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JOURNAL OF ENGINEERED FIBERS AND FABRICS

Original Article

Journal of Engineered Fibers and Fabrics
Volume 20: 1–8
© The Author(s) 2025
DOI: 10.1177/15589250241312302
journals.sagepub.com/home/jef
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Upcycling aquaculture waste for textile functional material to facilitate the creation of novel and sustainable jeans

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Abstract

With the increasing emphasis on health, environment, and advancements in science and technology, the sustainability of denim products has garnered growing attention. This study proposes a new denim fabric to enhance the sustainability of jeans in terms of raw materials and usage. UMORFIL Beauty Fiber, a bionic cellulose fiber composed of collagen peptides upcycled from fish-scale waste, was used for this purpose. Considering that fibers combine collagen and plant fibers, they are an excellent choice for fabricating skin-friendly and wash-resistant clothing. Notably, its excellent deodorant properties make it highly suitable for producing denim clothing that requires minimal washing. Therefore, a novel denim fabric utilizing fibers to envelop Lycra elastane was designed and used in this study. The analysis in this study demonstrates that the upgraded denim fabric possesses favorable tactile attributes and effective deodorizing properties. By preventing the occurrence of unpleasant odors in the denim fabric, the number of washings can be reduced, thereby preventing consumer dissatisfaction with deformations and early discarding of jeans. Because contemporary jeans encompass not only durability but also various design and styling elements, rendering them essential in the world of fashion, this innovation holds significant importance. Furthermore, a reduction in the number of washing cycles led to decreased detergent usage and a decline in the generation of pollutants during discharge, thereby contributing to a more sustainable and environmentally friendly denim fabric. These findings are crucial for promoting the sustainable development of the jeans industry.

Keywords

Circular economy, sustainable production, deodorant jeans, denim fabric, UMORIL Beauty Fiber, environmental stress

Date received: 16 November 2023; accepted: 21 December 2024

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Introduction

The global jeans market is a large, growing industry. Jeans holds a significant position in the fashion world, transcending both economic and temporal boundaries.[1,2] Jeans have several advantages including high durability and good elasticity. In addition, they are stylish. These can be mixed and matched to create a variety of fashion senses without losing orthodoxy.[3] They are easy to wear, practical, stylish, and are suitable for the public. Many globally renowned designers and brands use jeans in their primary designs, promotions, and sales.[4] The annual production of jeans is estimated to be between 3 and 4 billion pairs, with a market value expected to grow from 64.5 billion USD in 2022 to 95 billion USD in 2030.[5] This growth is driven by several factors, including the increasing global population, rising disposable income, and growing popularity of jeans in developing countries.

