Textile & Leather Review

ISSN 2623-6281| www.tlr-journal.com | 10.31881/TLR

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How to cite: Yan W. Research on Brand Packaging Design Based on Sustainable Textile Materials. Textile & Leather Review. 2026; 9:154-167. https://doi.org/10.31881/TLR.2026.154

How to link: https://doi.org/10.31881/TLR.2026.154

Published: 23 January 2026

Research on Brand Packaging Design Based on Sustainable Textile Materials

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Article

https://doi.org/10.31881/TLR.2026.154

Received 3 June 2025; Accepted 21 July 2025; Published 23 January 2026

ABSTRACT

This study explores the feasibility and advantages of sustainable textile materials in brand packaging design. A control experiment was constructed using recycled polyester fiber, organic cotton, and bamboo fiber as the experimental group materials, while ordinary polyester fiber and conventional cotton were used as the control group materials. The evaluation was carried out using eight dimensions, including environmental protection performance, physical performance, and cost-effectiveness. A life cycle assessment model was established to quantify environmental indicators, while professional instruments and consumer research were employed to obtain data and use statistical methods were used for analysis. The results show that the experimental group outperforms the control group in terms of environmental performance, brand fit, consumer acceptance, and reuse rate; however, the cost-effectiveness and printing adaptability are slightly inferior. The research indicates that, although room for improvement can be observed in certain indicators, sustainable textile materials have the potential to replace traditional materials, which can effectively enhance the brand's environmental image and market competitiveness, providing a theoretical and practical reference for the sustainable development of the textile packaging industry.

KEYWORDS

renewable textile materials, brand packaging design, sustainable development, LCA

INTRODUCTION

Global environmental protection policies have become much stricter in recent years, driving a strong push for green transformation across various industries. Many countries have responded to the environmental call by implementing "plastic restriction orders," strictly controlling the use of traditional plastic packaging. Some developed countries have set "carbon neutrality" goals, with the aim of achieving net-zero greenhouse gas emissions and requiring significant reductions in carbon emissions from all sectors. In the textile industry, the environmental issues associated with traditional textile packaging are particularly severe. According to data from the United Nations Environment Program, global textile waste amounts to approximately 12 million tons annually, with EU countries generating 12.6 million tons of textile waste each year. However, the recycling rate is only 22%, leading to a significant amount of resources being wasted. The production of traditional packaging materials accounts for 20% of global industrial water consumption, and producing one ton of textiles emits approximately 17 tons of greenhouse gases, placing a significant burden on water resources and the climate. Additionally, a large amount of non-biodegradable materials end up in the soil and oceans. The European Commission's investigation reveals that a substantial amount of plastic waste enters the ocean annually, with some originating from textile packaging, severely disrupting the ecological balance and threatening the survival of marine life. Meanwhile, consumer environmental awareness has increased significantly. [1] A report by the market research firm Statista shows that 75% of consumers prefer environment-friendly packaging products and are willing to pay more for them [2]. This shift in consumer preferences has prompted companies to prioritize eco-friendly packaging and explore sustainable development paths. For example, in the fashion textile sector, some brands have actively responded by using recyclable or biodegradable materials for packaging, which not only meets consumer environmental demands but also enhances their brand image and elicits positive market feedback. With the characteristics of recyclability, degradability, and low energy consumption, sustainable textile materials have opened up a new path for brand packaging design [3]. For example, Patagonia uses recycled polyester fiber in its clothing packaging, not only reducing carbon emissions by 75% but also strengthening the brand's image as an "environmental pioneer", as well as driving an 18% increase in product repurchase rates [4]. However, at present, the application of sustainable textile materials in the field of brand packaging continues to face problems of insufficient performance stability and high cost. In this context, scholars have investigate sustainable textile materials and brand packaging design. Research on sustainable textile materials, such as that by Xinhua, highlights that the industry is facing increased and stricter scrutiny, demanding improvements in sustainability, with the most critical measure being the selection of sustainable materials [5]. Fathy pointed out that in sustainable interior design, the textile player that consumes the least resources plays an increasingly important role, especially in the sustainable development of the textile industry. Hence, choosing sustainable textile materials has become a crucial measure for textile enterprises to achieve a systematic transformation of production and consumption [6].

