

Exploring Structural Features of Bovine, Ovine, Fish, Poultry, Reptile, Amphibian, and Porcine Skins through Scanning Electron Microscopy: Insights for Material Science and Sustainable Design

by

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Abstract

In leather research, the Scanning Electron Microscope (SEM) proves to be an invaluable tool, offering detailed and high-resolution images of both the surface and fiber structure. This information plays a critical role in optimizing manufacturing processes within the leather industry, enhancing the quality of leather products, and contributing to the development of new materials. In the current study, our focus is on unraveling the microscopic details of skins sourced from various biological origins. We aim to provide insights into the distinctive morphological features, fiber arrangements, and surface topographies of bovine, ovine, fish, poultry, reptile, amphibian, and porcine skins, which were converted into crust leathers. We captured microphotographs of the surfaces and cross-sections of the leathers through scanning electron microscopy analysis. This paper presents a comprehensive comparison and discussion of the findings, seeking to identify key differences and similarities. Such a comparative analysis contributes to our understanding of material science, fashion, and sustainable design, offering potential implications for these diverse fields.

Introduction

The Scanning electron microscope, often referred to as SEM analysis, has emerged as a pivotal technology with widespread applications across various disciplines, ranging from materials science to biology. The German scientist Max Knoll is credited with building the first scanning microscope, laying the early groundwork in 1935.¹ Manfred von Ardenne further contributed to the development of both the SEM and the Transmission Electron Microscope (TEM) in 1938.² The first true SEM was a contribution from U.S. scientists Zworykin, Hillier, and Snyder in 1942.³ However, the commercial development and widespread use of SEMs occurred in the past four decades.

The SEM has proven to be an indispensable tool, providing researchers with the ability to explore and analyze the surface characteristics and fiber structures of leather materials. In leather science, SEM is extensively employed to understand the impact of tanning and post-tanning systems on the collagen fiber structure.⁴⁻⁷

This utilization of SEM is crucial in optimizing emerging processes within the leather industry. By providing detailed insights into the structure of leather fibers, SEM enables researchers to assess the effectiveness of different tanning methods and post-tanning treatments, ultimately contributing to the enhancement of product quality and the development of innovative manufacturing techniques.^{8,9} Furthermore, SEM plays a pivotal role in examining the fiber structure of new types of raw materials in the leather industry.¹⁰⁻¹³ The capability to study the structural details of these materials allows for a comprehensive understanding of their characteristics and properties.

SEM is also used in identifying and characterizing defects or irregularities in leather, such as cracks, pores, or surface imperfections. Understanding the nature of these defects contributes to improving the manufacturing process.^{14,15} Thus SEM plays a crucial role in the quality control and improvement of leather manufacturing processes by providing detailed insights into the surface morphology and structure of leather. Identifying and characterizing defects at a microscopic level enables manufacturers to take targeted measures to enhance the quality and consistency of their leather products. Understanding the surface morphology and structure of leather at a microscale helps in optimizing the manufacturing process to enhance the durability and longevity of the material. This aligns with sustainable design principles, prioritizing the creation of products with a longer lifespan.

SEM could also be used to examine the particle size and morphology of leather auxiliaries, aiding in the understanding of the physical characteristics of the materials used in tanneries. SEM, coupled with Energy Dispersive X-ray Spectroscopy (EDX), also provides information on the elemental composition and spatial distribution of metal ions within the leather sample.^{4,12} By leveraging SEM in the present study, we aim to provide a better understanding of the structural intricacies of leathers from various biological origins. The comparative analysis seeks to identify key differences and similarities, shedding light on the potential implications for material science, fashion, and sustainable design. The findings have broader implications for the development of innovative materials and sustainable practices.

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Experimental

Materials

This study involves the use of skins from different biological origins, specifically sourced from legal and reputable channels in Africa and India. The various sources of skins used in this study are as follows:

Bovine and Ovine: Cow, Buffalo, Goat and Sheep

Fish: Tilapia, Salmon, Stingray

Poultry: Ostrich, Chicken

Reptiles: Crocodile, Lizard (Teju), Python, Cobra

Procine: Pig

Ambibians: Frog

Material Preparation for Structural Investigation

All skins from diverse biological sources utilized in this study underwent tanning using 8% basic chromium sulfate, followed by fatliquoring, retanning, and drying. The resulting crust leathers were employed for SEM analysis.

