Nurturing Sustainable Solutions in the Fashion Industry Through Eco-friendly Product Development from Fruit Waste

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Abstract

Globally, 1.3 billion tonnes of organic waste are generated annually, with fruit waste significantly contributing to environmental harm and resource depletion. In India, millions of tonnes of fruit waste are discarded annually, highlighting the urgent need for sustainable solutions. This study explores eco-friendly product development in the fashion industry by repurposing fruit waste into sustainable fasteners. These fasteners provide an eco-friendly alternative to conventional options, such as plastic buttons and other non-eco-friendly fasteners. Although buttons represent a minor component of the fashion industry, their production and material usage have a disproportionately large environmental impact. The study promotes innovative waste management practices and presents a sustainable solution for the fashion industry through eco-friendly product development from fruit waste.

The research evaluates current waste utilization methods in the fashion industry, develops eco-friendly products from fruit waste, and gathers expert and consumer feedback to ensure industry standards are met. Employing exploratory and experimental methodologies, the study integrates data from interviews with juice center owners and secondary sources, emphasizing sustainable material sourcing and advanced techniques like cutting-edge technologies.

This approach supports ethical, socially responsible practices while aligning with Sustainable Development Goals (SDGs) such as waste reduction and sustainable consumption. Additionally, the study highlights the socioeconomic benefits of empowering local communities through job creation and economic opportunities.

The findings validate the feasibility of transforming fruit waste into valuable resources, showcasing the successful development of buttons and accessories approved by industry experts. By advocating for circular economy principles and fostering collaboration, this research underscores the potential of sustainable fashion to drive environmental and social change while preserving cultural heritage.

Keywords: Eco-friendly solutions, Fruit Waste management, Recycling, Innovative techniques, Sustainable Future.

INTRODUCTION

Globally, around 1.3 billion tonnes of organic waste are generated annually, with fruit waste forming a significant share. This waste contributes to severe environmental issues, including pollution, resource depletion, and inefficiencies in waste management systems. In India, millions of tonnes of fruit waste are discarded yearly, highlighting the pressing need for sustainable solutions to tackle this growing problem. The fashion industry, known for its creativity and innovation, is also a significant contributor to environmental challenges due to its reliance on non-sustainable materials and practices. Among these, plastic buttons and other non-eco-friendly fasteners stand out as seemingly minor components that cause disproportionately large environmental impacts through resource-intensive production and waste generation.

Plastic and conventional (eco-unfriendly) fasteners significantly contribute to the ecological footprint of the fashion industry. Despite their small size and minor presence in overall garment manufacturing, their production involves high energy consumption and reliance on petroleum-based materials, exacerbating environmental damage. This study identifies a dual opportunity in addressing waste management inefficiencies and the environmental concerns of the fashion industry by repurposing fruit waste into sustainable fasteners.

This research aims to develop eco-friendly alternatives to conventional fasteners using fruit waste, particularly orange and sweet lime peels, as raw materials. By leveraging innovative waste management and sustainable product design practices, the study seeks to minimize the environmental impact of fasteners in the fashion industry. This aligns with broader sustainability goals, including promoting circular economy principles, reducing dependency on non-renewable materials, and fostering socially responsible business practices.

The outcomes of this study have the potential to address multiple layers of sustainability challenges. Firstly, they contribute to environmental conservation by reducing organic waste and replacing harmful materials. Secondly, they provide socioeconomic benefits by empowering local communities through job creation and fostering ethical production practices. Lastly, the research aligns with Sustainable Development Goals (SDGs) by promoting waste reduction, sustainable consumption patterns, and the advancement of green technologies.

LITERATURE REVIEW

Waste Management Practices in the Fashion Industry

The fashion industry is a major contributor to global waste and environmental degradation, with an estimated 92 million tonnes of textile waste generated annually (Ellen MacArthur Foundation, 2017). Traditional waste management practices often emphasize recycling and downcycling; however, these approaches fail to address the growing challenges of waste reduction and sustainable material innovation. In recent years, the adoption of circular economy principles has emerged as a significant trend. Circular models aim to retain the value of materials and extend product life cycles through reuse and remanufacturing (Stahel, 2016).