Jovanoska pointed out that low-cost production and porous structure based on waste recycling make recycling textile materials and building sustainable eco-acoustic panels possible. The acoustic efficiency of textile materials is determined by comparing, analyzing, measuring, and calculating the acoustic quantity [7]. Research on sustainable design of brand packaging have focused mainly on the use of sustainable materials. Ou-Yang Li analyzed 84 winning cases of sustainable packaging in the Pentaward and Dieline competitions from 2021 to 2022 and reported that the judges in these competitions were particularly concerned about whether the raw materials used in the products are natural and whether the brands are sustainable [8]. From the perspective of natural resources, this paper analyzes how sustainable development goals can be achieved through sustainable packaging design [9]. Sundaresan To highlighted the latest advances in smart food packaging, including active, smart, and biodegradable packaging technologies, their role in improving sustainability, the challenges and obstacles to their adoption, and future research opportunities in the field [10]. The sustainable plastics group pointed out that many packaging suppliers, brand owners, and large enterprises will be required to honor their promises regarding plastic packaging and the circular economy. They will need to create reusable, recyclable, and compostable packaging by increasing the use of recycled materials to enable them to remain in within the circular economy and achieve sustainable development [11]. The previously mentioned studies have certain achievements and limitations. In terms of achievements, the studies have explored multiple fields, clarifying key areas such as sustainable material selection and resource recycling, providing theoretical support and practical examples for industry development, and revealing market trends and brand strategic value. In terms of limitations, these studies have a general lack of in-depth exploration into practical operational challenges, such as cost control, technical barriers, and market acceptance. Some studies have limited sample size, lack broad applicability, and offer insufficiently guidance for corporate implementation. In exploring brand packaging design based on sustainable textile materials, this study will focus on the following issues and content. First, it will compare and analyze the differences in physical properties (strength, flexibility, water resistance), processing adaptability (printing, cutting, forming difficulty), and cost structure of various sustainable textile materials (such as recycled polyester, organic cotton, bamboo fiber, etc.), to clarify their applicability boundaries in packaging manufacturing. Second, it will simulate real-world scenarios of brand packaging use and test the performance of sustainable textile material packaging in transportation protection, display, and user experience. It will also conduct comparative experiments with traditional packaging materials in terms of impact resistance, weather resistance, and ease of opening and closing. Third, consumer research will be conducted to explore the acceptance, awareness, and purchase willingness of different consumer groups towards sustainable textile material packaging, as well as its potential advantages in enhancing brand image and conveying environmental concepts. Finally, it will analyze the challenges faced in large-scale application of sustainable textile material packaging, such as supply chain integration and process transformation by integrating the company's production process and propose systematic solutions to provide a reference with theoretical depth and practical value for the industry.

MATERIALS AND METHODS

Materials

The experimental group consisted of three sustainable textile materials: recycled polyester, organic cotton, and bamboo fiber.

Recycled polyester was sourced from post-consumer PET bottles and manufactured via a melt-spinning process, which reduces energy consumption and carbon emissions by approximately 59% compared to virgin polyester. Organic cotton was cultivated without synthetic pesticides or fertilizers and processed using eco-friendly dyes, ensuring biodegradability and minimal environmental pollution. Bamboo fiber was derived from sustainably harvested bamboo through a mechanical pulping and spinning process known for its rapid renewability and natural antibacterial properties.

The control group included two conventional materials: ordinary polyester fiber and conventional cotton. These materials represent industry-standard packaging options and were produced using traditional, resource-intensive methods involving petroleum derivatives and extensive use of agrochemicals.

Experimental Design

This study employed a comparative experimental design to evaluate the performance of sustainable textile packaging against traditional alternatives. All material samples were subjected to a standardized set of tests covering physical properties, printing performance, life-cycle impact, and consumer perception, ensuring a direct and objective comparison.

Performance Evaluation Methods

Analysis of Physical Properties and Printability

We conducted objective measurements of the physical properties of each material. For each material type, five independent samples (n = 5) were tested under controlled laboratory conditions (23 ± 2 °C, 50 ± 5% relative humidity). The tests included the following:

Tensile Strength measured according to ISO 527.

Tear Strength measured using the Elmendorf method in accordance with ASTM D1922.