SEM Study of Crust Leathers

A systematic and detailed examination of the structural characteristics of leather samples from various biological sources was conducted and compared using a scanning electron microscope. The key steps and procedures involved in the analysis are given below:

Sample Preparation:

Samples were obtained from crust leathers.

Dimensions of the samples: 5mm × 2mm.

Fresh stainless steel blades were used for cutting.

Mounting Procedure:

Samples were mounted on aluminum stubs.

Both vertical and horizontal orientations were used.

An adhesive tape was employed for mounting.

Coating:

Gold coating was applied to the mounted samples.

Hitachi E-1010 sputter coater was used for the coating process.

Scanning Electron Microscope Setup:

A Hitachi S-3400N scanning electron microscope was used.

The stubs were introduced into the specimen chamber.

The stubs mounted on the stage were adjustable for tilting, rotating, and moving to the desired position and orientation.

Imaging Process:

Micrographs for the surface and cross-section were obtained.

The microscope was operated at 10 – 20 kV for imaging.

Results and Discussion

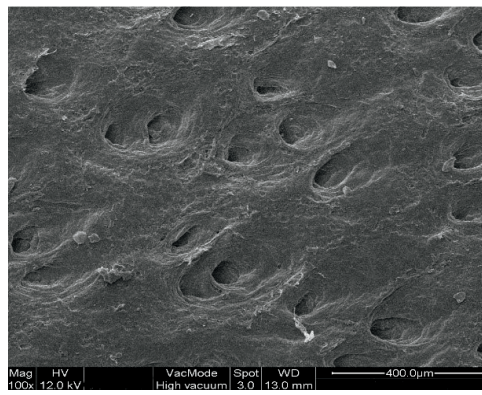
Structural Characterization of Bovine and Ovine Leathers

The scanning electron microphotographs presented in Figure 1 offer insightful visualizations of the surface and fiber structures of cow, buffalo, goat, and sheep leathers. The microphotographs confirm that cow leather surface does not contain any papillation, which accounts for roughness of grain (Figure 1A). The number of hair follicles present in this figure is high compared to the buffalo leather microphotograph. The hair follicle is deep rooted in the case of buffalo which is clear in the microphotograph (Figure 1C) since buffalo leathers have two types of hair, the coarse hairs are rooted deeper a little below the junction of the grain and corium.¹⁶ The fine hairs present in the buffalo hides are not deep rooted which is also clear in this microphotograph. The Figure 1C reveals the presence of papillation on the buffalo leather surface. This papillation may contribute to the distinct characteristics of buffalo leather and could be a factor influencing its grain texture. The microphotographs in Figure 1B and 1D reveal that collagen fiber bundles are quite big and are compactly woven in both cow and buffalo leathers which is different from goat and sheep leathers.

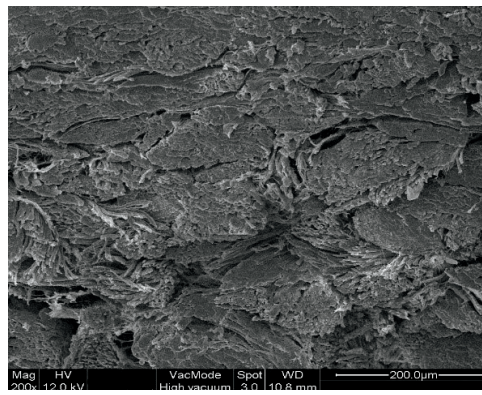
The scanning electron microphotograph of goat leather presented in Figure 1E indicates the presence of a specific trios pattern on its surface makes the leather different from sheep. The cross-section microphotograph presented in Figure 1F reveals that the collagen fibers are firmer and fuller than the corresponding ones in the sheep skins (Figure 1H). The collagen fiber bundles in the sheep leather microphotograph are extremely thin and are not closely interwoven which accounts for the looseness of the structure.