Despite these advancements, most fashion brands struggle to incorporate sustainable materials due to limited availability and high costs (Fletcher and Grose, 2012). While some brands have begun utilizing recycled plastics and organic fibers, the environmental impact remains significant, as traditional materials dominate production processes. Studies also highlight the lack of integration of biodegradable materials in accessories such as fasteners and trims, leaving a substantial gap in sustainable product development.

Impact of Conventional Fasteners

Fasteners such as buttons, zippers, and hooks are small yet essential components of garments. Most conventional fasteners are made from plastics, metals, or synthetic polymers, contributing to resource depletion and pollution during production and disposal (Fletcher, 2014). Studies indicate that plastic fasteners are particularly problematic, as their production consumes non-renewable petroleum resources and emits greenhouse gases (Greenpeace, 2016).

While fasteners represent a minor proportion of the fashion industry's output, their environmental impact is disproportionately high. This discrepancy stems from high-volume production and widespread disposal practices, which contribute to long-term pollution and hinder recycling efforts. Research suggests that transitioning to biodegradable alternatives can significantly mitigate these impacts (Muthu et al., 2016).

Innovative Use of Organic Waste

Organic waste, particularly from fruits, has gained attention as a sustainable resource for material development. Fruit peels, seeds, and pulp are rich in cellulose and other natural polymers, making them viable candidates for biodegradable product creation (Mohanty et al., 2002). Studies have demonstrated the potential of fruit waste to be processed into materials such as bioplastics, leather alternatives, and paper (Gupta and Pathak, 2020).

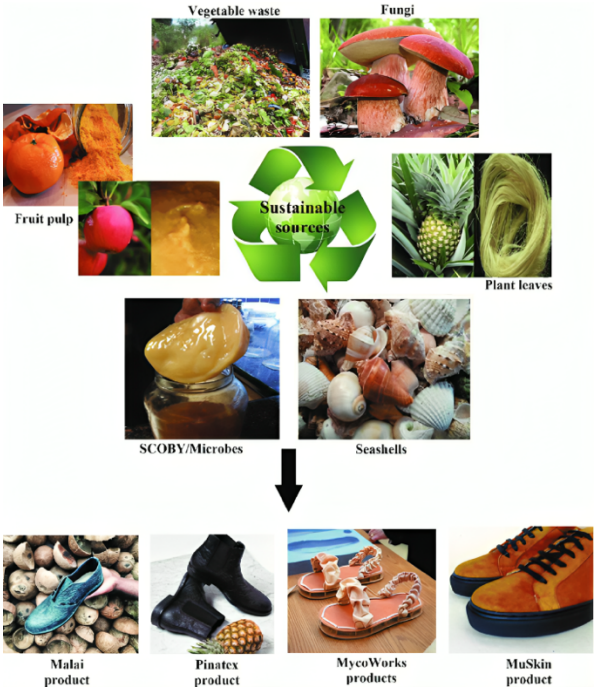


Figure 1 Recent innovations in transforming fruit and agro waste (Illustration of some new-generation sustainable fiber sources and products. Images credit: MycoTech, Pinatex®, Malai.eco and MuSkin (Grado Zero Innovations 2017; Malai Design & Materials 2017; Orange Fiber S.R.L 2015; Pinatex 2017; MycoWorks, 2019a; SwicoFil 2018)

Organic waste offers a unique opportunity in sustainable fashion due to its natural properties. The potential of waste as a sustainable material is particularly compelling, as it addresses both environmental degradation from organic waste and the resource intensity of fashion production. Research by Kaur & Sheoran (2021) explores the use of fruit peels and pulp in producing alternative materials, highlighting unique attributes such as natural durability and a lower environmental footprint. When dried, ground, and treated with natural binders, these organic materials can be molded into durable products suitable for accessories like buttons, presenting a sustainable replacement for traditional plastic components (Kaur & Sheoran, 2021).

