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COFFEE-BASED BIOMATERIAL FOR THE FASHION INDUSTRY

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Abstract: *The fashion industry is facing challenges related to reducing its negative environmental impact, sustainability becoming one of the central directions of development in the contemporary textile sector. The aim of this study is to investigate the possibility of developing a biodegradable biomaterial, specifically a bio-based leather alternative derived from coffee grounds, intended for use in experimental fashion design. The research includes a theoretical analysis of biomaterials obtained from organic waste and their areas of application in the fashion industry, as well as an experimental component focused on the development, production, and practical testing of the proposed biomaterial. As a part of the study, multiple experimental samples were created using natural ingredients such as gelatin, agar-agar, glycerin, water, and coffee grounds, different conditions of processing and drying being analyzed to optimize composition and structural stability. The obtained biomaterials were evaluated from both physico-mechanical and aesthetic perspectives by examining flexibility, handling resistance, dimensional stability, and behavior during processing. To validate the material's practical applicability, a wearable physical prototype was developed in the form of a corset, confirming the feasibility of integrating the biomaterial into contemporary garment structures. The research results confirm the potential of coffee ground–based biomaterial as a sustainable alternative for the development of experimental fashion products and open perspectives for future research aimed at improving mechanical performance and expanding its commercial applicability.*

Key words: *sustainability, bio-leather, circularity, biodegradation, textiles, innovation*

1. INTRODUCTION

Sustainable fashion promotes an integrated approach in which environmental responsibility is aligned with the social and economic dimensions of garment production. This orientation involves rethinking how clothing items are designed, produced, distributed, and used, with an emphasis on quality, durability, and long-term value. One of the key aspects of sustainable fashion is the selection of materials. The use of responsibly cultivated natural fibers, recycled materials, or those obtained from innovative alternative sources, contributes to reducing the ecological footprint. Organic cotton, certified wool, regenerated cellulosic fibers, as well as biomaterials developed from agricultural or organic waste, represent viable solutions for decreasing the consumption of non-renewable resources and the pollution associated with traditional textile production processes.

This study aims to investigate the potential of valorizing coffee grounds as a secondary raw material for the development of a biodegradable biomaterial, specifically a bio-leather alternative intended for applications in experimental fashion design. The research focuses on the development of the biomaterial, the analysis of process parameters involved in its production, the evaluation of its physico-mechanical properties, and the practical validation of its applicability through integration into an experimental garment prototype.

2. BIO MATERIALS FROM ORGANIC WASTE

Against the backdrop of growing environmental concerns, the textile industry is increasingly exploring alternative resources, transforming organic waste into innovative textile materials. These solutions not only reduce pollution and the consumption of natural resources, but also support the circular economy by promoting the “waste-to-fashion” concept whuch represent the transformation of biodegradable residues into sustainable, aesthetic, and durable products.

Organic waste represents biological resources with high potential, generated after crop harvesting or as a result of food processing [1]. In the last 10 years, numerous start-ups, university laboratories, and sustainable fashion brands have demonstrated that these resources can be transformed into high-performance textile materials, with aesthetic and technical properties comparable to leather or synthetic fibers. Through this circular approach, fashion not only gains access to new materials, but also achieves a reduced impact on soil, water, and carbon dioxide emissions.

Through the application of innovative technological processes, organic waste is valorized and transformed into sustainable biomaterials, contributing to the development of eco-friendly alternatives for the fashion industry. Relevant examples include AppleSkin [2], made from apple peels; VEGEA Wine Leather [3], manufactured from grape processing waste; mycelium-based bio-leather [4], derived from the filamentous structure of fungi; SCOBY leather [5], created through fermentation using Kombucha bacteria; bio-leather with propolis additives [6], based on biopolymeric components and propolis; coffee-based bio-leather [7], developed by incorporating coffee grounds into the material composition; and bioplastic derived from orange peels [8], obtained from biopolymers extracted from citrus waste. The materials developed in this way are sustainable and biodegradable, emphasizing the reduction of environmental impact compared to animal leather or other synthetic materials.

3. EXPERIMENTAL PART

3.1. Material and method

The experimental research presented in this study aims to develop a bio-leather by valorizing natural ingredients and organic waste, with a particular focus on the use of coffee grounds as the main raw material.

The adopted methodology in this study is of experimental-artisanal matter and is based on successive testing, direct observation, and the progressive adjustment of process parameters. Given the innovative and experimental character of the investigated biomaterial, the study does not exclusively aim the obtaining of a fully functional final product, but also the examiningof the difficulties encountered throughout the fabrication process, in order to identify technological limitations and opportunities for further optimization.