Structural Characterization of Fish Leathers

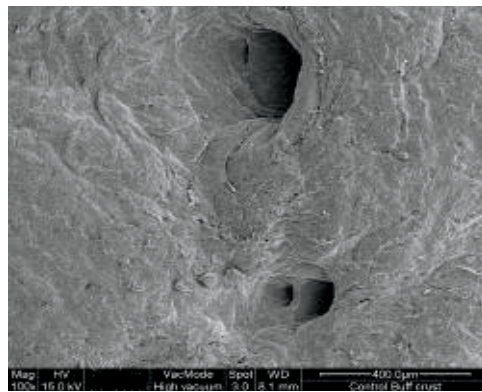
In this study, we have analyzed three different types of fish, namely tilapia, salmon, and stingray. Each fish species exhibits distinct surface morphologies, as illustrated in Figure 2. Both tilapia and salmon exhibit a porous grain structure formed after removing the scales during processing. Despite this similarity, each fish species possesses its own unique surface morphology (Figure 2A and 2C). Due to the porous nature of tilapia and salmon, finishing is typically not applied to these leathers. Unlike tilapia and salmon, stingrays have denticles (Figure 2E) that contribute to their unique skin texture. The stingray leather, characterized by an attractive grain surface, is primarily used in the production of ornamental goods and has also found applications in reflexology.¹⁷ SEM cross-sections



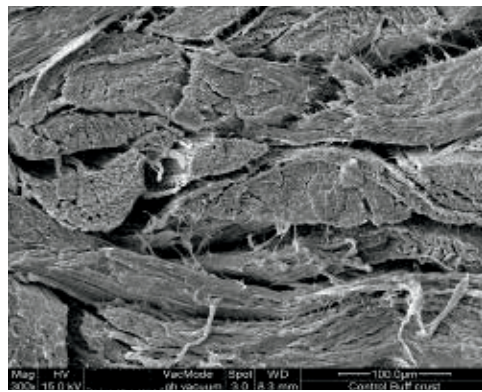
A. Cow surface



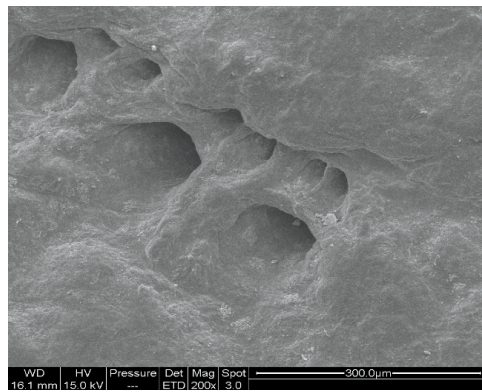
B. Cow cross-section



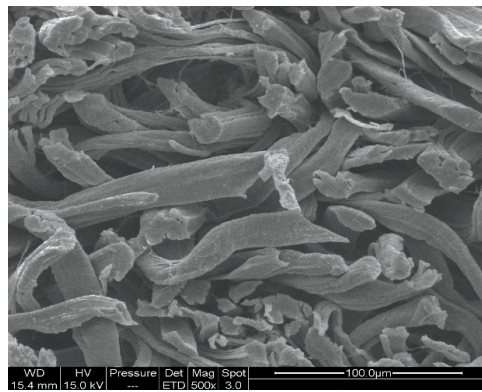
C. Buffalo surface



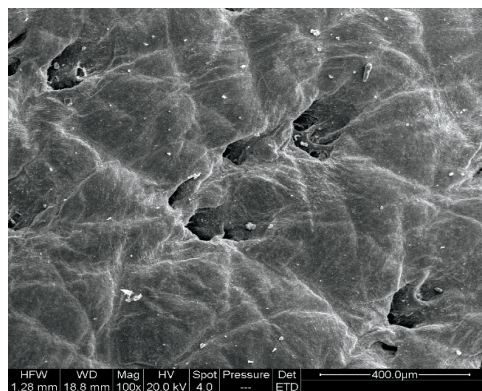
D. Buffalo cross-section



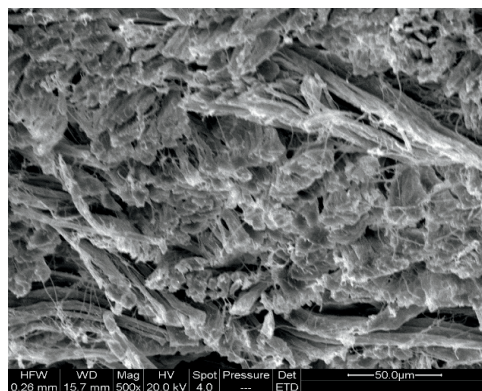
E. Goat surface



F. Goat cross-section



G. Sheep surface



H. Sheep cross-section

Figure 1. Scanning electron microphotographs of bovine and ovine leathers A. Cow surface B. Cow cross-section C. Buffalo surface D. Buffalo cross-section E. Goat surface F. Goat cross-section G. Sheep surface H. Sheep cross-section