Moreover, the use of organic waste materials aligns well with circular economic principles by extending product life cycles and minimizing landfill waste, consistent with the United Nations Sustainable Development Goals (UN Environment Programme, 2019).

Recent innovations (see fig. 1) are further transforming agro and fruit waste into sustainable raw materials for footwear and textiles. Fungal leather alternatives are gaining traction due to their biodegradability, renewability, and mechanical properties. Nonwoven fabric technology is evolving towards eco-friendly materials, incorporating lignocellulosic fibers as both binders and reinforcement. Additionally, kombucha-

derived bacterial cellulose shows promise as a cost-effective leather substitute, offering good mechanical properties. A systems approach to garment production that prioritizes sustainability and considers the entire production lifecycle. However, challenges such as dimensional stability and resistance to degradation must be addressed for new biomaterials to meet industry standards. Emphasizing the circular economy and recycling of waste materials is crucial for the sustainable transformation of the textile and footwear industries.

METHODOLOGY

This study employs a mixed-method approach, integrating qualitative stakeholder feedback with experimental material Development, to examine the feasibility of transforming fruit waste into sustainable fashion accessories. The methodology involves secondary research, primary data collection using structured questionnaires and interviews, and experimental phases focused on material and product development. By combining qualitative and practical methods, the research provides a holistic perspective on waste repurposing.

To gather insights into current practices and challenges, qualitative data was collected from juice center operators and potential consumers in Pune, Maharashtra. The primary data collection tool was a structured questionnaire designed to capture detailed information on fruit waste generation, existing disposal practices, and the willingness of stakeholders to adopt innovative eco-friendly methods. Key areas of inquiry included the operational details of fruit usage and waste volume, regulatory compliance, awareness of sustainability, and the feasibility of adopting waste-repurposing solutions.

The questionnaire was structured around four primary themes: *current waste management practices, interest in sustainability, regulatory challenges, and openness to new practices*. Sample questions included inquiries about the primary methods of fruit waste disposal, the perceived interest of consumers in eco-friendly alternatives, and the challenges associated with adhering to waste disposal regulations. Additionally, questions explored the respondents' *willingness to adopt new waste-repurposing techniques and the support they might require transitioning to more sustainable practices*. This structured approach ensured the collection of actionable insights to inform both the experimental material testing and the broader feasibility study of sustainable waste repurposing for fashion accessories.

Material and prototype development

The experimental phase aimed to transform fruit waste into a usable, sustainable material for fashion accessories, focusing on material and prototype development (see fig. 2). The process began by collecting fruit waste, such as sweet lime and orange peels, from juice centers. After cleaning and preparing the waste, it was blended into

a paste using mechanical techniques. Natural binders like gelatin, starch, glycerin, and water were added to enhance cohesion, strength, and durability while maintaining eco-friendliness. The paste was then spread onto a cotton fabric substrate to form a surface layer, which was dried under sunlight or at room temperature to achieve a solid structure. Once dried, the material was smoothed with sandpaper and treated with oil and Mod Podge fixative to lock the moisture and retain its natural appearance. This finalized material formed the basis for prototype development, aligning sustainability and functionality goals in the prototype development.