Abrasion Resistance evaluated using a Martindale abrasion tester based on ASTM D4966. Results were recorded as the number of cycles before the breakage of two threads.

Water Resistance assessed using the spray test method AATCC 22, with ratings ranging from 0 to 100.

Printability was qualitatively assessed by two independent printing technicians. All samples were printed using a standardized digital direct inkjet process. The technicians evaluated ink adhesion, pattern sharpness, and color fidelity.

Durability Evaluation

To evaluate the structural integrity of the packaging prototypes under extreme logistics and long-term service conditions, a composite stress accelerated degradation experiment was designed. Distinguishing from conventional tests that focus solely on mechanical wear, this experiment simulated a chain reaction of UV aging, mechanical fatigue, and hygrothermal degradation.

Initially, all prototypes—manufactured with identical geometry and seam configurations—were subjected to 48 hours of intense ultraviolet radiation in a UV aging chamber (consistent with ASTM G154 standards). This pretreatment simulated the photodegradation of polymers caused by prolonged display in retail windows or open-air warehousing. Subsequently, the samples entered a cyclic testing phase. Each reuse cycle consisted of three consecutive steps: (1) 10 minutes of vibration at 50 rpm under a 2 kg standard load to simulate transportation-induced fatigue; (2) 20 repetitions of manual 180-degree folding and unfolding to mimic repeated user handling; and (3) one standardized domestic machine wash at 60°C followed by a tumble-dry cycle (in accordance with ISO 6330).

The experiment was continued until the samples exhibited any of the following predefined failure criteria: (i) material body cracking or rupture exceeding 10 mm due to embrittlement; (ii) seam opening or stitch failure exceeding 20 mm caused by fiber degradation; or (iii) complete inability to safely support the standard load for 10 seconds. It should be noted that failures were mainly observed at structural connection points, such as seam rupture or stitch breakage, rather than within the material body itself.

Life Cycle and Social Performance Assessment

We conducted a Life Cycle Assessment (LCA) using "1 square meter of packaging film" as the functional unit and a "cradle-to-gate" system boundary to quantify environmental impact. Data were sourced from the Ecoinvent v3.5 database. Given the scope of this study, a simplified assessment was performed, reporting industry averages without conducting Monte Carlo uncertainty simulations.

Social impacts were evaluated using a Social Life Cycle Assessment (S-LCA) framework. Social health and labor rights were translated into a unified "Social Performance Score" (on a 0–20 scale), with higher scores indicating better social performance. This score was derived from a synthesis of data from the Social Hotspots Database (SHDB) and region-specific reports by the International Labor Organization on the textile sector. A weighted sum model was applied, in which labor rights (e.g., child labor risk, working hours) were weighted at 60%, and health impacts (e.g., volatile organic compound \[VOC] emissions) at 40%. The model was adapted from existing literature frameworks [12,13].

Consumer Perception Analysis

We designed a consumer questionnaire to assess brand alignment and consumer acceptance. The reliability and validity of the questionnaire were confirmed (Cronbach's $\alpha = 0.82$; KMO = 0.76, $p < 0.01$). A total of 107 valid responses were collected.

We applied K-means clustering to segment the respondents and ultimately identified two groups: "Environmentalists" ($n = 52$) and "Price-Sensitive Consumers" ($n = 55$). The silhouette coefficient was 0.41, indicating a reasonable but not highly significant cluster structure. While this finding presents a limitation, we consider the result suitable for the purposes of this exploratory analysis.

Statistical Analysis

All statistical analyses were performed using SPSS Statistics (Version 26). An independent samples t-test was used for consumer cluster comparisons. A p-value < 0.05 was considered to be statistically significant.

RESULTS AND DISCUSSION

Environmental Performance and Life Cycle Assessment

As shown in Table 1, the LCA revealed clear environmental advantages of sustainable materials. Bamboo fiber had the lowest carbon footprint (3.0 kg CO_2 per square meter), representing a 42.3% reduction compared to conventional cotton-based materials. This finding can be attributed to its rapid renewability and lower energy consumption during processing. Recycled polyester also showed a significant reduction of 32.7%, highlighting its benefits in reducing plastic waste and avoiding the extraction of virgin fossil fuels. In contrast, the control materials exhibited significantly higher carbon emissions, reflecting their energy-intensive production processes.