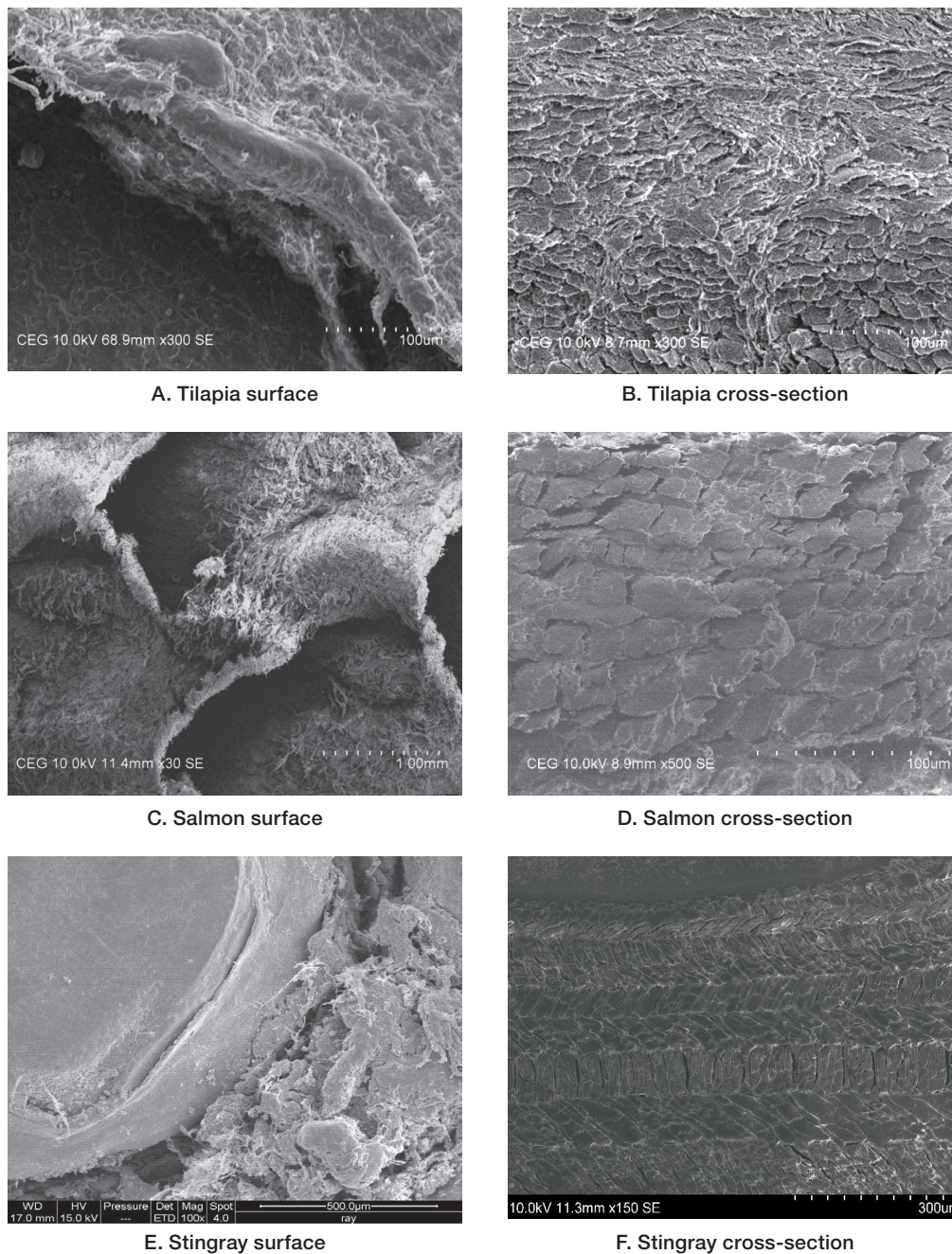


Figure 2. Scanning electron microphotographs of fish leathers **A.** Tilapia surface **B.** Tilapia cross-section **C.** Salmon surface **D.** Salmon cross-section **E.** Stingray surface **F.** Stingray cross-section

of tilapia, salmon, and stingray are given in Figures 2B, 2D, and 2F, respectively. The microphotographs confirm that tilapia and salmon have loosely packed thin collagen fiber bundles, whereas stingrays have very compactly woven parallel collagen fiber bundles running perpendicular to the grain surface, leading to high-strength properties.