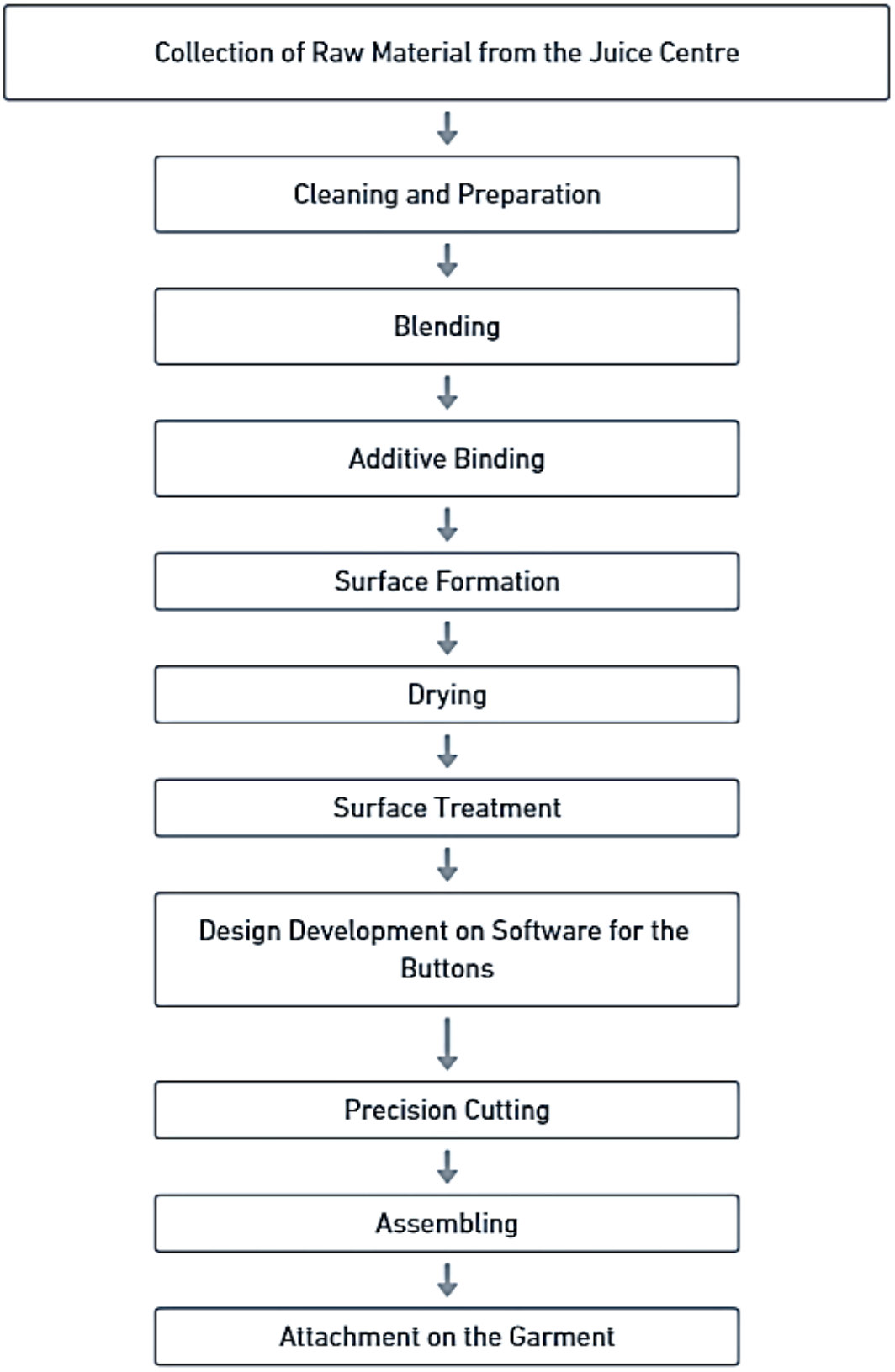


Figure 2 Stepwise Development of Prototype

RESULTS AND DISCUSSIONS

Qualitative Data Insights

The qualitative data, derived from structured questionnaires and interviews with juice center operators and consumers in Pune, revealed key findings related to waste management practices, sustainability awareness, and the feasibility of waste repurposing for sustainable fashion accessories:

