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Casein Fabric Management: A Sustainable Approach with Enhanced Moisture Transmission Behavior

Mehreen IJAZ

Department of Home Economics, Lahore College for Women University, Pakistan

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Abstract
The current study is aimed at manufacturing milk fabric using casein, a protein derived from the discarded milk. It is a sustainable procedure of converting waste materials into useful textiles. The study is further extended to assess the moisture management properties of prepared casein fabric following test procedure (AATCC-195 (2011). The use of casein fibers offers a promising way of waste reduction and depicts the environmental responsibility of textile manufacturers who seek out innovative and sustainable solutions. The results showed that casein fiber revealed very good moisture transmission behavior and it wicked away the moisture from the skin. This characteristic made the fabric maintain a dry and comfortable environment for the wearer thus making it suitable for various textile applications. The result of this study leads to further investigation of sustainable materials in the textile industry and can pave the path for a wide range of end uses for casein fibers.

Keywords
Casein, Moisture transmission, Milk fiber, Sustainable, Environment.

Introduction

The current study aims to investigate a sustainable approach by transforming waste materials into a usable product. The milk fiber was produced as a sustainable alternative to synthetic materials. The prepared material was finished to enhance its characteristics and appearance. Afterward, the moisture transmission behavior of the prepared fabric was evaluated using an international standard test procedure. The study contributes to the manufacturing of eco-friendly materials in the textile industry.

It has been observed that each year over 2 million tons of milk is wasted. To convert this wastage into milk provides opportunities for sustainable production in the textile industry. Casein in the milk absorbs water content and induces softness in the skin, making it a comfortable material. Additionally, casein has an inherent antibacterial ability, giving hygienic protection to the wearer (Peixoto et al., 2015). One of the research studies attempted to investigate casein by mixing casein powder with water in different ratios. The mixture was stirred and heated at 75°C, then the hot solution was extruded into fibers through a spinneret. Casein was also used as a lamination material on various fabrics. These experiments investigated the viability and properties of casein fibers and coatings, potentially opening new horizons for environment-friendly textile applications (Bier et al., 2016).

Since it was first developed in the 1930s to compete with wool, milk fiber has a long history in the textile industry as a promising and environmentally sensitive material (Choudhury, 2023). Around 3 pounds of milk fiber can be produced from 100 pounds of skim milk. Casein is produced by giving skim milk an acid treatment. The milk fiber is extracted from 18 amino acids which benefits skin hydration. Blending milk fiber with other fibers establishes the versatility of both natural and synthetic fibers, combining their best properties for different uses in the textile industry (Bier et al., 2017). Milk fiber effectively wicks away the moisture from the skin thus improving moisture control and providing comfort to the wearer. Due to its exceptional air permeability characteristic, it offers breathability, hence making it good for a variety of applications such as clothing items, sportswear, and other protective textiles. It also exhibits great tensile and abrasive strength (Tasnim, 2019; Sevgisunar & Yavas, 2020).

Corresponding author: *Mehreen Ijaz – Department of Home Economics, Lahore College for Women University, Lahore, Pakistan, e-mail: mehreenijaz@hotmail.com*

The widespread adoption of formaldehyde was hampered due to its initial difficulties and high-water consumption. Modern-day technological and environmental practices are experiencing a revival in the interest of milk fiber and accelerated research and development in this area (Domaske, 2013). Milk fiber complies with the concepts of a bio-based and circular economy, where resources are regenerated and repurposed to minimize the environmental effects, by turning discarded milk into marketable fibers. Additionally, milk fiber's inherent qualities such as its pH similarity to human skin and potential advantage for people with skin conditions further enhance its demand as a practical and comfortable textile material (Yang & Reddy, 2012; Chauahn et al., 2018). This study adds to the expanding body of knowledge on milk fiber and its role in improving sustainable practices in the textile industry using a combination of empirical findings and published literature.

Casein, a protein obtained from discarded milk, to produce milk fabric contributes to the significant achievement in the sustainable textile industry. By converting waste materials into usable textiles, this study states two important environmental aspects: waste reduction and resource sustainability. By identifying the moisture management behavior of casein fibers, this research provides a strong base for the broader adoption of milk fabric in different applications of textile industry. This approach not only contributes to the environmental sustainability but also opens new possibilities for innovation in textile production.