Structural Characterization of Poultry Leathers

Among poultry skins, ostrich skins are very expensive due to their unique natural grain patterns.¹⁸ Ostrich leather is renowned for its distinctive quill or 'diamond' patterns, as illustrated in the

microphotograph shown in Figure 3A. These patterns, interwoven by collagen fiber bundles, require careful processing. Each quill mark creates a unique pattern (Figure 3A) that adds to the aesthetic appeal of the leather. Both ostrich leg and chicken leg skins share a similar and unique surface morphology, characterized by reptile-like grain structures without follicles, as illustrated in Figures 3C and 3E. SEM cross-section of ostrich skin is presented in Figure 3B, whereas ostrich leg and chicken leg skin are presented in Figures 3D and 3F, respectively. The microphotographs reveal that ostrich skin has thicker and compactly woven collagen fiber bundles compared to the leg skins of chicken and ostrich.

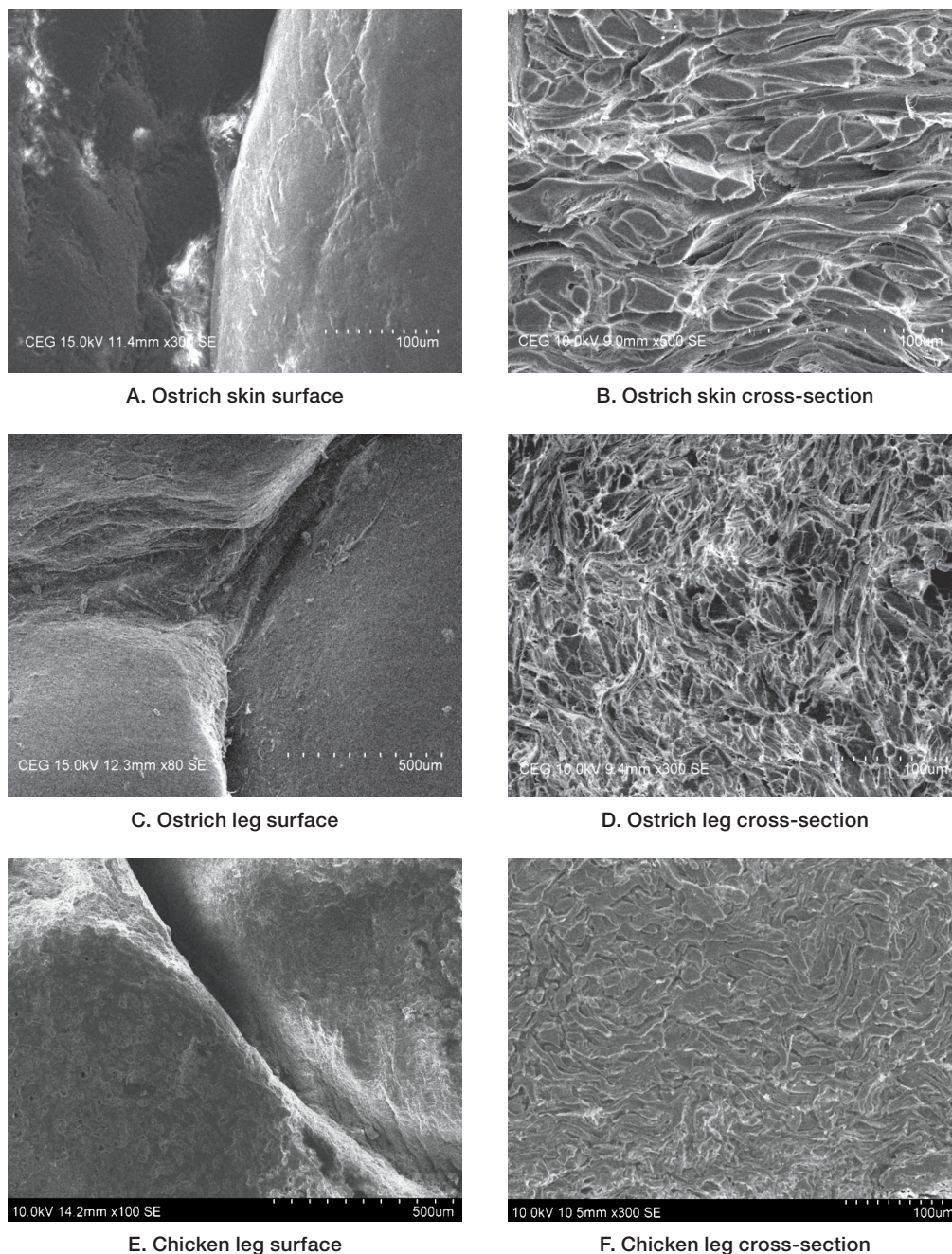


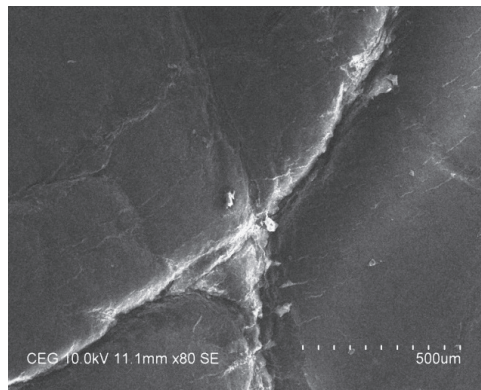
Figure 3. Scanning electron microphotographs of poultry leathers **A.** Ostrich skin surface **B.** Ostrich cross-section **C.** Ostrich leg surface **D.** Ostrich leg cross-section **E.** Chicken leg surface **F.** Chicken leg cross-section

Structural Characterization of Reptile Leathers