The environmental impact associated with the production of jeans has become an issue of global concern.[6,7] Jean production is a water-intensive process. The manufacturing of a single pair of jeans can consume up to eight gallons of water, which is equivalent to the daily drinking water requirements of six adults.[8] Additionally, jeans are often dyed with indigo. At the same time, in order to achieve different washing effects, various chemicals are used during the washing process of jeans, such as bleach, stone grinding agent, resin, etc.[9] Approximately 50,000 metric tons of indigo dye,[10] 84,500 metric tons of sodium hydrosulfite, and 53,500 metric tons of caustic soda were used annually.[11,12] This number is expected to increase with jean production. Textile wastewater is toxic and carcinogenic. Therefore, wastewater must be properly treated before it can be discharged from factories; otherwise, it damages the ecological environment.[13] In recent years, sustainability has become an important goal in the jeans industry. Different brand designs of jeans include various matching designs, including holes, blasting, wear, the addition of metal trims, buttons, leather labels, and other styling designs. Jeans with styled designs must be maintained carefully.[14] In addition, because denim fabrics are made of cotton fibers, jeans are prone to wrinkles and shrinkage after washing, which makes the wearer uncomfortable and destroys the appearance of the jeans. Therefore, for the appearance and fit of jeans to be maintained, they should not be washed frequently. In addition, microfibers released from the wash of jeans flow into lakes or oceans and may cause environmental pollution and harm aquatic animals.[15] Furthermore, to diversify a season's fashion collections, jeans manufacturers can use different post-processing technologies that involve wet or dry washing.[16] Dry cleaning agents are used in dry methods, such as beard removal, hand sanding, grinding, and destruction.[9,17–20] Similarly, wet processes, such as enzyme washing, bleaching, and stone washing, although employing fewer chemicals, still contribute to water damage and microfiber pollution.[19] Denim fabric is made from coarse cotton yarn and is heavier than regular cloth. In summer, people wearing jeans tend to sweat more, and this sweat is absorbed by their pants, causing the jeans to smell sweaty and require cleaning. If jeans are dirty, they must also be cleaned. However, in addition to daily wear, 50% of the wear and tear of jeans is caused by washing.[21,22] According to a consumer study, consumers wash a pair of jeans after 10 wears and throw them away after 20 wears.[23] Discarded jeans may lead to increased waste from landfills or incinerators, thereby increasing greenhouse gas emissions and causing environmental damage.[24] Extending the service life of jeans is a way to improve sustainability in the clothing industry.[25] Reducing washing frequency is a key strategy for enhancing the sustainability of denim garments. This approach not only extends garment lifespan but also minimizes water and energy consumption associated with laundering. In response to this challenge, we present a novel denim fabric specifically designed to mitigate sweat odor generation in jeans. This innovation has the potential to significantly reduce washing frequency, thereby promoting sustainable denim production and use.[26–28] This innovative approach involves the use of supramolecular polymerization to create a collagen-modified viscose called UMORFIL Beauty Fiber, which significantly reduced clothing odor in a face mask study.[29] Therefore, the purpose of this study was to investigate whether applying UMORFIL Beauty Fiber to denim fabric can address the issue of the odor of jeans and prolong their use. Furthermore, reducing production and pollution and extending product lifecycles are crucial strategies for reducing carbon emissions and ensuring the maintenance of environmental and ecological integrity.

Wastefish scales are upgraded and reused to reduce environmental pollution and land acidification. Improved raw textile materials should be created and applied to denim fabrics to revolutionize the denim industry and extend the service life of clothing made from denim fabrics.[30] This approach offers the dual advantages of reducing environmental harm and prolonging the usage time of jeans. Frequent washing of jeans leads to deformation, deterioration, loss of the original design essence, and potential rejection by customers, particularly when dealing with high-end brands. By extending the usage time of jeans, this discovery significantly alleviates economic pressure on customers and bears paramount importance to the jean industry.

Materials and methods

New denim yarn and denim fabric

Various jean fabrics, including cotton and blended denim, are available. Blending denim offers several advantages, such as reducing the environmental impact of cotton production, enhancing the elasticity and comfort of the denim,

