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MODIFICATION OF COTTON FABRICS WITH CHITOSAN FOR IMPROVED DYEABILITY WITH ACID ORANGE 7

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Abstract: *Cationized cotton fibres, achieved through chemical modification with cationic compounds, have been explored to improve dye uptake while also addressing the concerns about the environmental impact of low exhaustion rates and the use of salts. Chitosan, a green biopolymer, is a potential eco-friendly textile chemical due to its nontoxic, biodegradable, and cost-effective nature. This study investigated the effects of chitosan modification, with and without citric acid crosslinking, on washing and dyeing using an anionic dye, Acid Orange 7. The experimental analysis included fabric preparation, chitosan solution formulation, padding application, curing, washing, and dyeing. Dye exhaustion percentages and colour measurements were analysed. The results demonstrated enhanced dye exhaustion in chitosan-modified cotton fabrics, with optimal results observed at 120°C curing. Chitosan modification led to darker and deeper shades in dyed fabrics. However, adding citric acid for crosslinking did not significantly improve dye exhaustion. In conclusion, chitosan modification improved dye exhaustion and colour intensity, showcasing its potential as an eco-friendly alternative for enhancing dye uptake in cotton fabrics. Further investigations could optimise solution preparation and application methods for optimal results. This study contributes to sustainable practices in the textile industry by highlighting the potential of chitosan as a dyeing enhancer.*

Keywords: *textile; dyeing; mordant; eco-friendly; cotton modification.*

1. INTRODUCTION

Low exhaustion of dyes from the dyeing bath brings economic and environmental concerns [1,2]. Salts have been used to enhance dye exhaustion. However, this approach can also cause the pollution of rivers and streams, which is harmful to aquatic life [3]. In an attempt to improve the dye uptake of fibres from the bath, cationised cotton fibres through chemical modifications with compounds containing cationic groups have been explored [4]. The textile industry continues to look for eco-friendly processes that can substitute for toxic textile chemicals. From this point of view, chitosan is an excellent candidate for the use of eco-friendly textile chemicals [5].

Chitosan, a green biopolymer, possesses multifunctional properties, including nontoxicity, biocompatibility, biodegradability, and low cost. Because of these characteristics, chitosan has been used in the agriculture, biotechnology, medical, textile, cosmetics, and food industries [6-8]. Chitosan is a linear polysaccharide sourced from the full or partial deacetylation of chitin, which consists of a molar fraction of randomly distributed β-(1→4)-linked D-glucosamine (deacetylated unit) and a fraction of N-acetyl-D-glucosamine (acetylated unit) [9].

While chitosan was initially used as a dye-deepening agent in the textile industry, it is also an ideal fixing agent for anionic dyes due to its cationic nature. Salt-free dyeing is possible by using chitosan with the help of some other additives [10]. A possible explanation for the level dyeing effect of chitosan may be explained by the capability of chitosan to form a uniform film on the surface of the fibre. It improves the surface properties of the fibre and reduces the Coulomb repulsion between the fibre and the anionic dyes, significantly improving the dye uptake rate. The deepening effect is also due to the protonation of the free amino group on the chitosan molecule under acidic conditions. When the fabric is immersed in the chitosan solution, the positive charge of the fibre is increased. Thus, the repulsion force between the fibre and the anionic dyes is reduced [11].

The crosslinking of chitosan on cotton fabrics has been considered to improve the durability of the treatment. Moreover, many studies have found that the use of polycarboxylic acids (PCAs) as a crosslinking agent is the best choice. The PCAs lead to the formation of covalent bonds between the chitosan and cellulose [12]. While 1,2,3,4-butane-tetracarboxylic acid (BTCA) appears to be the most promising crosslinker for cellulosic materials, its cost is too high, preventing its application on a commercial scale [13]. An alternative to this is the use of citric acid (CA) as a crosslinker. It has been proven that CA with sodium hypophosphite (SHP) as a catalyst promotes effective crosslinking [12].

This study investigated the effect of chitosan modification with and without citric acid as a crosslinker on the washing and dyeing of cotton fabrics with Acid Orange 7, an anionic azo dye.

2. EXPERIMENTAL

2.1 Materials

The fabric used for this study was 100% bleached cotton with an openwork fabric, plain weave and a density of 46 ends/cm, 36 picks/cm and a grammage of 116 g/m2. It belongs to the Department of Textile Engineering (DITEXPA) of the UPV (Campus Alcoy, Spain). Medium molecular weight chitosan was provided by Sigma Aldrich and was used without any purification. Citric acid was provided by Scharlau, and sodium hypophosphite was provided by Acros Organics. The detergent used for washing was the low foam non-ionic liquid detergent Proindeter ECM supplied by Proindiver S.L. (Barcelona). All chemicals and reagents used in this study were of analytical grade.

A 1 L solution of chitosan was prepared (1% w/v) with the addition of acetic acid (0.5% v/v) to aid in the dissolution of the powder. The solution was magnetically stirred for 2 hours to ensure that the chitosan was fully dissolved. Another 1 L solution which contained chitosan (1% w/v), citric acid (7% w/v), non-ionic surfactant Tween 80 (1% v/v), and sodium hypophosphite (1:1 CA-SHP mole ratio) was prepared. The solution was magnetically stirred overnight. This method is based on the study by Grgac et al. (2020) and Chung et al. (1998).

2.2 Application of chitosan on cotton fabric

A roll of cotton fabric was padded with the chitosan solution and the chitosan with a citric acid solution using a small-scale foulard at a controlled pressure of 2 bar. The cotton fabric was allowed to pass through the rollers twice. The wet pick-up of the fabric was obtained. The padded cotton fabric was dried using S.P.E Screen Engineering TD-20 at 80ºC.

The cotton fabrics were cut into smaller parts to weigh approximately 10 g each. Cotton fabrics modified with chitosan (CO_X) and chitosan with citric acid (CO_X_CA) were heated in the oven (Argo Lab TCF 120) for 3 minutes at 120ºC and 150ºC. Pure cotton fabrics (CO) were also heated in the same manner.

2.3 Washing

A solution of Proindeter ECM (0.5 g/L) was prepared for the washing of the cotton fabrics. 500 mL of the solution was placed in each glass tube of the laboratory dyeing equipment (Tint Control Renigal Multi-Mat), which agitated the y-axis of the samples. The washing cycle was done for 30 minutes at 60ºC. The samples were then air-dried overnight.

2.4 Dyeing

A stock solution of Acid Orange 7 dye (1 g/L) was prepared for the dyeing of cotton fabrics (1% o.w.f) with a liquor-to-goods ratio of 1:40 in a laboratory dyeing machine (Paramount Open Bath dyeMaster). The dyeing process was carried out at 25ºC for 6 hours.

2.5 Characterization

2.5.1 Dye Exhaustion

The dye bath exhaustion (%E) was determined from the measurement of the dye solution absorbance before (A_0) and after (A_1) the dyeing process at maximum absorbance wavelength (485 nm) using a UV-Vis spectrophotometer (Thermo Scientific – Helios Epsilon). The dye bath exhaustion (%E) was calculated as in Eq. (1):

$$\%E=\frac{(A_0-A_1)}{A_0}\times 100 \qquad \textbf{(1)}$$

2.5.2 Color Measurements

The colour yield values of treated and controlled dyed cotton fabric samples were measured under D65/10º illuminant using a Datacolor Spectro 700 spectrophotometer. Samples were measured in three different sites, and the average measurements were recorded.

3. RESULTS

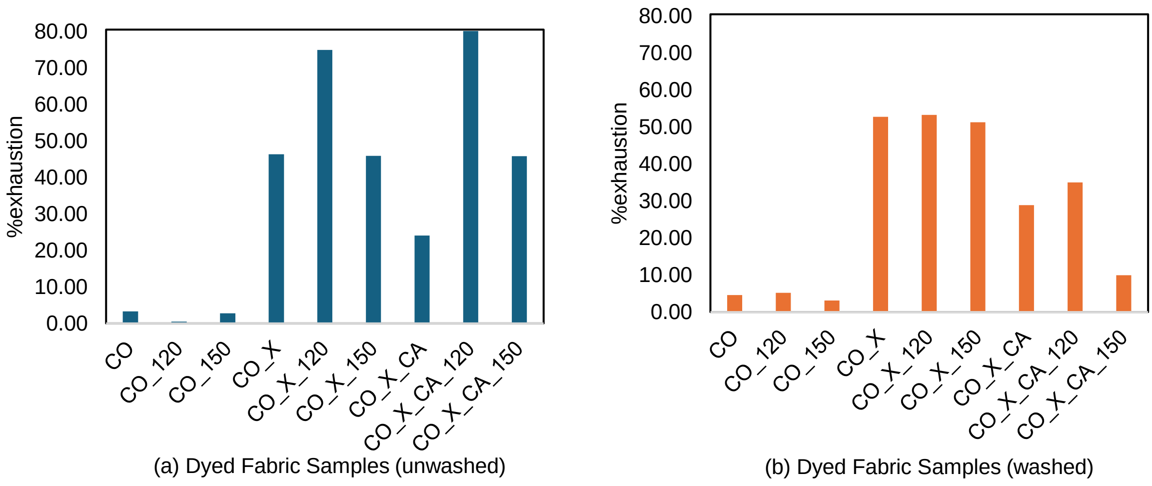

Fig. 1*: Dye Exhaustion Percentages of (a) unwashed and (b) washed cotton fabric samples*

The data in Figure 1 shows the improved dye exhaustion with the impregnation of chitosan and chitosan with citric acid solutions on the cotton fabric before dying. In Figure 1(a), modified cotton fabrics cured at 120ºC showed higher dye exhaustion percentages compared to the other dyed samples. Meanwhile, in the washed cotton fabric samples in Figure 1(b), cotton fabrics modified with chitosan only showed higher dye exhaustion percentages over those modified with chitosan and citric acid. This could indicate that the cotton fabric has better intermolecular interaction with chitosan alone, and the addition of citric acid was ineffective in improving chitosan attachment to the cotton fabric.

Table 1: Colour measurements of pre-dyed cotton fabrics (unwashed)

Sample	L*	a*	b*	dE*
CO	96.85	3.28	-14.86	
CO_120	96.88	3.24	-14.99	0.15
CO_150	96.84	3.21	-14.78	0.11
CO_X	96.54	2.73	-13.93	
CO_X_120	96.69	2.53	-14.05	0.28
CO_X_150	96.56	2.36	-13.13	0.88
CO_X_CA	97.13	-0.47	-10.17	
CO_X_CA_120	97.07	-0.54	-9.48	0.75
CO_X_CA_150	96.57	-1.06	-7.17	3.12

Table 2: Colour measurements of pre-dyed cotton *fabrics (washed)*

Sample	L*	a*	b*	dE*
CO	97.12	0.32	-11.41	
CO_120	96.85	0.04	-11.1	0.57
CO_150	96.68	0.28	-11.11	0.54
CO_X	96.44	0.53	-11.28	
CO_X_120	96.5	0.5	-11.22	0.11
CO_X_150	96.44	0.46	-10.3	1.06
CO_X_CA	96.69	-0.46	-9.22	
CO_X_CA_120	96.34	-0.23	-9.08	0.44
CO_X_CA_150	96.12	-0.58	-6.14	3.35

Based on the L*a*b values of the pre-dyed cotton fabrics in Tables 1 and 2, fabric samples padded with chitosan slightly reduced the* values compared to plain cotton fabric. There was no significant difference in colour between non-cured cotton fabrics with chitosan and cotton fabrics with chitosan cured at higher temperatures. However, curing at 150ºC increased the colour difference slightly. For cotton fabrics padded with chitosan with a citric acid solution, there was a significant colour difference when the fabric samples were cured at 150ºC, appearing to be more yellowish. After washing, the cotton fabric samples showed a decreasing trend in the* values.

Table 3: *Color measurements of cotton fabrics dyed with Acid Orange 7 (unwashed)*

Sample	L*	a*	b*	dE*
CO_AO7	79.74	27.95	18.88	
CO_120_AO7	80.23	27.49	17.42	1.61
CO_150_AO7	79.86	27.76	18.29	0.63
CO_X_AO7	68.4	38.67	33.32	
CO_X_120_AO7	66.25	44.89	49.72	17.67

CO_X_150_AO7	67.37	38.80	32.86	1.14
CO_X_CA_AO7	65.37	46.09	53.64	
CO_X_CA_120_AO7	69.36	40.59	35.49	19.38
CO_X_CA_150_AO7	73.09	34.52	34.6	23.58

Table 4: *Color measurements of cotton fabrics dyed with Acid Orange 7 (washed)*

Sample	L*	a*	b*	dE*
CO_AO7	79	28.78	21.63	
CO_120_AO7	79.04	28.4	20.51	1.18
CO_150_AO7	79.18	28.71	20.81	0.85
CO_X_AO7	64.98	33.14	33.34	
CO_X_120_AO7	68.41	42.15	39.75	11.57
CO_X_150_AO7	68.32	41.95	39.61	11.31
CO_X_CA_AO7	71.24	40.13	43.66	
CO_X_CA_120_AO7	69.97	40.18	42.73	1.57
CO_X_CA_150_AO7	76.83	31.28	28.56	18.37

As shown in Table 2, the cotton fabrics modified with chitosan and chitosan with citric acid have lower L* values than dyed pure cotton fabrics, showing a darker shade of orange. This shows that the addition of chitosan improves the dyeing of the cotton fabrics and supports the date of improved dye exhaustion when the cotton fabrics were pre-treated with chitosan. Washing the modified cotton fabrics has more effect on the dyeing of the modified cotton fabrics than the pure cotton samples. This indicates that the washing resulted in a reduced amount of chitosan that has been attached to the cotton fabric. The curing of chitosan-modified cotton fabrics also influences the dyeing of the fabrics. There is a considerable colour difference between the cured samples compared to their non-cured counterparts.

4. CONCLUSION

Eco-friendly textile agents have been explored to improve dye exhaustion on textiles while reducing the harmful impact on the environment. Chitosan, a biopolymer sourced from chitin, has multi-functional properties that make it a good candidate for a more sustainable treatment for cotton fabrics to improve dye uptake. The results of this study showed that the dye exhaustion of the cotton fabric was improved by modifying the cotton with chitosan before dyeing. Chitosan improves dyeing with the anionic dye Acid Orange 7 due to its cationic nature. The modification of cotton fabrics with chitosan and citric acid solution for crosslinking did not show substantial improvement with dye exhaustion compared to the modification of cotton fabrics with chitosan only. Further exploration can be done on the solution preparation and padding method to optimise the chitosan pre-treatment of cotton fabrics.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

ADVANCES IN TEXTILE MANUFACTURING WITH 3D PRINTING TECHNOLOGY

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Abstract: *This paper explores the most used technologies and materials in 3D printing for textiles. It presents an overview of additive manufacturing techniques such as Fused Deposition Modeling (FDM), Stereolithography (SLA), and Selective Laser Sintering (SLS), highlighting their applications in textile manufacturing. Various materials, including PLA, ABS, PETG, TPU, and specialized resins, are examined for their mechanical properties, flexibility, and suitability for textile integration. The study also reviews recent advancements in 3D-printed textiles, emphasizing innovations in material composition, structural designs, and process optimization. Research findings on chain structures, auxetic materials, and bio-compatible resins demonstrate the potential of 3D printing in producing functional, wearable textiles with enhanced comfort and durability. Furthermore, the integration of smart materials, such as shape memory polymers, elastic liquid crystals, and hydrogels, opens the way for 4D printed intelligent textiles that adapt to environmental stimuli like temperature, humidity, and mechanical stress. Sustainability and customization are key drivers in the adoption of 3D printing in the fashion industry, as the technology reduces material waste, enables on demand production, and offers new possibilities for personalized garments. Despite significant progress, challenges remain in scalability, material limitations, and adherence to traditional textile properties. Future research will focus on enhancing material performance, refining printing techniques, and exploring hybrid manufacturing approaches.*

Key words: *Additive Manufacturing, Fused Deposition Modelling (FDM), PLA, flexibility*

1. MATERIALS AND TECHNOLOGIES USED IN TEXTILE 3D PRINTING

3D printing, also known as additive manufacturing, involves creating three-dimensional objects from digital models by laying down successive layers of material until the object is complete. There are several technologies employed for this process [1], [2]:

- Fused Deposition Modeling (FDM), the most common for home or semi-industrial use, where a plastic filament is melted and extruded layer by layer
- Stereolithography (SLA), that uses a laser to cure liquid resin into a solid object, which is also recognized for its high accuracy
- Selective Laser Sintering (SLS), where a powder made from plastic, ceramic, or a metal is fused by a laser, commonly used in industrial applications.

The FDM technology applied to textile printing utilizes the following materials, each one with properties benefits and drawbacks:

- PLA (Polylactic Acid), a biodegradable plastic made from renewable resources like corn starch or sugar cane, easy to print with and available in many colors. Otherwise, it is not as robust or heat-resistant as other materials and can be easily breakable. Nowadays, it is widely used for prototyping, in various educational projects and the production of simple household items. PLA composites can be combined with natural fibres such as jute, cotton and hemp and are biodegradable.

- ABS (Acrylonitrile Butadiene Styrene), known for its strength and durability, making it suitable for functional parts, with higher heat resistance than PLA. As a disadvantage, it requires higher temperatures to print, can emit toxins and could deform, especially in cold air. This material is suitable for prototyping and short series production of automotive parts, toys, or other casings.
- PETG (Polyethylene Terephthalate Glycol), combines the benefits of PLA and ABS, being strong, flexible, less prone to warping and with good layer adhesion. Further, it is more expensive than PLA, can be challenging to print with for beginners. General applications range from containers, drone parts or medical equipment.
- Nylon (Polyamide - PA6, PA11, PA12 in 3D printing contexts) is a versatile material used across various 3D printing technologies, particularly known for its strength, durability, flexibility and excellent abrasion resistance. Among cons properties are hygroscopic, difficult to print because it requires a heated bed. It can be used for printing gears, hinges and wear-resistant parts.
- TPU (Thermoplastic Polyurethane), is a versatile and flexible material used in 3D printing, known for its rubber-like elasticity, making it ideal for applications that require flexibility and durability. TPU is used in various industries, including automotive, healthcare, and consumer goods like flexible hoses, footwear components, and even prosthetics. Printing can be challenging due to its elastic properties, that requires careful handling to avoid issues like clogging and stringing.

In the case of SLA, where materials are resin-based and cured using UV light, for textile applications, the following resins are commonly used [1], [2]:

- Photopolymer Resins, that allows high detail and resolution, smooth surface finish, suitable for jewelry, dental models, miniatures. Often requires post-processing (like curing), can be toxic if not handled properly and it is more expensive.
- Tough or Engineering Resins, which are strong, durable, with properties imitating traditional engineering plastics. Tey are more costly, might need additional curing or post-processing and might be used for functional prototypes, tools or connectors.
- Bio-Compatible and Conductive Resins. These resins are used for skin-safe, medical-grade, and wearable applications in textiles and soft prosthetics. Among the existing products, BioMed Clear Resin is an ISO 10993 certified, used for medical and skin-contact applications; BioMed Amber Resin which is rigid but biocompatible, suitable for semi-flexible textile components; Silicone-Based SLA Resins used for soft, flexible, and skin-safe applications, mimicking textile properties.
- Conductive Resins utilized for E-Textiles and Smart Wearables, are infused with conductive additives, allowing electricity flow for sensors and circuits in textiles. It can use Graphene-Infused Resin, that provides electrical conductivity while maintaining flexibility, Carbon-Nanotube Resins used in flexible circuits for wearable tech or Silver-Based Conductive Resins employed in flexible and stretchable e-textiles for smart garments.

2. THE LATEST DEVELOPPEMENTS IN ADDITIVE MANUFACTURING

However, additive manufacturing in the textile and garment industry is still highly specialized and has only recently started to show its potential for broader adoption. The paper of [3] provides a comprehensive analysis of the advancements and challenges in 3D and 4D textiles using Additive Manufacturing (AM). The authors are claiming that even if significant scientific progress has been made, the field remains in its early stages due to technological limitations in scalability. The study highlights the diverse applications of AM in textiles, including functional filament fibers, direct 3D printing on fabrics, fully 3D-printed garments, and dynamic 4D textiles.

In the case of FDM, a more cost-effective alternative to other 3D printing methods, the authors of [4] are employing FilaFlex, a material providing enhanced wearability. The paper explores the growing role of 3D printing in the fashion industry, emphasizing its potential for garment production. Statistics presented in [5] have shown a strong interest in 3D printed fashion, due to its potential to reduce waste and enable customized or home-based production, responding to the growing demand for sustainable and personalized manufacturing solutions in the fashion sector.

The authors of paper [6] studied the properties of PLA, ABS and TPU in FDM. To create flexible structures with textile-like behavior, TPU, a flexible filament, is preferred over PLA and ABS, which, despite the printing of chain-like structures, did not meet the requirements for a garment collection inspired by Vivaldi’s Four Seasons. Paper [7] provides an overview of the key performance parameters of materials commonly used in FDM printing for textiles and apparel. The authors conclude that ABS and PC require higher printing temperatures than PLA, with PC offering the highest heat resistance and PLA the lowest. As a result, PLA-based garments are unsuitable for high-temperature environments. Additionally, PLA experiences minimal shrinkage compared to ABS and PA. In terms of tensile strength, PLA, PC, and PA perform well, whereas TPU has the lowest tensile strength. Other authors [8] had innovated new chainmail-like structures that blend creativity with wearability, that are enhancing softness, comfort and flexibility in 3D printed fabrics made from polymers. The structures are inspired by ancient chain mail armor, composed of interlocking hollow nylon polymer octahedrons. These fabrics can transition from a flexible, fluid-like state to a rigid, load-bearing structure under pressure, offering potential applications in wearable technologies and motorcycle gear, exoskeletons, and even military-grade apparel.

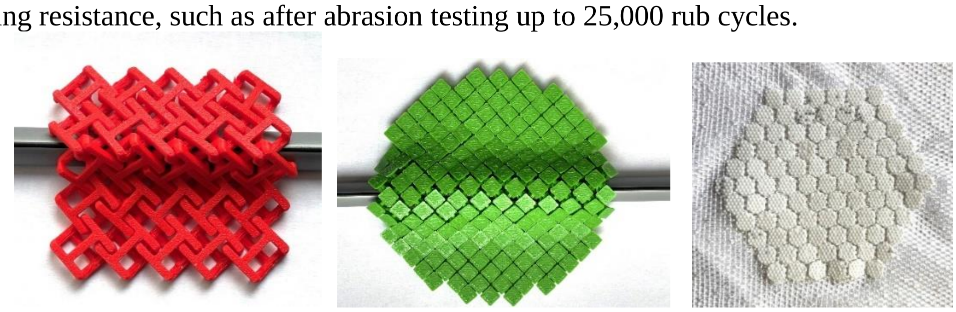
Fig. 1*: Printed parts assembled in a dress with stitches and belts [4]*

Paper [9] resume design methods for auxetic mechanical metamaterials, which exhibit a negative Poisson's ratio and unique deformation properties. Traditional auxetic materials have lower mechanical stiffness, but recent advancements have led to high-stiffness designs suitable for energy absorption, load-bearing, and thermal-mechanical applications. It also explores multifunctional applications, including textiles and apparels, aiming to provide guidelines for developing auxetic materials with tailored mechanical properties.

The relationship between design parameters and the mechanical properties of 3D printed wearable interfaces made from soft materials like TPU are described in [10]. It focuses on how factors such as strand thickness, strand distance, rotation angle, and layer height influence tensile strength, elongation at break, and Young’s modulus. The research introduces a modeling technique for flexible mesh structures and provides experimental analysis to understand these effects. A regression model is developed to guide future design considerations for 3D printed flexible structures in wearable applications. The paper of Wirth et al. [11] explores the mechanical characterization of 3D printed biaxial weaves, enabling complex yarn structures and enhanced manufacturing flexibility. A generative model is developed to analyze the relationship between design parameters and mechanical properties using a two-stage Design-of-Experiments approach. Samples are made by material jetting and tested under tension, revealing a bilinear stress–strain behavior influenced by load direction, weave pattern, yarn diameter, and spacing. The study also highlights reduced layer-wise delamination, demonstrating the potential of material printing for creating quasi-continuous textile structures with tunable mechanical properties.

Paper [12] proposes a parameter optimization method combining the Kriging model and Cuckoo Search (CS) algorithm for enhancing the tensile strength in FDM for 3D printed PLA parts. Printing speed and temperature were analyzed, with optimal values determined as 31 mm/s and 225°C, respectively. The Kriging model demonstrated high accuracy, with a prediction error of only 0.62%, validating its effectiveness in optimizing FDM process parameters. In the paper of Lekeckas et al. [13], the adhesion strength between 3D printed materials and chiffon fabrics are investigated in order to enhance garment functionality. By testing different fabric and material combinations using uniaxial tensile tests, the research demonstrates that 3D printed TPU elements can improve the comfort and durability of low-elasticity chiffon garments. The proposed system enables garment renewal, repair, and customization, extending the functional and aesthetic possibilities of clothing within a sustainable framework.

Two fabric types, weft knitted and braided, obtained by 3D printing methods with PLA filaments, were tested for mechanical properties in [14]. The research includes one yarn knitted structure and diamond, Hercules, and triaxial braids. Results showed that the weft knitted fabrics exhibited good ductility, with a tensile displacement ranging from 12-15 mm and a peak force of approximately 250 N. The braided structures were able to bear significant compressive loads, with displacement at failure exceeding 25 mm. Optical microscope analysis revealed that the yarns contained voids and cracks, contributing to sample failure. The additively manufactured weft knitted fabrics are suitable for wearable, filtration, and geotextile applications, while braided structures are ideal for shock absorption applications. However, challenges remain, particularly in material development, as current 3D printed materials do not yet fully replicate textile properties and often exhibit stiffness. The authors of [15] explore the role of 3D printing, in extending the lifecycle of textiles within a circular economy, by integrating bacterial cellulose and PETG as a printed medium onto fabrics. The method is tested using 3D printed woven samples and standard equipment for determining resistance, such as after abrasion testing up to 25,000 rub cycles.



a. *b.* *c.*

Fig. 2*: FDM printed structures using PLA. a) and b) chain structure; c) hexagonal elements on nylon fabric. Models downloaded from [24] and printed using PLA*

The use of cotton fibers as a raw material for 3D printed textiles to overcome the flexibility and comfort limitations of current 3D printing materials in presented is [16]. By dissolving cotton fibers in a LiCl/DMAc solvent and incorporating hydroxyethyl cellulose, a printable ink was developed and processed using material extrusion. The research optimized dissolution, ink viscosity, and post-processing methods, leading to improved flexibility, breathability, and moisture absorption in 3D printed cellulose fabrics compared to conventional 3D printed textiles. Additionally, these fabrics exhibited superior abrasion resistance over traditional cotton fabrics. As a proof of concept, garments and gloves were successfully produced, demonstrating the potential of this approach for producing flexible, wearable 3D printed textiles. Other authors have enhanced flexible materials by incorporating reinforcing fibers or infill particles, improving performance while also giving printed textiles and garments unique qualities [17], [18], [19], [20]. 3D printing also has applications in footwear, both for uppers and soles. According to tests conducted in paper [7], functional footwear, such as 3D printed upper of the FDM sports shoes incorporating layers of TPU fibers, offers advantages like lightweight (aprox. only 197 g), good moisture absorption, and enhanced comfort. The design not only minimizes weight but also reduces energy consumption during long-distance runs. Beyond the upper, the FDM process is also widely used for 3D printing soles using TPU material, as Latiz technology [7], and also by Nike, Adidas, and New Balance [21].

Many studies position 3D printed garments as a complementary innovation rather than a replacement for traditional fashion. With its benefits of low cost, considerable creative freedom, and a variety of material options, 3D printing has been advocated in the textile industry [22]. This type of technology combined with smart materials with shape memory opens a new avenue for exploring 4D printed smart textiles. The essential elements of 4D printed smart textiles, therefore, include the development and synthesis of new materials with different responsive forms using equipment and the ability to print complex shapes using advanced additive manufacturing techniques [23], [7].

3. CONCLUSIONS

Combining 3D printing with smart materials (shape memory, elastic liquid crystals, hydrogels), it enables the development of 4D printed intelligent textiles with environmental adaptability. The key to 4D printed textiles lies in creating new materials that respond to external stimuli (humidity, temperature, light, pressure, electric and magnetic forces) and have the ability to print complex shapes and new colors using advanced techniques.

The 3D printing sector is projected to experience substantial growth, offering considerable advancements for the textile industry. Recent innovations in manufacturing, such as the introduction of precision alignment stations have significantly enhanced the capabilities of high-end fashion printing. In terms of sustainability, 3D printing techniques are instrumental in reducing waste and fostering sustainable manufacturing practices through precise production methods. This technological evolution also supports customization, enabling the creation of personalized garments and unique designs, thereby transforming conventional manufacturing paradigms. A shift towards localized manufacturing is evident, promoting faster and more cost-efficient production processes. Optimal results in 3D printing are achieved with the use of open-weave fabrics such as tulle, which allow for superior adhesion between printed layers. 3D printing can reinforce and repair materials, constituting an alternative to traditional assembly technologies while extending product lifespan and conserving raw materials. The most inspiring part of these advancements is their transformation of our perspective on textile and fashion production. Rather than relying on conventional manufacturing techniques, the industry is shifting toward a digital, adaptable, and eco-friendly approach that not only meets market demands but also minimizes environmental impact.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

ANALYTICAL AND CONTROL METHODS FOR ASSESSING QUALITY AND NON-QUALITY PARAMETERS. A CASE STUDY PART I

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Abstract: *In this study, a case analysis was conducted to evaluate the application of graphical and tabular methods in monitoring and controlling both quality and non-quality parameters of webbings manufactured using a webbing loom. The analysis and control of product and process quality can be achieved through various methods, including graphical, tabular, and matrix-based approaches. To address most quality-related issues, graphical methods known as the Seven Basic Quality Tools can be employed. These include the cause-and-effect diagram (also known as the fishbone diagram or Ishikawa diagram), the histogram, the Pareto chart, the scatter diagram, the stratification diagram (also referred to as the process diagram or data sequence diagram), the check sheet, the control chart and tabular methods. Information presented through charts and tables is structured in a way that enhances clarity, making it easier to comprehend and retain.*
Charts are two-dimensional visual representations that facilitate easy and quick understanding of the situation and the analyzed data, allowing for the rapid identification of trends, relationships, and variations in the characteristics being examined. They can be used to highlight patterns within a dataset, compare information, and support decision-making. Tables are structured in a matrix format and are used to present data in a clear and systematic manner. Unlike charts, which provide a quick visualization of trends, tables allow for a detailed and precise presentation of information. They are particularly useful when accurate comparison of values is required or when access to specific individual data points is necessary.

Key words: *Graphical methods, tabular methods, webbing, defects, quality*

1. INTRODUCTION

In a globalized and competitive economy, quality is a key determinant of an organization's success. The concept of quality not only refers to compliance with standards but also to customer satisfaction, process efficiency, and cost optimization. On the other hand, non-quality results in significant losses, including scrap, repairs, complaints, and the loss of customer trust. [1], [2]. This paper aims to analyze several methods through which quality can be ensured and the impact of non-quality. In the webbing industry, where safety and reliability are critical, a rigorous approach to quality is essential to avoid significant risks, such as structural defects or accidents. [3].This paper aims to demonstrate the importance of the systematic analysis of defects and the factors that generate them, thereby contributing to process optimization and the improvement of product or service quality [4], [5].