Table 1. Comparison of Environmental and Physical-Economic Attributes of Textile Materials

Group	Material Type	Carbon Emissions per unit (kg CO_2/m^2)	Tensile Strength (MPa)	Avg. Purchase Cost (Yuan/m^2)
Experimental Group	Recycled Polyester	3.5 (−32.7%)	24.1 ± 1.5	16.0
	Organic Cotton	4.0 (−23.1%)	22.5 ± 1.8	18.0
	Bamboo Fiber	3.0 (−42.3%)	26.2 ± 1.3	15.0
Control Group	Common Polyester	5.5 (+5.8%)	18.3 ± 1.1	22.0
	Conventional Cotton	5.2 (Baseline)	19.1 ± 1.2	21.0

Note: Percentage change is calculated relative to the conventional cotton baseline.

Tensile strength is presented as mean ± standard deviation (n = 5).

Objective Physical Properties and Printability

The physical performance of the materials was evaluated based on standardized objective tests, with key results shown in Figure 1. Traditional materials, benefiting from decades of process optimization, demonstrated strong performance in certain areas. Conventional polyester had the highest abrasion resistance (over 30,000 cycles in the Martindale test), while bamboo fiber had the highest tensile strength (26.2 ± 1.3 MPa). Although organic cotton displayed excellent flexibility, it had lower strength and water resistance.

In terms of printability, qualitative assessments indicated that conventional polyester, with its smooth and uniform surface, allowed for the highest fidelity and color saturation. Sustainable materials, organic cotton in particular, faced challenges due to their more porous fiber structure, requiring specialized ink formulations or surface pretreatments [14,15].