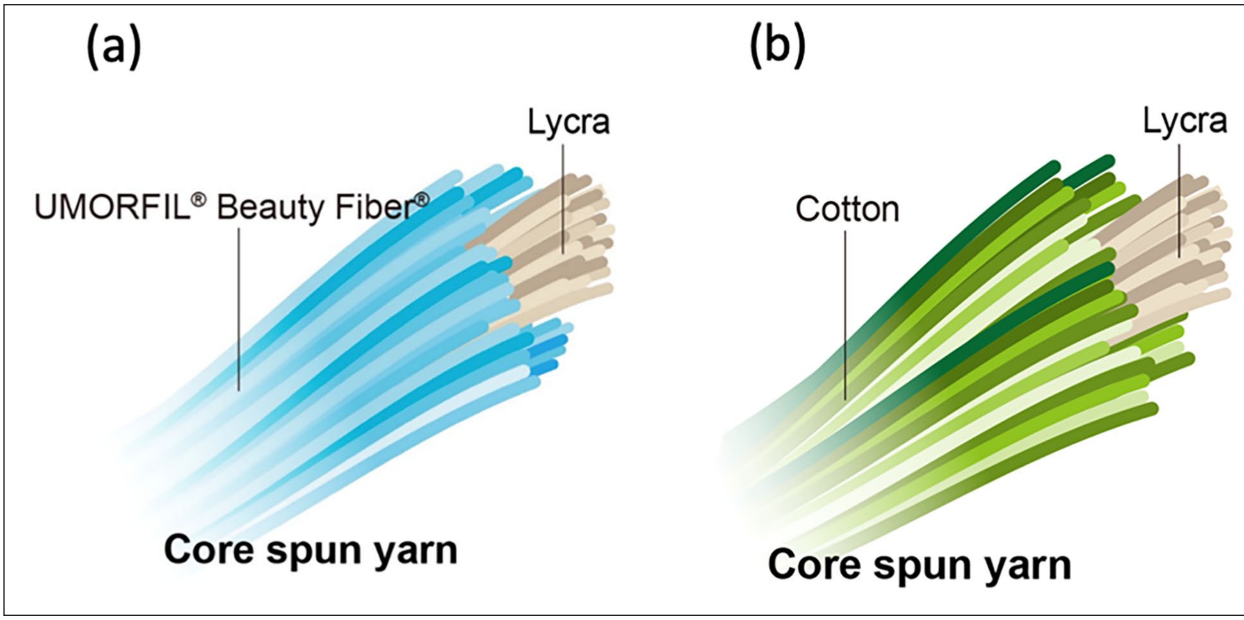

Figure 1. Core spun yarn for denim fabrics: (a) UMORFIL Beauty Fiber/Lycra (beauty fiber denim: 3/1 twill, cotton 82%, UMORFIL Beauty Fiber 17%/lycra 1%, 9.8 oz/yd^2) and (b) cotton/lycra (cotton denim: 3/1 twill, cotton 99%/lycra 1%, 9.8 oz/yd^2).

and improving its durability and resistance to wrinkles.[31,32] In this study, a novel denim core-spun yarn composed of UMORFIL Beauty Fiber and 70 Denier Lycra elastane was used.

Typically, blended denim comprises cotton and artificial fibers. Denim warp yarns primarily consist of cotton fibers, whereas weft yarns are blends of cotton and lycra. In contrast, our proposed denim blend employs UMORFIL Beauty Fiber + Lycra for the weft yarns. This approach combines the softness and breathability of cotton fibers with the added benefits of UMORFIL Beauty Fiber/Lycra fibers, including elasticity, wrinkle resistance, improved tactile sensation, and deodorization (Figure 1(a)), as opposed to conventional blends of cotton and Lycra (Figure 1(b)).

Deodorization tests of fabric

Preserving the original shape and color of jeans often entails a reduction in washing frequency. Consequently, wearing jeans multiple times without washing can lead to the accumulation of odor residue, especially during warmer seasons, such as summer. A deodorization test was conducted to investigate this issue. A comparison was made between the novel UMORFIL Beauty Fiber/Lycra denim fabric (Figure 2(a)) and regular cotton denim fabric (Figure 2(b)), with all tests adhering to the latest industrial standards. A deodorization test was conducted to quantify the efficacy of the textile material in reducing the unpleasant odor of the gas. The detector tube tests were conducted following the standard test method, ISO 17299-2.[33] This method allowed the measurement of odor-component gases, including ammonia and acetic acid.

The test conditions included (1) amount of specimen: $10 \times 10\,cm^2$, (2) test vessel: Tedlar bag of 5 L, (3) gas volume of 3 L, (4) temperature and relative humidity of 20°C and 65%, respectively, (5) test time of 2 h, (6) wash method: JIS L0217:1995 – Method 103 – Machine wash at 40°C – JAFET detergent – line drying.

Gas chromatography (GC) was performed according to the standard ISO 17299-3 test method. This method specifically targets odor component chemicals such as indole, isovaleric acid, and nonenal, with this study focusing on isovaleric acid.