This study presents a novel perspective on how sustainable materials can help meet the functional requirements of textile materials. The ability of these fibers to maintain a comfortable physical environment for the wearer determines their potential to compete with less environment-friendly conventional synthetic fibers. The result gained from the current study can help pave the path for manufacturing other waste-derived textiles materials. It can foster a circular economy within the textile industry.

Materials and Methods

Milk fiber was produced using sour milk collected from the dairy plant. The casein was separated from the liquid part of milk by adding an acetic acid to further coagulate the casein. It was converted into a solid curd and then separated from the whey and filtered off. After the separation of curd, they were dried so that any remaining moisture could be driven off using an air-dry method. The dried curd containing casein was then grounded into a fine powder and mixed with a solvent N-methylmorpholine-N-oxide, to prepare a spinning solution. This solvent showed an excellent solubility with the casein. The solution was extruded though the spinneret to develop continuous filaments. After the solidification of filaments, these were drawn to align the fibers and orient their molecular structure. The fibers were air-dried to remove any excess moisture retained during the spinning process. The prepared yarns were used to weave the fabric through a plain interlacing pattern. The construction specifications of milk fabric are given in Table 1.

Table 1
Construction specifications of casein fiber

Fiber	Table Column Head			
	Linear density (warp / weft)	*Thread count per inch*	Weave type	Weight (GSM)
Casein fiber	7.343 / 6.987	75 × 65	Plain	95

The fabric was immersed into a dye bath and agitated gently to ensure the even penetration of the dye. The dyeing temperature was set at 70°C. The fabric remained in the dyebath for an hour. After dyeing, the fabric was removed from the dye bath and rinsed thoroughly with water to remove any excess dye liquor. Finally, it was rinsed and dried.

The fabric was treated with ethoxylated alcohol by adding a silicon softener to give it a soft handle. It produced wickability and improved absorption. It was coated using padding mangle and dried to fix it. It was then evaluated for its moisture management behavior following the (AATCC-195 (2011) test procedure. It helped to determine the effectiveness of casein fibers in transporting moisture away from the skin surface (AATCC-195, 2011). The specimens were firstly conditioned before testing following directions mentioned in the ASTM D 1776 (ASTM, 2020). Five specimens with the measurement of 80 × 80 mm were cut diagonally using a template to ensure that various sets of yarns in length and width were extracted for testing. 9 gm sodium chloride was dissolved in 1 liter of distilled water to prepare the standardized test solution. A moisture testing oven comprised of two sensors (upper and lower) was used. The specimen was placed on the lowest sensor of the moisture testing device with its front surface facing upwards to conduct the moisture test. The upper sensor was gently lowered to rest on the specimen surface to make a closed chamber for the testing environment. After closing the oven's door, the timer was set to 20 seconds, allowing the prepared solution to be dispensed onto the specimen. The time taken for the moisture absorption was recorded using the attached electronic device. Finally, the specimen was taken off by lifting the upper sensor.

Fig. 1. Sample of prepared fabric

The efficiency of produced milk fiber compared to other materials such as cotton is notable, mainly when considering the sustainability aspects. While cotton is a widely used material in the textile industry, its production demands an extensive range of resources including water, pesticides, and adequate land. Additionally, its cultivation may lead to soil degradation and water pollution. Whereas the production of milk fiber presents many sustainable benefits. Firstly, it utilizes a waste product that is casein extracted from the milk. It reduces the environmental impact. Moreover, its production process requires less water and land resources compared to the cotton cultivation.

Results and Discussions

Casein fibers are well known for their physical properties such as softness, fineness, biodegradability, flexibility, and hypoallergenic nature. However, their water resistance behavior needs further improvement to enhance their application in various textile products. Many researchers have experimented with different techniques to produce casein fibers. One of the common approaches is to mix casein powder with different water ratios. This ratio plays an important role in identifying the consistency, performance, and quality of the prepared fiber. Moreover, this casein has also been used as coating and lamination material on various fabrics to enhance their moisture transmission behavior (Domaske, 2013).

Table 2 explains the moisture transmission behavior of tested samples. According to the test procedure, wetting time falls under the category of an average rating (20–119). It can be observed that the specimens showed good to average values for both sides. Absorption time also falls within the acceptable range (30–49) and spreading time was also good. Additionally, one-way transport depicted extremely good values. Overall moisture management capacity rate was very good for casein fiber as it ranges between 0.6–0.8 for both surfaces.