To obtain the biomaterial, exclusively natural-origin ingredients were selected, without the inclusion of plastic, synthetic, or toxic additives, in order to ensure the full biodegradability of the product and its compatibility with the principles of eco-design and the circular economy. The raw materials used in the biomaterial composition are gelatin, agar-agar, glycerin, coffee grounds, and water.

From a methodological perspective, the research is based on the application of the experimental method through the practical fabrication of the biomaterial, complemented by direct observation used to monitor structural and behavioral changes during the drying process. Comparative analysis is employed to evaluate the material's behavior under different temperature conditions and drying methods, while the iterative method enables the repetition of the fabrication process and the adjustment of parameters, following the identification of defects or nonconformities. At the same time, photographic documentation is used to record the experimental stages and to highlight the difficulties encountered throughout the process.

3.2. Stages of obtaining coffee-based biomaterials

The process of obtaining coffee-based biomaterials has many steps, including raw material preparation, composition development, thermal treatment, casting into molds, and drying of the material, each stage influencing the final properties of the biomaterial. The research aimed to establish optimal ingredient ratios in order to obtain samples with characteristics similar to natural leather.

The basic recipe used, according to bibliographic sources [9], included 3 g of agar-agar, 20 g of gelatin, 15 ml of glycerin, and 400 ml of water, with the mixture being boiled at approximately 80°C for 25–35 minutes.

To obtain a biomaterial sample, the following quantities of ingredients were used: 20 g of coffee grounds, 30 ml of glycerin, 4 g of agar-agar, 20 g of gelatin, and 400 ml of water. The ratio of ingredients was determined through repeated experiments until a biomaterial sample with properties similar to natural leather was obtained. The ingredients were accurately weighed and placed into a heat-resistant container, then mixed to ensure homogeneity. The mixture was heated and boiled for 20–25 minutes under continuous stirring until a viscous liquid was obtained.

Subsequently, the resulting solution was poured into a rectangular mold with dimensions of 27 × 18 cm, where it was left to dry at room temperature. After 3 days, the material was removed from the mold and placed under a press for a period of 7 days to ensure dimensional stabilization and to prevent deformation. The drying process was monitored to avoid the formation of possible imperfections.

Although the results obtained were satisfactory, replication of the process revealed several technological difficulties. At temperatures between 25–30°C, cracks and fractures become visibls (Figure 1a), a phenomenon associated with rapid water loss and irregular material shrinkage. Under lower temperature conditions, between 12–16°C, mold growth was detected, caused by high humidity and prolonged drying time (Figure 1b). Additionally, differential drying between the edges and the center of the molds was noted, a phenomenon determined by the uneven distribution of coffee grounds in the composition and variations in the particle size of the solid components (Figure 1c).

a) *b)* *c)*

***Fig. 1**: Biomaterial samples*

Samples that exhibited defects, such as cracks or biological contamination, were reintegrated into the process through reprocessing. They were dissolved by adding a small amount of water, reheated for 5–7 minutes until a homogeneous composition was obtained, and subsequently reused for casting new experimental samples.

The research results demonstrate that obtaining bio-leather is a process that requires successive adjustments and careful monitoring of each technological parameter. Although difficulties such as mold growth, uneven drying, cracking, or texture variations were identified, these can be mitigated through optimization of the composition, control of material thickness, and regulation of drying conditions.

3.3. Analysis of the proprieties of the experimental biomaterial

After obtaining the coffee ground–based biomaterial, its physical, mechanical, and aesthetic properties were evaluated to determine its compatibility with specific applications in fashion design. It was used methods as the experimental and practical methode, being conducted through direct observation, manual manipulation, and comparative testing between the obtained samples.

To validate the obtained biomaterial from a scientific perspective, it was subjected to biodegradability and thermal stability tests. For the assessment of biodegradability, the material was immersed in an aqueous environment for 24 hours and subsequently left to dry for another 24 hours. A surface mass reduction of approximately 40% was observed, allowing an estimated complete degradation time of about 60 hours.

The melting temperature of the biomaterial was determined to be 85°C.

The flexibility of the biomaterial was analyzed through repeated bending test. The results indicating that the samples from initial experiments exhibited high rigidity and rapid cracking, while the optimal sample demonstrated satisfactory elasticity and structural stability. This behavior was supported by the appropriate proportion of glycerin and the reduced amount of coffee grounds, which contributed in the development of a more uniform structure.