The test conditions were as follows: (1) amount of specimen: $50\,cm^2$; (2) test time of 2 h; (3) wash method: JIS L0217:1995 – Method 103 – Machine wash at 40°C – JAFET detergent – line drying.

Testing of denim fabric properties

We conducted comparative studies to evaluate the physical properties and durability of UMORIL Beauty Fiber/Lycra denim and cotton denim fabrics. The tensile and tear strengths of the developed denim fabric were determined using the ASTM D5034 and ASTM D1424 testing methods, respectively.[34–36] A Martindale pilling tester was used to determine the wear resistance of the denim fabrics using the standard testing method of ASTM D4966.

The fabric hand was evaluated using the testing method AATCC EP5. There are many physical attributes of fabric hands such as hard, soft, stiff, crisp, tight, loose, coarse, and warm. However, the focus of the physical attributes of the fabric hand in this study was only on soft attributes. Two denim fabric samples were prepared: (a) UMORIL Beauty Fiber/Lycra denim and (b) regular cotton denim.

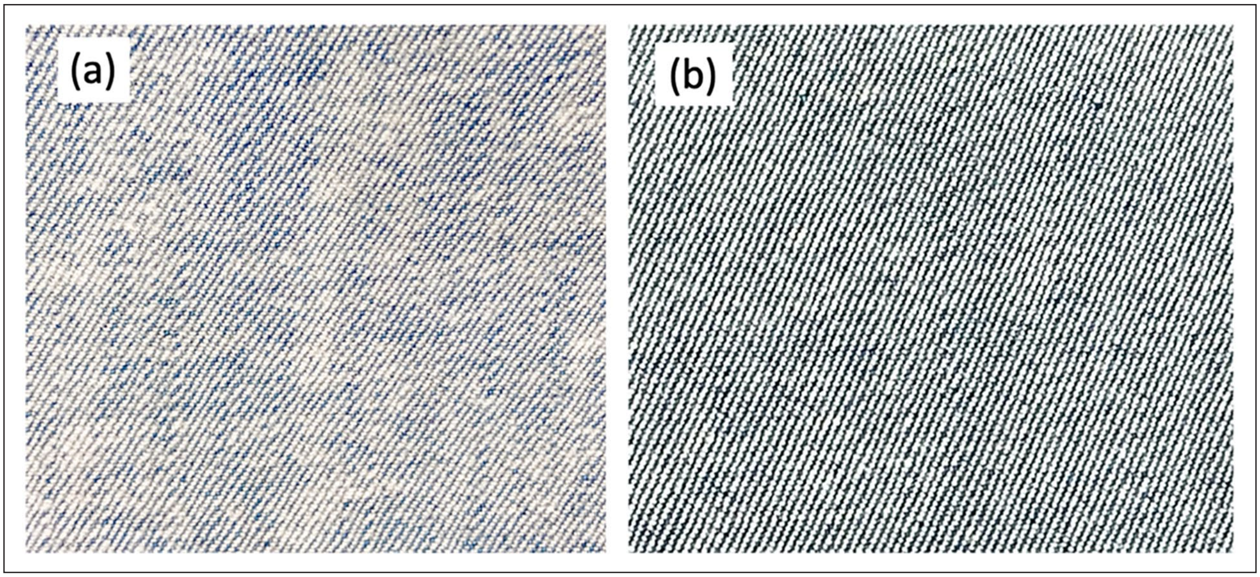

Figure 2. Denim fabric: (a) UMORFIL Beauty Fiber/lycra and (b) cotton/lycra.

Table 1. Physical and durability properties of regular and proposed denim fabric.

Test item	Test standard	Cotton denim fabric	UMORFIL Beauty Fiber denim fabric
Breaking strength	ASTM D5034	Warp: 210 lbf Weft: 80 lbf	Warp: 198 lbf Weft:74 lbf
Tearing strength	ASTM D1424	Warp: 13 lb Weft:8 lb	Warp: 12 lb Weft:7.8 lb
Martindale abrasion	ASTM D4966	>15,000 rubs	>15,000 rubs

Twenty evaluators performed fabric hand tests. The results were then analyzed using a paired *t*-test ($\alpha = 0.05$).

