2017). At the national level, the development of a sustainable supply chain and the export of high-quality leather products could contribute to economic diversification and an improved trade balance (Gereffi et al., 2001). Finally, at the international level, the supply of sustainable and high-quality leather products can strengthen the country's presence in global markets and improve its image as a responsible and sustainable supplier (Conferencia de las Naciones Unidas sobre Comercio y Desarrollo [UNCTAD], 2018).

- The quality and sustainability of the leather produced from the paiche vegetable tanning process are crucial for the implementation of a national plan or public policy. Given that these results meet technical and environmental standards, they serve as a solid foundation for promoting the adoption of sustainable practices in the leather industry nationwide. One approach could be the introduction of incentives for companies that implement vegetable tanning processes and comply with established standards. Furthermore, investing in workforce training and research and development of sustainable technologies can be a critical component of a national plan to strengthen this industry.
- The positive results obtained in this research have demonstrated that the effluents generated during the paiche vegetable tanning process conform to the maximum allowable limits. This has a significant positive impact on the environment, as it reduces the release of harmful chemicals into the surroundings and ensures that the effluent produced meets specific pH and COD requirements. As a result, water pollution is significantly reduced, which in turn minimizes the negative impact on aquatic ecosystems (Organización de las Naciones Unidas para el Desarrollo Industrial [ONUDI], 2020).

CONCLUSIONS

The process of vegetable tanning of paiche skin using quebracho and mimosa extracts involves several stages. It begins with the reception of raw material followed by the conditioning of skins, soaking, degreasing, pickling, tanning, neutralization, dyeing, stretching, drying, sanding, fatliquoring, and finishing. It is important to note that the treatment of wastewater produced during the tanning process is crucial. By reducing the emission of harmful chemicals and ensuring compliance with specific standards regarding pH and COD in liquid waste, we can substantially reduce water pollution and prevent adverse impacts on aquatic ecosystems.

Different treatments of paiche skin leather were evaluated for their physical-mechanical and chemical properties. The experiments revealed significant variations in flexural strength and tear strength among the treatments. Specifically, treatments T1 (mimosa 20% and quebracho 0%) and T5 (mimosa 15% and quebracho 5%) showed significant differences in tear strength. Moreover, when it came to tensile strength, treatment T4 (mimosa 5% and quebracho 15%) outperformed the other treatments that used mimosa and quebracho extracts.

On the other hand, the chemical properties did not show any significant differences in ash, moisture, and chromium oxide content for different combinations of quebracho and mimosa.

The pH and COD analyses of the effluents treated after the tanning process were carried out for all five treatments. The results were found to be in compliance with the limits established by Supreme Decree No. 071-2022-MINAM for the treatment of wastewater generated during the tanning process.

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REFERENCES

[1] Abdón, M. (2018). *Manual: Curtido de piel de paiche de forma artesanal*. Lima: Editorial Biblioteca Nacional del Perú N.° 2018-00104.

[2] Alcántara Bocanegra, F., & Guerra Flores, H. (1992). CULTIVO DE PAICHE, Arapaima gigas, UTILIZANDO BUJURQUI, Cichlassoma bimaculatum, COMO PRESA. *Folia Amazónica, 4*(1), 133-144. https://doi.org/10.24841/fa.v4i1.187

[3] Alfonso, C., Caballero, J., Castillo, O., Flores, I., Perez, G., & Maria, S. (2015). Biocueros: Pieles marinas curtidas con savia de la *Musa paradisiaca*. *Journal of Undergraduate*

Research, (1). https://revistas.utp.ac.pa/index.php/ric/article/view/349/343

[4] Álvarez Acosta, R., Núñez Guale, L., Calderón Pineda, F., & Mendoza Tarabó, E. (2020). Producción y comercialización de productos de curtiembre de piel de pescado, Santa Elena - Ecuador. *Revista de ciencias sociales*, *26*(4), 353-367. https://doi.org/10.31876/rcs.v26i4.34667

[5] Barrera Clavo, M. B., & Símpalo López, W. B. (2014). *Determinacion del tiempo y temperatura óptima en la operacion de teñido de cuero de piel de pescado perico (*Coryphaena hippurus*) utilizando el colorante natural carmín de cochinilla (*Dactilopius coccus costa*)*. (Degree thesis). Universidad Señor de Sipan, Pimentel. https://repositorio.uss.edu.pe/bitstream/handle/20.500.12802/1776/INGENIERIA%20AGROINDUSTRIAL.pdf?sequence=1&isAllowed=y

[6] Campos Baca, L. (2001). *Historia Biológica del Paiche o Pirarucu* Arapaima gigas *(Cuvier) y Bases para su Cultivo en la Amazonía Iquitos, Perú*. http://www.iiap.org.pe/Archivos/publicaciones/ArapaimaGigasHist.pdf

[7] Conferencia de las Naciones Unidas sobre Comercio y Desarrollo (2018), *Identifying Regional Value Chains in Leather and Leather Products in Africa*. https://unctad.org/system/files/official-document/gdsecidc2017d6_en.pdf

[8] De los Ríos, C., Monge, P., & Cortez, C. (2017). Desarrollo de la cadena de cuero en la región Moquegua. *Revista Científica Teoría y Praxis*, 17, 87-99.