2. GENERAL INFORMATION

In quality control practice, [6], [7], [8] there are different types of cause-and-effect diagrams (Ishikawa) that vary in terms of structure, the way causes are organized and systematized, and the purpose for which the diagrams are used, such as:

a) Diagrams for analyzing the variation of quality characteristics
b) Diagrams structured by process stages
c) Diagrams for listing causes

The cause-and-effect diagram is used for the following purposes:

- ✓ To identify potential causes of a known effect
- ✓ When working in a team, to foster a common understanding of the problem's causes and their interrelationship
- ✓ To highlight other causes of the desired effects
- ✓ It is preferably used when a problem exists and the causes are primarily hierarchical

The Pareto chart is a graphical method that highlights the relative frequency of various issues or characteristics (scrap, defects, complaints, errors, etc.) and presents the information in descending order, from the most frequent to the least frequent. The column chart is accompanied by a concave curve, plotted on the same graph, representing the cumulative percentages of the columns

3. RESULTS AND DISCUSSIONS

The defects in the fabric are determined by factors such as the technical condition of the weaving machines, the quality of the warp and weft threads, the operation of the weaving machines, the quality management system, a.s.o. By recording the defects occurring per 1000 meters of webbing produced on the webbing loom, the following defects were identified, as shown in Table 1

Table 1: *Types of Defects*

No.	Defect	Defect Image	No.	Defect	Defect Image
1.	Yarn Binding Errors		5	Frayed/ Destroyed Webbing (nests)	
2.	Weft Yarn Omission		6.	Warp Yarn Omission	

3.	Warp Float with Varying Lengths	 	7.	Knots	
4.	Over-Tensioned Warp Yarn				

3.1. The **C Method (Causes)** is a quality analysis technique with a preventive character, focused on identifying the root causes that lead to defects. It emphasizes the investigation of the underlying causes of a problem, rather than merely addressing symptoms. [9]. This method enables the logical categorization of contributing factors, facilitating a more structured and efficient analysis. One of the variations of this method is the cause-and-effect diagram, also known as the fishbone diagram or Ishikawa diagram. This tool allows for the identification of potential quality issues and the development of optimal solutions within a sufficiently short timeframe, ensuring that delays in the production flow are avoided. [10],[11],[12] The Ishikawa diagram is a fundamental tool in quality analysis, primarily used for product design and defect prevention. For practical analysis, developing a cause-and-effect diagram involves applying the brainstorming technique to identify the potential causes of a problem, which are then progressively detailed into primary, secondary, and tertiary categories, along with specific contributing factors. [13],[14],[15] When analyzing the causes of variation in a quality characteristic — regarded as the effect — the six categories of influencing factors, known as the 6Ms, are: Man (human resources and workforce), Machine (equipment and technological systems), Material (raw materials and components), Method (operational and organizational procedures), Measurement (inspection and control methods), and Environment (ambient conditions affecting the process). [9].

When analyzing the quality of a product during both the manufacturing phases and its usage, it may be observed that in some cases, incompatibilities arise between these two types of quality. To manage such incompatibilities, the Ishikawa method can be applied, [16] which classifies quality and non-quality characteristics into primary (those that directly influence the end user's experience) and secondary categories.

For some of the defects presented in Table 1, the primary and secondary factors are identified. For the defect “knots” it is considered that two primary factors interact, namely: the raw material and the weaving machine, as presented in Table 2. Other factors exert an indirect influence.

Table 2: *The factors influencing the formation of knots*

Raw material	The direction of influence	Weaving machine	The efect	The knot type
Over-twisted weft or warp	→	High tensions in the yarn	Yarn breakage caused by the working components in contact with the yarn	Improper knots caused by yarn over-tensioning
Yarn with excessively large knots	→	Improper functioning of the yarn monitoring devices	Weaving yarns with excessively large knots	Knots from previous stages of weaving
Yarn damage	←	Working components in contact with the yarns	Yarn breakage	Improper knots caused by yarn over-tension
High-tensioned yarn	→	Mismatch of the technological parameters of the weaving machine	Frequent yarn breakage	Improper knots caused by excessive yarn tension

The Ishikawa diagram applied in the analysis of the knots in the fabric is presented in Figure 1.

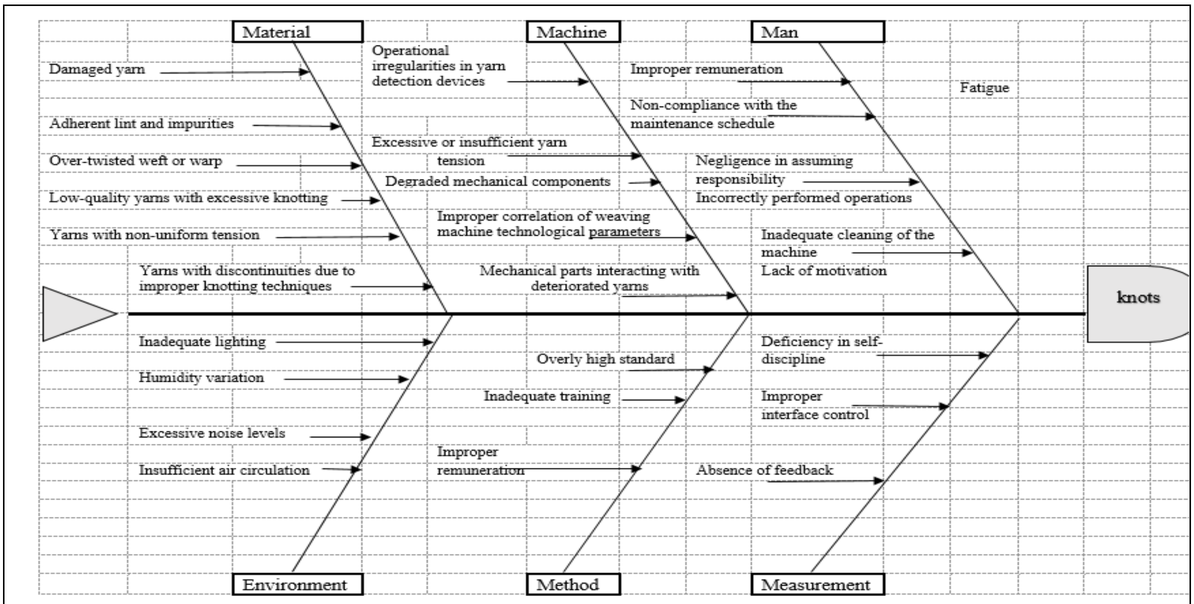

Fig. 1*: Ishikawa diagram applied in the analysis of the knots*

For the 'missing weft yarn' defect, it is considered that two primary factors interact, namely: the raw material and the weaving machine, as presented in Table 3. Other factors exert an indirect influence.

Table 3: *Factors influencing the missing weft yarns*

Raw material	**The direction of influence**	**Weaving machine**	**The efect**	Type of defect
Yarn with thinning	→	High tension in the yarn	Yarn breakage	Missing weft yarns due to yarn breakage
Broken weft yarn	→	Defective weft yarn detection sensors	Operation of the weaving machine without weft yarn	Missing weft yarns due to improper functioning of the weaving machine
Incorrect weft yarn feeding	←	Malfunctions in the weft yarn feeding mechanism	Operation of the weaving machine without weft yarn	Missing weft yarns due to improper functioning of the weaving machine
Overstress of the weft yarn	←	Mismatch between the needle mechanism and the weft yarn feeding mechanism	Yarn breakage	Missing weft yarns due to yarn breakage

The Ishikawa diagram applied in the analysis of the missing weft yarn defect is presented in Figure 2.

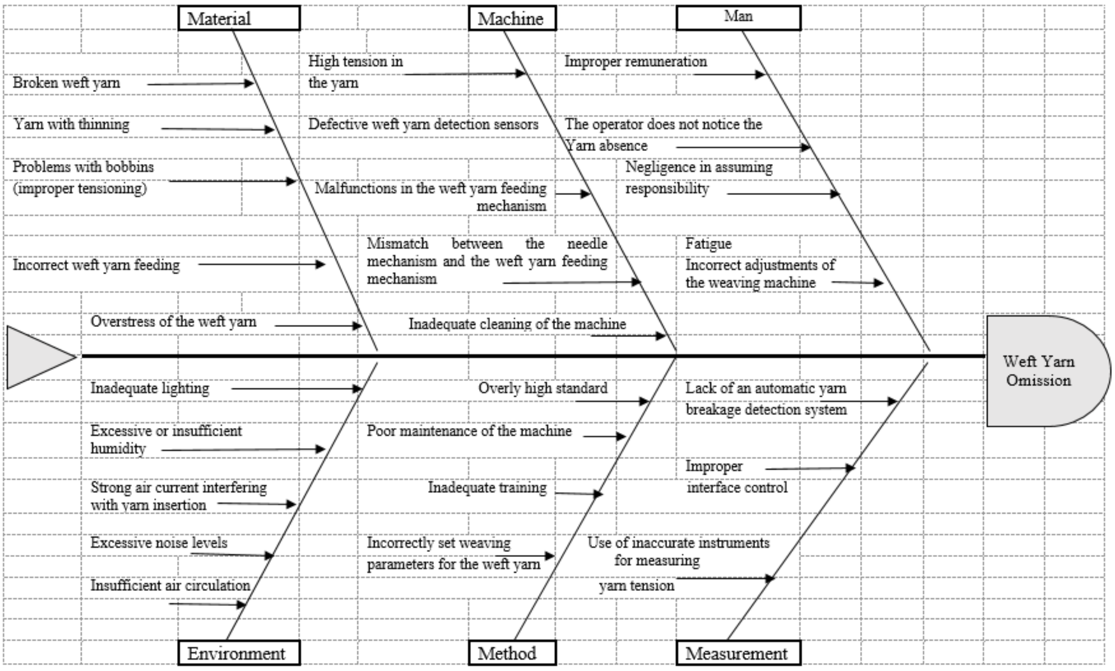

Fig. 2*: Ishikawa diagram applied in missing weft yarn*

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ANNALS OF THE UNIVERSITY OF ORADEA
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ANALYTICAL AND CONTROL METHODS FOR ASSESSING QUALITY AND NON-QUALITY PARAMETERS. A CASE STUDY PART II

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Key words: *Graphical methods, tabular methods, webbing, defects, quality*

3. RESULTS AND DISCUSSIONS (continuation)

3.2. CP Method (Causes, Remediation Possibilities)

Using this method, the main defect-causing factors and possible remediation options can be identified through preventive and corrective actions. Preventive actions are taken with the aim of avoiding the occurrence of defects and include proper organization, ensuring that the production process is carried out under optimal conditions, and implementing appropriate measures for transportation, packaging, and storage. Corrective actions are implemented when an issue arises, and measures must be taken on both machines and products to eliminate or mitigate the problem. Table 4 presents the correspondence between the causes of defects and the remediation options.

Table 4: *Defects – Causes – Remedies in webbing weaving machines*

No.	Defect	Causes of defect occurrence	Corrective and Preventive Actions
1.	Yarn binding errors	- malfunction of the shed formation mechanism -incorrect command for the heddle movement	-inspection and adjustment of the shed mechanism -correct handling of shed searching -adjustment of the warp and weft yarn control mechanisms -adjustment of the shed searching mechanism
2.	Missing weft yarn	-malfunctions in the weft yarn feeding -malfunctions of the weft yarn feeding mechanism --errors in shed selection during yarns -breakage clearance -improper adjustment of the temple	-inspection of the weft bobbins before use - proper adjustment of the weft yarn controller and the main shaft brake - inspection and adjustment of the shed mechanism
3.	Warp yarn floating with varying lengths	- yarn tension release - incorrect shaft position - defective healds - slub - different warp yarn contractions - low warp tension - improper adjustment of the shed	- bobbins inspection - healds Inspection - removal of slubs - proper adjustment of the shed - increased attention to the warping operation
4.	Excessively tensioned warp yarn	-overloading of the yarns due to lint -tension differences between the warp yarns -stuck yarns -defects in the yarn knotting operation	-air blowing for cleaning the heddles -proper use of spools -proper adjustment of the yarn tensioning devices -proper positioning of the bobbins in the rack
5.	Frayed/ Destroyed Webbing (nests)	-warp yarn breakage -warp yarn snagging - lint - devices not replaced on time on the weaving machine -use of inappropriate yarns (linted, with thinning and thickening)	-inspection of yarn bobbins -performing preventive maintenance -carrying out current repairs -removal of lint
6.	Missing warp yarn	- incorrectly adjusted machine -improper functioning of the warp controller -non-compliant accessories leading to warp yarn breakage -use of warp yarns with different tensions -breaking of heddle teeth -operator negligence -improper microclimate	-proper adjustment of the machine -Proper adjustment and maintenance of the warp controller -replacement of worn accessories -adjustment of the warp yarn tension
7.	Knots	-large yarn end lengths -incorrect joining of warp or weft yarns -too large knots	-stronger knots - use of knotting machines - familiarizing operators with the proper knotting procedure

3.3 The frequency method

The frequency of each defect is determined by formula (1)

$$\text{Frecvency} = \frac{\text{Number of defects}}{\text{Controlled length}} \cdot 100 \quad (1)$$

Table 5: *Frecvency of defects*

No	Defect type	Number of defects	Frecvency (defects /100 m)
1.	Warp yarn floating	70	7
2.	Missing weft yarn	49	4,9
3.	Excessively tensioned warp yarn	13	1,3
4.	Yarn Binding Errors	12	1,2

5.	Knots	8	0,8
6.	Missing warp yarn	7	0,7
7.	Frayed/ Destroyed Webbing (nests)	5	0,5

If the frequency is >1 defect per 100 meters, it is considered that exists a recurring issue, and corrective actions must be taken (Warp yarn floating, Missing weft yarn, Excessively tensioned warp yarn, Yarn binding errors.

If the frequency is between 0,5 and 1 defect per 100 meters, the process is monitored, and are checked possible adjustments (Knots, Missing warp yarn, Frayed belt (nests)).

If the frequency is <0.5 defects per 100 meters, the defect is considered minor and does not require urgent interventions.

Corrective actions: are presented in table no. 4.

Conclusion: This method enables a clear assessment of fabric quality and contributes to the reduction of defects during the manufacturing process [1]

The Pareto method is a graphical tool with wide-ranging applications, based on the frequency of defect occurrence over time (e.g., number of defects per unit time) or relative to the product (e.g., number of defects per square meter, per meter, per kilogram of product, etc.). [2], [3].

Industrial practice has shown that only two or three types of defects account for the highest proportion (70–80%) of total occurrences, generating the most significant losses in production efficiency and product quality.

For the application of the Pareto chart in defect analysis, the following steps can be undertaken [4], [5]:

- identification of potential defects and the method of recording them
- determination of the data collection period
- calculation of defect frequency and documentation in the observation sheet
- construction of the Pareto chart

Table 6: *Defect frequency*

No.	Defect type	Number of defects	Percentage, %	Cumulative number of defects	Cumulative percentage,%
1	Warp yarn floating	70	42,7%	70	42.7%
2	Missing weft yarn	49	29,9%	119	72,6%
3	Excessively tensioned warp yarn	13	7,9%	132	80,5%
4	Yarn Binding Errors	12	7,3%	144	87,8%
5	Knots	8	4,9%	152	92,7%
6	Missing warp yarn	7	4,3%	159	97,0%
7	Frayed/ Destroyed Webbing (nests)	5	3,0%	164	100,0%

The Pareto chart [6], obtained by plotting the defects on the x-axis in descending order of frequency, with the number of defects on the left y-axis and the cumulative percentage on the right y-axis, is shown in Figure 3.

Analyzing the Pareto chart obtained, it can be observed that the first two types of defects account for over 70% of the total defects. The red line represents the cumulative percentage of defects and is crucial in Pareto analysis, helping to identify the causes that have the greatest impact on the problems. Each point on the red line indicates what percentage of the total defects could be eliminated if we focus solely on the primary causes of defects.

Looking at the first two bars (Warp yarn float and Missing weft yarn), the red line indicates that they account for over 70% of the total defects. This suggests that if the company improves these two aspects, it could resolve the majority of the defects without necessarily focusing on the other, less significant causes. In practice, the red line helps apply the 80/20 principle: 80% of the defects are caused by 20% of the problems. Without this line, it would be more difficult to identify this pattern.

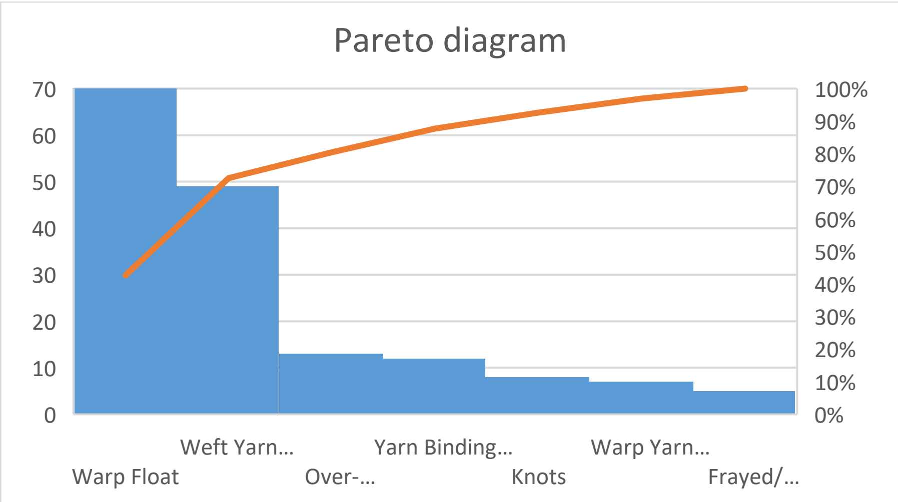

Fig. 3: *Pareto Diagram*

If the first two types of defects (Warp yarn float and Missing weft yarn) are associated with their root causes (yarn tension release, incorrect shaft position, defective healds, slub, different warp yarn contractions, low warp tension, improper adjustment of the shed, defects in the machine's weft feeding system, malfunctions of the weft yarn feeding mechanism, errors in shed selection during yarns breakage clearance, improper adjustment of the temple) presented in table no. 4 . The most effective corrective and preventive actions to improve the quality of webbings can be established, concomitant with the increase in machine productivity - bobbins inspection, healds Inspection, removal of slubs, proper adjustment of the shed, increased attention to the warping operation, inspection of the weft bobbins before use, proper adjustment of the weft yarn controller and the main shaft brake, proper adjustment of the weft yarn controller and the main shaft brake, inspection and adjustment of the shed mechanism.

Based on this diagram, both the defects of the products and an analysis of the machine malfunctions involved in the process, as well as the planning of maintenance activities, can be analyzed.

Conclusion: By directing preventive and corrective actions towards the defects with the highest weight, an improvement in product quality can be achieved, resulting in an increase in economic efficiency.

3.4. The MGF method (size, gravity, frequency)

Is used to assess production defects based on three factors:

- ✓ **Size** – the dimension of the defect in relation to the product (1 – minor, 5 – major),
- ✓ **Severity** – the impact of the defect on functionality and quality (1 – insignificant, 5 – critical),
- ✓ **Frequency** – how often the defect occurs (defects /100 m).

The score is calculated as follows: MGF Score = M x G x F

Table 7: *The MGF method*

No.	Type of defect	Size (1-5)	Gravity (1-5)	Frecvency (defects /100 m)	Scor MGF	Risk classification
1.	Warp yarn floating	3	4	7	84	Very high
2	Missing weft yarn	5	5	4,9	178,43	Very high
3	Excessively tensioned warp yarn	3	3	1,3	11,7	Low
4	Yarn Binding Errors	2	5	1,2	12	Low
5	Knots	2	4	0,8	6,4	Low
6	Missing warp yarn	5	5	0,7	17,5	Low
7	Frayed/ Destroyed Webbing (nests)	4	5	0,5	10	Low

The following scales can be used:

- 1-3 – for quick and simplified evaluations (1 – minor, 2 – medium, 3 – major), used when detailed analysis is not required.
- 1-5 – for precise and simplified evaluations (1 – minor, 3 – medium, 5 – major), most commonly used in production.
- 1-10 – for finer evaluations (1-3 – minor defect, 4-6 – medium defect, 7-9 – major defect, 10 – critical defect), used when there are large variations in the impact of defects.

Interpretation table:

- Score 1-20 – low risk – requires standard monitoring and quality control.
- Score 21-40 – medium risk – requires stricter monitoring and quality control.
- Score 41-60 – high risk – requires optimization and quick interventions to prevent major defects.
- Score >60 – very high risk – critical issue, requires revision of the manufacturing process.

Proposed measures:

- ✓ For Floating Warp Yarn – score 84 – high risk:
  It is necessary to check the bobbins, check the heddles, remove lint, and properly adjust the shed formation mechanism.
- ✓ For Missing Weft Yarn – score 178.43 – high risk:
  It is necessary to check the weft bobbins before use, properly adjust the weft yarn controller and the main shaft brake, and inspect and adjust the shed formation mechanism.
- ✓ For Excessively Tensioned Warp Yarn – score 11.7 – low risk:
  It is necessary to blow air to clean the heddles, use the dividing correctly, properly adjust the yarn tensioning devices, and properly position the bobbins in the rack.
- ✓ For Yarn Joining Errors – score 12 – low risk:
  It is necessary to inspect and adjust the shed formation mechanism, adjust the warp and weft yarn control mechanisms, and adjust the shed searching mechanism
- ✓ For Knots – score 6.4 – low risk:
  It is necessary to make firmer knots, use knotting machines, and familiarize operators with the proper knotting procedure.
- ✓ For Missing Warp Yarn – score 17.5 – low risk:
  It is necessary to properly adjust the machine, ensure correct adjustment and maintenance of the warp controller, replace worn-out accessories, and adjust the tension of the warp yarns.

- ✓ For Frayed Ropes (Nestings) – score 10 – low risk:
  It is necessary to check the yarn bobbins, perform preventive maintenance, carry out current repairs, and remove lint.

Conclusion: The MGF method allows for an objective and efficient assessment of defects resulting from the weaving of cords and enables quick decision-making to improve the quality of the cords.

4. CONCLUSIONS

- The Pareto diagram is a fundamental tool in decision-making regarding quality improvement.
- By directing preventive and corrective actions towards the defects with the highest weight, an improvement in product quality and, implicitly, an increase in economic efficiency can be achieved.
- The Ishikawa diagram, used in the analysis of industrial processes (product design and quality defect prevention), quickly identifies major causes, which are then broken down into sub-causes and further subdivisions.
- Identifying the main types of defects and their causes has allowed the proposal of effective corrective measures aimed at reducing error rates and improving the quality of the final product.
- The methods used, such as Ishikawa and Pareto diagrams, have highlighted that most problems are generated by factors related to machine parameters and raw materials.
- By implementing corrective actions, production can be optimized, minimizing losses and increasing customer satisfaction.
- This case study confirms the effectiveness of quality and non-quality analysis techniques in defect prevention and in increasing the competitiveness of the textile industry.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

APPLICATION OF KERMES OAK (*QUERCUS COCCIFERA*) IN LEATHER DYEING: A NATURAL AND SUSTAINABLE APPROACH

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Abstract: *Leather, as an organic material, has been used and continuously developed since ancient times, maintaining its value through various dyeing and finishing techniques. Although the widespread use of synthetic dyes led to a decline in the use of natural dyes, recent concerns about environmental impact and health hazards have renewed interest in natural alternatives. This study explores the dyeing potential of kermes oak (Quercus coccifera), a species of the Fagaceae family native to the Mediterranean region of Anatolia, as a sustainable natural dye source for leather. The effects of dyeing temperature (60°C, 80°C, and 100°C) and mordant concentration (0.5%, 1%, and 1.5%) on the color and color strength (K/S) of leather were systematically investigated. The most intense and uniform coloration was achieved at 100°C with a 1.5% mordant ratio. The results highlight the effectiveness of kermes oak in producing aesthetically pleasing and environmentally friendly dyeing results. Overall, this study demonstrates the potential of natural dyes to serve as viable, eco-conscious alternatives to synthetic dyes in leather production, contributing to sustainable practices in the leather industry.*

Key words: *Leather, dyeing, kermes oak, Quercus coccifera, natural dye, coloration*

1. INTRODUCTION

Until the mid-nineteenth century, natural dyes represented the sole source of coloration for textiles and garments across the globe [1]. These dyes were not only utilized in textile applications but also extensively used in the dyeing of leather and furs, as evidenced by various studies [2], [3]. These practices show how natural dyes served as essential agents for coloration in multiple materials until synthetic dyes were introduced.

Natural dyes are renewable, biodegradable, and non-toxic, making them a promising alternative for reducing the environmental impact of synthetic dyes [4], [5]. However, despite these ecological benefits, natural dyes often exhibit limitations in terms of color vibrancy, shade diversity, and durability, particularly concerning fastness to light, washing, and rubbing. To address these challenges, the use of mordants—substances that facilitate dye fixation on fibers and enhance fastness properties—plays a crucial role [6].

For centuries, one of the primary plant sources of natural dyes used in leather dyeing has been the Kermes oak (*Quercus coccifera*). It belongs to *Quercus* genus (Fagaceae), which comprises over 200 species, in the temperature areas of Northern hemisphere and tropical mountains and found in Southern Europe from Portugal to Turkey [7]. Previous researches demonstrated that Kermes oak can be effectively used as a natural dye for coloring textile fabrics [8] and wool [9].

Despite the extensive use of Kermes oak as a natural dye in textile applications, no studies have been identified in the literature regarding its potential for leather dyeing. Given the growing demand for sustainable and eco-friendly alternatives in the leather industry, this study aims to explore the feasibility of using Kermes oak as a natural dye for leather. Furthermore, the research examines the influence of key dyeing parameters, specifically temperature and mordant ratio, on color uniformity and strenght. By addressing these aspects, the study seeks to contribute to the development of environmentally sustainable dyeing methods for leather.

2. EXPERIMENTAL

2.1 Material

Twelve crust sheep leathers from the Metis breed were used in this study. The root woods of *Quercus coccifera* (Kermes oak) (Figure 1.a) were collected from the forest region of Hatay, located in the southern part of Turkey (humid climate, 36°45′ N, 36°26′ E) during November 2024. The harvested woods were air-dried at room temperature and subsequently ground into sawdust (Figure 1.b). The experimental design can be seen in Table 1.

Fig. 1: *The woods (a) and sawdust (b) of kermes oak*

Table 1: *The layout of the experimental design*

Code	Mordan Ratio (%)	Temp. (°C)
A1	non-mordant	60
A2	non-mordant	80
A3	non-mordant	100
B1	0.5	60
B2	0.5	80
B3	0.5	100
C1	1	60
C2	1	80
C3	1	100
D1	1.5	60
D2	1.5	80
D3	1.5	100

Copper sulfate, obtained in technical grade from BOR-KİM Chemicals, was used as a mordant due to its minimal influence on altering the inherent color of the leather during the dyeing process. As a fatliquoring agent, a high lightfastness, electrolyte-stable, and colorless sulfone oil from TFL was employed.

Color measurements were conducted using a Konica Minolta CM-3600d spectrophotometer under a CIE D65 light source and a 10° standard observer angle.

2.1 Methods

2.1.2 Extraction Process and Extraction Yield

Dried *Quercus coccifera* (Kermes oak) sawdust (40 g) were weighed and boiled in 1 liter of water at 90°C for 1 hour to initiate extraction. Following the boiling process, the mixture was allowed to stand at room temperature for 24 hours to enhance the extraction efficiency. Afterward, the solution was filtered to obtain the extract. The resulting extract was transferred into a glass dish and dried in a hot-air oven at 100 ± 2°C until complete evaporation of the water content, ensuring the residue reached a constant weight. The total solid content was determined by weighing the remaining residue in the dish. The extraction yield was calculated using the following equation (1):

$$Evaporation\ Residue\ \left(\frac{mg}{L}\right) = (A - B) * 1000/\ V \quad \textbf{(1)}$$

A = Total weight of the evaporation dish and solid residue (mg)
B = Weight of the empty evaporation dish (mg)
V = Volume of the sample (mL)

2.1.3 Leather dyeing

The initial weights of the crust leathers were recorded prior to processing. The recipe applied to the crust leathers is presented in Table 2. The temperatures (60, 80, and 100 °C) and mordant concentrations (0.5, 1, and 1.5%) used in the process are specified in the recipe.

Table 2: *Dyeing recipe*

Process	Amount (%)	Chemicals	Temp. (°C)	Time (min.)
Rewetting	100	Water	50	
	0.5	Wetting agent (Nonionic)		60
Washing	100	Water	40	45
Dyeing	60	Water	***60/80/100***	
	2	Dye auxiliary material (Ethoxylated fatty amine sulphate)		15
	5	Dye (Kermes oak extract)		60
	0.5/1/1.5	Mordant (Copper Sulfate)		45
	3	Fatliquor agent (Combination of synthetic fatliquors and esters)		40
	2	HCOOH		30 (10*3)
Washing	100	Water	30	45 (3*15 min)

2.1.4 Determination of color measurement

A Konica Minolta CM-3600d spectrophotometer was used to quantitatively assess the color differences of leathers dyed using different ratio of mordants and temperatures. Color measurements were conducted in accordance with the CIE L^*, a^*, b^* color system. In this system, the L^* value represents the lightness of the color, ranging from 0 (black) to 100 (white). The $a*$ value indicates the position of the color on the red-green axis, where negative values correspond to green and positive values to red. Similarly, the $b*$ value denotes the position on the blue-yellow axis, with negative values indicating blue and positive values indicating yellow.

To ensure accuracy and consistency, color measurements were taken from five distinct points on the leather surface using the standard measurement area of the device, and the mean of these readings was calculated.

Additionally, the color strength (K/S) values were calculated at the maximum absorption wavelength (λmax = 400 nm) using the Kubelka–Munk equation (2). K is the scattering coefficient, S is the absorption coefficient, and R is the reflectance. R is the decimal fraction of the reflectance of dyed leather, R = 1.0 at 100% reflectance. This approach allows for an objective evaluation of the dyeing efficiency and color performance of the processed leathers.

$$K/S = (1 - \mathrm{R})^2 \,/2R \qquad \textbf{(2)}$$

3. RESULTS AND DISCUSSIONS

3.1. Extraction Yield

A total of 1000 mL of kermes oak extract was obtained through aqueous boiling, and the extraction yield was determined to be 14.57% based on the dry matter content of the plant material.

3.2. Color Measurement Findings

The color measurement results for the leathers are provided in Table 3. According to the CIE Lab color system, the $L*$ values range from 60.82 to 70.41, indicating a general trend towards lighter shades, especially in the A and B group samples. Samples A1 and A2 have the highest $L*$ values (70.17 and 70.41, respectively), suggesting they are the lightest among the group. In contrast, sample D3 shows the lowest $L*$ value (60.82), reflecting a relatively darker appearance.

The $a*$ values, which represent the red-green axis, ranged from 1.09 to 6.47 across the dyed samples and increase progressively from group A to group D. A1 and A2 have values close to 1, whereas C3 and D3 reach over 6. Given that undyed crust leather typically exhibits low $a*$ values due to its slightly greenish undertone, the observed increase after dyeing suggests a clear shift toward the red axis. This trend is consistent with the inherent reddish hue of kermes oak extract, which enhanced the red component in the leather, contributing to a warmer and more vibrant appearance.

Since undyed crust leather typically displays a slightly bluish-green undertone, the increase in $b*$ values observed in all dyed samples — ranging from 12.42 to 17.32 — indicates a noticeable shift toward the yellow axis after dyeing. This shift reflects the influence of the reddish hue of kermes oak extract, which effectively counteracted the cool base tone of the crust leather.

Regarding the K/S values, which are associated with the color depth or saturation, a notable increase is observed from A1 (1.16) to D3 (2.57). This gradual enhancement suggests that the leather samples in later groups (especially D3 and C3) have more intense and deeper coloration, potentially due to higher dye uptake, which is likely influenced by the increased mordant ratio and temperature during the dyeing process.