- *Current Waste Management Practices:* Respondents indicated a reliance on unsustainable disposal methods such as landfill dumping and informal composting due to the absence of structured systems. Limited infrastructure and a lack of awareness regarding eco-friendly waste repurposing techniques were identified as significant barriers.
- *Interest in Sustainability:* While stakeholders showed increasing awareness of sustainability concepts, challenges such as cost concerns and inadequate knowledge of waste management alternatives hinder adoption.
- *Regulatory Challenges:* Compliance with waste disposal regulations varied among respondents, with some citing high operational costs and unclear guidelines as significant obstacles. This highlights the necessity for clearer policies and support mechanisms.
- *Openness to New Practices:* Stakeholders expressed a willingness to adopt innovative, cost-effective waste-repurposing solutions. However, they emphasized the importance of capacity-building programs and technical assistance to facilitate this transition effectively.

Experimental Data Insights

Surface Development and Analysis

The initial phase of material development involved transforming fruit waste into functional surfaces. Orange and sweet lime peels, collected from juice centers, were processed using the paper-mâché technique with natural binders such as gelatin and starch. The resulting paste was spread onto cotton fabric, dried, and refined using sandpaper to enhance smoothness and durability (Figure 2).

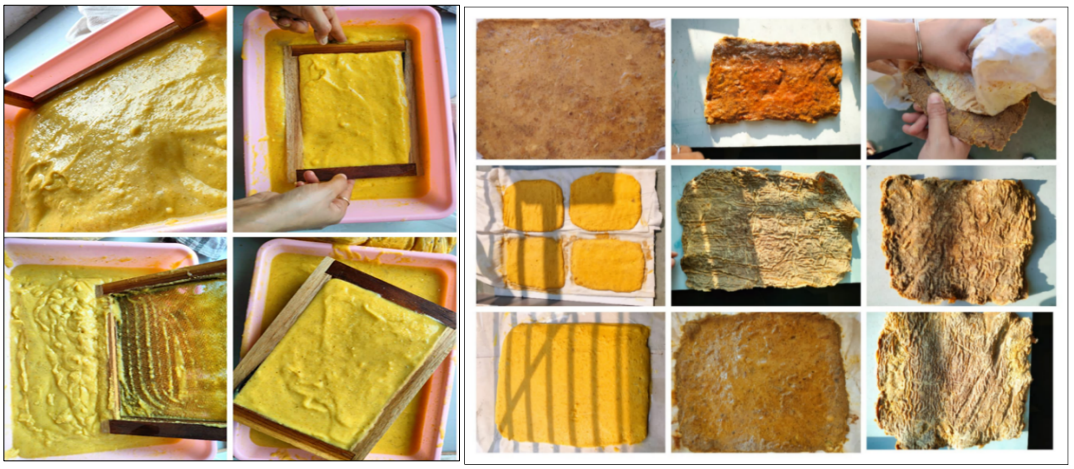


Figure 3 Surface Development (Spreading and Drying)

Digital Design and Laser Cutting

Using Adobe Illustrator, digital templates for fasteners, buttons were created (Figure 3). These designs ensured uniformity, precision, and aesthetic appeal, serving as guides for the laser cutting process.

The laser cutting phase showcased the material's adaptability to modern manufacturing technologies. The ability to craft intricate designs with precision highlighted the scalability of this method for broader applications in the fashion industry.

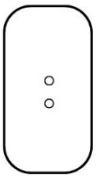
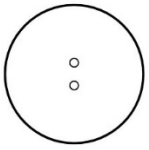
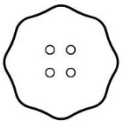
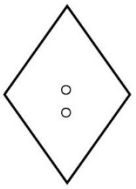
Code	Designs	Measurments
B001		2 Buttonhole 1X2.5cm
B002		2 Buttonhole 1X3.5 cm
B003		2 Buttonhole 3X3cm
B004		4 Buttonhole 2.5X2.5cm
B005		2 Buttonhole 3X4cm
B006		2 Buttonhole 2X2cm