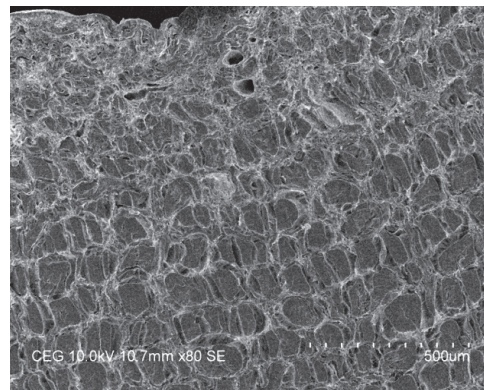
In this study, we have analyzed four species in the reptile class, namely crocodile, lizard, cobra and python. Figure 4A and 4B represents the crocodile leathers' SEM microphotograph for surface and cross-sectional examination. Figure 4A reveals the rectangular morphology of the crocodile skin surface resulting from the removal of the scaly epidermis during the processing of the skin into leather. The intricate geometric pattern left by the scales imparts a distinctive and aesthetically pleasing quality to the finished products, capturing the attention of those who appreciate both the functional and decorative aspects of crocodile leather.²⁰

In Figure 4B, the cross-sectional microphotograph demonstrates the densely packed and highly organized collagen fiber bundles within crocodile leathers. This distinctive basket-weave meshwork of collagen fiber bundles, as observed in both crocodile and stingray leathers (Figure 2F), plays a pivotal role in enhancing the mechanical strength.

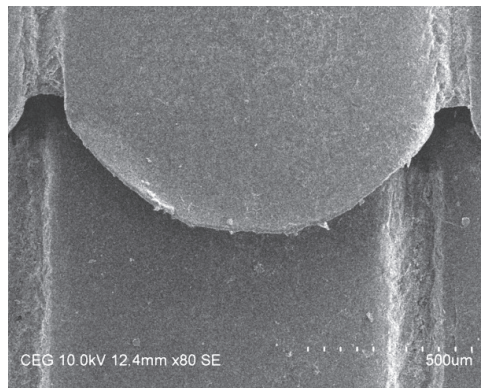
Figure 4C illustrates the surface morphology of lizard leather, where the distinctive small-scale pattern of the lizard is clearly visible in this microphotograph. The unique features of lizard leather, characterized by uniform scales and a distinctive texture,