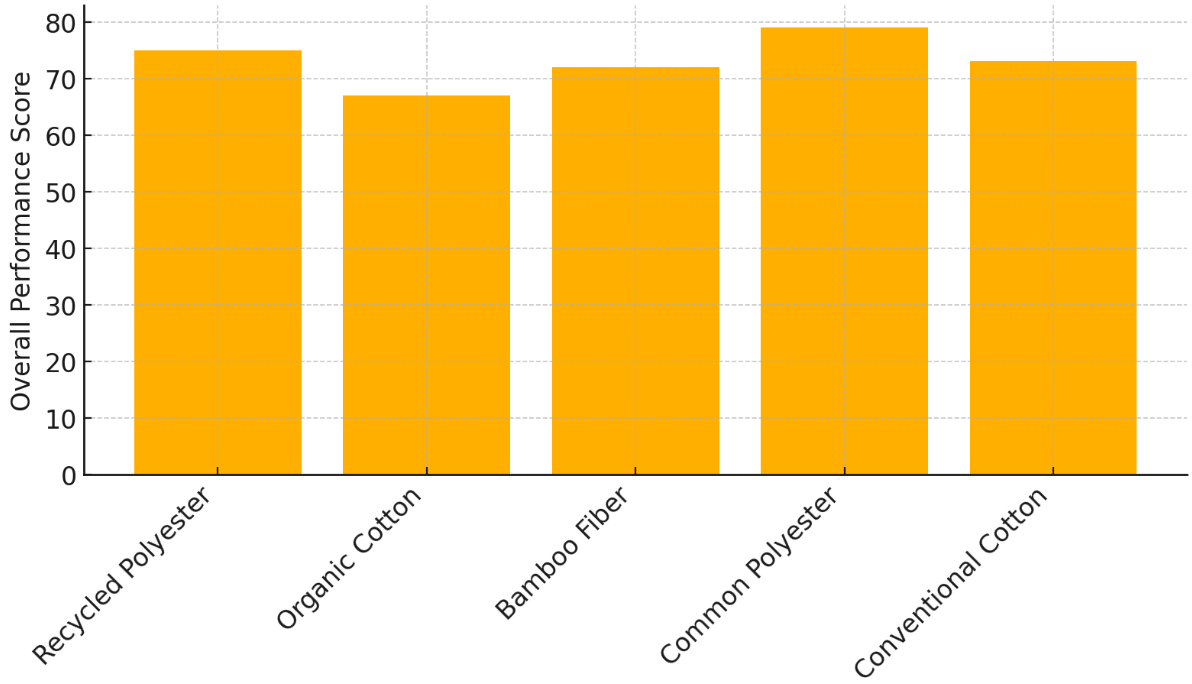

Figure 1. Physical and Printing Comprehensive Performance

Durability and Economic Impact

The long-term value of packaging materials was assessed by analyzing their durability in relation to their initial cost, with the results summarized in Figure 2. Durability, measured by the number of reuse cycles a material can withstand before structural failure, is a critical indicator of its lifespan and overall value. The data reveal that sustainable materials offer superior durability. The reusability test results show bamboo fiber and recycled polyester fiber withstood 10 and 8 reuse cycles. This performance is in stark contrast to conventional polyester, which failed after just two cycles, and conventional cotton, which failed after three cycles. This early failure was primarily attributed to rupture at structural joints rather than degradation of the material body itself.

We create a nuanced economic picture by calculating the cost per use cycle by dividing the initial purchase cost (from Table 1) by the number of reuse cycles. Figure 2 shows this analysis challenges the perception that sustainable materials are less cost-effective. Bamboo fiber emerged as the most economical option, costing only 1.5 Yuan per use cycle, followed closely by recycled polyester at 2.0 Yuan per use cycle. Conversely, the traditional materials were significantly more expensive in the long run, with conventional cotton costing 7.0 Yuan and conventional polyester costing 11.0 Yuan per use cycle. However, organic cotton presents a unique profile. Despite its environmental benefits, its high initial cost (18.0 Yuan/m²) and moderate durability (5 reuse cycles) make it a less cost-effective option (3.6 Yuan per use cycle) than bamboo or recycled polyester in multi-use scenarios. This result suggests its value proposition may lie more in brand storytelling for premium, single-use applications rather than in long-term durability.