Figure 4 Digital designs of fasteners, buttons created in Adobe Illustrator

Final Prototype Development and Feedback Analysis

The processed surfaces were laser-cut into various fastener shapes, including buttons which were then assembled into functional fashion accessories. Stakeholders, including industry professionals and potential consumers, evaluated the prototypes. (fig.5)

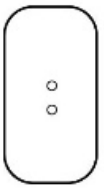
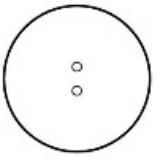
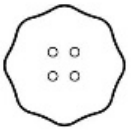
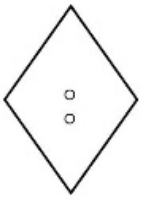
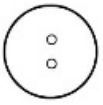
Code	Designs	Measurments	Prototype
B001		2 Buttonhole 1X2.5cm	
B002		2 Buttonhole 1X3.5 cm	
B003		2 Buttonhole 3X3cm	
B004		4 Buttonhole 2.5X2.5cm	
B005		2 Buttonhole 3X4cm	
B006		2 Buttonhole 2X2cm	

Figure 5 Final prototypes of fasteners, buttons made from fruit waste.

Feedback Highlights:

- *Aesthetic Appeal:* The designs were well-received for their uniqueness and visual appeal.(fig.4)
- *Eco-Friendliness*: Respondents appreciated the use of biodegradable materials and the innovative use of fruit waste.
- *Market Potential:* Positive feedback regarding the scalability and market readiness of the products reinforced the feasibility of integrating such accessories into mainstream fashion.