As observed in the pseudo colors, the dyed leathers exhibit increasingly darker shades with rising dyeing temperatures. This visual change corresponds with higher K/S values, confirming enhanced dye uptake. The results highlight the significant influence of temperature on the aesthetic outcome, demonstrating the potential of kermes oak to produce rich and appealing tones through controlled dyeing conditions.

Table 3: *The color measurement results*

Code	*L**	*a**	*b**	K/S	Pseudo Color
A1	70.17	1.09	13.84	1.16	
A2	70.41	1.15	14.04	1.23	
A3	68.13	2.90	14.50	1.45	
B1	70.03	2.04	12.52	1.17	
B2	68.85	3.29	14.91	1.32	
B3	64.94	5.14	16.62	1.77	
C1	70.09	2.32	12.75	1.17	
C2	66.92	3.55	14.98	1.61	
C3	62.51	6.47	17.32	2.18	
D1	69.54	1.17	12.42	1.18	
D2	65.72	4.03	15.69	1.78	
D3	60.82	6.47	17.01	2.57	

Figure 2 illustrates the effect of mordant concentration (0–1.5%) on the K/S values at three different dyeing temperatures (60 °C, 80 °C, and 100 °C). The results indicate that increasing the temperature significantly enhances the interaction between the dye and the collagen fibers, leading to higher color strength values. At 60 °C, K/S values remain nearly constant regardless of the mordant ratio, suggesting limited dye uptake due to insufficient thermal activation. At 80 °C, a moderate increase in K/S values is observed as the mordant ratio increases, particularly beyond 1%, indicating improved dye fixation. The most pronounced effect is seen at 100 °C, where the K/S values rise sharply with increasing mordant ratios, reflecting enhanced dye affinity and deeper shade formation. These findings demonstrate that higher dyeing temperatures, in combination with appropriate mordant ratio, facilitate better dye-fiber interactions and result in more intense coloration.

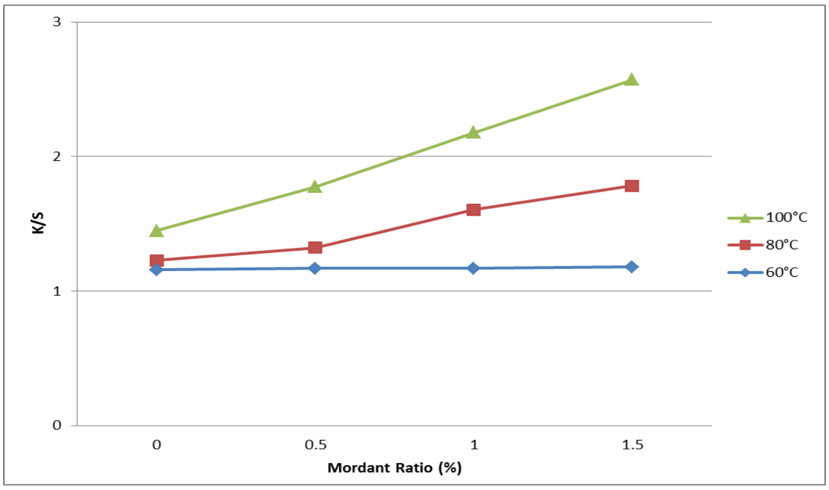

Fig. 2: *The effect of mordant ratio and dyeing temperature on K/S of leather dyed with kermes oak*

4. CONCLUSIONS

This study demonstrated the potential of kermes oak as a sustainable and natural dye source for leather dyeing. The results indicated that variations in mordant concentration and dyeing temperature significantly affected the color tone and uniformity of the dyed leathers. Higher mordant ratios and elevated temperatures generally enhanced color depth, suggesting improved dye-fiber interaction under these conditions. Moreover, the leathers dyed with kermes oak exhibited visually appealing and homogeneous coloration, highlighting the applicability of this natural dye in aesthetic-driven leather applications.

In addition to its technical performance, the use of kermes oak contributes to environmentally responsible leather production by reducing dependence on synthetic dyes and petrochemical-based auxiliaries, which are often associated with ecological toxicity and wastewater pollution. As a locally available, plant-based resource, kermes oak represents a low-impact alternative that aligns with circular economy principles and supports the transition toward greener manufacturing practices in the leather industry.

These findings provide a valuable basis for the development of environmentally friendly dyeing techniques in the leather industry. Future studies may focus on optimizing process parameters for industrial scalability, investigating the long-term stability of the dyed leather, and evaluating the use of kermes oak in combination with other natural mordants or auxiliaries. This research contributes to the advancement of sustainable leather processing practices by promoting the use of bio-based, locally available resources.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

EFFECT OF PHYTIC ACID ON ANTI-FLAMMABILITY IN LEATHER PRODUCTION

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Abstract: *Anti-flammability properties are increasingly demanded in leathers used for upholstery applications in a variety of industries, including furniture, aerospace, automotive and motorcycles. Traditionally, halogen-based compounds have been widely used in the commercial leather industry to impart flame retardant properties. However, due to increasing environmental regulations and the unfavorable environmental and health effects of halogen-based products, bio-based flame-retardant alternatives have attracted great interest in recent years. Considering this, the present study aims to evaluate the efficiency of phytic acid-based retanning agents in enhancing the flame-retardant properties of leather. To investigate the influence of phytic acid on leather flammability, five novel retanning agents were synthesized through various combinations of phytic acid with pentaerythritol, 1,2,3,4-butanetetracarboxylic acid (BTCA), citric acid, and glycerol. These synthesized compounds were applied during the retanning stage of chrome-tanned leather at concentrations of 5% and 10%, calculated based on leather weight. Laboratory analyses conducted on the treated leathers revealed that, with the exception of the formulation containing phytic acid, glycerol, and citric acid, all synthesized phytic acid-based retanning agents contributed to improved flame retardancy and enhanced hydrothermal stability. These findings suggest the potential of phytic acid-based systems as environmentally friendly alternatives for producing flame-retardant leather materials.*

Key words: *phytic acid, anti-flammability, flame retardancy, retannage, leather*

1. INTRODUCTION

Upholstery leathers are used in areas like furniture, aviation, automotive, and motorcycles, where properties such as light fastness, abrasion resistance, and flame retardancy are required [1]. Leather is preferred for its durability, breathability, and abrasion resistance [2]. However, despite its strengths, leather remains flammable due to its natural polymeric structure containing carbon, nitrogen, oxygen, and sulfur [3]. Additionally, chemicals used in tanning, retanning, dyeing, fatliquoring, and finishing can increase its flammability [2].

To expand leather's use in technical fields such as maritime, aviation, and automotive, it must meet certain flame retardancy levels [4]. The automotive industry enforces special flame resistance standards [3]. However, current flame-retardant methods in leather production are limited. These methods typically fall into three categories: halogenated compounds (e.g., chlorinated, brominated), halogen-free options (e.g., ammonium phosphate, organophosphorus), and nanocomposites/minerals [1].

Halogenated flame retardants are cost-effective but have been banned in textiles due to environmental and health risks [5]. As a result, industries are shifting toward safer alternatives. In leather, research has focused on phosphorus-nitrogen compounds, nanocomposites, fullerenes [6], and mineral-based flame retardants—all showing promising results. These compounds are mostly applied during retanning and finishing, and occasionally during fatliquoring.

Bio-based, renewable substances are also gaining attention. Natural materials like chitosan, lignin, tannic acid, deribonucleic acid, and phytic acid are being explored for flame retardancy in textiles and polymers. Phytic acid, derived from beans, grains, and oilseeds, contains negatively charged phosphate groups that interact well with metal ions and positive compounds [7]. It has shown positive flame-retardant effects in protein-based fibers like wool and silk [5].

Though not previously used in leather, which also has a protein structure, phytic acid is expected to bond strongly with leather's NH_3^+ groups. This study builds on prior research where phytic acid-based esters improved flame retardancy in wool [5]. The goal was to synthesize flame retardants from phytic acid combined with pentaerythritol, BTCA, glycerol, and citric acid, and evaluate their effects on the flame resistance and properties of chrome-tanned leather.

2. MATERIAL AND METHODS

2.1. Materials

Within the context of this study, phytic acid (50% aqueous solution, MW 660 g/mol), pentaerythritol (conc. 99%, MW 136.15 g/mol) and 1,2,3,4-butanetetracarboxylic acid (BTCA) (conc. 99%, MW 234.16 g/mol) were used in the synthesis of flame retardant retannage agents. Also, citric acid (conc. 99%, MW 192.124 g/mol) and glycerol (conc. 90%, MW 92.1 g/mol) were used in the synthesis process with these substances. To occur a comparison group in leather applications, a commercial flame retardant was used as blind. Six wet-blue sheepskins used in the application of the synthesized chemicals were supplied by Akaylar Deri Inc.

2.2. Methods

2.2.1. Synthesis of Flame Retardant Retanning Agents

The synthesis process of the flame-retardant retanning agents is shown in Table 1. It was conducted using a single-neck flask connected to a cooler and heated with a magnetic stirrer. Glycerin, used to achieve the high temperatures required for esterification, filled the pot in which the reaction flask was placed.

Table 1. *Synthesis process of flame-retardant retanning agents*

	Mol	**Weight (g)**	**Temperature (C°)**	**Time (s)**
PAno1				
Phytic Acid	0.01	13.2	130	
Pentaerythritol	0.03	4.08	130	120
BTCA	0.03	7.02	130	30
PAno2				
Phytic Acid	0.02	26.4	130	
Pentaerythritol	0.06	8.16	130	120
Waiting 24 hours in the room temperature (23° C)				
BTCA	0.06	14.04	130	40

PAno3				
Phytic Acid	0.02	26.4	130	
Pentaerythritol	0.06	8.16	130	120
Waiting 24 hours in the room temperature (23° C)				
Citric acid	0.06	11.5	130	40
PAno4				
Phytic Acid	0.02	26.4	130	
Glycerol	0.06	6.1	130	120
Waiting 24 hours in the room temperature (23° C)				
BTCA	0.06	11.5	130	40
PAno5				
Phytic Acid	0.02	26.4	130	
Glycerol	0.06	6.1	130	120
Waiting 24 hours in the room temperature (23° C)				
Citric acid	0.06	11.5	130	40

After each reaction, the pH was adjusted to 4.5–5 with NaOH to make the products suitable for retanning.

2.2.2. Material Characterization Analysis

The quantity of solid substances of the synthesized products was determined by the Shimadzu MOC63 Moisture Analyzer.

Perkin Elmer brand Spectrum-100 model FT-IR+ATR spectrometer device was used in the structural determination of the synthesized flame retardants. IR spectra of the samples obtained in dried solid form were obtained after 4 scans using 2 cm^{-1} resolution power at 4500 - 600 cm^{-1} wavelength.

Differential Scanning Calorimetry (DSC) analysis was performed by Shimadzu DSC-60 Plus on the synthesized substances to examine the changes in their structures when they exposed to heat.

2.2.3. Retanning Processes with Flame Retardants

The PAno1 sample was excluded from retanning due to its unsuitable form, while the other four synthesized samples were used in the retanning of wet-blue leathers at the rates of 5% and 10% based on the leather weight from trial 1 to trial 8, respectively. Similarly, commercial flame retardant was used at the rates of 5% and 10% for trial 9 and 10. In the blank trial, the process was continued without using flame retardant as trial 11. The coding of leather trials can also be seen in Table 2.

2.2.4. Horizontal Flammability Test

The horizontal flammability test was carried out in accordance with ISO 3795 standard in SL-S33 Horizontal Burning Testing Device with the support of Sun Tekstil Inc.. In this test, the burning distance (mm) and burning seconds (min) are obtained and the burning speed rate (mm/min) is obtained.

2.2.5. Vertical Flammability Test

The vertical flammability test was carried out in accordance with the ISO 15025 standard on the SL-S18T Vertical Combustion Test Device with the support of TDU Defense and Trade Inc.

3. RESULTS AND DISCUSSION

3.1. Results of Solid Substances Determination

Five flame retardant synthesis samples were conducted, yielding light brown liquids as a result of the processes in Table 1. Water solubility was tested, as it's essential for wet finishing. PAno1 was eliminated due to poor solubility, and the remaining four samples were used for leather production trials. The results of the solid substances determination of the flame retardants PAno 2, PAno 3, PAno 4 and PAno 5 were found 70.1%, 69.4%, 71.4% and 70.8% respectively.

3.2. Results of Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR transmittance–wavenumber graph for pentaerythritol, BTCA, citric acid, and the 4 flame retardants is shown in Figure 1. The synthesized substances showed similar profiles to the analytes, with abundant C–O bonds, indicating their strong potential to bind effectively to leather.

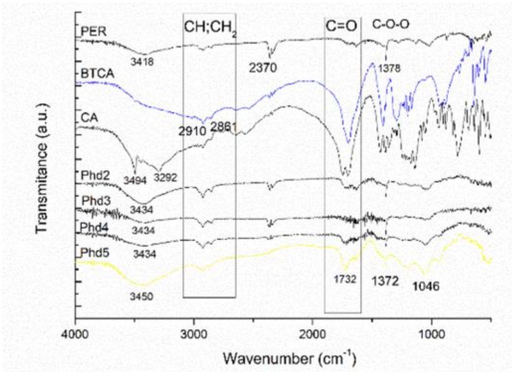

Fig. 1. *FTIR (transmittance-wavenumber) analysis graphic*

3.3. Results of (Differential Scanning Calorimeter) DSC Analysis

DSC analysis results are shown in Figure 2 as thermograms of phytic acid, pentaerythritol, citric acid, and the four synthesized substances. The synthesized flame retardants showed no broad endothermic transitions below 150 °C. Their decomposition temperatures ranged from 130–140 °C, indicating thermal stability and suitability for leather applications.

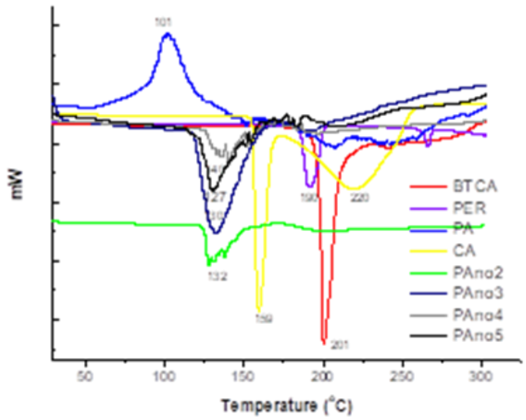

Fig. 2. *DSC (Differential Scanning Calorimeter) analysis graphic*

3.4. Horizontal Flame Retardancy Test Results

Burn tests showed all leather samples resisted flame, with none reaching the textile reference point—thus considered non-burning by standard. The blind trial (Leather 11) burned more than others. Leathers with commercial flame retardants (9 and 10) showed better resistance, especially at 10%. PAno2 samples (1 and 2) had similar performance, with better resistance at 10%. PAno3 leather at 5% (3) matched commercial flame retardants, but at 10% (4), it resembled the blind. PAno4 samples (5 and 6) showed the best performance, comparable to commercial flame retardants at both concentrations. PAno5 samples (7 and 8) performed better than the blind at 5% but worse than commercial; the 10% sample was closest to the blind. Overall, flame retardant samples approached the performance of commercial ones, though leather thickness and raw material properties also influenced burning behavior.

3.5. Vertical Flame Retardancy Test Results

The test showed no significant differences on the grain side of all leather samples. Only trails 7 and 8 burned through to the flesh side, likely due to their raw material properties, as also noted in the horizontal flammability test.

3.6. Shrinkage Temperature

The shrinkage temperatures of all the produced leathers are presented in Table 2, which reflects their hydrothermal stability. Upon examination of Table 2, it is evident that, with the exception of the leathers treated with the flame retardant from PAno5, the remaining samples exhibited significantly higher hydrothermal stability compared to the blind leather trial. Leathers numbered 7 and 8 demonstrated poorer hydrothermal stability than the blind leather, consistent with the results from the horizontal and vertical flame retardancy tests.

Table 2. *Shrinkage temperatures of leather trials*

Leather Trials	Shrinkage Temperature (C°)
Leather 1 (%5 PAno 2 sample)	138
Leather 2 (%10 PAno 2 sample)	136
Leather 3 (%5 PAno 3 sample)	134
Leather 4 (%10 PAno 3 sample)	133
Leather 5 (%5 PAno 4 sample)	135
Leather 6 (%10 PAno 4 sample)	135
Leather 7 (%5 PAno 5sample)	130
Leather 8 (%10 PAno 5 sample)	130
Leather 9 (%5 the commercial sample)	137
Leather 10 (%10 the commercial sample)	136
Leather 11 (blind)	132

4. CONCLUSIONS

Upon examination of the results obtained from the horizontal burning test, vertical flame retardancy test, and shrinkage temperature analysis, it was determined that the leather samples treated with the synthesized flame retardants designated as PAno 2, PAno 3, and PAno 4 exhibited fire retardancy behavior comparable to that of leathers treated with conventional commercial flame retardants. In contrast, the leather sample treated with the PAno 5 formulation demonstrated thermal and flammability characteristics more closely aligned with those of the untreated control (blind test) leather sample. Further evaluation of the physical properties revealed no significant variations attributable to the type or presence of flame retardants applied. This finding indicates that the incorporation of the synthesized flame retardants did not adversely impact the mechanical integrity or sensory quality of the finished leather.

In conclusion, the experimental flame retardants, synthesized through varying formulations involving phytic acid—a naturally derived, bio-based compound known for its efficacy in enhancing the flame resistance of protein-based and cellulosic substrates—demonstrated a favorable influence on both the flame retardancy and hydrothermal stability of chrome-tanned leathers. These results suggest that phytic acid-based formulations can serve as sustainable and effective alternatives to conventional flame retardants, offering environmental and performance-related benefits without compromising the essential qualities of leather materials.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

FROM THEORY TO PRACTICE: THE EUROPEAN UNION'S LEGISLATION ON WASTE MANAGEMENT AND THE CURRENT SITUATION OF TEXTILE RECYCLING IN ROMANIA

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Abstract: *Waste, regardless of its nature and origin, has a serious impact on several areas of life, causing a multitude of negative effects on both human health and the environment, climate and, last but not least, the economy. The amount of clothes produced globally has experienced a significant increase with the emergence of the concept of fast fashion. A direct consequence of this is the increase in textile waste. In order to reduce the negative impact on the environment, the European Union has implemented various regulatory acts which aimed at reducing textile waste and increasing the life cycle and recycling of textiles, like the Directive 2008/98/EC of the European Parliament and of the Council, amended by the Directive (EU) 2018/851 of the European Parliament and of the Council. In Romania, nowadays, the Government Emergency Ordinance no. 92 of August, 19, 2021 is in force. One of the most important provisions that can be found in the above-mentioned Emergency Ordinance is that by January 1, 2025, the national authorities must introduce separate collection of textiles. This measure of separate collection of textiles represents an important step towards sustainable resource management and reducing environmental impact. This paper will show which are the theoretical refererences to textiles made in the European Union's Directive, as well as the current legal situation in our country regarding the transposition of the European regulatory acts. At the same time, it will also present the stage in which textile waste collection is in Romania, by the analytical study of the data provided by the European and Romania institutions, as well as the information provided by the various organizations involved in the textile recycling process in our country. As a result of the study undertaken, the conclusions will show some practical ways in which both the collecting and the recycling process in our country could be improved.*

Key words: *EU's Directive, waste, recycle, sustainability, circular economy*

1. INTRODUCTION

The Directive 2008/98/EC of the European Parliament and of the Council [1], amended by the Directive (EU) 2018/851 [2] is the one that establishes a legislative framework for waste management in the European Union (EU), so at the level of each State Member. The regulation was designed to create certain rules in order to protect the environment, as well as the health of the population, by implementing certain appropriate techniques for the management, recovery and recycling of waste, in order to reduce the pressure on resources and improve their use. All these elements are crucial for the existence of a circular economy, as well as for maintaining an optimal level of competitiveness at the Union level for a long-term. A very important fact is that the Directive also introduces the concept of "extended producer responsibility", which means that it places financial responsibility on manufacturers, who, from now on, have to pay for every new textile product they put on the market. Furthermore, the manufacturers are the ones that must ensure that those products, when they are no longer used, do not end up having a negative impact on the environment.

Within the directive, in art. 3, the notion of waste is defined as "any substance or object which the holder discards or intends or is required to discard" [2].

Regarding the concept of "extended producer responsibility", at the European Union level, a representative country from this point of view is France, which since 2007 has implemented an EPR scheme for clothing, shoes, and household linens and also expanded to include curtains in 2020, setting a target collection rate of 50% [3]. At the beginning, the policy required producers to pay the net costs for separate collection and sorting, research and development projects, and costs for local authorities' awareness campaigns. From 2023, the scheme also covers the costs of some other features, like: re-use (the scheme covers the net-costs of social enterprises facilitating re-use of garments); repair (the scheme provides households with a credit for the repair of their products, a credit that is applied directly to households as a discount on the invoice of the repair by approved businesses); eco-modulation (the scheme introduces a new fee modulation schedule which will not necessarily be tied to the size of the fee contribution). Although the target collection rate is that of 50%, this has not been achieved yet; it has been observed that the collection rate has decreased from 39% in 2020 to 31% in 2022 due to a 66% increase in products placed on the market over this period. The European Commission, in its impact assessment for a preferred option of a targeted amendment to the Waste Framework Directive, estimated that the EU-27 average collection rate was 22% in 2019. On the other hand, the collection rate in France, that of 31%, is about 50% higher than the EU-27 average. However, there are some countries, like Germany for example, that managed to achieve a high collection rate even without a mandatory EPR scheme [3].

2. TEXTILES IN THE EUROPEAN DIRECTIVE

References to textiles are made, first of all, within the framework of art. 3 para. 2b of the Directive, where municipal waste is defined as "mixed waste and separately collected waste from households, including paper and cardboard, glass, metals, plastics, bio-waste, wood, textiles, packaging, waste electrical and electronic equipment, waste batteries and accumulators, and bulky waste, including mattresses and furniture" and "mixed waste and separately collected waste from other sources, where such waste is similar in nature and composition to waste from households" [2].

Also, another reference is met in art. 9 of the Directive, which regulates some issues related to waste prevention. The provision in this article states that member states shall take certain measures in order to prevent waste generation, which includes "encourage the re-use of products and the setting up of systems promoting repair and re-use activities, including in particular for electrical and electronic equipment, textiles and furniture, as well as packaging and construction materials and products" [2].

The next reference is the one provided in art. 11 of the Directive and this is one of particular importance: "Member States shall set up separate collection at least for paper, metal, plastic and glass, and, by 1 January 2025, for textiles". Also, in the content of art. 11 we find the following provision: "By 31 December 2024, the Commission shall consider the setting of preparing for re-use and recycling targets for construction and demolition waste and its material-specific fractions, textile waste, commercial waste, non-hazardous industrial waste and other waste streams, as well as preparing for re-use targets for municipal waste and recycling targets for municipal bio-waste. To that end, the Commission shall submit a report to the European Parliament and to the Council, accompanied, if appropriate, by a legislative proposal" [2].

3. CIRCULAR ECONOMY AND TEXTILE RECYCLING

The European Union has a Strategy for Sustainable and Circular Textiles, in order to create a greener, more competitive textiles sector. The Strategy for Sustainable and Circular Textiles aims to create a coherent framework and a vision for the transition of the textiles sector whereby: "by 2030 textile products placed on the EU market are long-lived and recyclable, to a great extent made of recycled fibres, free of hazardous substances and produced in respect of social rights and the environment. Consumers benefit longer from high quality affordable textiles, fast fashion is out of fashion, and economically profitable re-use and repair services are widely available. In a competitive, resilient and innovative textiles sector, producers take responsibility for their products along the value chain, including when they become waste. The circular textiles ecosystem is thriving, driven by sufficient capacities for innovative fibre-to-fibre recycling, while the incineration and landfilling of textiles is reduced to the minimum" [4].

Circular economy means sustainability and respecting the 3Rs is crucial: reduce, reuse, recycle. To reduce means to use less, understood as buying fewer brand-new items (for consumers) and using less material per item and designing for recycling (for companies) [5]. By reusing a product, the item is used multiple times and it includes taking into consideration concepts like functionality, usability and longevity of usefulness. To recycle involves collecting and processing materials that would otherwise become waste in creating new products.

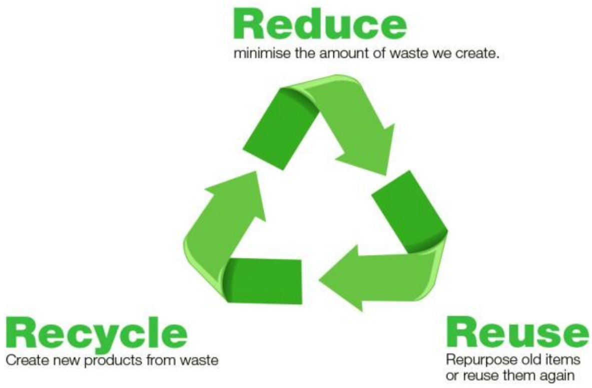

Fig. 1. *The 3Rs. Source: https://innovation-yachts.com/3r-reduce-reuse-recycle/*

The impact of textile production and consumption on the environment is shown in the following figure:

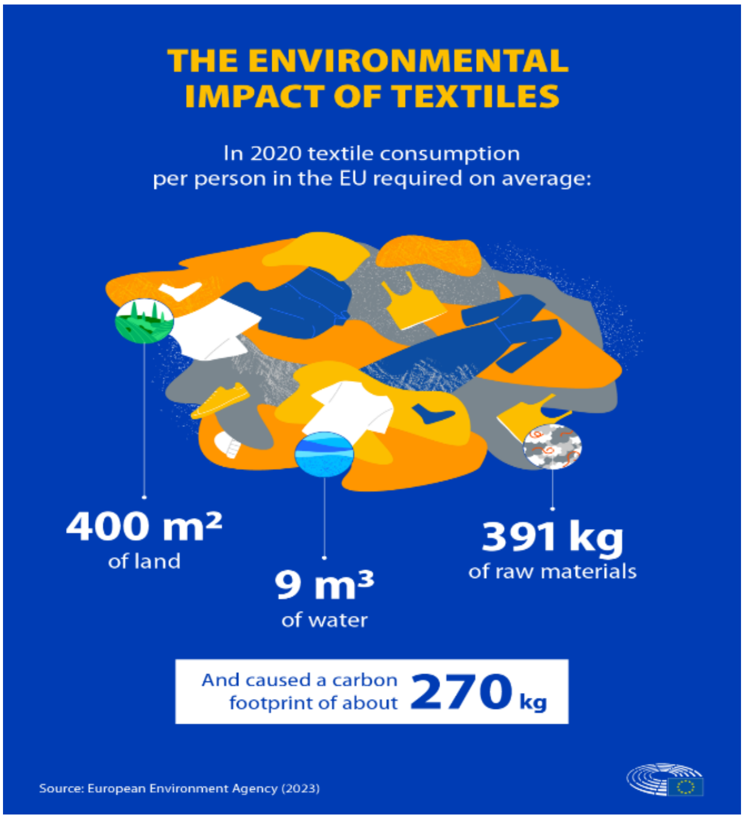

Fig. 2. *The environmental impact of textiles. Source:*
https://www.europarl.europa.eu/topics/en/article/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographics

The fashion industry, especially fast-fashion, is globally recognized as a major producer of waste, and the statistics claim that of the 100 billion garments produced each year, 92 million tonnes end up in landfills, which means that the equivalent of a rubbish truck full of clothes is thrown away every second [6]. At the EU's level, in 2020 there has been estimated 6.95 million tons of textile waste, which means approximately 16 kg per person and only 4.4 kg per person were collected separately for use and recycle [7]. There is also a major problem with reusing, as nowadays many items are worn only seven to ten times before being thrown away.

As shown in our previous paper [8], the major problems of the environment created by the textile industry include, besides waste, are: the use of water, water pollution and air pollution. The solution to these problems include, first of all, the awareness that they really exist and that the environment is seriously affected by it. Also, it requires a systemic change towards circularity, a fact which involves taking into consideration effective policies related to the manufacturing process and what happens after that: materials and design, production and distribution, use and reuse, collection and recycling in this industry.

By textile recycling there are many benefits brought to the environment. There can be mentioned: reducing the amount of used water and less pollution, which means a cleaner environment and a more sustainable economy.

4. THE CURRENT SITUATION IN ROMANIA

As shown in the Romanian media [9], our country is among the top polluting countries when it comes to textile waste management., Over 95% of the textiles present in Romanian households end up being thrown away and incinerated, according to a report by the European Environment Agency, cited by the Humana People to People Organization. This happens due to the lack of a collection, sorting and reuse or recycling infrastructure. The effects are disastrous, because synthetic fibres thrown into nature release dangerous microplastics, and natural ones generate a greenhouse effect when they decompose.

Waste management legislation establishes that by January 1, 2025, separate collection of textiles must be implemented, both by companies and local authorities, a fact that had to be applied in Romania, too. The European Commission has also proposed the introduction of mandatory extended producer responsibility for textiles in all Member States, to make producers take responsibility for the entire life cycle of textile products, from their design to waste management. The Commission proposal also introduces separate collection rules for textiles and sorting requirements for the transport of used textiles [9].

The above-mentioned Directive (2008/98/EC) was transposed by Law no. 211 of 2011 on the waste regime, republished, with subsequent amendments and additions, this law being repealed by the Government Emergency Ordinance no. 92 of August, 19, 2021 [10]. The Emergency Ordinance provides that that by January 1, 2025, the authorities must introduce separate collection of textiles. Based on this Ordinance, local authorities have the following obligations: to create the infrastructure necessary to install collection points and transport textile waste, to carry out advertising campaigns to raise awareness of the importance of recycling and the correct recycling of textiles, as well as to monitor and verify how the regulations are respected. In order to verify compliance with legal provisions, certain competent authorities such as the National Environmental Guard or the Romanian Military Police are delegated in this regard. Individuals and legal entities that do not comply with the rules may be subject to fines, for example for local authorities, fines of up to 45,000 lei for the lack of an efficient textile collection system.

The circular economy is an extremely important topic which Romania, nowadays, is striving to give all the attention it deserves. It represents an efficient solution to manage the collection and reuse of all types of waste. Although things are moving quite slowly and in small steps, in recent years, Romania has been trying to comply with European Union requirements regarding recycling, but there are still some problems with the practical application of existing regulations, such as the existence of a lot of unsorted waste that cannot be reused [11]. A study claims that each European citizen consumes approximately 14 tons of raw materials per year and also produces five tons of waste annually. This is why it is important to point out the fact that these materials could be reused, recycled or repaired so that they can be used again.

Fig. 3. *Collection bins in Romania.* Source: https://texcycle.ro/en/

From January 1, 2025, Romania has implemented a new fraction that has to be collected separately, namely textiles. In addition to this, our country has undertaken through the Romania's Recovery and Resilience Plan to establish at least 26 waste recycling facilities that will be put into operation by June 30, 2026, with funds earmarked for the construction of recycling facilities under the program amounting to 220 million euros [12].

According to data provided by the Ministry of Environment, about 250,000 tons of textile waste are generated annually in Romania. However, only about 15% of textile waste is currently collected and recycled in the country [13].

Nowadays, in our country there can be found, in some cities like: Oradea, Ștei, some collection bins, like those shown in figure 2, which belong to TexCycle and which reached over 200 textile collection units in Romania [14]. Clothes and shoes that are still in good condition are sorted and sold as reusable items. On the other hand, textiles that are no longer suitable for reuse are sorted according to their composition and condition and are then transformed into new fibers for the production of recycled textiles.