[9] Duran, D. F., & Lopez Cortez, F. J. (1993). *Industrialización y comercialización de la piel de pescado (merluza, berrugate y tiburón)*. (Degree thesis). Corporación universitaria autónoma de occidente. https://red.uao.edu.co/bitstream/handle/10614/2190/T0000475.pdf;jsessionid=78B26F78278998246590D08951CFA773?sequence=1

[10] Gereffi, G., Humphrey, J., Kaplinsky, R., & Sturgeon, T. (2001*)*. Introduction: Globalisation, value chains, and development. *IDS Bulletin*, *32*(3), 1-8.

[11] Gonzales Delgado, G. (2019). *Oportunidad de inversión en la producción de cuero a partir de piel de Paiche con fines de exportación, en la Región Ucayali 2018*. (Degree thesis). Universidad Nacional de Ucayali, Pucallpa.

[12] Gutiérrez Pulido, H., & De la Vara Salazar, R. (2008). *Análisis y diseño de experimentos* (2nd ed.). México DF, Mexico: Mcgraw-Hill/Interamericana Editores, S.A. de C.V.

[13] Hernández, S., Fernández, C., & Baptista, L., (2014). *Metodología de la investigación* (6nd ed.). México DF, Mexico: Mc-Graw Hill.

[14] Hourdebaigt, R., Iade, J., Le Rose, C., & Damonte, D. (2007). Estudio comparativo de taninos de tara, mimosa y pino como recurtientes*. INNOTEC*, (2), 24-27. https://www.redalyc.org/pdf/6061/606166689008.pdf

[15] Instituto Forestal de Chile. (2005). *La investigacion con* Acacia dealbata*,* Acacia melanoxylon *y* Acacia mearnsii *en Chile*. Concepción, Chile: INFOR. https://doi.org/10.52904/20.500.12220/4875

[16] Jones, C. (2002). *Manual de Curtición Vegetal.* Buenos Aires, Argentina: Lemin.

[17] Lizarraga Velásquez, F. N. (2015). *Evaluación comparativa de los métodos de curtido con tara y glutaraldehido aplicados en piel de pollo*. (Master thesis) Universidad Nacional del Ccentro del Perú*,* Huancayo. https://repositorio.uncp.edu.pe/bitstream/handle/20.500.12894/4612/Lizarraga%20Velasquez.pdf?sequence=1&isAllowed=y

[18] Melgar, D. (2000). *Tecnología del cuero.* Ministerio de Industria, Turismo, Integración y Negociaciones Comerciales Internacionales

[19] Organización de las Naciones Unidas para el Desarrollo Industrial. (2020). *Leather and Leather Products Industry.* https://www.unido.org/our-focus/creating-shared-prosperity/agribusiness-and-rural-entrepreneurship-development/leather-and-leather-products-industry

[20] Organización de las Naciones Unidas para la Agricultura y la Alimentación. (2010). *Peces nativos de agua dulce de América del Sur de interés para la acuicultura: Una síntesis del estado de desarrollo tecnológico de su cultivo*. https://www.fao.org/3/i1773s/i1773s.pdf

[21] Prado Pasos, L. A. (n.d.). *Piel de pescado*. Biblioteca Virtual Universal. https://biblioteca.org.ar/libros/cueros/pescado.htm

[22] Puente Guijarro, C. A. (2018). *Aplicación de un proceso de curtido de pieles bovinas sin cromo utilizando oxazolidina en combinación con* Caelsalpinia spinosa *(tara).* (Doctoral thesis). Universidad Nacional Mayor de San

Marcos, Lima. https://cybertesis.unmsm.edu.pe/handle/20.500.12672/7710

[23] Ramírez, Y. (2015). *Obtención de cuero a partir de piel de tilapia (Oreochromis niloticus), utilizando como curtiente extracto de quebracho, en el laboratorio de química de la UNAN-Managua. Segundo semestre del año 2014.* (Degree thesis). Universidad Nacional Autónoma de Nicaragua, Managua. https://repositorio.unan.edu.ni/6671/1/70235.pdf

[24] Resolución Ministerial N.° 071-2022-MINAM. Establecen los valores límites máximos permisibles para efluentes líquidos de las actividades de curtido de cueros y pieles. Diario Oficiial El Peruano (2022, March 18).

[25] Soler, J. (2004). *Procesos de curtidos.* Barcelona, Spain: Consorci Escola Tècnica d'Igualada.

[26] Valdez Ortiz, H. E. (2015). *Estudio técnico - económico para la creación de una empresa que elabore zapatos de cuero a base de la piel de pescado en la ciudad de Esmeraldas*. (Degree thesis). Universidad de Guayaquil, Guayaquil. http://repositorio.ug.edu.ec/bitstream/redug/17639/1/TESIS%202015%20VALDEZ%20HEVER1111.pdf

[27] Vilca, N. (2019). *Evaluación del curtido de piel de alpaca (*Vicugna pacos*) para peletería en un reactor batch.* (Degree thesis). Universidad Nacional del Altiplano, Puno. https://repositorioslatinoamericanos.uchile.cl/handle/2250/3280451