Results and discussion

Comparison of physical and durability properties

The breaking strength of the cotton denim fabric was 210 lbf warp and 80 lbf weft, whereas that of the Umorfil denim fabric was 198 lbf warp and 74 lbf weft. The tearing strength of cotton denim fabric was 13 lb in warp and 8 lb in weft, respectively, whereas that of Umorfil denim fabric was 12 lb in warp and 7.8 lb in weft, respectively. The test results showed that both the breaking and tearing strengths of the developed fabric were slightly lower than those of the regular cotton denim fabric (Table 1). These differences were caused by different after-treatments on the surface of the denim jeans and different filling yarns. However, the physical properties of these two denim fabrics meet industrial standards. Moreover, at least 15,000 cycles were required to prevent hole formation in the Martindale abrasion test for both fabrics.

Fabric hand test

According to AATCC EP5, the evaluation procedure for the fabric hand, we placed the two denim fabric samples into different boxes: box A was the UMORFIL denim fabric, and box B was the regular denim fabric. Evaluators reach the hand in the box, touch the fabric, and grade it from 1 to 4; a higher score indicates softer fabric. There percent 85 the evaluators (17 of 20) gave higher scores to the UMORFIL denim fabric, 10% (2 of 20) gave the same score, and only one (5%) gave a lower score. The average score of box A 3.2 ± 0.7 is significantly higher than that of box B 2.3 ± 0.5 ($p < 0.05$). The results showed that the UMORIL denim fabric was much softer than regular cotton denim, and the difference between the two fabrics was reasonable because of the UMORIL denim fabric with rayon material.

Deodorization tests

In this study, the SGS was commissioned to conduct deodorization tests. After 10 washes, the odor reduction rates (ORR) of ammonia, acetic acid, and isovaleric acid for the cotton denim fabric were 52%, 93%, and 37%,

Table 2. Deodorization test results after 10 washes.

Gas	Sample	Time	Blank test (ppm) (A)	Testing sample (ppm) (B)	Reduction (%) (A − B)/A × 100
Ammonia (ISO	Cotton denim fabric	0 h	100	100	
17299-2)		After 2 h	84	40	52
	UMORFIL Beauty	0 h	100	100	
	Fiber denim fabric	After 2 h	84	5	94
Acetic acid (ISO	Cotton denim fabric	0 h	30	30	93
17299-2)		After 2 h	30	2	
	UMORFIL Beauty	0 h	30	30	
	Fiber denim fabric	After 2 h	30	0.3	99
Isovaleric acid (ISO	Cotton denim fabric	0 h	38	38	37
17299-3)		After 2 h	38	24	
	UMORFIL Beauty	0 h	38	38	
	Fiber denim fabric	After 2 h	38	0.2	99

respectively, whereas those for the Umorfil denim fabric were 94%, 99%, and 99%, respectively (Table 2). The standards of deodorizing performance set by the Japan Textile Evaluation Technology Council[37] are as follows: unqualified (ORR < 70%), requiring further human sensory testing (70% ≤ ORR < 80%), and no need for human sensory testing (ORR ≧ 80%) for ammonia; unqualified (ORR < 70%) and no need for human sensory testing (ORR ≧ 70%) for acetic acid; unqualified (ORR < 85%), requiring further human sensory testing (85% ≤ ORR < 95%), and no need for human sensory testing (ORR ≧ 95%) for isovaleric acid. The deodorizing performance of ammonia and isovaleric acid for cotton denim fabric was unsatisfactory according to this standard, but the deodorizing performance of acetic acid was excellent. The deodorizing performance of ammonia, acetic acid, and isovaleric acid for Umorfil denim fabric was excellent, and human sensory testing was not required.