A few samples of fasteners (Buttons) Attachments on the Garment

Figure 6 Attachment of fasteners, buttons (B004) to the Garment

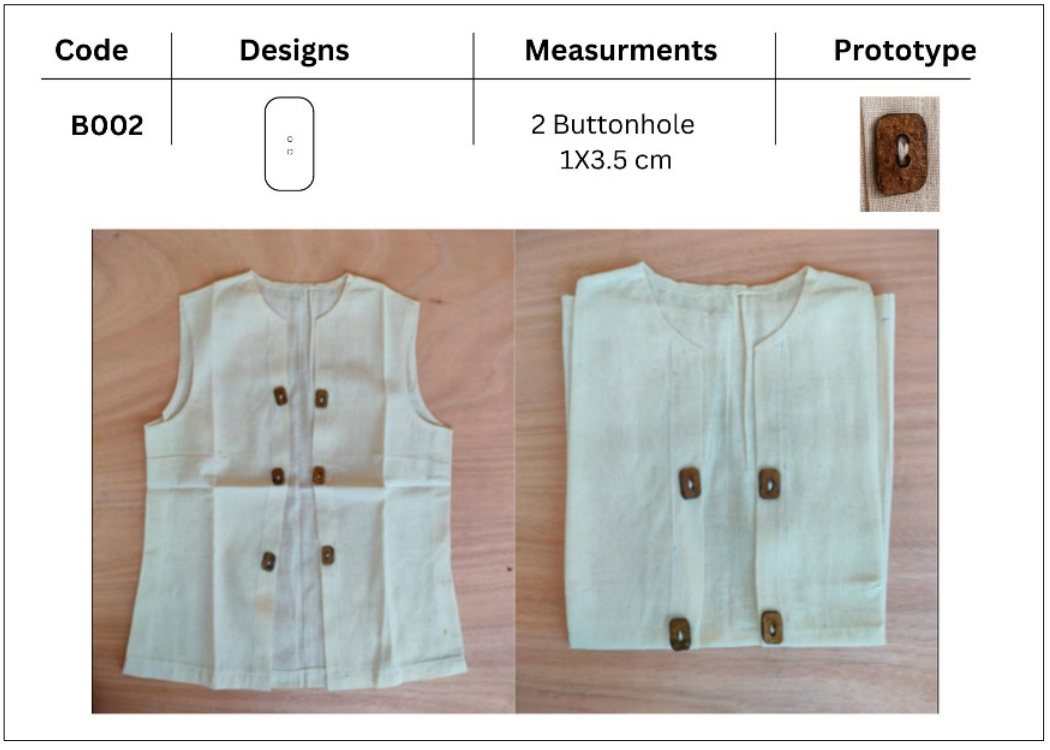


Figure 7 Attachment of fasteners, buttons (B002) to the Garment

Figure 8 Attachment of fasteners, buttons (B003) to the Garment

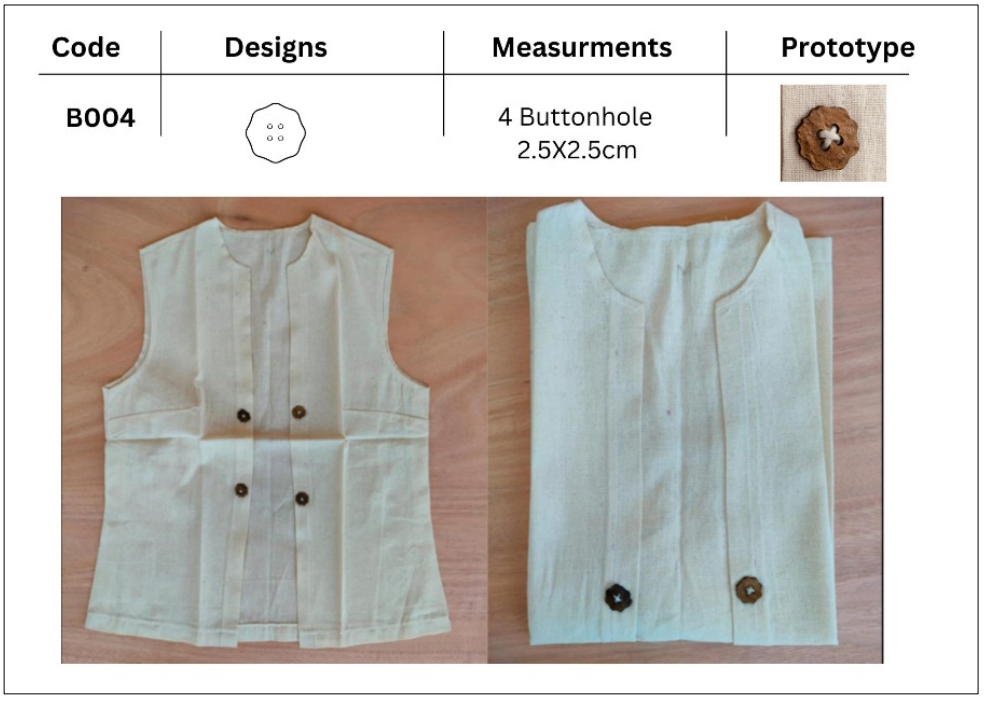


Figure 9 Attachment of fasteners, buttons (B004) to the Garment

Stakeholder Feedback

Stakeholder responses highlighted promising **market potential for fruit-waste-based fashion products**:

- **Industry Expert Insights**: Industry professionals saw value in the material's eco-friendly aspects, suggesting that integrating such sustainable materials

could enhance brand reputation and appeal. Experts also noted that scalability would depend on cost reduction and consumer demand but expressed optimism regarding the material's potential in niche markets.

- **Consumer Willingness to Adopt**: Surveys and interviews with consumers indicated a high willingness to adopt fruit-waste-based products, particularly if they are competitively priced. Respondents showed a preference for sustainable products and expressed interest in supporting environmentally conscious fashion, further supporting the feasibility of these innovations.

The findings of this study underscore the potential of transforming fruit waste into eco-friendly fashion accessories, particularly as sustainable alternatives to plastic fasteners. By addressing the pressing need for biodegradable and resource-efficient solutions, the research aligns with environmental, practical, and socioeconomic goals.