Also, in Romania, there are some companies specialized in the industry of sorting and reusing used textiles, like the Roseco company, which was established in 1992 and is one of the pioneers in this field [15]. Their goal is to respect resources and raw materials by extending their lifespan and considerably reduce the consumption of natural resources for the production of virgin raw materials. Among other things, the company claims that it contributes to the annual reduction of 4,000 tons of textile waste, preventing its energy recovery through incineration or landfilling.

5. CONCLUSIONS

As the paper shows, nowadays, the subject of textile waste in Romania is viewed with great interest and responsibility by the central and local authorities, as in our country there are normative acts that specifically regulate this field. The efforts of the authorities consisting in implementing the provisions provided for in the European regulations regarding the management of textile waste, in order to reduce the negative impact that they have on the environment, must necessarily be doubled by the responsible attitude of each citizen.

Although, as we have shown in the paper, there are sanctions provided for in the Government Ordinance for those who do not comply, the success of the separate collection of textiles will also be influenced by the strict application of these sanctions. Specifically, it would be absolutely necessary for all bodies involved and competent in applying sanctions to demonstrate strict application of the legal norms and to closely supervise the fulfillment by both companies and citizens of the obligations in their charge. Also, we consider that there is an absolute need for much more advertising campaigns in which an eco-friendly attitude is promoted because nowadays, in our country, the subject of textile recycling is not so much advertised. Although in law there is a well-known principle according to which no one can claim ignorance of the law, however, a recommendation would also be that the legal provisions relating to all aspects of textile recycling be promoted intensively on various media channels, be it TV, radio, internet, with an emphasis on the sanctions that exist in case of non-compliance. At the same time, it would be useful to print flyers that would contain this information for citizens, as well as to indicate the places where the recycling collection bins are located. We believe that all these suggestions, if implemented, would lead to a much higher percentage of textile waste collection than currently exists and to a higher success rate of textile recycling.

There are some challenges that have to be pointed out, in the consideration of the extended producer responsibility, which aims at helping to overcome some of the environmental impact generated by the production, use, and disposal of textiles, like the use of new recycling technologies, which will require investment.

After all, in this field of recycling, the path from theory to practice is not an easy one.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

TEXTILE WASTE MANAGEMENT IN ROMANIA IN THE CONTEXT OF THE CIRCULAR ECONOMY

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Abstract: *The circular economy in Romania's textile industry represents a sustainable resource management model that aims to reduce waste and maximize the value of materials throughout their entire life cycle. This concept promotes the reuse, repair, and recycling of textile products, in contrast to the traditional linear economic model based on "take, make, and dispose."*
In Romania, the textile industry has a long-standing tradition, but in recent years it has faced challenges related to managing textile waste. Selective textile recycling is essential to prevent pollution and conserve natural resources. This involves the separate collection of textile waste from consumers and sorting it based on the type of material and the degree of wear. The materials can then be reintroduced into the economic cycle in the form of recycled fibres, new products, or even fuel for energy production.
This article explores the potential and challenges of implementing a circular economy in Romania's textile sector, focusing on sustainable resource management and waste reduction. The study highlights the limitations of the current linear economic model, which heavily relies on the consumption of non-renewable resources and generates a significant amount of textile waste. It emphasizes the need for a transition to circular practices, including reuse, repair, and recycling, to improve sustainability.

Keywords: *TIR, TMW, reuse, repair, recycling.*

1. INTRODUCTION

The Circular Economy is a new model of production and consumption (fig.1). The evolution of industrialization over the past 100 years has been based on a linear production model: raw material – processing – consumption – waste. This leads to rapid resource depletion and an explosive increase in waste.

The Circular Economy (CE), developed on the principle that "everything is an input for something else," is the key to sustainability [1]. The transition from a linear economy to a circular economy is one of the key priorities in pursuing the Sustainable Development Goals (SDGs), where governmental institutions play a fundamental role, supported by developed digital technologies [2]. The EU Strategy for Sustainable and Circular Textiles addresses fast fashion, textile waste, and the depletion of unused textiles while ensuring that their production respects human rights [3]. The textile industry consumes 98 million tons of non-renewable resources annually, such as oil and raw materials for fertilizers and treatment chemicals. Simultaneously, the volume of textile waste is considerable, with only 13% of the materials used for clothing being recycled, and even these are mainly directed towards low-value applications [4].

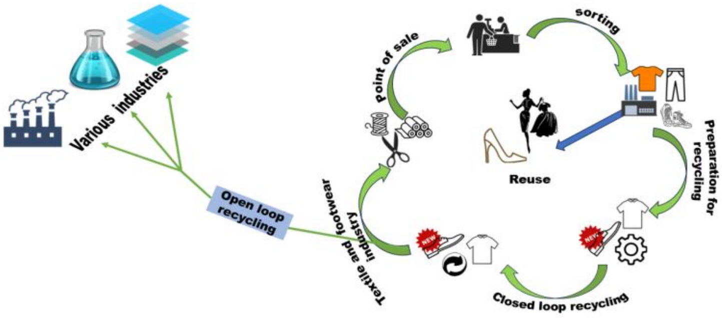

***Fig. 1**: The Circular Economy principle*

Currently, global textile consumption has the third-largest negative impact on the environment and climate change, following food, housing, and transport. Textiles rank third in water and soil consumption and fifth in raw material use and greenhouse gas emissions [3].
Europeans consume nearly 26 kg of textiles and discard around 11 kg of textiles each year. Used clothing can be exported outside the EU, but the majority (87%) is incinerated or sent to landfills. To reduce the environmental impact of this phenomenon, the EU aims to decrease textile waste and increase the lifespan and recycling rate of textiles. This is part of the plan to achieve a circular economy by 2050 (European Parliament, 2024).

In Romania, approximately 160,000 tons of textile waste are discarded annually, according to the Romanian Association for Textile Reuse and Recycling (ARETEX). Out of the total generated textile waste, 6-10% is recyclable under current legislative and market conditions, and this percentage could increase to 25% with developed selective collection and a robust reuse and recycling industry supported by large sorting capacities based on composition and quality, along with an Extended Producer Responsibility (EPR) structure (ARETEX source)

Currently, most textile waste in Romania ends up in landfills or is used for energy recovery. On the other hand, Romania reuses approximately 8-10% of its reusable potential and recycles 2-4%. Of the volume currently collected separately for reuse, about 30-35% is reusable. However, separate collection is relatively low, amounting to 6,000-9,000 tons per year. The current collection rate in Romania is 0.5-0.7 kg per person per year, while in Western countries, the collection ranges between 6-14 kg per person per year.

Globally, all waste management systems are currently guided by the "polluter pays" principle. The European Union adopted this principle for waste management 40 years ago, starting from the idea of determining who the polluter is.

2. MATERIALS AND METHODS

To identify the current pathways for managing textiles intended for reuse, recycling, and disposal, textile waste collected by social organizations (TIR) and specialized companies (TMW) were involved.

The obtaining of each textile product's characteristics was made in two steps: 1) the scanning of each piece of textile, by a volunteer using the NIR handheld device, to assess its composition; 2) organoleptic examination of the characteristics of the related piece of textile-like product type, age group, colour and presence of disruptors, degree of degradation, etc, that were captured in the app on the electronic device through a short predefined multiple-choice survey, using an application designed by Matoha Instrumentation Ltd.

The research laboratories typically use FT-IR and NIR spectroscopy devices to determine the chemical composition of a textile material:

1. ***FTIR*** (Fourier Transform Infrared Spectroscopy) is a method applied for analysing both organic and inorganic materials. This method analyses the chemical structure of a material by examining its chemical bonds and composition.
2. ***NIR*** (Near-Infrared Spectroscopy) is a method based on the structure-spectrum correlations present in the measured spectral response, caused by the overtones of fundamental vibrations in the regular IR region.

2.1 Textiles Intended for Reuse (TIR)

TIR (Textiles Intended for Reuse) waste fractions refer to categories through which collected used textiles are sorted for various reuse and recycling purposes. These textiles are sold on different local and global markets, are specific to each sorting facility, and are regularly updated based on market demand, resale prices, waste transport regulations, and other factors.

The analyses were conducted in two stages: January 2024 (batch I) and May 2024 (batch II). The batch I consisted of 1500 kg of used clothing, with 8720 pieces of clothing weighing an average of 172 grams per item. Batch II consisted of 1520 kg of used clothing, with 5396 pieces weighing an average of 280 grams per item. The activities in both stages were carried out by staff from INCDTP, who were trained by Fashion for Good, Netherland.

The TIR samples analysed were selected from textile waste after the so-called "main sort" and consisted of 4 fractions:

I. Wearable textiles sorted for reuse within the EU;
II. Wearable textiles sorted for reuse outside the EU;
III. Non-wearable textiles intended for wipers, downcycling, and fiber-to-fiber recycling;
IV. Non-wearable textiles directed towards energy recovery through incineration or disposal.

2.2 Textile Municipal Waste (TMW)

Additionally, the issue of the post-consumer textile fraction (as the last link in the chain in the current linear economy) destined for municipal waste landfills was analysed. These textiles are disposed of together with mixed waste (TMW). After selection and sorting by categories, the TMW textile fraction is analysed in terms of the type of clothing/non-clothing, structure, and blend of component fibres, as well as the level of degradation, providing insight into the possibility of "downcycling" reuse. The batches were analysed to identify the textile fractions.

The analyses were conducted in two stages: January 2024 (batch I) and May 2024 (batch II). Batch I consisted of 1055 kg of used clothing, 381 pieces of clothing weighing an average of 419,9 grams per item. Batch II consisted of 1350 kg of used clothing, with 684 pieces weighing an average of 377 grams per item.

Each batch consists of two types of waste:

1. those collected more or less separately, identified as textile bins (TB);
2. those found directly in mixed solid waste, identified as textile non-bins (NB).

3. RESULTS AND DISCUSSIONS

The results obtained by analysing the components of the TIR and TMW waste batches (both batches) identified the following aspects:

3.1. Fibrous composition

Fibre composition is a criterion for classifying textile materials based on the type of fibre from which they are made. Each fabric or knitted material of a given composition has specific uses.

Figure 2 graphically represents the results obtained from the analysis of clothing items (TIR), showing that the majority is composed of fibre blends, followed by those made from single fibres such as cotton, polyester, viscose, or acrylic.

In the analysis of clothing items from the TMW category, it was observed that garments composed of fibre blends predominate, followed by those made from single fibres such as cotton, polyester, viscose, and acrylic.

Viscose is an artificial fibre produced from natural raw materials, such as cellulose from wood. It has properties similar to cotton, being a pleasant and soft material. Unfortunately, it is also characterized by low durability and a tendency to wrinkle significantly.

Polyester is known for its exceptional durability and resistance to wrinkling, shrinking, and stretching. It withstands regular wear and tear, making it suitable for durable clothing items. Initially, consumers were enthusiastic about polyester's improved durability profile compared to natural fibres, and these benefits still hold today. However, in recent decades, the harmful environmental impact of this synthetic fibre has been detailed, and consumer attitudes towards polyester have significantly shifted.

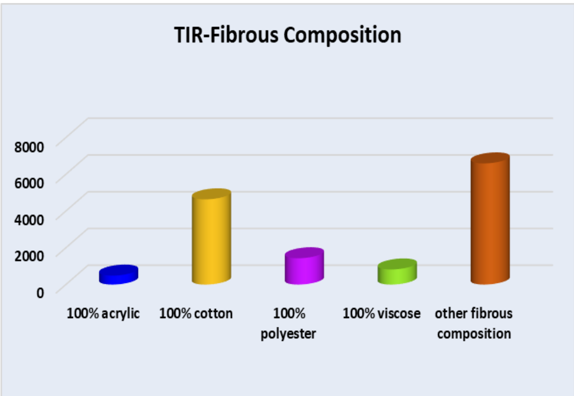

Fig. 2: *The fibrous composition of garments in the TIR category*

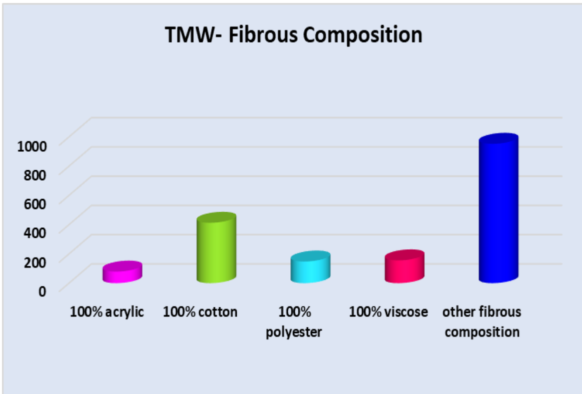

Fig. 3: *The fibrous composition of garments in the TMW category*

3.2. Material structure

The structure of textile materials is the most relevant characteristic for evaluating their potential use as raw materials for mechanical recycling. The specific features of knitted or woven products differentiate them: thread density in the two systems, weight per square meter, elongation, flexibility, tensile strength, abrasion resistance, thickness, shrinkage, bend resistance, degree of coverage, etc.

Figure 4 graphically represents the analysis of clothing items in the TIR category, highlighting that knitted garments predominate over those made from woven fabrics.

For the TMW category, it was demonstrated that the predominant structure of clothing items is knitted, followed by items made from woven fabric.

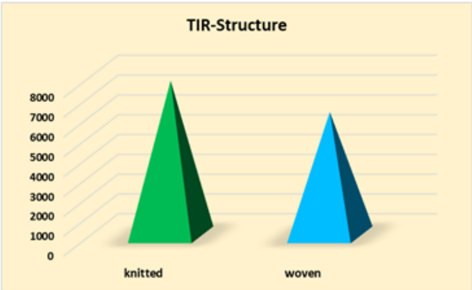

Fig. 4: *The structure of garments in the TIR*

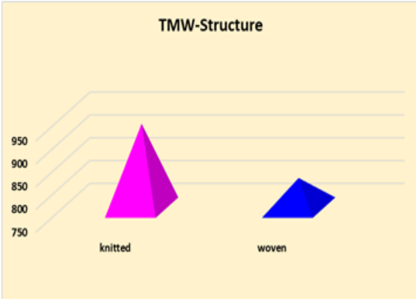

Fig. 5: *The structure of garments in the TMW*

3.3. Grade of reuse

Clothing articles were classified based on their degree of wear using well-established criteria, where: Grade 1 represents items with the highest degree of wear, and Grade 5 represents items in near-perfect condition.

In the case of the TIR category, the analysis of data revealed that most clothing items primarily fell into Grade 4 and Grade 3 of wear, followed by Grade 2 and Grade 1. This highlights the consequences of the fast fashion phenomenon, which has led to a reduction in the lifespan of products (a design, creation, and marketing approach in a fashion that emphasizes the rapid and inexpensive availability of fashion trends to consumers).

For the clothing items analysed in the TMW waste category, it was found that the primary degrees of wear are Grade 2 and Grade 1, followed by Grade 3 and Grade 4.

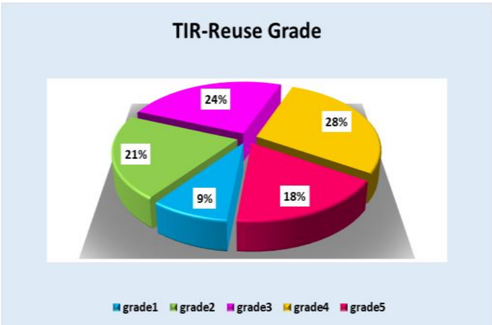

Fig. 6: *The reuse grade of garments in the TIR*

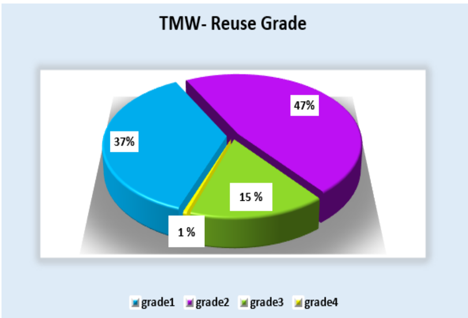

Fig. 7: *The reuse grade of garments in the TMW*

3.4. Color

In our study, the color of clothing items was considered to be the predominant color. If defining a single predominant color was not possible, the item was classified as multicolored. From the data analysis, it can be observed that in both the TIR and TMW waste categories, most clothing items are multicolored. This is followed by predominant colors such as blue, black, beige, grey, and white. Multicolor items limit the potential applications after mechanical recycling. In contrast, single-color items, after recycling and transformation into fibres, provide designers with multiple combination options that extend their range of use.

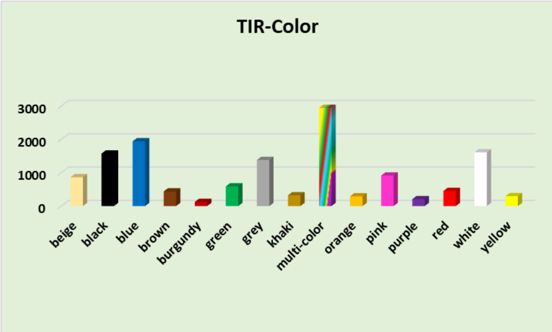

Fig. 8*: The colour of garments in the TIR*

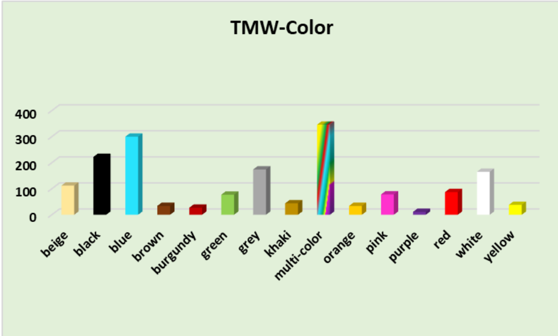

Fig. 9*: The colour of garments in the TMW*

4. CONCLUSIONS

The study underscores the urgent need to improve the selective recycling system in Romania, where the textile waste recycling rate is alarmingly low, ranging between 6 - 10%.

The fibre composition of textile materials, mainly fibre blends, and woven structures, complicate the recycling process, requiring specific treatments and complex processing technologies for each type of waste.

Additionally, the analysis of the wear degree of clothing items highlighted the negative impact of fast fashion, which promotes short product lifespans and contributes to increased waste volumes. This trend is further exacerbated by the preference for multicoloured items, which limits efficient recycling options compared to single-colour items made from a single fibre type, offering more reuse possibilities.

Implementing a circular economy in Romania's textile sector is not only necessary for environmental protection but also a strategic opportunity to develop new markets and create new jobs, thereby contributing to sustainable economic growth. This transition requires a firm commitment from all involved institutions to ensure the effective and responsible management of textile resources in the future.

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THE CLOTHING-PERSON RELATIONSHIP: COMPARATIVE ANALYSIS OF A STANDARD T-SHIRT ON A HEALTHY BODY AND ONE AFFECTED BY A NEURO-IMMUNE CONDITION WITH CLO3D

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Abstract: *Clothing is more than a basic necessity; it plays a crucial role in self-perception, emotional well-being, and social interaction. This study explores the significance of functional clothing and digital garment simulation to highlight the essential role of functional clothing for individuals with neuro-immune conditions. Based on the concept of enclothed cognition, the research emphasizes how clothing influences psychological well-being, confidence, and social interaction. The main focus of this research paper is individuals with disabilities resulting from autoimmune neurological conditions, for whom clothing must not only be accessible and functional but also aesthetically empowering. Using CLO 3D simulation software as a central methodological tool, this research visualizes and compares the fit and comfort of garments on both healthy and minimally affected body types. By modifying the avatar to realistic postures, the authors were able to analyse garment behaviour under two physical conditions. The main tool used was the stress and tension mapping in CLO 3D, which revealed significant areas of discomfort—particularly around the neck and shoulders—in the affected body, underscoring the need for design adaptations. The findings reinforce the value of integrating user-specific needs into product development to improve autonomy, comfort, and emotional well-being through functional and inclusive fashion solutions to improve the quality of life for individuals with disabilities, ensuring that fashion is both functional and empowering.*

Key words: *Enclothed cognition, functional clothes, inclusivity, ergonomic design, comfort, Clo3D.*

1. INTRODUCTION

The saying "When you look good, you feel good" perfectly encapsulates the deep connection between clothing and personal well-being. While it may seem like a simple statement, it highlights the significant role that garments, their form, and aesthetics play in shaping identity and overall psychological comfort. Clothing is far more than a superficial choice—it is a dynamic expression of self-perception and an influential factor in how individuals engage with the world around them [1].

Research in fashion psychology reveals that clothing is not just fabric draped over the body but an integral part of human experience, affecting emotions, behaviour, and even cognitive performance. Acting as a "second skin," what we wear can significantly impact our mood, confidence, and state of mind. Studies further suggest that feeling comfortable in one's attire enhances focus and social interaction, reinforcing the concept of enclothed cognition—the idea that clothing influences cognitive processes and psychological states. Thus, beyond aesthetics, fashion becomes a reflection of personal aspirations, emotions, and identity, shaping not only how individuals see themselves but also how they are perceived by others [2].

For individuals with disabilities as an aftermath of an autoimmune neurological conditions, clothing takes on additional significance in terms of accessibility, autonomy, social perception, and emotional well-being. [2,3].

Functional clothing must not only be functional but also aesthetically pleasing, providing users with emotional comfort, self-esteem, and independence. Accessibility and ease of dressing is equally important, meaning garments should be easy to put on and take off, incorporating functional elements, ergonomic cuts, and minimal seams to prevent irritation. Mobility and adaptability must also be integrated into the design so that clothing allows freedom of movement and can be adjusted based on the wearer's physical condition. Beyond these functional aspects, the psychological impact of clothing should not be overlooked. Garments should be visually appealing, boost the wearer's confidence, and reduce the feeling of social exclusion [3,4].

2. THE CLOTHING-PERSON RELATIONSHIP

In recent years, the fashion industry has begun to address the needs of individuals with disabilities and chronic conditions by offering adaptive clothing that combines comfort with accessibility. Although there is still a long way to go, some brands have made significant progress in creating garments that meet the requirements of diverse user groups.

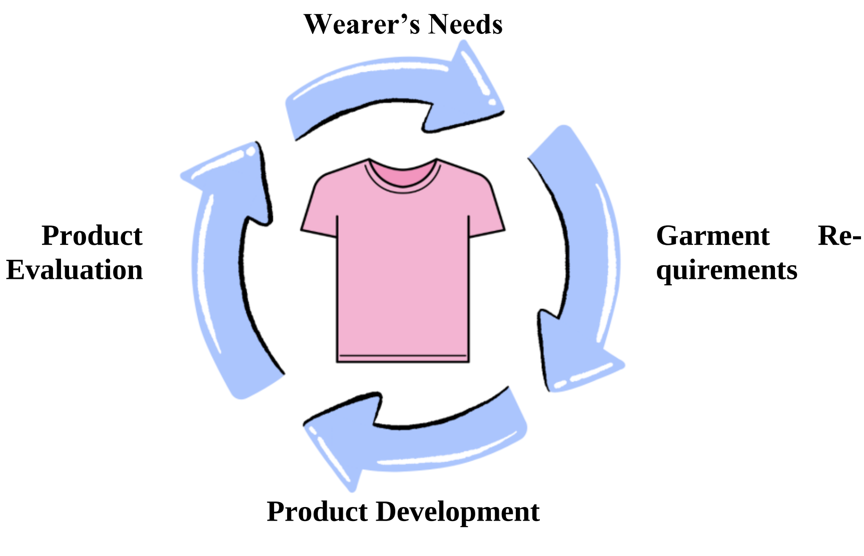


Fig. 1: *The Development Process of a Functional Product [5]*

The four stages illustrated in ***Fig. 1*** are interdependent, contributing to an improved quality of life and enhanced comfort for individuals with neuro-immune conditions.

The first stage involves identifying the wearer's needs through a detailed analysis of specific requirements, such as temperature sensitivity, limited mobility, or the necessity of integrating functional medical devices. Based on this analysis, garment requirements are defined, including the selection of suitable materials and textile properties that contribute to creating a functional product.[1]

The next stage is prototyping and testing, where information from the previous phases is combined to develop and refine a prototype with the benefit of user feedback. Based on this input, the product is optimized so that, in the final stage, it can be tested under real-life conditions to determine its effectiveness in daily use. The product evaluation phase includes an analysis of key indicators, such as the comfort provided and its impact on the user's quality of life.[1]

By properly integrating these stages, functional clothing becomes an essential tool for managing symptoms of neuro-autoimmune diseases, increasing user independence, reducing physical and emotional discomfort, monitoring and preventing symptom aggravation, and improving self-esteem and overall well-being. Thus, functional clothing is not just a necessity but also an innovative and personalized solution designed to significantly enhance the lives of individuals with neuro-autoimmune conditions.[1]

3. A VISUAL ANALYSIS OF FIT AND COMFORT

3.1. Method

To facilitate realistic avatar postures within the CLO 3D simulation environment, the pose of the avatar can be modified by manipulating the skeletal joints using two kinematic systems: Forward Kinematics (FK) – each joint is moved individually to control the avatar's pose manually. and Inverse Kinematics (IK) - where moving one joint automatically adjusts the connected joints to create a natural, realistic pose. [6]

The joint structure of the avatar must first be made visible in the 3D workspace. This is accomplished by selecting the avatar and enabling the Show Avatar Joints option within the Avatar Display menu. [6]

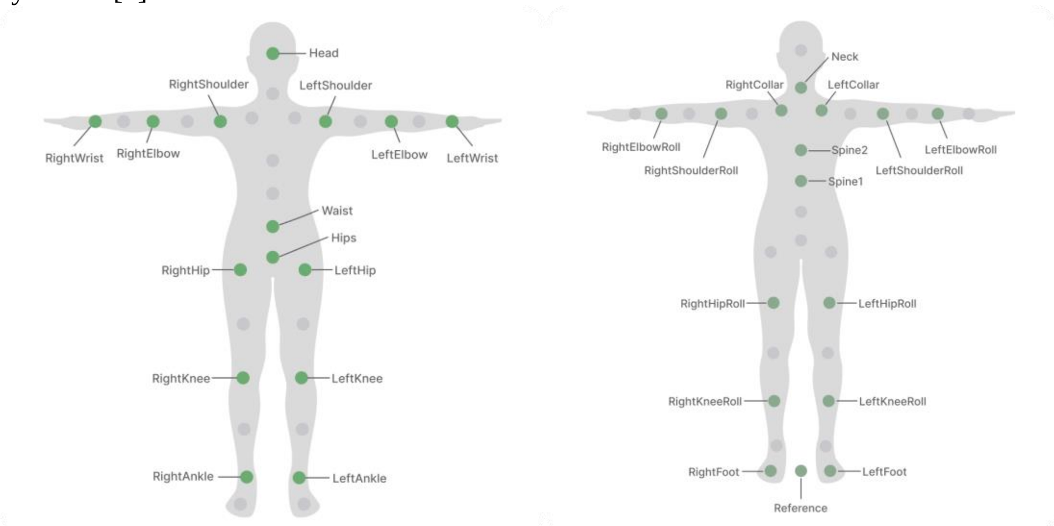
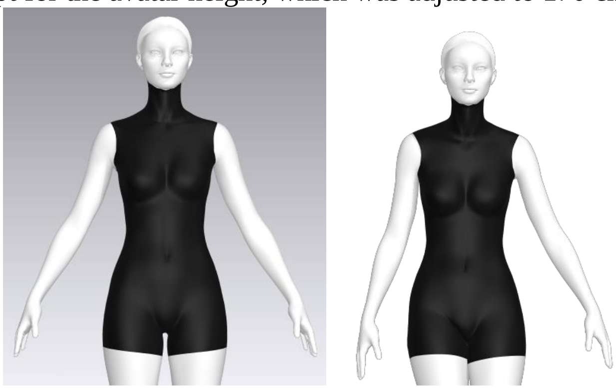


Fig. 2: *Scheme of the skeletal joints of the avatar in Clo3D [6]*

3.2. Practical use

To further illustrate and analyse the importance of these functional clothing products and to present a visual representation of the clothing-person relationship, a simulation was conducted. This simulation compares a healthy body with a body affected by a neuro-immune condition at its mildest level based on the public available information, both wearing the same clothing piece. [6,7,8]

Both the healthy and neuro-immune affected body prototypes were generated using CLO 3D, following the procedure described in Section 3.1. All default body parameters provided by the system were retained, except for the avatar height, which was adjusted to 170 cm.

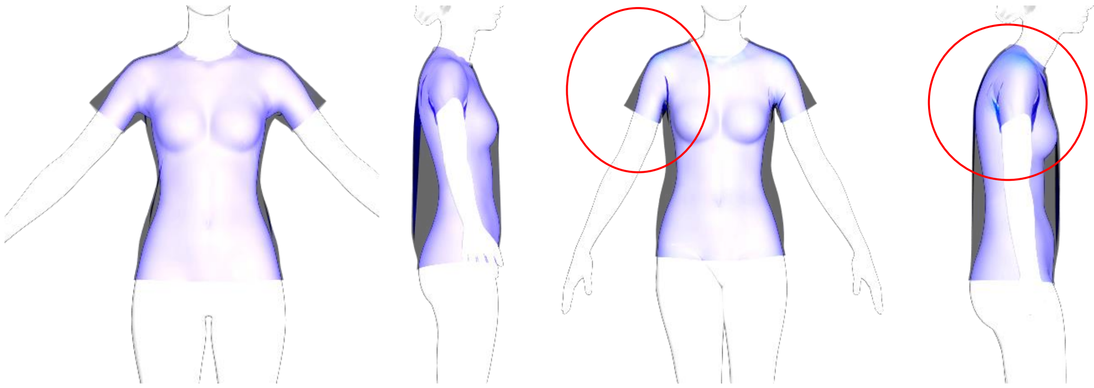


a) b)

Fig. 3: *Side-by side comparison of a healthy body with a body affected by a neuro-immune condition at its mildest level*
a) healthy body; b) affected body.

By analysing ***Fig. 3***, the visible differences in posture and arm positioning can be observed in the affected body. All these differences dictate the how clothing fits and interacts with the body. To explore this further, the same clothing item—a short-sleeved t-shirt—was simulated on both body types.

To be able to appreciate how the t-shirt sits on the body, in the soft CLO3D the function of transparency was used to clearly see the lines of the body and the lines of the clothes and how they interact with each other.



a) b) c) d)

Fig 4. *Simulation of the body wearing a short-sleeved t-shirt*
a) &b) healthy body c) &d) affected body

Based on the results obtained in ***Fig 4*** in image c) and d) that are the avatar with the affected body, we can see an area that may indicate some kind of tension and disconfirm around the neck-shoulders area. To further assure ourselves that this tension is present, we switched from the transparency function to the tension and stress map and got the following results:

Fig 5. *Tension mapping of the clothing on the affected body.*

The results obtained in ***Fig 5*** using stress-mapping functions in CLO3D reveals areas of tension, particularly around the neck and shoulders, confirming the need for a functional and adapted garment to be able to accommodate the physical variations present in individuals with neuro-immune conditions.