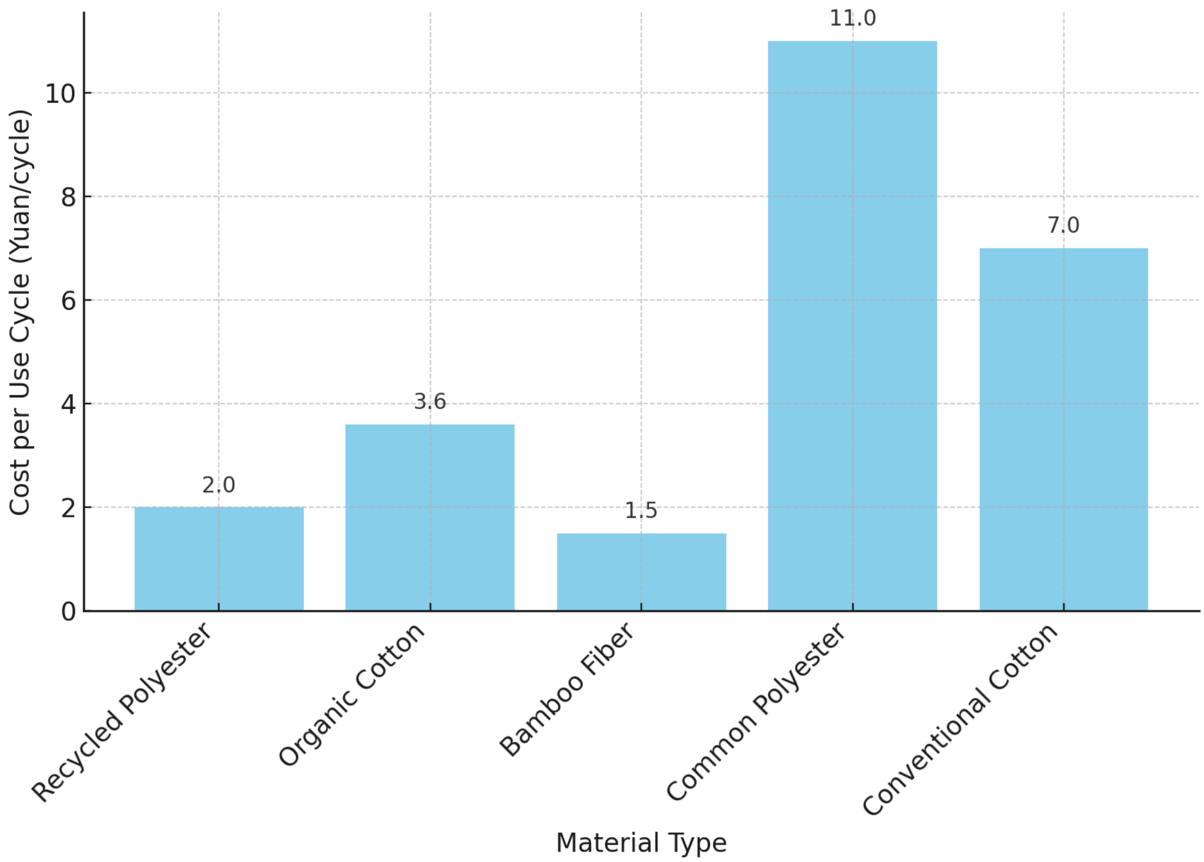

Figure 2. Cost-effectiveness analysis

Consumer Perception and Brand Fit

Consumer analysis revealed a significant market segmentation based on environmental attitudes, as illustrated in Figure 3. Environmentalists consistently rated the three sustainable materials higher in terms of brand alignment and purchase intention (average acceptance score: 92 ± 4), compared to price-sensitive consumers (average acceptance score: 74 ± 6). This difference was statistically significant ($t = 13.2$, $p < 0.001$).

However, the silhouette coefficient of the clustering was moderate (0.41), indicating that these consumer groups represent strong behavioral tendencies rather than strictly distinct segments. Therefore, the findings should be interpreted as directional insights for marketing strategies.

The results strongly suggest that materials such as bamboo fiber and organic cotton serve as powerful tools to enhance brand image and increase purchase intention for brands targeting sustainability-conscious audiences.

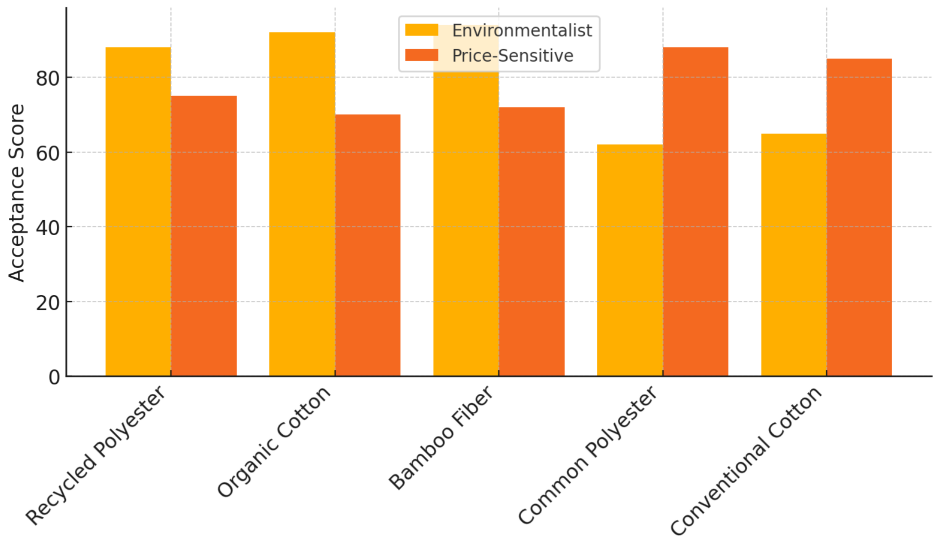

Figure 3. Consumer Acceptance by Group

Reusability and Social Performance

Figure 4 shows that the S-LCA assessment highlights the significant advantages of sustainable materials in terms of social responsibility. Bamboo fiber achieved the highest social performance score (15.1 points), reflecting fair labor practices and low community health risks within its supply chain. In contrast, conventional cotton scored much lower (8.5 points), indicating higher associated risks in its production processes. This metric provides a quantifiable measure of a brand's commitment to ethical sourcing. Outstanding social and environmental performance, combined with proven durability, presents a highly compelling strategic value proposition for brands seeking to establish long-term trust and loyalty with modern consumers [16,17].