According to a deodorization experiment, the denim fabric produced using this new fiber had an excellent deodorization effect, which aligns with the primary goal of odor elimination. Moreover, the experimental data showed that after repeated washing, the deodorizing effect of the UMORFIL Beauty Fiber/Lycra denim fabric remained effective. Therefore, the deodorizing function was continuous and could not be reduced by washing.

Human beings must socialize and engage in external activities. Therefore, the smell of the human body is an essential courtesy in social behavior, and there is a demand for perfumes and cosmetics. However, body odor varies with people, seasons, and climate. For example, in the summer, humans tend to sweat and produce an unpleasant sweaty smell. Therefore, eliminating odors is an option that must be included while wearing it.

Sustainability

The sustainability of denim has always been a serious concern.[38,39] The two fabrics were supplied by PROSPERITY TEXTILE Co., Ltd. which has been a Bluesign® system partner for many years, which already regarded as one of the cleanest denim mills in the world.

Typically, the life cycle of jeans consists of the following five stages (Figure 3)[40]: (1) fabric production, (2) garment production, (3) packing and distribution, (4) use and maintenance, and (5) recycling or disposal. Several sustainability issues exist at the different stages, some of which are listed in Table 3. This study focuses on addressing sustainability issues A2, B1, and D2. This new material was developed from collagen derived from fish-scale waste.[41] Except for approximately 1% lycra, the rest of the fabric is decomposed back to nature without increasing the burden on the environment.

This study presents a method for reducing environmental stress in the denim jeans industry. Our approach involves the use of novel deodorant fabrics to prevent odor accumulation in denim fabrics, which are highly sought after by the global fashion industry. Resolving the issue of odor accumulation holds immense importance for the denim fabric industry and has potential applications in other types of fabrics, yielding similar beneficial outcomes. This discovery and its application are significant for the sustainable development of textiles.

Currently, the fashion apparel industry lacks a sustainable solution to odor-related challenges. The solution proposed in this paper represents a noteworthy advancement in an industry that increasingly embraces sustainable fashion practices. Nonetheless, further research is required to explore the full potential of collagen-modified viscose fibers in effectively eliminating odors, warranting continued investigation and discussion.

Our findings offer essential data, particularly concerning the effective elimination of odors in older individuals, yielding excellent results. In many countries where societies are aging, the presence of odors associated with older individuals can sometimes lead to social issues. For instance, older men may inadvertently produce the smell of uric acid when urination, leading to social discomfort.