5. CONCLUSIONS

This research highlights the vital importance of functional clothing for individuals with neuro-immune conditions, where even mild physical changes can significantly affect garment fit and comfort. Through the use of CLO 3D simulation software, the study examined how a standard garment interacts with both healthy and minimally affected body types. The simulation revealed visible differences in posture and garment behaviour, with stress mapping indicating discomfort—particularly around the neck and shoulders—in the affected body. These findings highlight the necessity of designing clothing that not only accommodates physical variations but also enhances emotional well-being and social inclusion. By demonstrating that discomfort can arise even in cases of mild physical deformation, the study reinforces the need for inclusive, personalized clothing solutions at every stage of a condition. Ultimately, this research advocates for a user-centred approach in fashion design, where function and aesthetics are equally prioritized to promote autonomy, confidence, and quality of life for individuals with disabilities.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

SOFTWARE APPLICATIONS FOR MILITARY EMERGENCY RESCUE EQUIPMENT

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Abstract: *Soldiers operating in combat zones face countless risks, often in unpredictable and hazardous environments. Among the leading causes of mortality for combatants in armed conflict is, blood loss, often resulting from trauma to the limbs. One of the most significant challenges in the design of military protective equipment is ensuring effective auto-hemostasis for individuals wounded on the battlefield. The current paper addresses this issue by proposing three advanced technological solutions aimed at integrating an innovative, autonomous primary hemostasis system within military equipment. The proposed system automatically activates a pneumatic tourniquet upon detection of bleeding in the limbs, thus inducing hemostasis and preserving lives of the combatants. This system not only focuses on functionality, specifically the automatic response to bleeding—but also takes into account the comfort and mobility of the combatant, which is essential during intense military operations. To visualize the components of the protective combat suit, 3D modeling and simulation technologies were employed using the OptiTex software suite. These simulations provided an effective technique of assessing the design and functionality of the suit's integrated hemostasis system. Additionally, the undergarment fabric was antibacterially treated, enhancing hygiene and preventing infections, while the combat suit was also designed with infrared camouflage through screen-printing technique, ensuring both tactical advantage and protection in diverse combat environments. The paper outlines the promising potential of these technological innovations in improving the safety and survival of soldiers in battlefield conditions.*

Key words: *conductive fabrics, electronic circuit, hemostasis, pneumatic tourniquet, combatant, 3D simulation.*

1. INTRODUCTION

The *smart textiles* market is experiencing significant growth, particularly within the Military and Defense sectors, due to the unique ability of these materials to monitor both the wearer and their environment. This allows them to respond to external stimuli, providing crucial support in dynamic and high-risk situations [1], [2].

Conductive textiles are a key category within the field of smart textiles, and it is projected that the market will show a remarkable expansion, with a compound annual growth rate (CAGR) of 15.8%, from $3.28 billion in 2024 to an estimated $10.63 billion by 2032 (Fig. 1) [3].

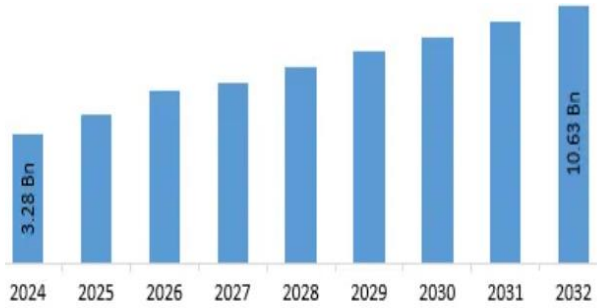


***Fig. 1**: Eatimated size of the conductive textiles market for 2024-2032* [3]

The integration of conductive textiles in the military and defense sectors represents a pivotal advancement, offering real-time monitoring, enhanced situational awareness and improved safety for personnel, all of which being critical in combat and emergency response scenarios. In the latest developments, fabrics conducting electricity have been integrated into military Personal Protective Equipment to enhance both protection and performance, offering unique functionalities such as real-time body monitoring, environmental sensing and energy harvesting, all crucial for modern military operations [4], [5].

Various electrical functionalizations of fibres, yarns and textile surfaces can be obtained, during:

- the fabrication process of the fibres;
- the spinning process of the yarns;
- the obtaining process of braided, woven, non-woven and knitted materials;
- the finishing process of fibres, yarns and textile surfaces,

enhancing the wearability and durability of protective military clothing, addressing key issues such as comfort and operational efficiency without compromising on protection, directly impacting the survivability and operational efficiency of soldiers [6].

2. MATERIALS AND METHODS

2.1 Materials

To identify the optimal technological solution for the design and production of intelligent combat suit equipped with an automatic primary hemostasis system, the basic need of the combatants in operation was considered, namely, ensuring survival after bleeding caused by shooting or cutting, through producing auto-hemostasis. The major challenges of this stage were given by the need to obtain the functionality for which the intelligent equipment was designed, namely the automatic activation of the pneumatic tourniquet upon detection of bleeding in the limbs, while ensuring the comfort of the combatant, in conditions of armed conflict.

Special fabrics were selected in order to respond to the critical needs: functionality, comfort and camouflage of the soldier:

- electroconductive knitted fabric, 90% cotton+ 10% elastane, with antibacterial surface treatments against gram-positive bacteria (eg. *S. aureus*) and gram-negative bacteria (eg. *E. coli*)- for undergarment ensemble;
- woven fabric, designed with infrared camouflage, achieved through screen-printing, 5 masking colours being used: navy, brown, bordeaux, green and black- for the camouflage suit.

The military rescue equipment consists of 2 modules, namely:
- *the undergarment ensemble*, consisting of a long-sleeved blouse and long trousers, made of antibacterial knitwear with electroconductive properties;
- *the infrared (IR) camouflage suit*, consisting of a combat jacket and trousers, made of woven fabric in IR camouflage colors.

2.2 Methods

Automatic hemostasis system

Three technological solutions were developed, which have in common *the principle of producing autohemostasis*, by automatic inflation of the pneumatic tourniquets (5), actuated by the pneumatic circuit (4), based on the signal received from the Central Unit (3) and triggered by the interruption of the electrical circuit of the textile material (2), by shooting or cutting (1) (fig. 2).

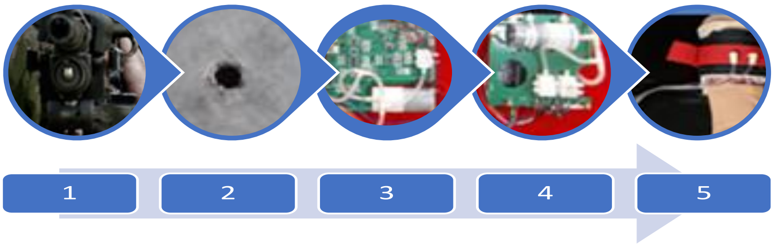


Fig. 2*: Activation of the automatic primary hemostasis system*

Military emergency rescue equipment

In order to define and visualize the components of the combat equipment, several 3D simulations were performed on a parameterized mannequin, corresponding in dimensions to size 48, using the OptiTex software suite [7]. Based on the autohemostasis principle presented in Fig. 2, the disposing of the system elements on the undergarment assembly, can be visualized in Fig. 3.

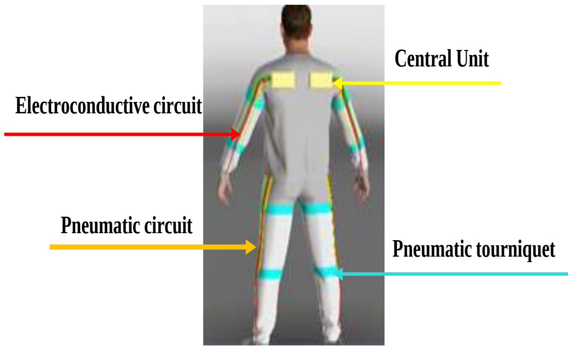
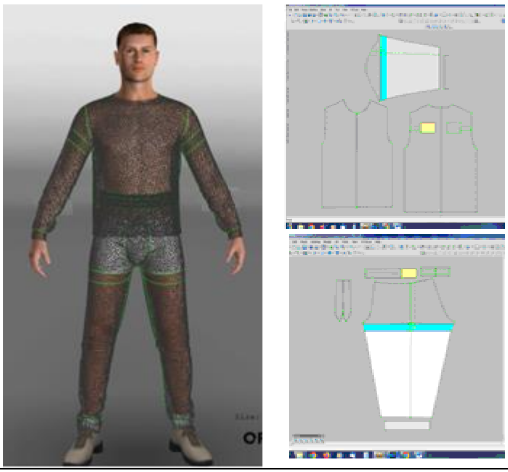
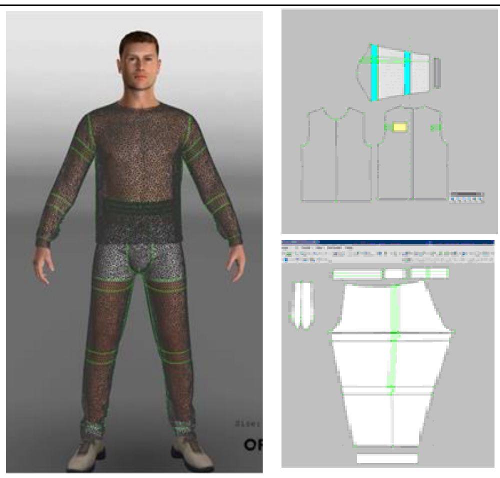
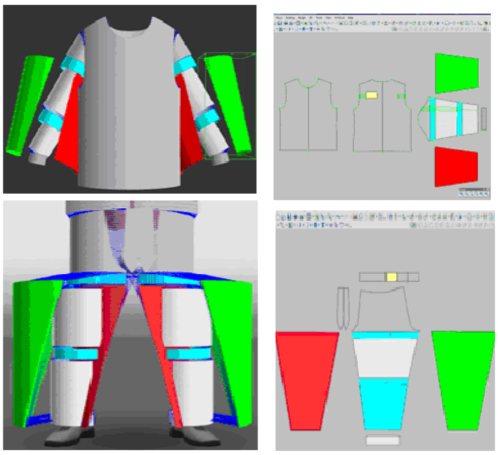
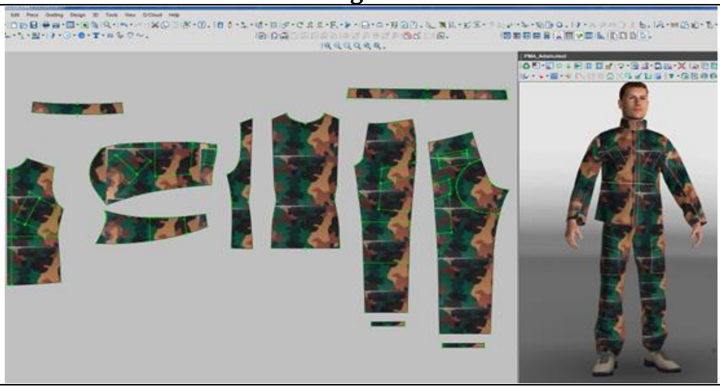


Fig. 3*: The elements of the automatic hemostasis system*

Three technological solutions were provided for the integration of the automatic primary hemostasis system into the undergarment assembly, which represents the inner layer of the intelligent equipment and one technological solution for the infrared camouflage suit, representing the outer layer of the intelligent equipment (Tab. 1).

Table 1: *Technological solutions for the design of military emergency rescue equipment*

Undergarment assembly	
Design 1. *4 pneumatic tourniquets and 4 electroconductive circuits*	
A single-layered undergarment assembly, made of antibacterial knitwear with electroconductive properties, equipped with the following configuration of the automatic primary hemostasis system: ❖ 4 pneumatic tourniquets: 1 for each limb; ❖ 4 control units: 1 for each tourniquet; ❖ 4 electroconductive circuits: 1 for each control unit; ❖ 4 pneumatic circuits: 1 for each tourniquet.	
Design 2. *8 pneumatic tourniquets and 8 electroconductive circuits*	
A single-layered undergarment assembly, made of similar fabric from the first solution provided, but with a different configuration of the automatic primary hemostasis system: ❖ 8 pneumatic tourniquets: 2 for each limb; ❖ 4 control units: 1 for each limb; ❖ 8 electroconductive circuits: 2 for each control unit; ❖ 8 pneumatic circuits: 1 for each tourniquet.	
Design 3. *8 pneumatic tourniquets and 8 electroconductive circuits, modular structure*	
A multiple layer undergarment assembly, composed of 3 layers in the conductive areas, made of antibacterial knitwear with electroconductive properties , equipped with the following configuration of the automatic primary hemostasis system: ❖ 8 pneumatic tourniquets: 2 for each limb; ❖ 4 control units: 1 for each limb; ❖ 8 electroconductive circuits: 2 for each control unit; ❖ 8 pneumatic circuits: 1 for each tourniquet.	

IR camouflage combat suit

For all the three proposed solutions for the creation of the Intelligent Equipment with integrated automatic primary hemostasis system, the IR Camouflage Suit will be used, a clothing ensemble composed of a combat jacket and trousers, made of woven fabric dyed and printed in IR masking colors, with the role of ensuring the camouflage of the combatant in operation.

4. CONCLUSIONS

The design and development of military emergency rescue equipment face significant challenges due to the critical need of integrating advanced technological solutions, the automatic primary hemostasis system, in this case. However, achieving this functionality is not enough on its own; the system must also ensure that the combatant's comfort and camouflage is maintained while the equipment functions optimally in high-stress environments.

To tackle these complex challenges, various technological solutions have been explored, and a series of 3D simulations were conducted using the OptiTex software suite on a parametrized mannequin. These simulations played a crucial role in visualizing and refining the component parts of the intelligent military equipment. By simulating the interactions between the equipment and the combatant's body, the effectiveness of the system in terms of functionality, ergonomics and user comfort were validated.

As a result, the development of this intelligent emergency rescue equipment represents a significant step forward in improving combatant survival rates and operational effectiveness in military settings.

ACKNOWLEDGEMENTS

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

VIRTUAL REALITY FOR SUSTAINABLE FASHION EDUCATION: THE FASHION.ED PROJECT EXPERIENCE

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Abstract: *Virtual Reality (VR) is transforming education by creating immersive and interactive learning environments that enhance student engagement, motivation, and knowledge retention. In higher education, VR offers new possibilities for experiential learning, allowing students to explore complex concepts, develop practical skills, and apply theoretical knowledge in simulated real-world contexts. Through realistic simulations and hands-on virtual activities, learners can engage with content in ways that traditional methods cannot provide, promoting critical thinking, creativity, and problem-solving. As digitalization becomes increasingly important in education, VR stands out as a powerful tool to support innovation, flexibility, and personalized learning experiences across various disciplines.*
This article presents the results of the Erasmus+ project Supporting Entrepreneurship in Eco Design– FASHION.ED (2023-1-ES01-KA220-HED-000157440). The main outcomes include the development of the e-learning course Eco-Design in Fashion, the creation of a Virtual Reality (VR) laboratory offering interactive 3D eco-design experiments, and the organization of an international competition focused on eco-design entrepreneurship for fashion and textiles students. These activities demonstrate the potential of combining digital innovation with sustainability education.
The project results underline the importance of integrating VR technologies in higher education to create immersive learning experiences, enhance practical skills, foster creativity, and better prepare students for the challenges of the modern labor market.

Key words: *Fashion.ED, Erasmus+ project, Virtual Reality, education*

1. INTRODUCTION

Virtual Reality (VR) is an advanced digital technology that enables users to experience and interact with computer-generated environments in a seemingly real or physical way. Although initially developed for fields such as military simulation and gaming, VR has evolved into a powerful tool across various sectors, notably education [1]. A historical overview of VR, including the definition of basic terminology, classification of system types, and its applications across science, work, and entertainment, is provided by Tomasz and Michael [2]. Their study also offers an in-depth analysis of typical VR systems, examining the relationships between input devices, output devices, and software components, while discussing the influence of human factors on the design of virtual environments and outlining future technological and social developments.

By immersing learners into realistic and controlled environments, VR offers unique opportunities to enhance understanding, motivation, and engagement, surpassing traditional teaching methods. In educational contexts, VR allows for experiential learning where students "learn by doing," which is considered crucial for the acquisition of complex skills [3]. For example, VR can simulate engineering operations, biological processes, or historical events, providing learners with experiences that are otherwise difficult to replicate in a classroom setting. This immersive approach can cater to different learning styles—visual, kinesthetic, and auditory—thus personalizing education and improving learning outcomes [4].

Recent research highlights that VR fosters not only technical skills but also cognitive and emotional competencies essential for future workplaces. Indrie et al. [5] emphasize that using VR technologies, such as those implemented in the CircuTex laboratory activities of Erasmus+ project, can make teaching processes more productive, significantly increase student motivation, and contribute to the development of vital social and interpersonal skills, including empathy and teamwork. Moreover, VR allows for highly flexible and customized educational content, adapting training to the specific needs of various industries and educational levels.

Furthermore, VR creates a safe environment for practicing tasks that could be dangerous or costly in real life, such as performing surgical procedures, flying an aircraft, or handling hazardous materials. According to Jensen and Konradsen [6], students who learn through VR demonstrate greater confidence and competence compared to those using conventional methods. Additionally, VR fosters collaboration and critical thinking, as many applications are designed to support group activities and problem-solving tasks.

As educational institutions face the challenges of the digital age, integrating VR offers an innovative pathway to bridge theoretical knowledge with practical application. Its potential to transform classrooms into dynamic, interactive spaces highlights the importance of continued investment in VR technologies for education, ensuring that future generations are better prepared for complex real-world scenarios.

This article presents the activities carried out within the framework of the Erasmus+ project *Supporting Entrepreneurship in Eco Design-FASHION.ED (2023-1-ES01-KA220-HED-000157440)*. The project leverages Virtual Reality (VR) technology to promote sustainability and innovation in the fashion and textiles industry. Recognizing that this industry is one of the world's largest polluters, the project addresses urgent environmental challenges by encouraging the adoption of eco-friendly materials, waste reduction, and ethical production practices. Fashion.ED aims to cultivate an entrepreneurial, digitally-driven educational environment that enhances students' skills in eco-fashion and stimulates the growth of the circular economy.

A key innovation of the project is the use of Virtual Reality to create a virtual library of 3D eco-design experiments, enabling fashion and textiles students to explore sustainable solutions remotely in six languages.

2. MATERIALS AND METHODS

In the present article, we introduce the activities developed within the Erasmus+ project FASHION.ED.

This project addresses the urgent need for sustainability in the fashion and textiles sector, an industry widely recognized as the second-largest global polluter after oil, responsible for excessive waste generation, the use of harmful chemicals, and significant pollution of water and soil resources. To confront these challenges, Fashion.ED aims to foster the creation of more sustainable clothing by emphasizing eco-friendly material sourcing, waste minimization, and ethical labor practices across the supply chain. The project also seeks to cultivate an entrepreneurial, digitally-driven, and innovative higher education environment, enhancing students' entrepreneurial skills and encouraging careers in eco-fashion.

A central innovation of the project is the creation of a virtual library of interactive 3D eco-design experiments. Through VR simulations, fashion and textiles students and professionals can explore sustainable design practices, test eco-design solutions, and develop critical skills remotely, without requiring physical presence in a laboratory. The VR activities are available in English, Greek, Spanish, Lithuanian, and Romanian, ensuring broad accessibility across Europe. By integrating VR into higher education, Fashion.ED not only fosters deeper engagement and knowledge acquisition but also prepares students to meet the future demands of a more responsible and sustainable fashion industry.

By doing so, Fashion.ED contributes to the development of the circular economy and promotes eco-design practices in alignment with the objectives of the EU Education Area.

Fashion.ED is implemented by a consortium of six European partners over a period of two years (01/11/2023 – 31/10/2025): the Polytechnic University of Valencia (UPV), Spain; Kaunas University of Technology (KTU), Lithuania; the University of Western Attica (UNIWA), Greece; the University of Oradea (UO), Romania; IDEC, Greece and BDF, Netherlands. This diverse partnership brings together expertise in fashion, textiles, digital education, and entrepreneurial training to ensure a multidisciplinary approach to sustainable innovation.

3. RESULTS

3. 1. E-learning course Eco-design in fashion

The e-learning course ***Eco-design in fashion*** targets students and professionals in the fashion and textile sectors who are interested in eco-design. It provides interactive content, such as case studies, centered on sustainable practices. By completing the course, participants deepen their knowledge of eco-design principles, strengthen their skills in sustainable processes, and are encouraged to adopt environmentally responsible approaches within the textile and fashion industries.

The courses were initially developed in English and then translated into Romanian, Spanish, Greek, Dutch, and Lithuanian. They were uploaded onto the project's e-learning platform (https://learn.fashionedproject.eu/) in Word and PowerPoint formats, as well as video presentations.

The course consists of five modules that have already been uploaded to the project's e-learning platform.

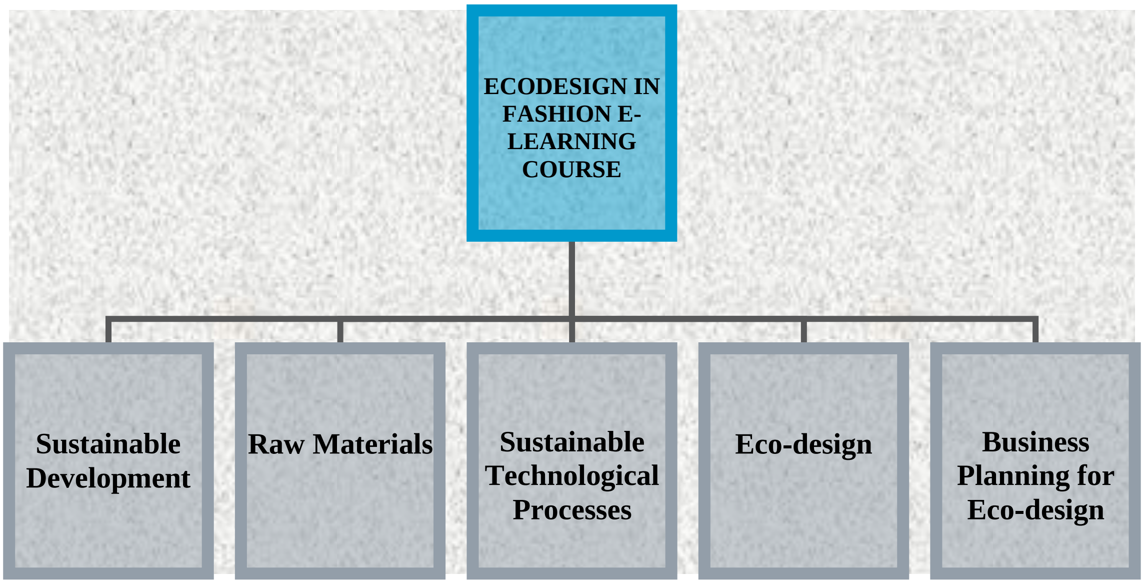
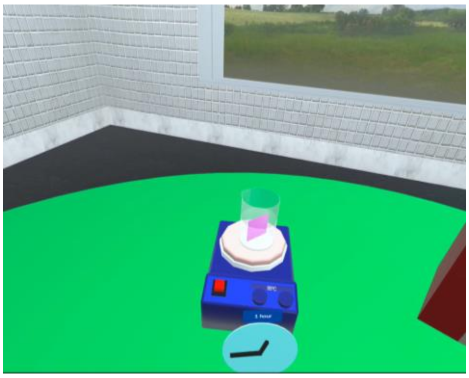


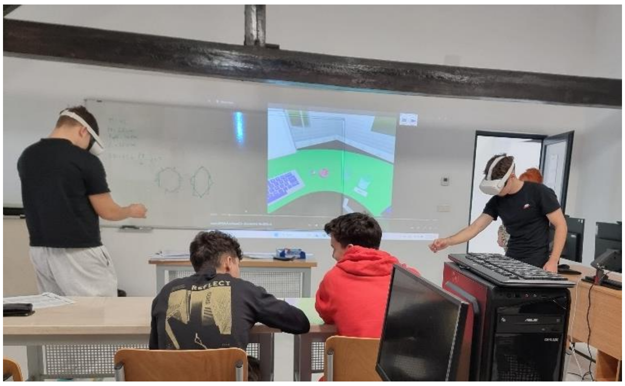
Fig. 1. *The modules of the e-learning course*

3.2. Virtual Experiments on ECO Design

A distinctive feature of the project is the integration of Virtual Reality (VR) technology to support experiential learning in eco-design. VR offers an immersive educational environment where students can engage directly with sustainable design concepts, enhancing motivation, creativity, and critical thinking. Among the key activities is the development of a virtual library of interactive 3D eco-design experiments. Through VR simulations, fashion and textiles students can conduct experiments that improve their understanding of eco-design principles and allow them to test sustainable solutions for the fashion and textiles industry without requiring physical presence in a traditional laboratory.

These experiments are accessible in six languages—English, Greek, Spanish, Lithuanian, Dutch, and Romanian—thus supporting a wide and diverse audience across Europe.





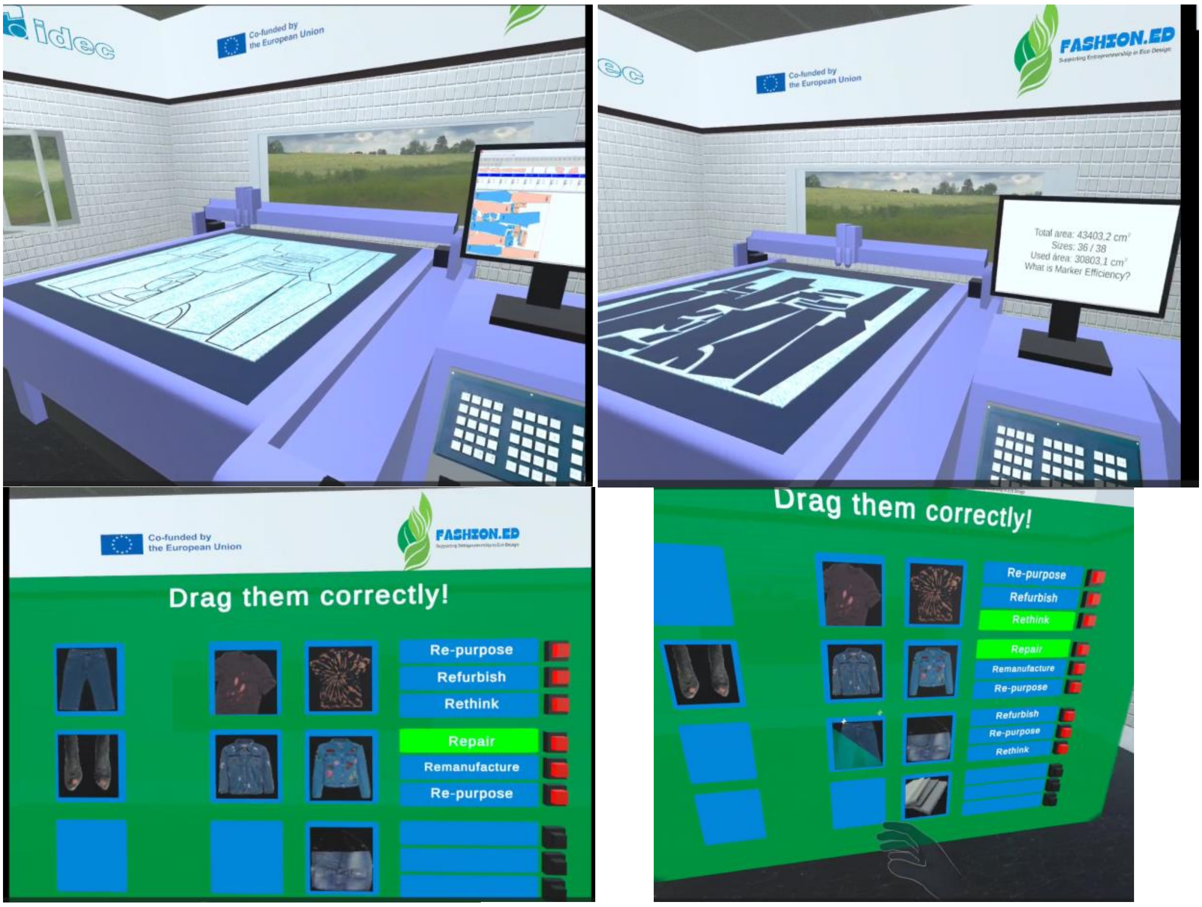


Fig. 2. *VR laboratory*

3.3. Eco-design challange

Between April 1–3, 2025, five students from each partner university — the University of Oradea (Romania), Kaunas University of Technology (Lithuania), University of Western Attica (Greece), and Polytechnic University of Valencia (Spain) — participated in the International Eco-Design Competition hosted by BDF in Leeuwarden, the Netherlands. During the event, students engaged in intensive training sessions focused on entrepreneurship, developed business plans based on eco-design principles, visited the FIRDA fashion department, and practiced effective pitching techniques. The competition concluded with each team presenting their sustainable business concepts, receiving valuable feedback to support their future entrepreneurial endeavors.

The students acquired the knowledge and competencies needed to establish successful and sustainable fashion businesses based on eco-design principles, while also fostering eco-design entrepreneurship.

5. CONCLUSIONS

The implementation of the Erasmus+ FASHION.ED project, clearly demonstrates that integrating Virtual Reality (VR) into higher education can significantly enhance students' engagement and understanding of eco-design principles. VR technology proved effective in offering an immersive, hands-on learning experience that helped bridge the gap between theoretical knowledge and practical application, even without the need for physical laboratory spaces.

Providing training materials in multiple languages greatly contributed to the accessibility and inclusiveness of the educational content, facilitating broader participation across different countries and educational systems. The creation of a virtual library of eco-design experiments offered students innovative tools to simulate sustainable solutions in the fashion and textiles industry, encouraging experimentation, creativity, and problem-solving.

The international eco-design competition successfully fostered entrepreneurial thinking, equipping students with the necessary skills to transform sustainable ideas into viable business concepts. The collaborative activities and personalized support provided during the competition organized in Netherlands further stimulated critical thinking, teamwork, and innovation.

Overall, the project outcomes highlight the strong potential of combining sustainability education with digital innovation. They also emphasize the importance of creating flexible, technology-enhanced learning environments that can support the development of future professionals committed to responsible practices in the fashion and textiles industry.

ACKNOWLEDGEMENTS

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

AVAILABILITY AND AWARENESS OF BANANA FIBER AS A SUSTAINABLE MATERIAL: A CASE STUDY OF KENYAN BANANA FIBER PRODUCTION

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Abstract: *Banana is a one of the important foods and cash crops in Kenya, yet its post-harvest byproduct, which includes the pseudo stem is largely underutilized. The limited utilization of banana pseudo stem poses a missed opportunity in promoting circular economy practices and reducing agricultural waste. This study sought to evaluate the availability of banana fiber in Kenya and assess stakeholder awareness and readiness for its sustainable use. A mixed-method approach was used, involving structured questionnaires, focus group discussions, and secondary data from agricultural agencies. Descriptive statistics were used to analyze production volumes and estimates of the potential for banana fiber extraction based on global standards undertaken. Based on 2023 data, findings indicated that Kenya has the potential to produce 2,800 metric tons of banana fiber annually. Awareness of banana fiber as a sustainable material was high (81%), with respondents recognizing its potential in eco-friendly products and agricultural waste reduction. However, significant gaps exist in hands-on training, policy support, and financial access for fiber-related enterprises. The study concludes that Kenya has untapped potential to scale up banana fiber production as a sustainable material. Bridging training gaps, enhancing supportive policy frameworks, and promoting circular economy initiatives are critical for unlocking this opportunity.*

Key words: *awareness; banana fiber; material; pseudo stem; sustainability*

1. INTRODUCTION

Banana is one of the the food crops recorded in New Guinea going as far back as 4000 BCE [1]; [2]. It was intitial cultivated as a source of food but later on used for paper and textiles. According to World data and statistics 2024, banana is one of the most often consumed fruit worldwide, which is a good source of energy and important vitamins. Considered a staple food in many tropical and subtropical areas, bananas are very vital for food security and stable prices of living. Over the years, banana production worldwide has been steadily rising; numerous nations lead the charge in growing this important commodity. The top nations in the world producing bananas are India (15% of total production), China, Ecuador, Brazil, and Philippines (5–6% each). About 15 to 20% of the total banana production in the world is traded internationally with an annual value of about US $6 billion [3]. The major exporting countries are Ecuador, Costa Rica, Philippines, Colombia, Panama, and Honduras. The major importing countries/regions are the United States, Canada, European Union, Japan, Russian Federation, and the Near East [3]. According to [4]; [5], banana fibers which extracted mostly from the pseudo stems of banana plants (Musa spp.), have attracted increasing attention in recent years for their sustainability, strength, and versatility. Traditionally, in many Asian and African countries, banana fibers have been used for making ropes, mats, and textiles. Banana fiber, in particular, has emerged as a promising alternative among natural fibers due to its low density, high strength, and biodegradability [6]; [7]; [8]. Recent studies, however, have explored its potential in a broader range of applications, from eco-friendly textiles to biodegradable composites [9].