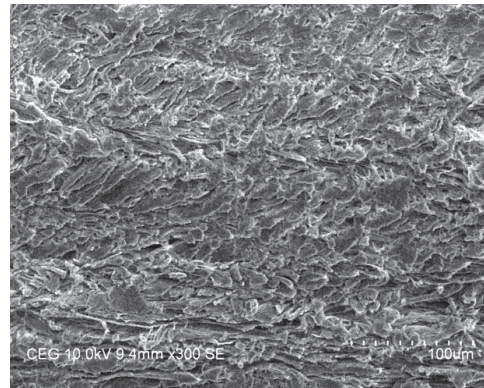
A. Crocodile surface



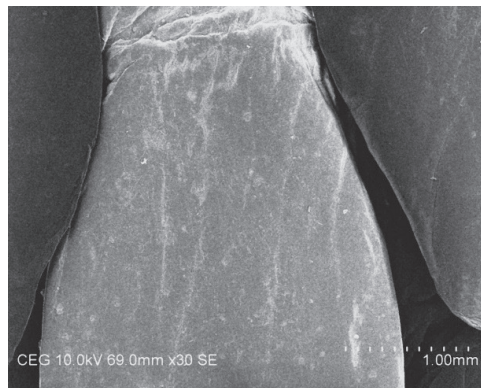
B. Crocodile cross-section



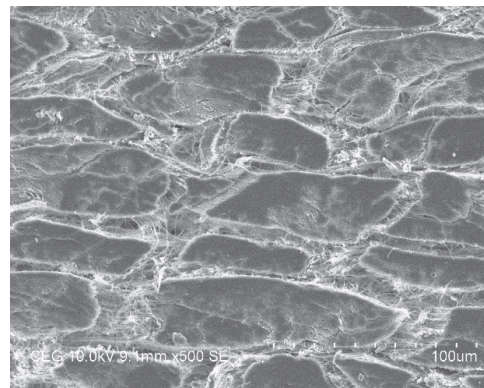
C. Lizard surface



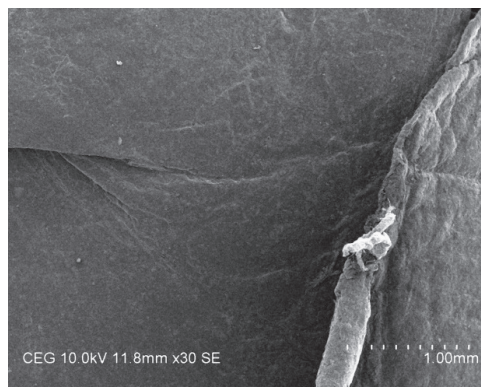
D. Lizard cross-section



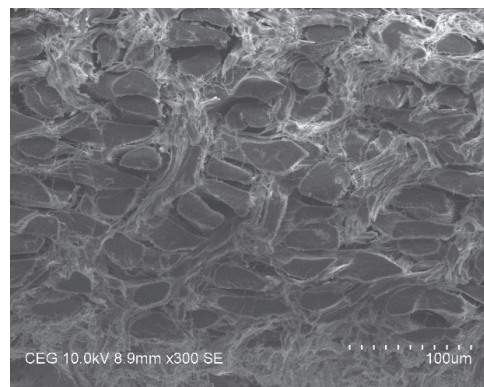
E. Cobra surface



F. Cobra cross-section



G. Python surface



H. Python cross-section

Figure 4. Scanning electron microphotographs of reptile leathers A. Crocodile surface B. Crocodile cross-section C. Lizard surface D. Lizard cross-section E. Cobra surface F. Cobra cross-section G. Python surface H. Python cross-section

contribute to its exclusivity and premium status in the fashion industry. The cross-sectional microphotograph of lizard leather reveals that the skin has very thin, organized collagen fiber bundles that split apart during the leather conversion process.

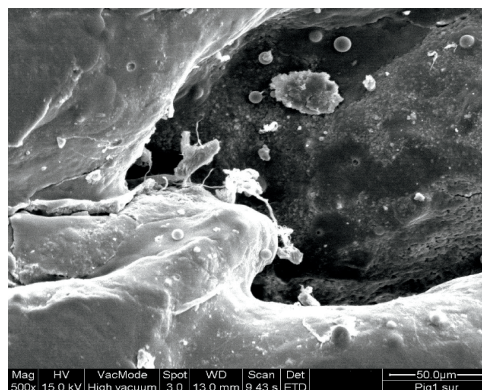
The SEM images of surface and the cross-section of the cobra and python leathers are presented in Figure 4E, 4F, 4G and 4H respectively. The surface morphology reveals that cobra leather is characterized by a prominent and visually striking scale pattern, offering designers a versatile material for creating a variety of visually appealing products. The surface morphology depicted in Figure 4G illustrates that python leather is distinguished by its prominent and sizable hexagonal scale pattern, setting it apart from cobra leather. The symmetrical arrangement of python scales imparts a distinctive texture, forming an intricate and visually appealing pattern in the final leather. This quality makes python leather a preferred choice for high-end fashion items.