Table 2
Moisture transmission behavior of casein fabric

Specimen surface	Wetting time [s]	Absorption rate [%/s]	Spread speed [mm/s]	OWTC [%]	OMMC
Top	115.67	12.98	0.78	216.14	0.64
Bottom	109.51	17.43	0.55	225.43	0.69

ANOVA was applied to evaluate the efficiency of casein fabric. P-value ≤ 0.05 was considered as significant. It is observed from the Table 3 that there is not a significant difference between the values of the tested materials. The significant increase in the efficiency of moisture transmission in fabrics after finishing treatment could be caused due to the improved surface smoothness. The coatings and laminations helped to enhance the fabric properties, appearance, handle, and functionality (Ijaz et al., 2023).

Table 3
Statistical analysis of specimens

Specimen	Mean square	F	p-value
Top surface	175.53	37.87	0.01
Bottom surface	174.87	31.98	0.01

Better contact and interaction between the fabric and moisture were made possible with a smoother fabric surface, which improved moisture transport. The fabric's wicking and capillary action were improved by the smooth surface, which made it easier for the moisture to disperse uniformly and swiftly throughout the fabric. As a result, sweat was effectively absorbed and removed from the body, thus improving moisture management behavior, and raising the fabric's general level of comfort (Nazir et al., 2014; Yanılmaz & Kalaoglu, 2012).The surface area of fabrics has a direct relationship with its surface free energy. The surface energy increases with the surface area, which increases the fabric's overall wettability. The textured or rough surface tends to present greater surface areas, which in turn leads to the increased wettability (Cerne, & Simoncic, 2004).

Casein fiber's superior water transport capabilities can wick moisture away from the skin and keep the wearer dry and comfortable. As the moisture spreads through the casein fiber, the structure permits it to effectively wick moisture to the outer area. This capillary action wicks away the moisture from the wearer's skin, creating a moisture gradient to promote moisture transfer from inner side to the outer side of the fabric. It has been observed that liquid moisture transported along the vertical direction of casein fiber was higher than cotton fiber. One of the possible reasons was the inherent nature of casein fibers. These fibers with their unique protein structure, offer efficient water transport properties. They can quickly wick away moisture from the skin and allow better moisture movement through the fabric, making the wearer stay dry yet comfortable (Rathinamoorthy, 2017). The results were similar to the study conducted in 2021. It was explored that casein fibers had greater moisture content compared with cotton and silk fibers (Patil et al., 2021). The produced fabric can be expected to provide lasting use over several years with proper care. Further research can be conducted to assess the lifetime of milk fiber.

Casein is a random coil polypeptide having a high degree of molecular flexibility. It can make intermolecular bonds with a low frequency of secondary structures. It gives cohesion and provides good coating ability (Minaei et al., 2019). The casein fabric has high efficiency concerning antibacterial properties as well. It was found to have high value for antibacterial agents in the textile industry. So, it can also be a good option against harmful agents, while promoting the recycled process of dairy waste (Belkhir et al., 2021).

Casein fiber has a slow aging process; thus, it can retain its appearance over many years. Fabrics made from casein do not deteriorate and damage quickly, making them functional and aesthetically appealing for a longer period of time. From a sustainable perspective, the durability of these fibers minimizes the need for frequent clothing replacements. It helps to support a sustainable consumption approach for the consumers, aligning with the general principles of waste reduction and resource management (Bier et al., 2017; Audic et al., 2003).

The use of non-food milk to extract casein provides a sustainable alternative by reusing the waste materials that would otherwise contribute to environmental pollution. This eco-friendly approach allows waste reduction and resource management, aligning with global sustainable goals. One of the best characteristics of casein fiber is its ability to absorb the moisture effectively. This is due to the presence of amide and carboxylic groups in its structure. The high moisture absorption ability allows these fibers to swell, thus increasing their softness. This feature is useful for those individuals who have skin issues including eczema and dermatitis. The moisture-wicking ability of casein fibers assists in maintaining skin comfort by reducing irritation and itching (Hassabo et al., 2024).

Conclusions

The results revealed that casein fabric can be an environment-friendly substitute for the textile industry. Textile manufacturers and technologists can take different initiatives to become ecologically conscious by using casein fiber in fabric production. The evaluation of casein fabric presents it as an efficient moisture material in improving comfort of clothing materials.

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