2. MATERIALS AND METHODS

2.1 Study Area and Data Collection

This study focused on the selected banana producing counties in Kenya which included Meru, Muranga, Taita Taveta, Kirinyaga and Kisii. The data for this study was collected using structured questionnaires and focused group discussion with several stakeholders who included farmers, college students, county and national government officers. Secondary data was collected from reports published by Kenya Agricultural and Livestock Research Organization (KALRO) and other government institutions which inclue but not liminted to Agriculture and Food Authority, Kenya (AFA) [10].

2.2 Characteristics of the Respondents

A total of 96 respondents filled the questionnaires. The gender distribution was 65% female and 35% male. Based on the main occupational distribution, 55.1% were youth and government workers, 30.5% were farmers and 14.4% were college students. Age-wise, the respondents were young with 56% being between 18 to 34 years. This is consistent with the Kenyan general demographic data, which has consistently reported a higher percentage of young people for the last 10 years.

2.3 Data Analysis

The data collected was analyzed using descriptive statistics to summarize production volumes of banana fruits and the sales value. The potential to produce fiber was calculated based on globally reported methods.

3. RESULTS AND DISCUSSION

3.1. Production of Banana in Kenya

According to the Kenya Agricultural and Livestock Research Organization (KALRO), One of the important cash food crops in Kenya is the banana, which ranks first in terms of both value and volume among horticultural crops accounting for 17.8% of the total value of domestic horticulture and 34.5 percent of all locally grown fruits. It is mostly farmed by small-scale farmers as a source of staple foods and as a business that generates revenue.

Banana cultivation has become more popular in recent years with an increase of 24% in production in 2020 compared to the previous year [9,10]. Accordingly, the sales value increased by 18% from KES 24.6 billion to KES 29.02 billion in 2020. Subsequent years have recorded marginal increases; the area under cultivation increased from 71,800 Ha in 2022 to 75,184 Ha in 2023 representing 4.7% percent increase while quantity-wise increase was 1.9 million MT valued at KES 35 billion down from 2.1 million MT valued at KES 27.5 billion in the previous year representing 8.3 percent decrease in volume and 31 percent increase in value respectively. In Table 1 a summary of banana production in Kenya from 2021 to 2023 is given, a notable increase in 2023 is recorded.

***Table 1**: Banana Production in Kenya between 2021-2023*

Area (Ha)			Volume (MT)			Value in Million (KES)		
2021	2022	2023	2021	2022	2023	2021	2022	2023
68,032	71,800	75,184	1,984,282	2,052,606	2,155,236	26,960	27,454	35,939

Source: AFA-Horticultural Crops Directorate

According to Table 2, the top counties in terms of production value in 2023 were Meru, Taita Taveta, Murang'a, Kirinyaga and Kisii accounting for 23.6%, 9.7%, 7.93%, 7.83% and 5.4% percent of the total value respectively. From the production data reported by Agriculture and Food Authority, Kenya (AFA), it can be deduced that Kenya has a potential of producing 2,800 MT of banana fibers (assuming all stems are used for the production of banana fibers. Compared to the potential of producing banana fibers in Pakistan (5,800 MT) and Uganda (300,000 MT) [3], Kenya lags behind but it can utilize its youthful population and arable land to increase its production.

***Table 2**: Kenyan Banana fruit production for 2021-2023 period*

County	Volume (metric tons)			County	Volume (metric tons)		
	2021	2022	2023		2021	2022	2023
Meru	14,209	14,660	14,453	Lamu	1,845	1,875	3,965
Murang'a	8,626	8,579	7,521	Kiambu	2,189	2,233	2,537
Taita Taveta	3,195	3,183	6,638	Kakamega	2,745	3,394	2,964
Kirinyaga	3,859	3,837	3,849	Siaya	1,873	2,255	1,939
Kisii	5,332	5,762	7,426	Bungoma	2,235	2,430	1,865

Source: Author elucidation based on AFA-Horticultural Crops Directorate data [9]

3.2 Production of Banana fibers and related products in Kenya

3.2.1 Awareness and Benefits of using Banana fiber

Kenyans reported a high level of awareness (81%) about the use of possible use of banana fiber as a sustainable textile material, where this practice has a positive impact on;

(i) Production of eco-friendly products
(ii) Reduction of agricultural waste and
(iii) Supporting of circular economy

3.2.2 Role of Policies of Regulations

Kenyans have a strong feeling that polices, and regulations should be used to; Subsidies eco-friendly manufacturing; Encourage public awareness campaigns; Provide tax incentives for sustainable products and Regulate use and manufacture of non-biodegradable products

3.2.3 Skills Gap training related to production and manufacture Banana fiber and related products

With respect to banana fibers, the training programs in Kenya, do not provide sufficient hands-on training, with 58.8 % of the respondents reporting that they have not participated in hands on training (Fig 1). Therefore, there is need for trainers to inculcate hands on training to bridge the skills gaps reported by the respondents. Specifically, the students listed the following as some of the key skills gaps that need to be urgently addressed; Policy and regulatory frameworks; Life Cycle assessment and Circular economy principles and Internship/apprenticeship.

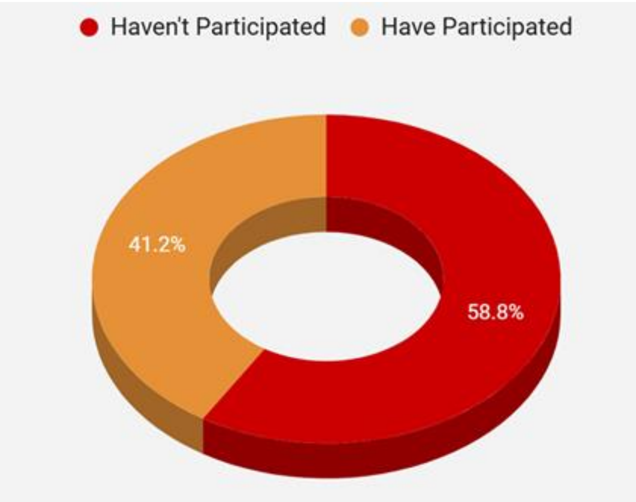

Fig. 1*: Participation in Hands-on training*

3.2.4 Use of Banana fibers and other related products

As per the respondents, the two products from banana fibers that the respondents are likely to use were Hair extensions and T-shirts and jeans (see Fig 2). 84.6% of the respondents indicated a willingliness to use banana fiber for T-shirts and jeans while 15.4% indicated a likelihood. For application of banana fiber as hair extension, 50.8 indicated an outright use while 38.5 recorded a n likelihood. However, 10.8% of the responded recorded contrary in the application of banana fiber application for hair extension.

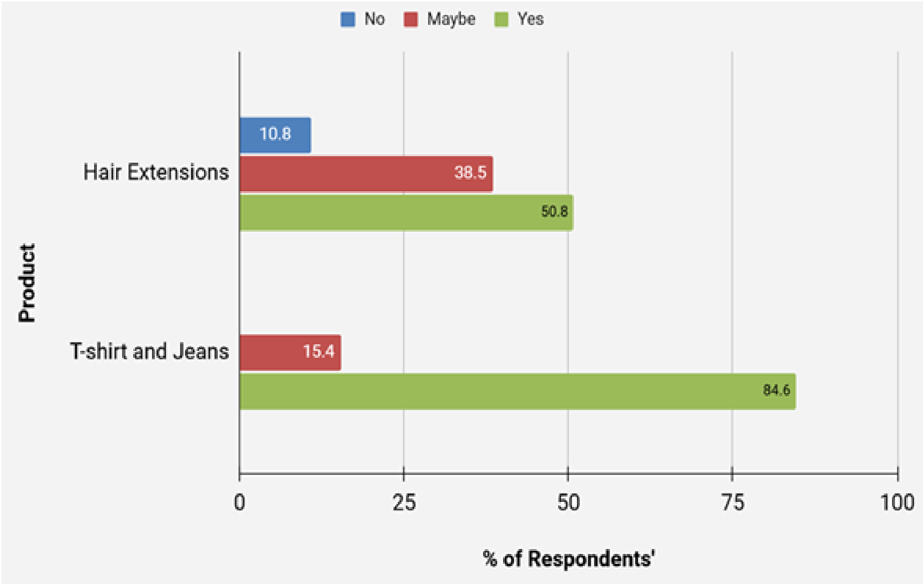

***Fig. 2**: Banana Fiber Products*

3.2.5 Size of land used for banana cultivation

Most of the farmers planted bananas on a small-scale farm, with the following land distribution; Less than 1 acres: 22.2%; 1-2 acres: 33.3%, 3-5 acres 27.8% and more than 5 acres: 16.7%

3.2.6 Access to financial empowerment

80.6% of the farmers and entrepreneurs reported that they did not get suitable financial products to enable them to carry out their business. This is due to high interest rates and requirements for collateral from financial institutions.

4. CONCLUSIONS

A study of the availability and awareness of banana fiber as a sustainable textile material was carried out, using questionnaires and focused group discussions (FGD). A total of 96 respondents were surveyed together with several FGD that composed of government workers, researchers, fashion and other stakeholders. Kenya's banana fiber industry is still in its infancy, with the optimal production capacity not yet fully realized. The potential exists for significant growth, especially considering the large quantity of banana stems that are discarded annually after the harvest of banana fruit. This research work confirmed that Kenya possesses both the capacity and growing awareness necessary to develop banana fiber as a sustainable material. While current production remains low compared to regional and global counterparts like Uganda and Pakistan, the high levels of awareness, favorable attitudes toward eco-friendly alternatives, and availability of banana biomass indicate strong potential. However, realizing this potential will require investment in hands-on training, supportive policies, financial access for farmers and entrepreneurs, and structured development of the banana fiber value chain. Harnessing Kenya's youthful population and expanding banana cultivation could position the country as a key player in sustainable fiber production within the region.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

ANTIMICROBIAL BEHAVIOR OF GREEN SILVER NANOPARTICLES DEPOSITED ON KNITTED TEXTILE SUPPORT

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Abstract: *Since the synthesis of nanoparticles by green methods is still an emerging trend in nanotechnology, many research projects aim to contribute with additional data to the existing knowledge related to nanotechnology applications for materials functionalization. Green synthesis of nanoparticles involves the use of metallic salts and different biological agents, such as enzymes, microorganisms, oligo- or polysaccharides, yeasts, fungi, or different parts of plants (root, leaf, petals, etc.). However, the most common green reduction agent remains the plant extracts, due to the ease of production, at low cost and lack of toxicity, without compromising the efficiency. The data presented in this work follow the application of green synthesised silver nanoparticles (AgNPs) on colored knitted textile fabric. The padding method was used for the fixation of the treatment. The antimicrobial evaluation was performed by the agar diffusion method. Thus, the treated knitted fabrics were incubated with Escherichia coli and Staphylococcus aureus bacteria strains and the size of the inhibition zone was measured. The physico-chemical characteristics of the resulted fabric were analysed, in terms of mass per unit area, knit density, permeability to air, and hydrophilicity. Nevertheless, the structure, morphology and integrity of the textile fibres were studied using the scanning electron microsope technique (SEM).*

Key words: *silver nanoparticles, antimicrobial activity, knitted textile*

1. INTRODUCTION

The synthesis of nanoparticles by *green* methods is an emerging trend in nanotechnology. These methods aim to overcome the limitations of conventional ones, such as high cost, toxicity of reagents, and environmental impact [1]. Green alternatives involve the synthesis of nanoparticles using different biological agents, such as enzymes, microorganisms, oligosaccharides, polysaccharides, yeasts, fungi, or different parts of plants (root, leaf, petals, etc.) [2].

The green synthesis of silver nanoparticles (AgNPs) involves the use of silver nitrate ($AgNO_3$) solution and various biological agents containing biochemical or phytochemical compounds with reducing character. These biomolecules can be alkaloids, terpenoids, phenolic compounds, flavonoids, proteins, vitamins, enzymes, co-enzymes, sugars, etc [3]. By varying the reaction medium, particles of different shapes and sizes can be obtained [4]. In figure 1, the synthesis procedure of AgNPs using various biological species is schematically represented.

The most common reducing agents used are plant extracts. The generation of AgNPs is indicated by the color change of the reaction mixture, from light brown to dark brown [5,6]. The synthesis of silver nanoparticles using bacteria can be carried out either intracellularly or extracellularly. In intracellular synthesis, silver accumulation occurs inside the cell, along with the nucleation process with formation of silver nanoparticles and continues with bacterial growth. The living microorganisms are harvested after the optimal moment of bacterial growth. The harvested cells require special treatment to release the synthesized nanoparticles. In the extracellular synthesis process, the extracellular secretion product of the bacterial populations is separated and used for synthesis [7,8]. The potential of fungi for the synthesis of metal nanoparticles is due to their metal bioaccumulation capacity and tolerance, as well as their high binding capacity and intracellular uptake [9]. They also secrete enzymes with reducing potential [10]. Vigneshwaran and his team reported that monodisperse AgNPs with particle sizes of 8.92 ± 1.61 nm can be synthesized using the fungus *Aspergillus flavus* [11]. In another method, Kathiresan and co-workers reported the in vitro synthesis of AgNPs using *Penicillium fellutanum* isolated from coastal mangrove sediment [12]. Ahmad studied the reduction of Ag ions when exposed to *Fusarium oxysporum*, leading to the formation of silver particles with sizes in the range of 5–15 that are stabilized by proteins secreted by the fungus [13].

For this study, AgNPs dispertion *green* syntheised was applied on a colored knitted textile support using the padding method and the characteristics of the resulted fabric were evaluated in terms of antibacterian activity, morphology, mass per unit area, knit density, permeability to air, and hydrophilicity.

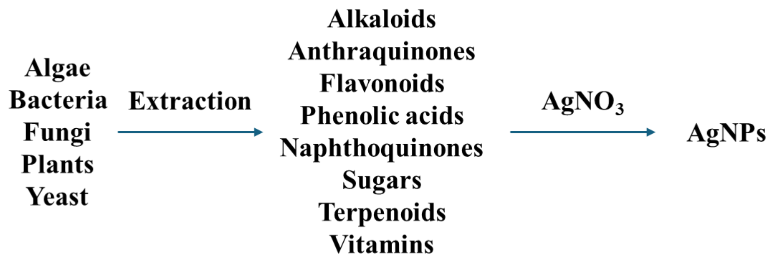

Fig. 1. *Schematic representation of AgNPs green synthesis using various biological species.*

2. EXPERIMENTAL

2.1 Materials and methods

The knitted textile support consisted of 95% cotton / 5% elastane (navy blue color) samples, made of Nm 50/1 yarn, with horizontal density: 13 rows / cm and vertical density: 19 rows / cm. The AgNPs dispersion was synthesized according to our previous report [14].

For depositing the AgNPs dispersion, a binder was used in the finishing process, which consisted of a self-crosslinking acrylic resin, in the form of a water-based emulsion (PERMUTEX® RA-9260) and was purchased from Stahl Europe B.V.. The knitted textile materials (20 cm × 30 cm) were treated with the dispersions obtained 24 hours after their preparation, using the pad method. The binder concentration used was 20 g/L.

The deposition was carried out according to the following technological flow: pad treatment with the dispersion of silver nanoparticles and binder → drying → condensation. Each sample was passed through the apparatus twice, then subjected to a drying operation for 4 min at 100°C, followed by a condensation step for 2 min at 150°C.

Standard laboratory glassware was used in the process of nanoparticle synthesis. The application of nanoparticles on textile supports was carried out using a padding instrument for impregnating textile materials with functionalizing substances (ROACHES, England) and a drying-heat-fixing-condensation device for superior finishing operations, for fixing functionalizing substances (ROACHES, England).

2.2 Characterization technique

To perform a qualitative antimicrobial evaluation, the agar diffusion method was applied, using the bacterial strains *Staphylococcus aureus* ATCC 6538 (gram-positive bacterium) and *Escherichia coli* ATCC10536 (gram-negative bacterium), according to SR EN ISO 20645/2005.

The treated knitwear samples were characterized in terms of mass per unit area (SR EN 12127-2003), density (SR EN 1049-2:2000), air permeability (SR EN ISO 9237:1999) and hydrophilicity, according to SR 12751/1989.

To evaluate the appearance and morphology of textile fibers following treatment, scanning electron microscopy (SEM) measurements were performed.

3. RESULTS AND DISCUSSIONS

3.1 Antimicrobial effect

Images of Petri dishes inoculated with the tested strains and incubated with the textile samples are illustrated in figure 2. According to the SR EN ISO 20645:2005 standard, the criteria for inhibition zones are as follows: if the size of the inhibition zone is zero and the sample shows visible bacterial contamination, the effect is assessed as unsatisfactory. When the contamination is minimal, the effect is at the limit of effectiveness. The effect is assessed as satisfactory when no bacterial growth is observed on the sample (even if the size of the inhibition zone is zero). When the size of the inhibition zone is greater than zero, the antimicrobial effect can be quantified.

Escherichia coli ***Saphylococcus aureus***

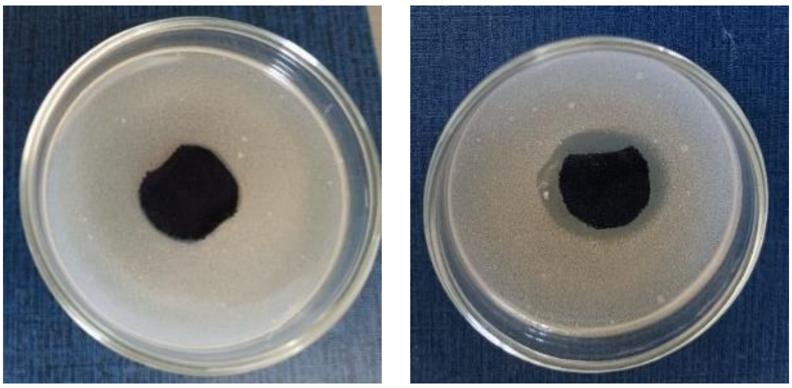

Fig. 2. *Images of Petri dishes inoculated with the tested bacterial strain and incubated with the colored knit textile samples treated with AgNPs*

The value of te inhibition zone was 2 mm in the case of *Escherichia coli* and 4 mm for *Staphylococcus aureus*. This difference is attributed to the general ability of gram-negative bacteria to be more rezistent to antibiotic agents [15], corroborated to the synergistic capacity of the AgNPs to exhibit both antimicrobian and antioxidant activity, wich disrupt predominantly the peptidoglycan thick layer within the cell wall of gram-positive bacteria [16,17].

3.2 Physico-mechanical characteristics

The color of the textile material was not altered by the presence of the treatment, while the physico-mechanical characteristics (table 1) suffered little change in mass per unit area, and density while air permeability decreased by 27,7% and the hydrophilicity decreased by almost 300%.

***Table 1**. Physical and mechanical characteristics of colored knitted textile support treated with AgNPs-based dispersions.*

Sample	Mass per unit area (g/m^2)	Knit density		Permeability to air (l/m2/s)	Hydrophilicity (s)
		Orizontal (no. of yarns/10 cm)	Vertical (no. of yarns/10 cm)		
Reference knit sample	175	148	191	305.3	105
Knit sample treated with AgNPs	173	140	190	220.6	390

3.3 Morpological characteristics

The appearance of the textile fibers, evaluated by scanning electron microscopy (figure 3), remained unaltered after the application of the dispersions. Moreover, no agglomerate formation was observed on this knitted support.

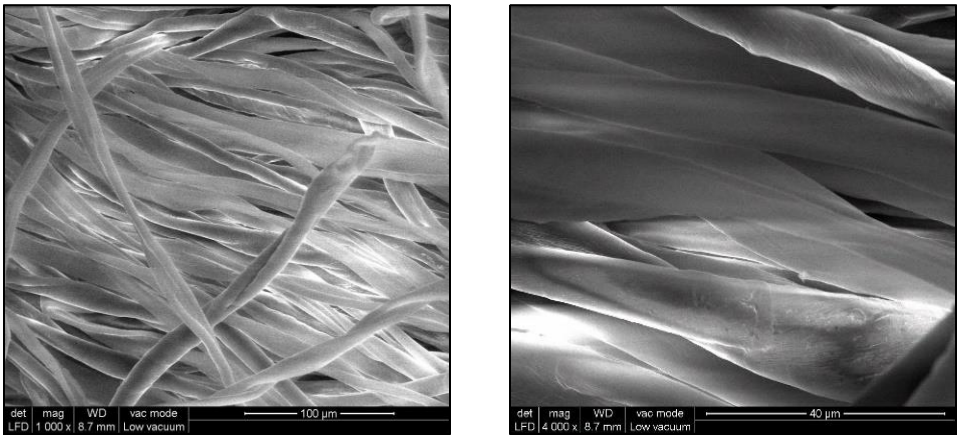

***Fig. 3.** Images obtained by scanning electron microscopy for colored knitwear textile samples treated with AgNPs*

4. CONCLUSIONS

A colored knitted textile fabric was functionalized in order to provide antimicrobian properties. For this purpose, AgNPs dispertion *green* syntheised in a previous reported manner was used. The finishing process involved the padding method and consisted of pad treatment with the dispersion of silver nanoparticles together with a comercialy available binder, followed by a drying and a condensation procedure.

The knitted textile fabric was characterised in terms of antibacterian activity, morphology, mass per unit area, knit density, permeability to air, and hydrophilicity. The value of te inhibition zone was 2 mm in the case of *Escherichia coli* and 4 mm for *Staphylococcus aureus*. While the color of the textile material, the mass per unit area and density were not altered by the presence of the treatment, the air permeability decreased by 27,7% and the hydrophilicity decreased by almost 300%.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

SMART CHROMIC DRESSING FOR NON-INVASIVE GLUCOSE MONITORING: A THEORETICAL DESIGN

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Abstract: *Diabetes is one of the most prevalent non-communicable diseases worldwide, with a rapidly increasing incidence that poses a serious public health challenge and economic burden. Current glucose monitoring systems, such as finger-prick glucometers and continuous glucose monitors (CGM), are often invasive, costly, and uncomfortable for patients, especially for long-term use. These methods also generate considerable medical waste, contributing to environmental concerns.*
This paper presents the theoretical design of a smart textile dressing for non-invasive glucose monitoring. The concept is based on a colourimetric response that indicates glucose concentration in sweat through a visible colour change. The dressing incorporates silk fibroin as the enzyme immobilisation substrate, glucose oxidase (GOx) as the active agent, and gold nanoparticles to enhance signal visibility. A cellulose acetate transparent film allows external colour assessment via the naked eye or a handheld colourimeter.
The proposed system offers multiple advantages over conventional glucose monitoring devices, including lower cost, greater comfort, and increased environmental sustainability. It also avoids skin puncture, improving usability for patients with diabetes who require continuous monitoring. This preliminary study sets the foundation for further research and prototyping of a low-cost, wearable biosensor that aligns with current trends in smart textiles and personalised healthcare.

Keywords: *biosensor, colourimetric, diabetes, disease, smart textile****.***

1. INTRODUCTION

People with problems with blood glucose disorders require constant use of a glucose measurement system, usually the finger-prick glucometer. These devices come in different types and models but are generally small, portable, accurate, simple, and intuitive. However, they are pretty invasive, as they require a small blood sample for measurement, which is obtained by a tiny fingertip prick. These meters are composed of the glucometer itself, the lancet (the needle that performs the puncture to obtain the blood sample) and the test strips. Diabetes prevalence has been growing at an alarming rate worldwide. According to the International Diabetes Federation, approximately 537 million adults were living with diabetes in 2021, a number projected to rise to 643 million by 2030 [1]. Beyond the health burden, diabetes management generates a significant amount of medical waste and environmental impact due to the single-use nature of many monitoring systems [2].

The operation of this type of device consists of measuring blood glucose based on the intensity of an electrical discharge detected on the strip, which is produced when the blood comes into contact with the test strips; these have enzymes (molecules that catalyse chemical reactions) that oxidise the glucose with glucose oxidase (GOx) as a catalyst [3-5], when this oxidation occurs, electrons are released, generating an electrical microcurrent as a result. This reaction generates a glucose titration value within 5 to 10 seconds.

Continuous Glucose Monitoring systems (CGM) are used to monitor blood glucose levels. These devices are inserted under the skin to measure glucose in interstitial fluid. To reach the interstitial fluid, the device usually has an automatic lancing device, which, using a needle guide, inserts a filament under the skin to act as a sensor. This sensor must be appropriately attached to the skin to ensure it does not become detached. The placement of the sensor depends on the manufacturer's recommendation; the most common areas are the arm, the abdomen or the upper part of the buttock.

This study proposes the theoretical design of a textile-based chromic dressing for non-invasive glucose monitoring through sweat, based on enzymatic reactions, as an alternative to conventional and invasive CGM systems. To achieve this objective, current non-invasive measurement methods are studied to select both the measurement technique and the device's design.

2. DEFINED DESIGN ELEMENTS

2.1 Blood glucose measurement technology

A textile sensor exhibits high flexibility and lightness, which is a great advantage over commonly used sensor systems. Sensors for non-invasive glucose monitoring currently developed are mostly electrochemical or colourimetric. Electrochemical sensors could easily achieve continuous monitoring by transmitting the data in real time to wireless electronics. In contrast, colourimetric sensors could be read directly with the naked eye without the aid of additional equipment.

After analysing various measurement techniques in both fields, the study by Zheng et al. proposes a reflective optical sensor based on surface plasmon resonance and a reflective fibre structure. This system uses immobilised glucose oxidase; the enzymatic reaction between glucose oxidase (GOx) and glucose is used to measure glucose concentration through a change in refractive index, which implies a change in wavelength. This change is exposed by the influence of a gold film that assists the excitation of the optical sensor to reflect the light [6]. This change in reflected wavelength can determine the relationship of % reflectance to blood glucose concentration.

2.2 Device design

To begin to design the dressing, the technology on which it is based must be taken into account, and the aesthetic and shape requirements for the dressing are as follows:

- The colours are restricted to those defined by the enzymatic reaction that will produce the smart textile. These colours fall within the chromatic range from yellow to red through orange, with these changes occurring as the glucose level rises.
- The parts that make up the dressing must be: absorbent textile impregnated with the enzyme, gold particle spray film and film of transparent material that allows the change of colour to be visualised, as well as including an adhesive and facilitating perspiration by not allowing perspiration in the area of the textile.
- The textile size must be at least 8 mm in diameter, as this is the standard size of the measuring aperture of the colourimeters on the market.

Considering these requirements and the fact that with this product, we are looking for total functionality, which will always prevail over aesthetics, we have designed a circular dressing. The shape was chosen to make measuring the colour with the colourimeter more intuitive since the measurement opening area is shaped like this.

Its size has been reduced as much as possible so that wearing it is of minimal inconvenience to the user, leaving a transparent film with a diameter of 20 mm on a textile with a diameter of 10 mm.

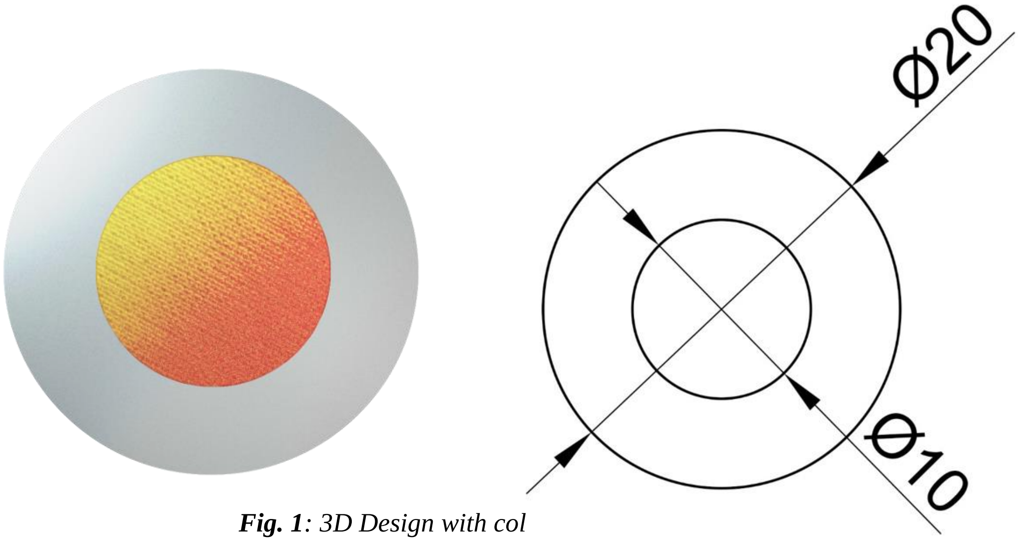

Fig. 1*: 3D Design with col*

2.3 Materials

In order to choose the textile material that would make up the absorbent pad, a prior search was carried out to determine which textile materials had the greatest affinity for glucose, from this search, several articles were found that demonstrated the aptitude of silk fibroin to immobilise glucose oxidase, so this material was chosen to be in contact with the skin, which will be impregnated with the enzymes defined above and subsequently sprayed with gold particles on its surface.

To protect this material, a transparent film of cellulose acetate is adhered to, which allows the colour of the dressing to be measured using a small manual reflection spectrophotometer.

2.4 Instructions for the use of the device

Since glucose measurement will be defined by sweat, the area of the skin where the dressing is applied must have a certain amount of perspiration. The areas of the body with the highest concentration of sweat glands are, in descending order, the palm of the hand and the soles of the feet, the head, the torso and the extremities. Bearing in mind that for colour measurement, the dressing has to be placed in an accessible area that is not restricted by clothing, the palm of the hand could be considered a suitable location. However, it is a highly articulated and uncomfortable area, so it could easily become detached and, therefore, discarded.

With the aforementioned limitations, the most suitable part, although it is not so easy to sweat, would be the arm, specifically near the wrist, but without reaching the articulated area as shown in Figure 2, so that in the case of wearing long-sleeved clothing, it would only be necessary to roll up the sleeves a few centimetres to achieve accessibility to the reading with the colourimeter.

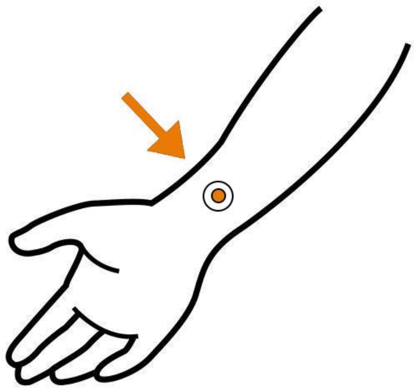

Fig. 2*: Placement area*

5. CONCLUSIONS

This paper presents the initial design of a non-invasive, low-cost glucose measurement dressing that provides a user-friendly and comfortable indicator for the user. Moreover, the proposed design contributes to sustainability by reducing electronic waste and promoting the use of biodegradable or recyclable materials. This study is the start of a larger project to prototype a device with a technology based on the colour change produced by the interaction of glucose with glucose oxidase enzymes and gold nanoparticles.