The resistance to the usage was evaluated through manual tensile tests, with the biomaterial demonstrating suitable properties for decorative uses, surface applications, and conceptual fashion elements, but limitations in areas subjected to high mechanical stress. Physical and mechanical testing of the biomaterial using standardized methods (tensile strength, elongation) represents a future research direction.

From an aesthetic perspective, the biomaterial exhibits a natural organic texture and a visual appearance similar to matte or semi-gloss leather. The surface quality was found to be directly influenced by the degree of coffee grounds grinding, with finer particles leading to more uniform and homogeneous surfaces.

Regarding to processability, the biomaterial allows cutting, perforation, and sewing operations, demonstrating good performance when technical parameters are adapted to its structure.

3.4. Results and discussion

The obtained results confirm that the coffee ground–based biomaterial can be integrated into simple garment structures, such as applications, decorative panels, or modular elements, validating its potential as a sustainable alternative for the development of experimental fashion prototypes. To validate the obtained results, it was decided to create a physical clothing prototype in the form of a corset.

In the preliminary stage, prototyping of the design and pattern development were carried out digitally using the CLO 3D platform, which enabled dimensional and structural optimization prior to physical execution (Figure 2).

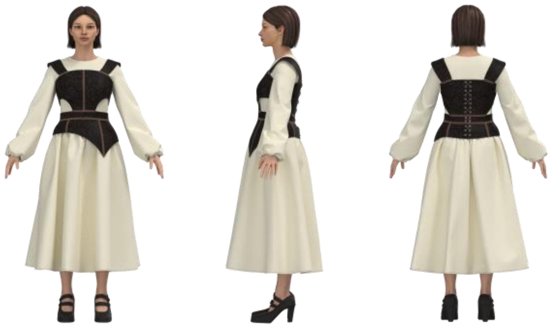

Fig. 2*: Prototipul digital al modelului*

The first stage of the physical realization of the garment involved pattern layout on the material, a process carried out with the aim of optimizing consumption and reducing technological waste. The cutting stage was performed manually, this method being considered optimal for precise control of contours and for preventing damage to the material edges. Observations made during the process highlighted that the biomaterial exhibits stable behavior during cutting, without pronounced tendencies toward cracking or delamination, confirming its satisfactory processability at the cutting stage. The sewing was carried out using specialized equipment for leather-like materials, and the technological parameters of the sewing machine were adapted to the specific characteristics of the biomaterial by adjusting stitch length and thread tension.

In the final evaluation stage, the prototype was analyzed from both an aesthetic and functional perspective, focusing on its behavior during wear and the interaction between structure, material, and the wearer's body. The results highlighted good dimensional stability, satisfactory comfort, and the maintenance of structural form during use, confirming the viability of the adopted technical solutions. The physical prototype made from the experimental biomaterial is presented in Figure 3.

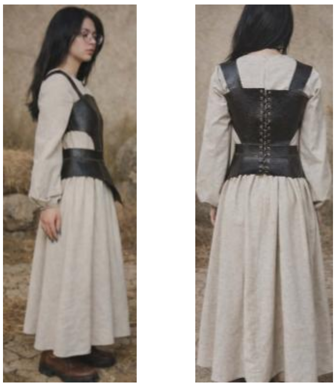

Fig. 3*: Physical prototype made from the experimental biomaterial*

4. CONCLUSIONS

This research highlights the importance of sustainable approaches in fashion design and the potential of valorizing organic waste for the development of innovative materials intended for the fashion industry. The experimental results demonstrated that the coffee ground–based biomaterial can be obtained by combining natural ingredients such as gelatin, agar-agar, glycerin, and water, resulting in a flexible, biodegradable material with an appearance similar to natural leather.

The final properties of the biomaterial are influenced by the ratio of ingredients, the grinding degree of the coffee grounds, material thickness, and drying conditions, with their optimization being essential to prevent structural defects. The realization of the physical prototype validated the applicability of the biomaterial and the proposed construction solutions, demonstrating their potential for integration into experimental fashion products and for the further development of commercial applications in the field of sustainable fashion.

The main original contribution on this research consists in the practical validation of the developed biomaterial through the creation of a wearable physical prototype in the form of an experimental corset, which demonstrates the material's real applicability in fashion design and confirms its functional and aesthetic potential. The realization of the prototype enabled the assessment of the biomaterial's behavior under real usage conditions and demonstrated the feasibility of integrating it into contemporary garment structures.

The obtained results confirm that the coffee ground–based biomaterial represents a viable sustainable alternative for the development of experimental fashion prototypes and for the creation of decorative elements in fashion industry. Future research may focus on improving mechanical strength, increasing moisture stability, and optimizing material durability in order to expand its potential applications at a commercial scale.

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