SEM cross-sections of python and cobra skins indicate that both species exhibit a stiffer and more organized collagen fiber structure. This structure requires additional fiber splitting during the fiber opening process to achieve fuller and softer skin.

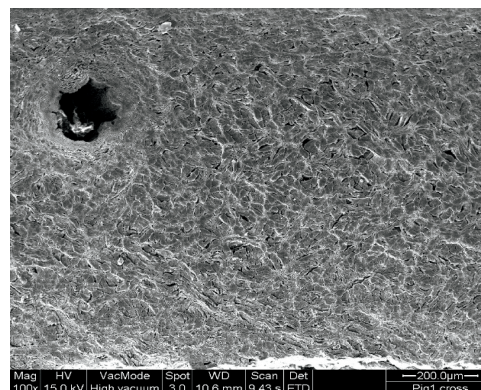
Structural Characterization of Pig and Frog Leathers

Scanning electron microphotographs of pig leather showing the grain surface and cross section are presented in Figures 5A and 5B, respectively. The pig bristles are generally in groups of three and penetrate through the entire skin, which is evident in these microphotographs. The surface analysis reveals that the hair follicles are deeper compared to other species, and the cross-section analysis indicates the presence of hair follicles below the grain layer, differing significantly from other bovine and ovine leathers used in leather manufacture. Furthermore, the cross-section microphotograph of pig leather reveals that collagen fiber bundles are loosely packed. Due to this structure, pig skins are predominantly used for lining and suede leather manufacture.

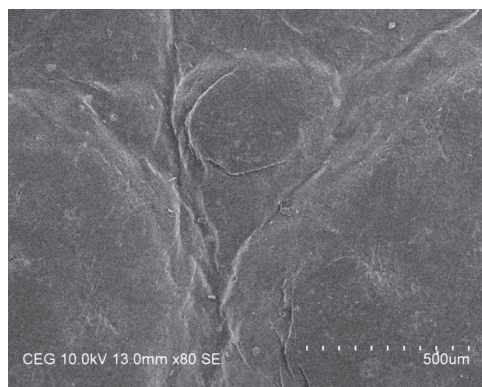
Figures 5C and 5D represent the surface morphology and cross-section view of frog skin, respectively. Surface analysis reveals that frog skin has very unique irregular tiny bumps and projections, making it suitable for smaller leather goods. The cross-section analysis shows that frog skin has very thin and loosely packed collagen fiber bundles, leading to poor mechanical properties.



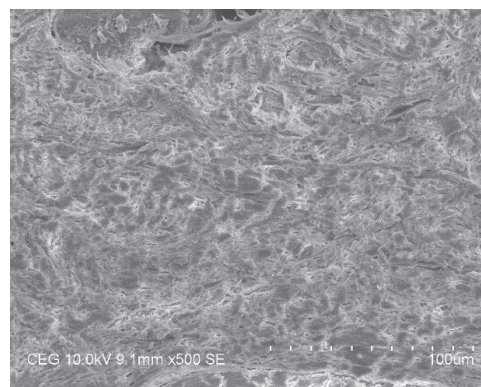
A. Pig surface



B. Pig cross-section



C. Frog surface



D. Frog cross-section

Figure 5. Scanning electron microphotographs of porcine and amphibian leathers
A. Pig surface B. Pig cross-section C. Frog surface D. Frog cross-section

Conclusion

Throughout this study, our focus was directed towards unravelling the microscopic intricacies of skins derived from diverse biological origins, including bovine, ovine, fish, poultry, reptile, amphibian, and porcine sources. The high-resolution images obtained through SEM have provided invaluable insights into the surface and cross-sectional fiber structure of various types of leathers from different biological origins. This information serves as a crucial asset in optimizing manufacturing processes within the leather industry, ultimately leading to enhanced product quality and the potential for the development of innovative materials. The insights gained from this comparative analysis not only deepen our understanding of material science but also bear implications for the realms of fashion and sustainable design. By shedding light on the distinctive morphological features, fiber arrangements, and surface topographies of different leather types, this study opens avenues for informed decision-making in leather-related industries and encourages sustainable practices.

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