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ANNALS OF THE UNIVERSITY OF ORADEA
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GEOPOLYMERS – SUSTAINABLE MATERIALS FOR ADVANCED TEXTILES, A SHORT REVIEW

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Abstract: *Geopolymers are inorganic polymers synthesized from alumino-silicate materials, presenting unique advantages such as high thermal stability, fire resistance, and low environmental impact. These properties make geopolymers highly suitable for applications in textiles, particularly in enhancing fabric performance while addressing sustainability challenges. This work investigates the potential of geopolymers as a coating or additive to textile fibers. It explores their role in providing textiles with improved fire resistance, durability, and moisture management. The incorporation of geopolymers into textiles could reduce the need for toxic and unsustainable chemical treatments traditionally used in the textile industry. The sustainability of geopolymers, coupled with their functional properties, offers significant potential for eco-friendly textile solutions. Furthermore, this paper discusses the challenges involved in the incorporation of geopolymers into textiles, such as issues with processing techniques, scalability, and compatibility with existing textile manufacturing processes. The paper also highlights emerging innovations and the ongoing research aimed at improving the properties of geopolymers, making them more adaptable to various textile applications. Additionally, the economic and environmental benefits of incorporating geopolymers in textile production are explored, offering insights into their long-term impact. The application of geopolymers in textiles is a promising area of research that could revolutionize the industry by providing environmentally friendly alternatives and improving fabric performance.*

Key words: *coatings, adhesion strength, fiber reinforcement, thermal stability, mechanical performance*

1. INTRODUCTION

The textile industry is continuously evolving to meet the growing demands for functional, durable, and eco-friendly fabrics. Traditional textile treatments, such as chemical finishes, often involve harmful substances that pose environmental and health risks. In response, the need for sustainable alternatives has led to the exploration of geopolymers, a class of inorganic polymers that exhibit promising characteristics such as high thermal stability, fire resistance, and low environmental impact. According to [1-3], geopolymers are formed via polymerization from alumino-silicate precursors, and their unique properties make them ideal candidates for enhancing the functionality of textiles. Geopolymers offer significant advantages when applied to textiles, especially in providing superior flame retardancy, moisture management, and enhanced durability. Textiles treated with geopolymers can resist high temperatures, reduce the risk of combustion, and offer protection in hazardous environments. Additionally, their ability to improve fabric strength and resistance to environmental factors like UV radiation and chemical exposure makes them highly valuable for industrial applications. Geopolymer coatings can also enhance fabric resilience against wear and tear, leading to a longer lifespan for textiles used in demanding environments. Moreover, geopolymers are considered a more sustainable option compared to conventional textile treatments. Papers [3-4] highlight that, as green materials, geopolymers are derived from abundant natural resources and their production typically involves lower energy consumption and reduced carbon emissions compared to traditional materials, according to the works of [5-6]. Therefore, incorporating geopolymers into textiles aligns with the growing push for eco-friendly alternatives in the textile industry. This paper explores the various applications of geopolymers in textiles, focusing on their ability to enhance fabric properties and reduce the environmental impact of textile production. Furthermore, it addresses the challenges of integrating geopolymers into textile manufacturing processes and discusses future directions for research in this innovative area.

2. SUSTAINABILITY

The environmental sustainability of geopolymers is another key advantage, as their production process is considered more eco-friendly than traditional textile treatments. Geopolymers are synthesized using low-energy processes and abundant raw materials, such as fly ash and clay, which are often waste by-products from industrial activities, as described by papers [3, 5, 7-8]. This makes geopolymers a more sustainable choice for textile manufacturers looking to reduce their carbon footprint, having almost no carbon atoms in their structure as well, thus not being able to release huge amounts of CO_2. Additionally, geopolymers do not contain harmful volatile organic compounds (VOCs) or other toxic substances commonly used in conventional textile coatings, ensuring that treated fabrics do not release pollutants during their lifespan. This sustainability is in line with the global shift towards greener manufacturing practices and the reduction of harmful chemicals in textile production. In **Fig. 1**, the life cycle assessment (LCA) of the geopolymers obtained using mine waste is presented.

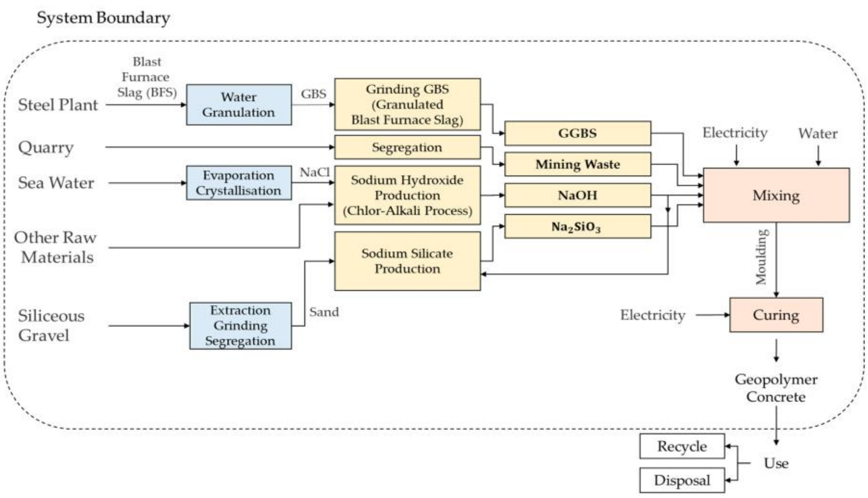

***Fig 1**: The LCA diagram of the geopolymerization process when mine waste is used [12]*

3. PROPERTIES AND APPLICATIONS

Geopolymers are increasingly being utilized in the textile industry to improve fabric performance, with applications primarily focused on providing textiles with enhanced properties such as fire resistance, strength, and durability. Depending on the Si:Al ratio, geopolymers can be used in various fields, as described in **Fig. 2**.

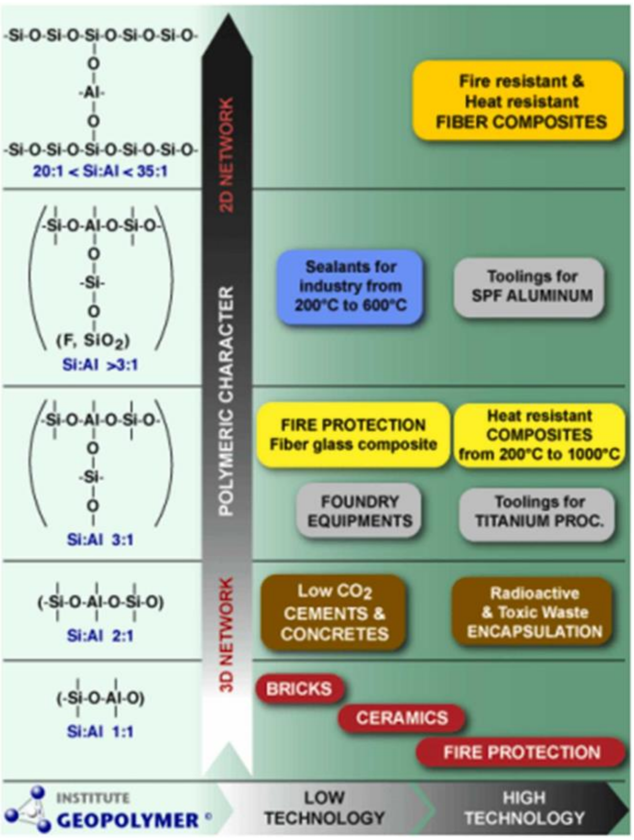

Fig 2*: The applications of geopolymers according to their structure [13]*

3.1 Fire resistance

The most notable use of geopolymers in textiles is as a flame-retardant coating. Textiles coated with geopolymers show remarkable resistance to fire, making them suitable for protective clothing, upholstery, and industrial fabrics exposed to high heat. One such example is the achievement of the contribution [5], where a geopolymer composite with polyvinyl alcohol fibers and manganese slag was obtained and applied on pine wood boards. The incorporation of PVA fibers lead to a crack-resistant fireproof material. This application is especially crucial in industries such as aerospace, manufacturing, and emergency response, where flame-resistant materials are vital for safety. Geopolymers act as a protective barrier, preventing ignition and reducing the spread of flames, thereby improving overall safety.

3.2 Strength and durability

In addition to fire resistance, geopolymers can enhance the mechanical properties of textiles, making them more durable and resistant to environmental degradation, since their have a multi-metal-oxide structure. By integrating geopolymers into fabrics, textile manufacturers can create materials that are not only strong but also highly resistant to chemical and UV degradation. **Fig. 3** shows how curing age contributes to the compressive strength of the product.

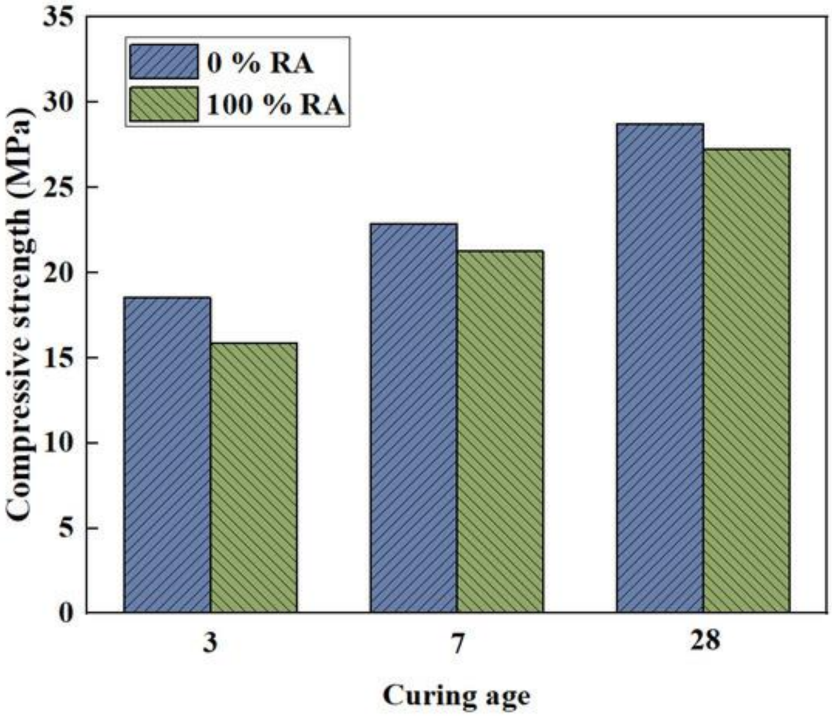

***Fig.3**: The effect of curing age upon compressive strength [14]*

This is particularly useful for outdoor textiles exposed to harsh environmental conditions, such as tents, awnings, and outdoor furniture. Geopolymers are somewhat hydrophilic due to their ionic structure. Moreover, their rigid structure is prone to cracks, which facilitates the infiltration of water, thus extending the existing cracks and promoting fungal growth, according to paper [9]. In order to address these issues, geopolymers are blended with hydrophobic materials such as polydimethylsiloxanes (PDMS), which was demonstrated by the works of [9-11]. **Fig. 4** describes the method through which a fly-ash-based geopolymer was coated with PDMS in order to obtain a hydrophobic material. Paper [10] has managed to achieve a contact angle of 113^o on the geopolymeric surface, which exceeds the minimum value of 90^o that is needed in order for a material to pass the hydrophobicity assesssment. Moreover, upon enhancing the hydrophobicity of the surface even more using calcium stearate and polytetrafluoroethylene (PTFE), the contact angle increased to 140^o and 159^o, respectively, which means that PTFE turned the geopolymer into a superhydrophobic material, the minimum contact angle value being 150^o.

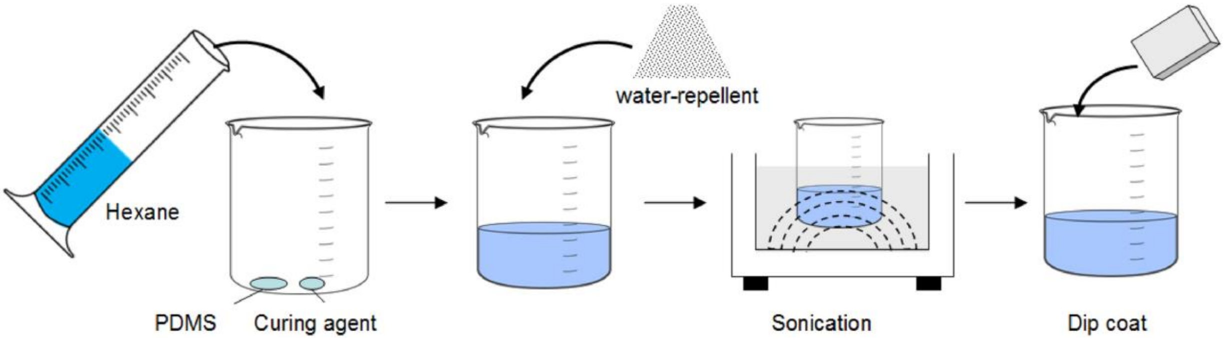

Fig.4: *Synthesis of a water-repellent geopolymer composite [10]*

Contribution [11] used two different coating materials – methylsilicone oil and an organic silicon agent, concluding that the first option is the best one, with a noticeable increase in the contact angle of the geopolymeric surface by almost 70º, which led to a value that is higher than 90º (enough to acknowledge the hydrophobicity of the geopolymeric surface).

4. CHALLENGES

Despite the promising advantages of geopolymers, their implementation in textile materials faces several challenges. One of the main obstacles is the difficulty in achieving uniform coating or integration of geopolymers with textiles due to their rigid, inorganic nature. Unlike organic polymers, geopolymers tend to form hard, brittle films that may not be flexible enough for certain fabric applications, as explained in work [2]. This inflexibility can limit their use in textiles that require high levels of elasticity or softness, such as clothing. Additionally, the integration of geopolymers into existing textile manufacturing processes poses challenges in terms of scalability. Many textile manufacturers are accustomed to using organic, more malleable materials and may need to adjust their processes to incorporate geopolymer-based treatments efficiently. Another challenge is ensuring compatibility between geopolymers and different textile fibers, as some fabrics may react differently to the geopolymer coating, affecting the final product's performance. Furthermore, the cost of producing and applying geopolymers to textiles is often higher than traditional treatments, which can deter widespread adoption in mass-market textile production.

5. CONCLUSIONS

Geopolymers present a promising alternative to traditional textile treatments, offering enhanced performance characteristics such as flame resistance, durability, and moisture management. Their eco-friendly nature, derived from natural and abundant resources, positions them as a sustainable option in the quest for greener textile manufacturing. Although challenges remain in terms of scalability and the integration of geopolymers into textile manufacturing processes, their potential to revolutionize the textile industry is evident. Future research into optimizing their properties and processing methods will likely pave the way for their widespread adoption in textile applications, contributing to both functional and sustainable advances in the industry. With increasing demand for environmentally responsible solutions, geopolymers could play a crucial role in the transformation of the textile sector towards more sustainable practices.

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ANNALS OF THE UNIVERSITY OF ORADEA
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LARGE-SCALE OPERATIONS CARGO PARACHUTE SYSTEM

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Abstract: *The article describes the design process for a low-cost aerial delivery system (LCADS) that is a one-time use, disposable, airdrop system consisting of cargo parachute and container. The parachute systems is developed for military resupply missions and for humanitarian relief efforts in areas where ground supply and/or recovery of airdrop equipment is difficult or not feasible. LCADS consists primarily of three types of cargo parachutes capable of supporting and delivering in a wide range of weights, from 70kg up to 1000kg. During the product development will be targeted three types of delivery topologies each with its own type of low-cost parachute: 'Low Velocity' delivery where the cargo is slowed down considerably by the parachute down to 5-7m/s for fragile and sensitive equipment using a cross type parachute made of fabric bands; 'High Velocity' delivery where the cargo is only stabilized during descent and only marginally slowed down by the parachute for non-fragile equipment also using a cross type parachute made of fabric bands; 'High Altitude Precision Delivery', where the cargo is driven to a specific target using a self-steering a ram-air parachute. The parachutes are made from woven polypropylene fabric obtained from recycled source materials. These parachutes are 55% to 80% less expensive than the traditional nylon cargo parachutes due to a much lower cost of material. An added benefit for the LCADS, which are made from woven polypropylene fabric, is that these parachutes have shown to have a lower rate of descent than standard nylon cargo parachutes.*

Key words: *LCADS, Cargo Parachute, Airdrop, Polypropylene Fabric, Recycling*

1. INTRODUCTION

The need for efficient, reliable, and cost-effective aerial delivery systems has grown significantly in recent years. This demand is driven by both military operations, which require the resupply of troops in remote or hostile areas, and humanitarian missions, where aid must be delivered to regions inaccessible by traditional ground transport due to natural disasters, conflict, or other barriers. The development of a Low-Cost Airdrop Delivery System (LCADS) addresses these challenges with an innovative solution that emphasizes affordability, disposability, and effectiveness.

Aerial delivery systems have historically been a crucial component of logistical operations, particularly in scenarios where ground access is limited or non-existent. Traditional airdrop systems, while effective, often come with high costs and complexities associated with the recovery and reuse of the airdrop equipment. These challenges are exacerbated in environments where retrieval of the dropped equipment is impractical due to hostile conditions, dense vegetation, or remote locations. The introduction of a low-cost, disposable system like LCADS offers a pragmatic alternative by eliminating the need for equipment recovery, thereby streamlining the resupply process and reducing operational expenses [1]. LCADS is designed as a one-time-use airdrop system comprising a cargo parachute and container. It aims to deliver supplies reliably while minimizing the logistical complexities and costs associated with recovering airdrop equipment. The system's versatility is highlighted by its capacity to support a wide range of payloads, from 70 kg to 1000 kg. By utilizing recycled polypropylene materials for parachute construction, LCADS not only reduces costs significantly but also aligns with environmental sustainability goals [2].

In summary, the Low-Cost Airdrop Delivery System addresses critical logistical challenges faced by both military and humanitarian operations. By offering a cost-effective, disposable, and environmentally sustainable solution, LCADS enhances the efficiency and effectiveness of aerial delivery missions. Its development marks a significant advancement in the field of aerial logistics, providing a robust and versatile tool that meets the demands of modern operational environments. This article outlines the design, development, and testing process of the LCADS, focusing on the benefits and performance of using recycled polypropylene, and highlights the potential impact of this innovative system on future logistical operations.

2. SYSTEM DESIGN

The development of LCADS is particularly timely given the increasing frequency and severity of natural disasters globally. Climate change has led to more intense and frequent hurricanes, floods, and other catastrophic events, heightening the need for rapid and efficient delivery of relief supplies. Humanitarian organizations often face immense challenges in reaching affected populations quickly, especially in the initial hours and days following a disaster [3]. An effective and affordable airdrop system can make a significant difference in these situations, ensuring that essential supplies such as food, water, medical supplies, and shelter materials reach those in need without delay. In military contexts, the importance of reliable resupply mechanisms cannot be overstated. Troops operating in remote or hostile areas rely heavily on consistent and timely delivery of supplies to maintain operational effectiveness. Traditional supply lines are often vulnerable to enemy actions, terrain difficulties, and logistical bottlenecks. LCADS offers a robust solution by providing a rapid, reliable, and low-cost method of delivering essential supplies, thus enhancing the operational flexibility and sustainability of military forces [4]. Beyond the immediate practical benefits, LCADS also represents a significant step forward in sustainable engineering. The system's reliance on recycled polypropylene not only reduces material costs but also addresses the growing concern over plastic waste. The use of recycled materials in critical applications demonstrates a commitment to sustainability and environmental stewardship, aligning with broader global efforts to reduce waste and promote recycling. This approach not only benefits the environment but also sets a precedent for other industries to follow, encouraging innovation and sustainability in product design [5].

The versatility of LCADS is another key strength. It is designed to accommodate a variety of payloads and mission profiles, making it suitable for a wide range of applications. Whether it's delivering humanitarian aid in the aftermath of a natural disaster, resupplying troops in a conflict zone, or providing logistical support in remote areas, LCADS can be tailored to meet specific operational needs. This adaptability ensures that the system remains relevant and useful across different scenarios and over time [6].

As such the LCADS comprises three types of cargo parachutes designed to cater to different delivery needs: Low Velocity, High Velocity, and High Altitude Precision Delivery. Each type is tailored to specific requirements based on the nature and sensitivity of the cargo [7].

Low Velocity Delivery: Designed for fragile and sensitive equipment, this parachute system ensures the cargo descends at a controlled speed of 5-7 meters per second. The parachute features a cross-type design made from fabric bands, which significantly reduces the descent rate and minimizes impact forces upon landing.

High Velocity Delivery: This system is intended for non-fragile items where the primary goal is stabilization rather than significant deceleration. The high velocity parachute also utilizes a cross-type design with fabric bands, allowing the cargo to descend rapidly while maintaining a controlled trajectory.

High Altitude Precision Delivery: For scenarios requiring precise delivery to a specific target, this parachute system employs a self-steering ram-air parachute. This advanced design enables accurate navigation and placement of the cargo from high altitudes [8].

Detailed Design Choices

Cross-Type Parachute Design:

The cross-type design employs fabric bands arranged in a cross pattern, which provides a balance between simplicity and effectiveness. This design choice is optimal for both low velocity and high velocity systems, as it offers stability during descent and is easy to manufacture at a low cost. This type of parachute is engineered to achieve an optimal drag coefficient, ensuring the desired descent speed is attained for various payload weights. This involves fine-tuning the surface area and the material properties to maximize aerodynamic efficiency. The fabric bands used in the cross-type parachutes are reinforced to withstand the stresses encountered during deployment and descent. The material selection and weave pattern are crucial in preventing tears and ensuring the structural integrity of the parachute [9].

Fig 1. *Cross-Type Parachute*

Ram-Air Parachute Design:

The ram-air parachute design incorporates a self-steering mechanism that uses GPS and automated control systems to navigate to the target location. This involves complex algorithms that adjust the parachute’s flaps to control direction and descent speed. The ram-air parachute features an aerodynamic shape similar to a rectangular wing, providing lift and allowing for precise control during descent. This design requires detailed aerodynamic analysis to ensure stability and accuracy. The materials used in the ram-air parachute must be lightweight yet durable, capable of withstanding high-altitude conditions and the stresses of guided descent. Advanced composites and reinforced polypropylene fabrics are typically used to achieve the required performance.

Additional Design Considerations:

Each type of parachute requires a reliable deployment mechanism to ensure successful deployment at the appropriate altitude. This includes the use of static lines, drogue chutes, or spring-loaded deployment systems, depending on the specific requirements of the mission. The parachutes are attached to the cargo container using reinforced harnesses and load distribution systems. These attachments are designed to evenly distribute the forces experienced during descent, minimizing the risk of damage to the cargo. The design of LCADS emphasizes modularity and scalability, allowing for easy adaptation to different payload sizes and mission requirements. This includes interchangeable parachute modules and adjustable harness systems to accommodate varying weights and dimensions

Material Selection

The selection of woven polypropylene fabric, sourced from recycled materials, is a pivotal aspect of the LCADS design. Polypropylene is known for its high tensile strength and resistance to abrasion, making it an ideal material for parachute construction. The fabric can withstand the forces encountered during deployment and descent, ensuring the parachute remains intact and functional. Polypropylene is lighter than many other materials, such as nylon, which contributes to the overall efficiency of the parachute system. The reduced weight allows for better control and stability during descent. Polypropylene exhibits excellent resistance to moisture, UV radiation, and temperature fluctuations. This ensures the parachutes maintain their integrity and performance in various environmental conditions, from arid deserts to humid tropical regions.

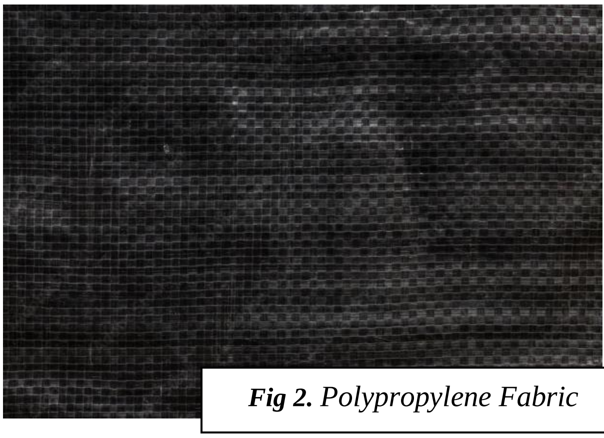

Fig 2. *Polypropylene Fabric*

Polypropylene offers several advantages over traditional nylon used in cargo parachutes:

Cost Efficiency: Polypropylene fabric is substantially cheaper than nylon, reducing the overall cost of the parachute by 55% to 80%

Recyclability: The use of recycled polypropylene aligns with sustainable practices, minimizing environmental impact and promoting the reuse of materials.

Performance: Tests have shown that polypropylene parachutes provide a lower rate of descent compared to nylon, increasing the likelihood of cargo survival upon landing.

Recycling polypropylene consumes significantly less energy compared to producing virgin polypropylene or other materials like nylon. This energy efficiency reduces greenhouse gas emissions and contributes to a lower carbon footprint for LCADS production. By using recycled polypropylene, LCADS helps divert plastic waste from landfills and incineration, supporting global efforts to reduce plastic pollution and promote a circular economy. This approach contributes to environmental sustainability by conserving natural resources and reducing environmental impact. The adoption of recycled materials in LCADS aligns with broader sustainability goals, promoting responsible resource use and supporting environmental conservation efforts. By prioritizing recycled polypropylene, the project exemplifies sustainable engineering practices that benefit both the environment and society at large.

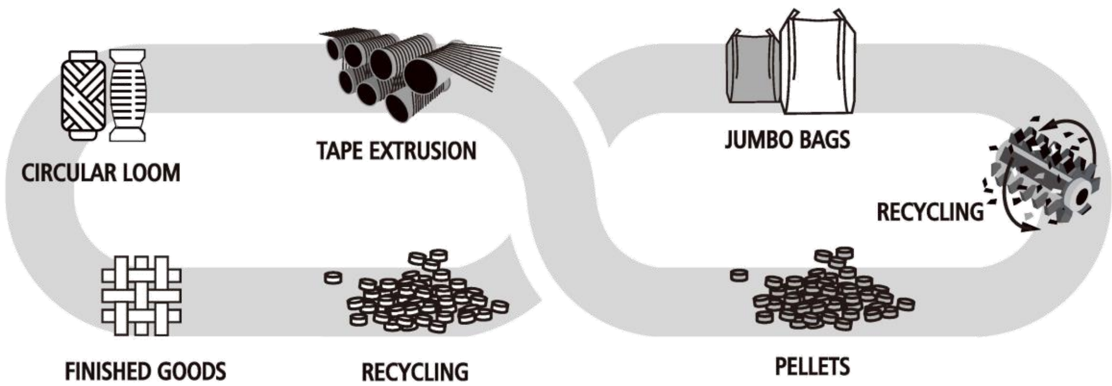

Fig. 3 *Recycling Process*

3. CONCLUSIONS

The Low-Cost Airdrop Delivery System (LCADS) represents a significant advancement in the field of aerial logistics. By focusing on affordability, disposability, and environmental sustainability, LCADS addresses the critical challenges associated with traditional airdrop systems. The use of recycled polypropylene fabric not only reduces production costs but also promotes the reuse of materials, contributing to environmental conservation efforts.

The development and testing of LCADS have demonstrated its capability to meet diverse operational needs, from low velocity delivery of fragile items to high velocity drops of non-fragile supplies, and precision delivery from high altitudes. The system's robust performance, combined with significant cost savings and environmental benefits, makes it a compelling option for both military and humanitarian applications.

As global challenges continue to evolve, the need for innovative and adaptable solutions like LCADS becomes increasingly critical. The success of this project highlights the importance of integrating sustainable practices into product design and development. Moving forward, further research and refinement of the LCADS will focus on enhancing its capabilities and exploring new applications, ensuring it remains a valuable asset in the arsenal of aerial delivery technologies.

The Low-Cost Airdrop Delivery System exemplifies how thoughtful design, material innovation, and a commitment to sustainability can come together to address pressing logistical challenges in a cost-effective and environmentally responsible manner. This system not only meets the immediate needs of military and humanitarian missions but also sets a precedent for future developments in the field of aerial delivery. By continuing to explore and improve upon these concepts, we can create even more efficient, reliable, and sustainable solutions for the complex logistical challenges of the future.

ACKNOWLEDGEMENTS

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

INNOVATIVE TECHNOLOGIES FOR OBTAINING NEW EMULSIONS, BASED ON PINE OIL AND SURFACTANTS

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Abstract: *New emulsions were obtained by innovative technologies based on pine oil and 2 surfactants: sodium dodecyl sulfate and Tween® 80 mixture: Ps- pine oil/ sodium dodecyl sulfate/water; Pt- pine oil / Tween® 80/water; Pst- pine oil/ sodium dodecyl sulfate and Tween® 80 (ratio 1:1)/water, for different concentrations of pine oil, in order to improved surface properties with applications in leather industry. Pine oil has a strong antimicrobial and antifungal effect due to its content in: vitamins C and E, phytosterols, fatty acids, antioxidants and amino acids. The order of introduction of the components in innovative technologies, the working conditions and especially the choice of the concentration of surfactants >CMC, is essential in the solubilization of pine oil and obtaining the new emulsions. The emulsions were characterized by optical microscopy with pine oil at 23-60°C. The changes in the aggregation process were observed for each type of emulsion, the influence of temperature and the solubilization of pine oil. Dynamic light scattering (DLS) for the emulsions showed the stability, concentration, particle size, polydispersity, zeta potential. The antimicrobial properties were analyzed by microbiological tests. FTIR measurements highlighted the interaction mechanism of surfactants with pine oil from the new emulsions. The leather samples were microbiologically tested and antimicrobial, antifungal effects were observed. The new emulsions are original due to the successful inclusion of pine oil with high potential for improved surface properties with applications in leather industry.*

Key words: *new emulsions, innovative technologies based on pine oil and surfactants, leathers processed*

1. INTRODUCTION

This paper presents innovative technologies to created new emulsions, based on pine oil and 2 surfactants: sodium dodecyl sulfate and/or Tween® 80, in order to improved surface properties with applications in leather industry.

Pinus sylvestris, the Scots pine (UK), Scotch pine (US), Baltic pine, (M. Gardner; 2013) or European red pine is a species of tree in the pine family *Pinaceae* that is native to Eurasia.

It can readily be identified by its combination of fairly short, blue-green leaves and orange-red bark. *Pinus sylvestris* is an evergreen coniferous tree growing up to 35 metres in height (J. Bispham; 2015) and 1 m in trunk diameter when mature, exceptionally over 45 m tall and 1.7 m in trunk diameter on very productive sites.

The tallest on record is a tree over 210 years old growing in Estonia which stands at 46.6 m.

Fig. 1*: Image of Pinus sylvestris (J. Bispham; 2015)*

Pine oil is an essential oil obtained from a variety of species of pine, particularly Pinus sylvestris. Typically, parts of the trees that are not used for lumber- stumps, are ground and subjected to steam distillation. As of 1995, synthetic pine oil was the "biggest single turpentine derivative." Pine oil is a higher boiling fraction from turpentine. Both synthetic and natural pine oil consists mainly of α-terpineol, a C_{10} alcohol (214–217°C). Other components include dipentene and pinene. The detailed composition of natural pine oil depends on many factors, such as the species of the host plant. Synthetic pine oil is obtained by treating pinene with water in the presence of a catalytic amount of sulfuric acid. This treatment results in hydration of the alkene and rearrangement of the pinene skeleton, yielding terpineols. Pine oil is used as a cleaning product, disinfectant, sanitizer, antimicrobial and antifungal. It is effective against Brevibacterium ammoniagenes, the fungi Candida albicans, Enterobacter aerogenes, Escherichia coli, Gram-negative enteric bacteria. Due to its properties and beneficial effect on health, pine oil is used in: cosmetics, medicine, pharmacy and food (M.Gscheidmeier, F. Helmut; 2000).