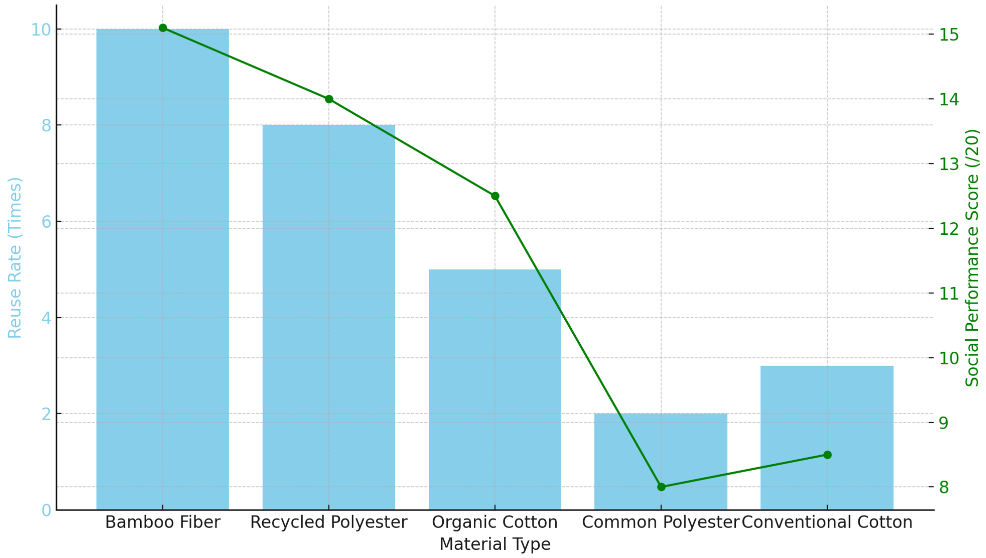

Figure 4. Reusability and Social Performance

CONCLUSION

This study experimentally validated the substantial potential of sustainable textile materials, particularly recycled polyester, organic cotton, and bamboo fiber, as viable and strategically meaningful alternatives for brand packaging. Our multifaceted analysis indicates that despite certain trade-offs, these materials present a compelling overall value proposition.

The findings demonstrate that sustainable materials offer decisive advantages in key areas. The LCA revealed significantly reduced environmental footprints, and outstanding social performance scores reflected more ethical and responsible supply chains. Moreover, these materials are favored by the growing segment of environmentally conscious consumers, making them powerful tools for building brand equity. Crucially, the study provides empirical evidence that materials such as bamboo fiber and recycled polyester exhibit superior durability and reusability, far surpassing those of traditional materials. However, these strengths are accompanied by notable challenges, including higher initial production costs and the need for specialized printing techniques to achieve optimal visual performance on their unique surfaces.

While this study adopted a comprehensive approach, several limitations remain. Durability and lifespan evaluations, although based on standardized lab protocols, may not fully capture the variability of real-world use and disposal. The consumer analysis, though insightful, was limited to a specific demographic, and the economic model did not encompass full life-cycle costs, such as end-of-life disposal. Finally, the scope was limited to three materials. Broader conclusions would require expansion to include a wider range of emerging options, such as hemp or seaweed-based fibers.

Based on these findings, future research should prioritize real-world logistics testing and expand the range of materials studied and the diversity of consumer samples. For the industry, this study offers a clear path forward. Brands can leverage sustainable packaging by focusing not on initial cost, but on the long-term value created through durability, reusability, and enhanced brand image. Brands can also collaborate with suppliers to develop printing and processing techniques optimized for sustainable textiles and integrate features such as RFID to create smart packaging that provides full life-cycle traceability, further strengthening consumer trust and operational efficiency.

In conclusion, the challenges related to physical performance and upfront costs are not barriers but engineering opportunities. Sustainable textile materials present a compelling and feasible path for the packaging industry to achieve its environmental, social, and commercial objectives. They are not merely substitutes for conventional materials, but a strategic upgrade, one that can redefine the relationship between brands, consumers, and the planet.

Availability of Data and Materials

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

Author Contributions

Wei Yan designed, collected and analyzed the data, and drafted the manuscript. Wei Yan conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Wei Yan participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Acknowledgments

Not applicable.

Funding

Not applicable.

Conflict of Interest

The author declares no conflict of interest.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Shanxi University of Applied Science and Technology. Participants were informed of the study's purpose and data usage prior to participation, and responses were collected anonymously. No personally identifiable information was stored.

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