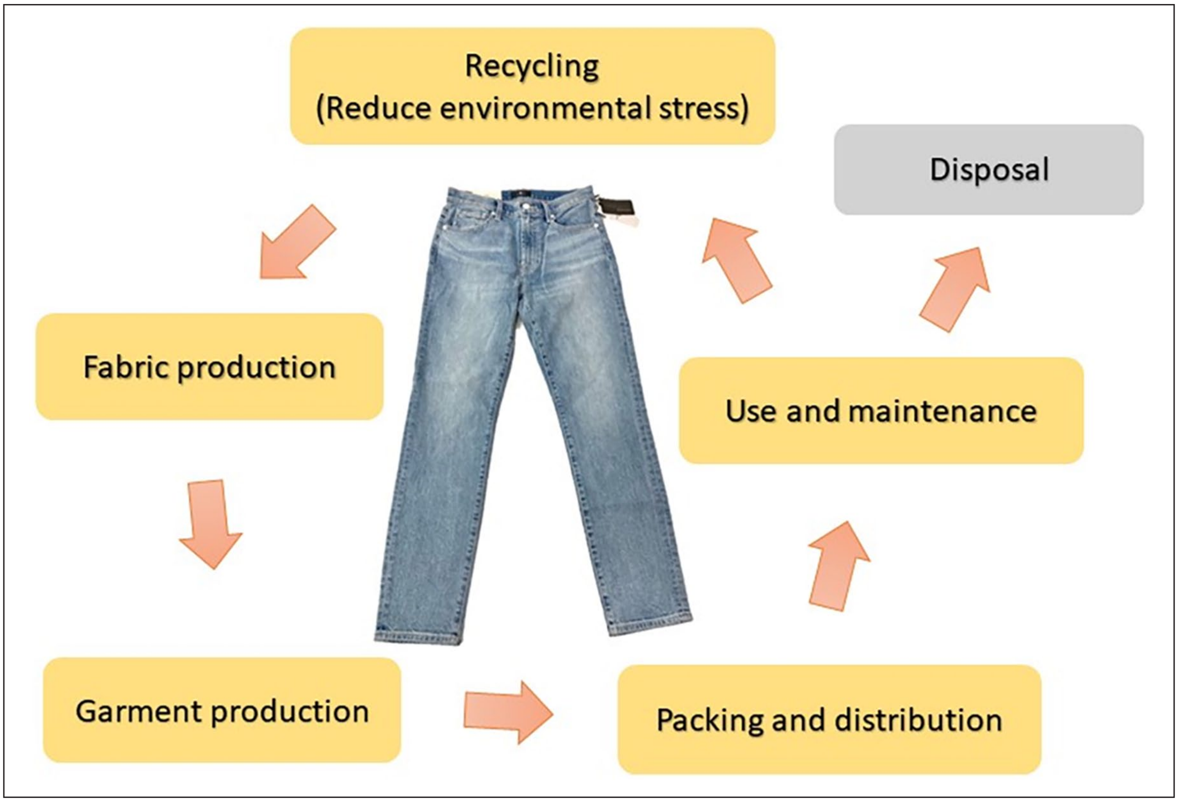

Figure 3. The lifecycle of a jean.

Table 3. Sustainability issues of a jean in lifecycle.

Stage	Sustainability issues
A. Fabric production	A1. Cotton farming
	A2. Blended material
	A3. Dyeing and finishing processes
B. Garment production	B1. Energy and water consumption
	B2. Work environment and labor justice
	B3. Waste generation
C. Packing and distribution	C1. Packaging material selection and over-packaging
	C2. Long-distance transportation
	C3. Return and reverse logistics
D. Use and maintenance	D1. Overconsumption
	D2. Energy and water usage
	D3. Chemical pollution
E. Recycling	E1. Contamination
	E2. Limited recycling infrastructure
	E3. Lack of consumer awareness and participation
	E4. Reduce environmental stress
F. Disposal	F1. Chemical Pollution
	F2. Landfill waste or incineration problem
	F3. Lost resources

Existing research has shown that the production of dopamine in the brains of older individuals during moments of happiness is beneficial to their health.[42–45] Consequently, the absence of odors in social interactions or while living with their families can significantly enhance the mood and self-esteem of older individuals. Hence, the role of clothes in eliminating odors plays a crucial role in promoting the well-being of older individuals.

Conclusions

In conclusion, this study demonstrates that the developed denim fabric has several environmental benefits.

(a) *Reduces water consumption*: The average pair of jeans requires 1800 gallons of water for production. Washing the jeans less significantly reduced the amount of water consumed.
(b) *Reduces energy consumption*: The energy used to wash and dry clothes accounts for a significant portion of the energy used at home. By washing jeans less, energy consumption is reduced.
(c) *Reduces microfiber pollution*: When washing clothes, tiny fibers are released into the water. These fibers eventually make their way into rivers and oceans, where they can harm aquatic life. The amount of microfiber pollution was reduced by washing jeans less.
(d) *Extending the lifespan of jeans*: The more jeans are washed, the more they fade and wear out. By washing them less frequently, one can extend their

lifespan and keep them looking good for a longer time. This is important because of the annual reduction in the number of jeans that end up in landfill.

Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: This research was sponsored by Camangi Corporation (Taiwan) and may lead to the development of products that may be licensed to Camangi Corporation (Taiwan), in which we have a business and/or financial interest.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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