Fig. 2*: Pinus sylvestris essential oil in a clear glass vial (M.Gscheidmeier, F. Helmut; 2000).*

Tween 80 is a polyethylene sorbitol ester, also known as Polysorbate 80, PEG (80) sorbitan monooleate, polyoxyethylenesorbitan monooleate (M.G. Hertog, E.J.Feskens, D.Kromhout, M.G Hertog, P.C.Hollman, M.G.Hertog, M.Katan; 1993). It has been used as emulsifying agent for the preparation of stable oil-in-water emulsions (D.S. Varasteanu; 2014). Tween is a group of non-volatile surfactant derivatives derived from glycerol esters (C.M Enescu; 2014). The most important usage of Tween is its application as an oil absorber and emulsifier (K.Walczak-Zeidler, A.Feliczak-Guzik, I. Nowak; 2012). Sodium dodecyl sulfate (SDS), also called sodium lauryl sulfate (SLS), is an anionic tenside used as a cleaning and hygiene product (H.Kallio, B. Yang, P. Peippo; 2002).

In this research the new emulsions created and leathers processed with them were analyzed by FTIR-ATR spectroscopy, DLS, optical microscopy and microbiological tests.

2. EXPERIMENTAL

Materials and Methods

In order to obtain new emulsions the following materials have been used: sodium dodecyl sulfate and Tween 80 from Sigma-Aldrich; pine oil from company “BIOCA”.

The experimental techniques used in this paper consist in: a zetasizer-nano "MALVERN" equipment, with measuring range between 0.3 nm- 60.0 microns and zeta potential determination with an accuracy of +/-2%; an FTIR-ATR spectrophotometer JASCO; optical microscopy with an ELTA 90 Medical Research S.R.L. equipment. A number of 3 samples of emulsions: **Ps, Pt, P**st were prepared in the working conditions: sodium dodecyl sulfate or/and Tween 80 at 1:1 ratio, temperature=50°C for 30 minutes with pine oil, fig.3. The Pst emulsion variant with the two surfactants sodium dodecyl sulfate and Tween 80 in a 1:1 ratio was selected because it is the most stable over time (1 month). The way of introducing surfactants and pine oil in obtaining emulsions is very important. The surfactant micellar solution is always made in water at a concentration above the micellar critical concentration- CMC and then the pine oil is added drop by drop and mixed. The chosen temperature is 50^{o}C for a good solubilization of the pine oil in the surfactant micelles. When there are two surfactants, micellar solutions in water are made separately for them, then the two solutions are mixed and mixed micelles in water are obtained. In the solution of mixed micelles, the pine oil is introduced drop by drop, stirring and at the appropriate temperature. In the end, the emulsion is obtained with pine oil solubilized in the mixed micelles. The yield of multiple drop formation decreases rapidly as the homogenization time increases. New emulsions are formed and the properties derive from the surfactants used, as well as the conditions and working parameters. This phenomenon is controlled by the concentration of: pine oil, surfactants, temperature, pH=4.

***Fig. 3**: Image of new structured emulsions a) **Ps**- pine oil/ sodium dodecyl sulfate/water; **Pt**- pine oil/ Tween® 80/water; **Pst**- pine oil / sodium dodecyl sulfate and Tween® 80 (ratio 1:1)/water*

The leathers were processed by cross spraying with the three obtained emulsions: **Ps, Pt,Pst** with a quantity of 0.5 l for 8 times on a leather surface from 10 cm.

Method used for microbiologically tests: -replication of the bacteria used in the test: *Aspergillus niger*, *Staphylococcus aureus ATCC* 6538 (gram-positive). We work with a pure, freshly propagated culture;

- dry sterilization of laboratory glassware in an oven at 180^{o}C;
- preparation of the culture medium, characteristic of the test bacteria used, namely: Nutrient Agar for *Aspergillus niger* and Mannitol Salt Agar for the genus *Staphylococcus aureus*;
- wet sterilization in the autoclave and Erlenmayer vessels with culture media;
- the samples must be circular, with a diameter of 25±5 mm.

Prepare the agar volume for the bottom layer without bacteria. Place (10 ± 0.1) ml in each sterilized Petri dish and allow the agar to solidify. Prepare the amount of agar for the top layer and cool to 45^{0}C on a water bath. Inoculate 150 ml of agar with 1 ml of bacterial working solution (1-5 x 108 cfu/ml). Shake the container vigorously to distribute the bacteria evenly. Add (5±0.1) ml to each Petri dish and allow the agar to solidify. The samples are placed on the surface of the nutrient medium and then incubated at 37^{0} C

3. RESULTS AND DISCUSSIONS

Obtaining new emulsions based on pine oil and surfactants

New emulsions were obtained using 2 surfactants, sodium dodecyl sulfate and Tween 80, in which pine oil were introduced. According to novel innovative technologies in fig.4, three types of new emulsions were made: **Ps, Pt, Pst.** The antimicrobial and antifungal effect were improved with the increase in the amount of pine oil.

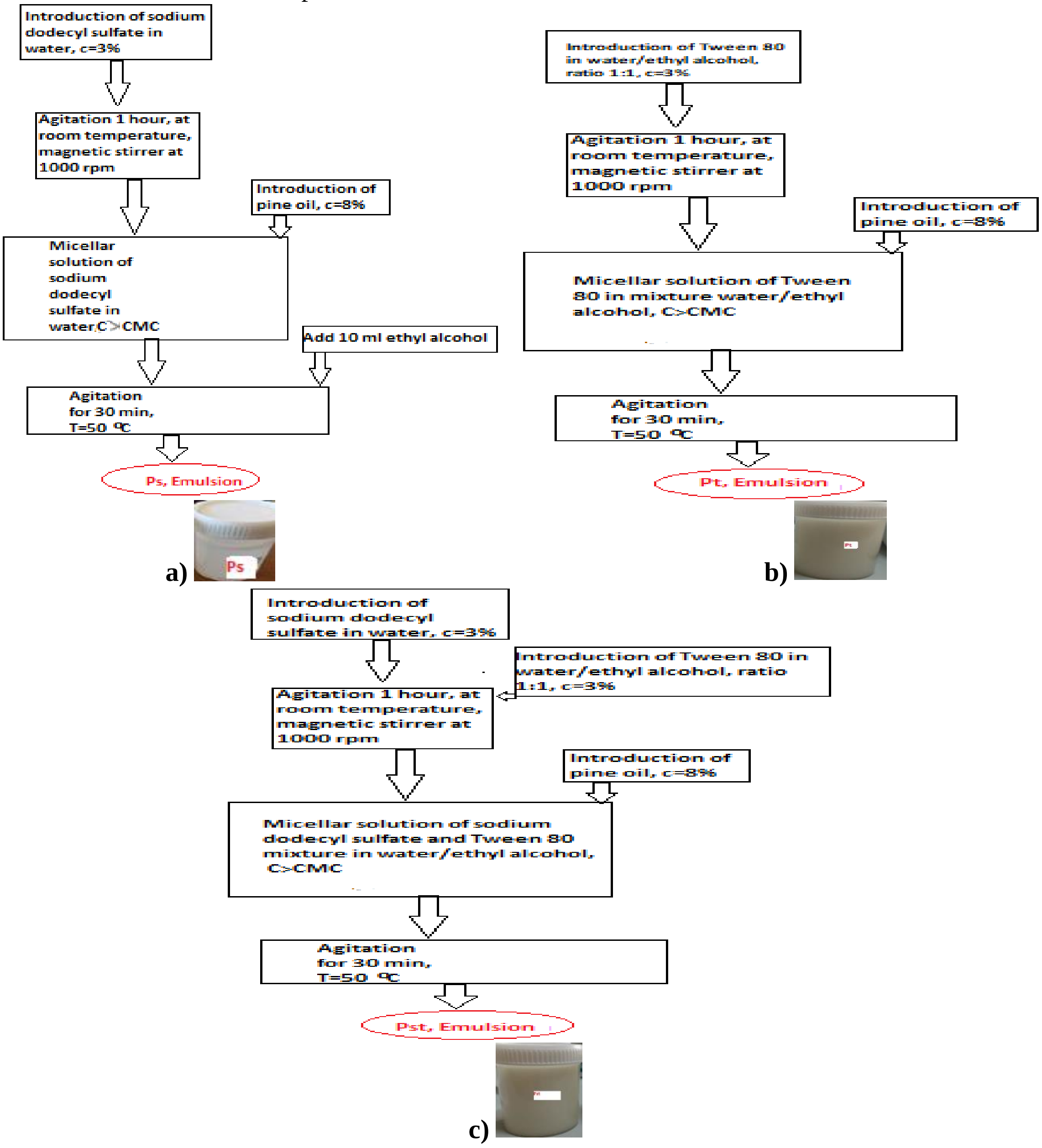


Fig. 4: Innovative technologies for obtaining 3 type of emulsions with pine oil: Ps-a); Pt-b); Pst-c)

Mechanism of pine oil solubilization in surfactant micelles

In this research, the interaction of pine oil with 2 surfactants, sodium dodecyl sulfate and Tween 80 was investigated. A mechanism for the solubilization of pine oil in micelles was proposed, fig. 5.

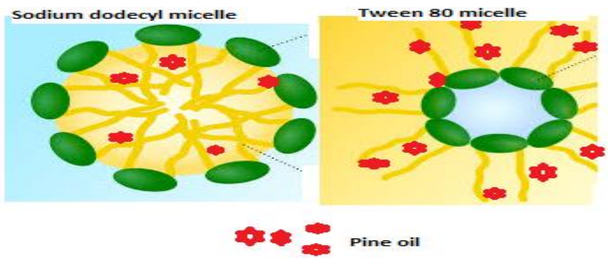


***Fig. 5**: Proposed mechanism for solubilization of pine oil in tensides: sodium dodecyl sulfate or Tween 80*

The effect of the length of the carbon chain on the interaction was analyzed by FTIR-ATR spectroscopy. The experimental results suggested that Tween 80 was most efficient out of the 2 surfactants taken for the study. The order of stability is given as sea pine oil-Tween 80 > pine oil - sodium dodecyl sulfate. Pine oil is hydrophobic and gets stuck in the core of the micelles but also on the alkyl ends of the hydrophobic chains. For Tween 80, the amount of solubilized pine oil is higher than in the case of sodium dodecyl sulfate, because interaction forces are responsible.

Characterization of the new emulsions obtained and the leathers processed

The optical microscopy images from figure 6 (a-f) show that all 3 emulsions obtained (at room temperature or 50 degree) are structured like irregular shapes, due to the influence of interaction between surfactants and pine oil.

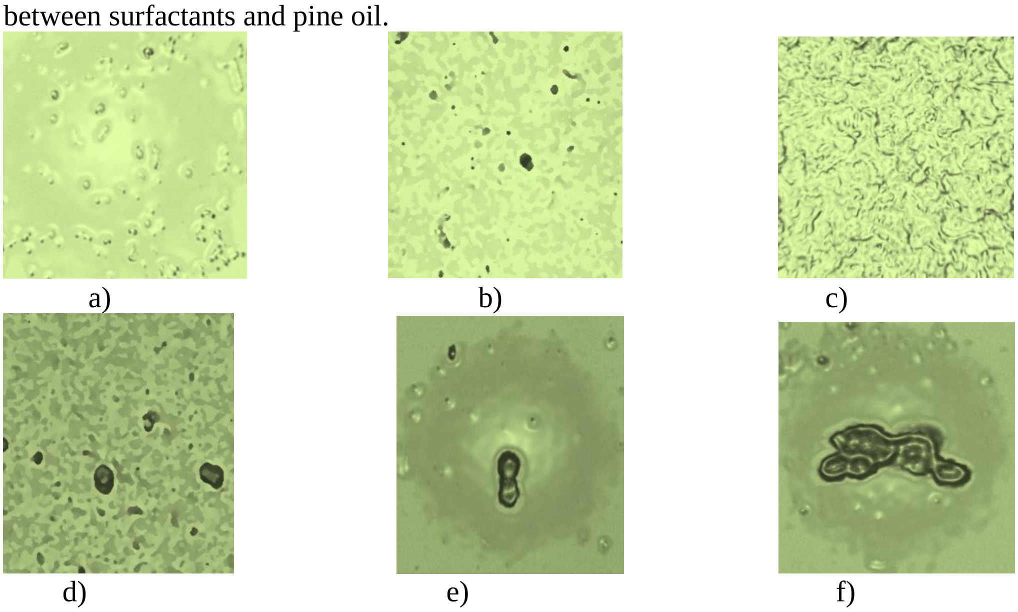


***Fig. 6**: Optical microscopy images of emulsions: Ps at room temperature-a); Pt at room temperature-b); Pst at room temperature-c); Ps at T=50ºC-d); Pt at T=50ºC-e); Pst at T=50ºC*

The average particle sizes of new structured emulsions showed dimensions between: (14-1020 nm), confirming the formation of the complex aggregates, table 1

The three types of emulsions were analysed by dynamic light scattering (DLS), table 1.

Table 1: *Results of DLS for 3 emulsions: Ps, Pt, Pst*

Sample	*Average diameter (nm)*	*% Intensity*	*Zeta Potential (mV)*
Ps	*14* *50* *107*	*20* *60* *20*	*-50*
Pt	*29* *300*	*30* *70*	*-35*
Pst	*600* *1020*	*21* *79*	*-69*

The leathers were processed by spraying with the three obtained emulsions: **Ps, Pt,Pst** and were marked **Psl, Ptl, Pstl** (figure 7) and then analyzed spectrophotometrically FTIR-ATR.

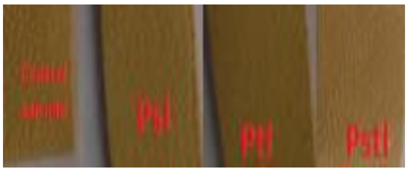


Fig. 7: *Image of the leathers processed with 3 emulsions: Ps, Pt, Pst and a control sample*

From figure 8 it can be seen that the largest amount of pine oil is found in the leather treated with the P**st** emulsion (the spectrum intensity is the highest in the entire spectral range).

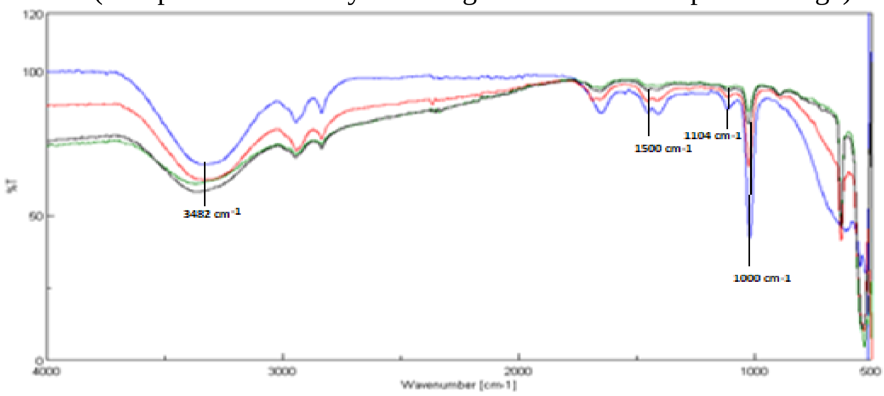


Fig. 8: *Overlay of FTIR-ATR spectra for leathers processed with emulsions: Psl---, Ptl--, Pstl--, control sample---*

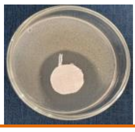
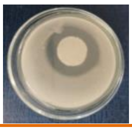
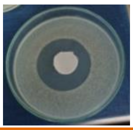
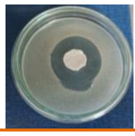
The P**st** emulsion is the most stable >2 month. The absorption maximum at the wavenumber =3482 cm^{-1} is the result of the overlap of the CH_2 deformation with the asymmetric CH_3 deformation (the intensity of the absorption maximum being proportional to the number of CH_2 and CH_3 groups present). The range of wavenumbers:1500–1000 cm^{-1} (1500 cm^{-1}, 1104 cm^{-1}, 1000 cm^{-1}) is specific to pine oil that have a high content of phenolic compounds and flavonoids.

The microbiological tests of leathers processed with 3 emulsions to the attack of *Staphylococcus aureus ATCC 6538* and *Aspergillus niger*, carrying out analysis three days from inoculations, are presented in table 2. Specimens of the material to be tested are placed on two-layer agar plates. The lower layer consists of a culture medium without bacteria while the upper layer is seeded with the selected bacteria. The level of antibacterial activity is assessed by examining the area of bacterial growth in the area of contact between the agar and the test tube, and if applicable the area of the zone of inhibition around the test tube.

Table 2: *Results of microbiological tests of leathers processed with 3 emulsions: Ps, Pt, Pst*

Sample	***Result, UFC/ml***	***R%***	***Log_{10} red***	***Sample***	***Result, UFC/ml***	***R%***	***Log_{10} red***
Aspergillus niger Inoculum concentration	$T_o=9,7x10^3$	-	-	*Staphyococcus aureus* Inoculum concentration	$T_o=9,2x10^3$	-	-
Psl	$T_{24}=3,6x10^3$	*90,6*	*2,5*	*Psl*	$T_{24}=4,8x10^3$	*99,5*	*2,1*
Ptl	$T_{24}=1$	*99,8*	*3,45*	*Ptl*	$T_{24}=3$	*99,6*	*3,9*
Pstl	$T_{24}=2,6x10^3$	*97*	*1,22*	*Pstl*	$T_{24}=1,5x10^2$	*97,8*	*1,8*

Table 3: *Images of Petri dishes obtained for leather supports treated with the obtained bioemulsions and microbiological testing*

Sample code	Zone of inhibition (mm)		Evaluation	
	A. niger	S. aureus	A. niger	S. aureus
Control sample	0	0	Insufficient effect	Insufficient effect
Psl	10 	7 	Satisfactory effect	Satisfactory effect
Ptl	11 	10 	Satisfactory effect	Satisfactory effect
Pstl	5 	10 	Satisfactory effect	Satisfactory effect

4. CONCLUSIONS

1.The aim of this research was fulfilled to develop new emulsions and to study the influence of surfactants and pine oil in obtaining structures with irregular shapes.The structures of new emulsions was demonstrated by optical microscopy.

2.The emulsions with particle sizes of 14- 1020 nm were obtained by DLS tests.

3. The new emulsions are original due to the successful inclusion of pine oil, with applications in leather industry.

4. A mechanism of solubilization of pine oil in micelles was proposed. Pine oil is hydrophobic and get stuck in the core of the micelles but also on the alkyl ends of the hydrophobic chains. For Tween 80, the amount of solubilized pine oil is higher than in the case of sodium dodecyl sulfate, because it has a larger hydrophobic chain. Van der Waals interaction forces are responsible.

5. The changes in the aggregation process were observed for each type of emulsion (Ps, Pt, Pst), the solubilization of pine oil by dynamic light scattering and optical microscopy.

6. In the process of finishing the leathers by spraying with 3 types of emulsions obtained compared to an untreated leather, was improved the antifungal, antimicrobial properties as well as appearance of the leathers.

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ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

A NEW MODELING APPROACH OF THE SURFACE PROPERTIES OF POLYMERIC SUPPORTS

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Abstract: *Sustainability and innovation in creating eco-friendly textiles are also growing areas of interest. Ozone layer depletion has been linked to a progressive increase in the incidence of skin cancer, primarily due to heightened exposure to ultraviolet (UV) radiation from the sun. A significant body of research has focused on the development of UV absorbers to mitigate this risk. However, most UV absorbers currently under investigation are water-insoluble and require emulsification or dispersion in aqueous media for effective application. This often necessitates the incorporation of organic solvents, posing challenges to formulation stability and effectiveness.*
Previous work emphasized the role of nanoparticles to modify the surface of textiles, creating new porosity and potentially improving UV protection and comfort, as
The present study aims both at the analyzsis of the relationships between the contact angle (wettability) and the concentration of the emulsion before and after UV exposure, and the development of a a mathematical model to analyze the data, for which the suggested model will identify two distinct values that describe how the concentration of the zinc oxide emulsion affects the coating after UV irradiation compared to before.
The model successfully predicts water permeability based on the engineered pore structure created by the nano-oxide coating. This paves the way for designing comfortable and potentially UV-protective textiles.
The results of this study could lead to the development of more effective and environmentally friendly UV protection strategies, reducing reliance on organic solvents and improving the efficacy of UV-blocking formulations in preventing skin cancer.
There is a linear or parabolic correlation between contact angle and nano-oxide concentration, with the lowest contact angle (least hydrophobicity) observed in uncoated fabric.

Key words: *mathematical model, polymeric textiles, nanoparticles, contact angle, porosity*

1. INTRODUCTION

To prepare UV absorber with water solubility, high affinity to cotton, satisfactory fastness properties together with good UV protection property, previous works designed novel polymeric UV absorbers by grafting benzotriazole type UV absorber onto polyvinylamine (PVAm). The prepared polymeric UV absorber not only exhibited water solubility and good anti-UV property, but it also showed very high utilization efficiency, satisfactory wash fastness and environmentally benign finishing process.
As a result, protection from sunlight, specifically ultraviolet (UV) radiation, has become a topic of

increasing interest. Methods for protecting ultraviolet sensitive materials from photo-oxidation include physically shielding the material from light (for example, clothing shielding skin), physical blockers such as titanium dioxide that scatter light, and chemical absorbers that absorb the radiation and emit it at a longer wavelength, which translates to a lower energy.

Encapsulating UV-sensitive materials within a polymer matrix offers UV protection through mechanisms such as light scattering [1-2] and limiting material movement due to restricted available free volume [3], characteristics that are not present in solution-based systems. UV absorbers, commonly used in sunscreens, are another effective means of shielding against UV radiation [4]. A combination of both encapsulation and UV absorbers could provide superior protection for materials vulnerable to UV-induced degradation [5]. Additionally, it has been demonstrated that particles incorporating protective materials with different mechanisms—such as a UV absorber and an antioxidant—can enhance the photostability of both protective agents [6]. Polymer films containing these UV-protective components have also been shown to offer UV shielding [7].

As a result, protection from sunlight, specifically ultraviolet (UV) radiation, has become a topic of increasing interest. Methods for protecting ultraviolet sensitive materials from photo-oxidation include physically shielding the material from light (for example, clothing shielding skin), physical blockers such as titanium dioxide that scatter light, and chemical absorbers that absorb the radiation and emit it at a longer wavelength, which translates to a lower energy [8-14].

This study investigates the protective capabilities of polymeric particles that incorporate both UV-sensitive and UV-protective materials, aiming to surpass the UV protection provided by encapsulation alone, especially when compared to solution-based systems. UV-protective particles hold significant promises for applications in sunscreens and pharmaceuticals, enhancing product stability. In addition, we propose a new technique of linearization and the proposed pseudo-power model, estimating more precisely the optimal value of the formulation of 3.5% of nano-oxide (ZnO) suspension as coating onto the polymeric support enhanced the water permeability.

2. A PSEUDO-POWER-BASED MODELING PROPOSAL

Considering the non-linear dependence between the contact angle and the concentration of the nano-oxide emulsion of the coating shown in Table 1, the shape of the data points can be parabolic, hyperbolic or logarithmic causal correlation, etc. The next step was the analyses of the degree of curvature using the linearization technique based on the probable pseudo-power behavior [15].

***Table 1**. Contact angle and concentration of nano-oxides emulsion of coating before and after UV irradiation, experimental and calculated values with pseudo-power model (Eq. 1), and percentage relative deviation*

[ZnO]	$\theta_{b,exp}$	$\theta_{b,cal}$	$100(\theta_{b,cal} - \theta_{b,exp})/\theta_{b,exp}$	$\theta_{a,exp}$	$\theta_{a,cal}$	$100(\theta_{a,cal} - \theta_{a,exp})/\theta_{a,exp}$
%	°	°	%	°	°	%
0	92[a]	92.000 [a]	0.0	88[b]	88.000 [b]	0.0
0.25		105.46			98.464	
0.50		111.67			105.07	
0.75		116.25			110.42	
1.0	120	119.86	0.11843	115	114.92	0.067145
1.5		125.16			122.07	
2.0		128.66			127.28	
2.5		130.81			130.89	

3.0	131	131.86	-0.65905	135	133.11	1.3998
3.5		131.99			134.08	
4.0		131.30			133.89	
4.5		129.87			132.61	
5.0	129	127.77	0.95511	127	130.32	-2.6130
5.5		125.05			127.05	
6.0		121.74			122.85	
6.5		117.89			117.74	
7.0	113	113.53	-0.46666	116	111.77	3.6485
7.5		108.67			104.95	
8.0		103.34			97.305	
8.25		100.50			93.182	
8.55**		96.955			87.973[b]	
8.75		94.503			84.343	
8.95*		91.982[a]			80.590	

a and b: (θ_0) before and after UV irradiation, respectively. * and **: ($[ZnO]_{max}$) before and after UV irradiation, respectively.

To analyze the graphical behavior of the contact angle-concentration dependence, a linearization test is performed which consists of the optimization of an adjustable parameter (α) in the ratio $\frac{\theta-\theta_0}{[\mathrm{ZnO}]^{\alpha}}$ which can give the best linearity on the concentration [ZnO] expressed as follows.

$$\frac{\theta-\theta_0}{[\mathrm{ZnO}]^{\alpha}} = B - A \cdot [\mathrm{ZnO}] \quad \mathbf{(1)}$$

Where A and B are two optimal adjustable positive parameters obtained by the least square method. After simplification by ($[\mathrm{ZnO}]^{1-\alpha}$) in the first derivation of Eq. 1, we obtain, at constant temperature, the following first order of a partial differential equation (PDE):

$$[\mathrm{ZnO}]\left(\frac{\partial\theta}{\partial[\mathrm{ZnO}]}\right)_T - \alpha(\theta-\theta_0) = -A[\mathrm{ZnO}]^{\alpha+1} \quad \mathbf{(2)}$$

Where the α-power must be different in unity ($\alpha \neq 1$). Then, after simplification by ($[\mathrm{ZnO}]^{1-\alpha}$) in the second derivation of Eq. 1, at a given temperature, the partial differential equation specific to the contact angle expressed is as follows:

$$[\mathrm{ZnO}]^2\left(\frac{\partial\theta^2}{\partial[\mathrm{ZnO}]^2}\right)_T - 2\alpha[\mathrm{ZnO}]\left(\frac{\partial\theta}{\partial[\mathrm{ZnO}]}\right)_T + \alpha(1+\alpha)(\theta-\theta_0) = 0 \quad \mathbf{(3)}$$

Where α must be different from unity ($\alpha \neq 1$) and the general solution is expressed as follows:

$$\theta = \theta_0 + \{B - A \cdot [\mathrm{ZnO}]\} \cdot [\mathrm{ZnO}]^{\alpha} \quad \mathbf{(4)}$$

The mathematical solving of this PDE shows that there are two possible solutions; $\alpha = 0.59$ and $\alpha = 0.75$ related to the two situations: before and after UV irradiation, respectively. The adjustable parameters in Eq. 1 (A and B) are evaluated by the straight-line plots of the said equation;

$\frac{\theta-\theta_0}{[\mathrm{ZnO}]^{\alpha}}$ *vs*. [ZnO] as shown in Figs. 1a and 1b. The values of adjustable optimal parameters are presented in Table 2 while the solutions for the calculated values of contact angle by Eq. 4 are presented in Table 1.

We note that we can mathematically solve the Eq. 3, as a second order homogeneous Euler-Cauchy equation specific to the contact angle by establishing its specific isobaric partial differential equation.

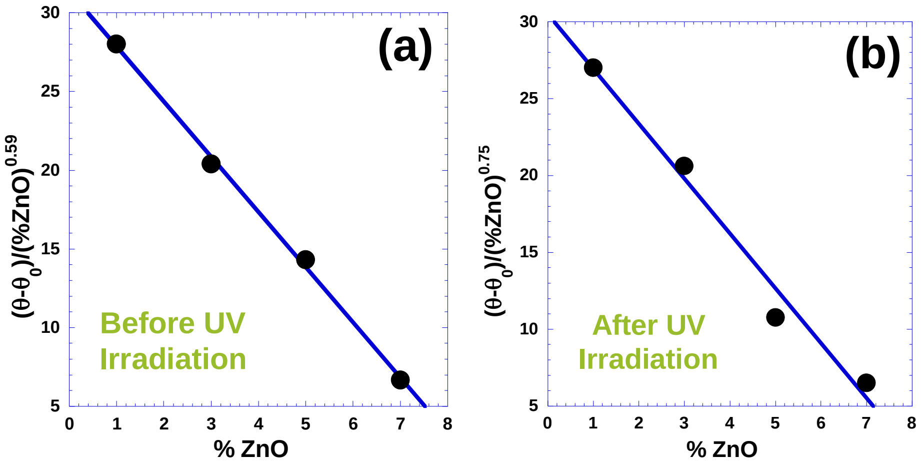

Fig. 1. *Linearization of the function* $\frac{\theta-\theta_0}{[ZnO]^{\alpha}}$ *of Eq. 1 as a function of Concentration of nano-oxides emulsion of coating [ZnO], (a): before UV irradiation and (b): after UV irradiation*

Using the Eq. 4, the concentration value ($[\mathrm{ZnO}]_0$) corresponding to the observed maximum contact angle (θ_{max}) using simply the following derivation equation can be calculated:

$$\frac{d\theta}{d[\mathrm{ZnO}]} = \{\alpha B - (1+\alpha)A \cdot [\mathrm{ZnO}]\} \cdot [\mathrm{ZnO}]^{\alpha-1} \quad \textbf{(5)}$$

After canceling the equation, we can write the following.

$$[\mathrm{ZnO}]_0 = \frac{\alpha B}{(1+\alpha)A} \quad \textbf{(6)}$$

Table 2. *Optimal parameters values of Eq. 1 and Eq. 6.*

Parameter	θ_0	B	A	α	$[\mathrm{ZnO}]_0$	θ_{max}	R
Before UV	92°	31.3626251	3.50474696	0.59	3.32%	132°	0.999026
After UV	88°	30.4894398	3.56665313	0.75	3.66%	134°	0.989875

CONCLUSION

In the present work, the contact angle and concentration of nano-oxides emulsion of coating before and after UV irradiation were subjected to mathematical modeling using linearization by pseudo-power technique and the partial differential equations. By combining both the linearization technique and the power law for concentration of zinc nano-oxides emulsion as the independent

variable, we detected two interesting optimal exponent-values apparently characteristic and specific for the present studied zinc nano-oxides emulsion, before and after UV irradiation. The mathematical handling was done for the two values of the concentration exponent: $\alpha = 0.59$ and $\alpha = 0.75$, before and after UV irradiation, respectively. Moreover, future similar investigations on other nano-oxides emulsion and comparison of their specific exponents can lead to deep interpretations of this phenomenon and some novel physical meanings. Three essential points should be highlighted:
(*i*) Thanks to this technique of linearization and the proposed pseudo-power model, we estimated more precisely the optimal value of the formulation of 3.5% of nano-oxide (ZnO) suspension as coating onto the polymeric support enhanced the water permeability.
(*ii*) Using the Interpolation Methods and the proposed pseudo-power model, we estimated the maximum contact angle after UV irradiation at about 133°.
(*iii*) Using the Extrapolation Methods and the proposed pseudo-power model, we found that other than the reached minimum contact angle is recorded without nano-oxides, we can also have this minimum condition for a maximum ZnO concentration estimated at approximately 8.55%.

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