Circular Economy

A pivotal concept underpinning this study is the circular economy, which shifts away from the linear “take-make-dispose” model to one focused on resource reuse, waste minimization, and extended product life cycles. Conventional plastic fasteners, while integral to garment manufacturing, follow a linear trajectory that involves high energy use during production and persistent environmental harm due to their non-biodegradability.

The transformation of fruit waste, such as orange and sweet lime peels, into functional fasteners represents a practical application of circular economy principles. Rather than allowing these organic materials to decompose in landfills and emit harmful methane gases, they are repurposed into biodegradable accessories like buttons and brooches. This approach adds value to discarded organic matter and reduces reliance on synthetic, petroleum-based materials.

By integrating these innovative practices into mainstream fashion, the need for virgin plastics and resource-intensive processes is diminished. As such, this circular approach not only addresses waste management challenges but also provides an eco-friendly alternative to conventional fasteners. The scalability and adaptability of this model demonstrate its potential to catalyze systemic change in material use and manufacturing processes across the fashion industry.

Eco-Friendly Solution to Plastic Fasteners

Plastic fasteners, despite being a minor component of garments, have a disproportionately large environmental footprint. Their production involves significant energy consumption and contributes to long-term pollution due to their resistance to degradation. This study’s fruit-waste-based fasteners present a sustainable alternative, offering comparable functionality while minimizing environmental harm.

These biodegradable fasteners decompose naturally after disposal, ensuring that they do not contribute to microplastic pollution or landfill accumulation. Furthermore, the production process relies on renewable, locally sourced waste materials, reducing the carbon footprint associated with material sourcing and manufacturing.

Stakeholders have praised the prototypes for their eco-friendliness and aesthetic appeal, emphasizing their potential to replace plastic fasteners in both small-scale and large-scale fashion applications. This solution aligns with growing consumer demand for sustainable alternatives and provides an opportunity for the fashion industry to meet environmental standards without compromising design or functionality.

Environmental and Practical Impact

The transition to fruit-waste-based fasteners addresses critical environmental challenges by:

1. **Reducing Waste:** Diverting organic waste from landfills into productive uses.
2. **Replacing Non-Renewable Resources:** Substituting plastic fasteners with biodegradable, renewable materials.
3. **Lowering Carbon Emissions:** Mitigating the environmental cost of synthetic material production and waste management.

From a practical perspective, the material development process demonstrated compatibility with modern manufacturing technologies, including laser cutting and surface refinement. These innovations ensure that the eco-friendly fasteners can meet industry standards for durability, precision, and scalability. The prototypes' adaptability to existing production systems further solidifies their potential as viable replacements for plastic fasteners.

Implications for Sustainable Fashion

The adoption of fruit-waste-based fasteners offers a transformative pathway for the fashion industry to embrace sustainable practices. By leveraging biodegradable alternatives, the industry can reduce its environmental footprint and align with Sustainable Development Goals (SDGs) focused on responsible production and waste reduction.

Moreover, the socioeconomic benefits of this approach include job creation and community empowerment through the utilization of locally sourced waste materials. These practices encourage ethical production methods while supporting the global shift toward sustainable consumption patterns.

By positioning fruit-waste-based fasteners as eco-friendly substitutes for plastic options, the study bridges the gap between environmental responsibility and market feasibility. This innovation not only addresses the fashion industry’s immediate

sustainability challenges but also sets a precedent for integrating circular economy principles into broader material development efforts.

CONCLUSION

This study demonstrates the feasibility and potential of repurposing fruit waste into sustainable fashion accessories, specifically fasteners such as buttons. By addressing the environmental challenges posed by conventional plastic fasteners, the research offers a biodegradable alternative that aligns with circular economy principles. The integration of innovative techniques, such as paper-mâché surface development and laser cutting, underscores the practicality of this approach for modern manufacturing processes.

Key findings reveal that fruit-waste-based fasteners may effectively replace their plastic counterparts, offering comparable functionality while minimizing environmental harm. The biodegradable nature of these products ensures that they decompose naturally after use, mitigating long-term pollution and reducing the fashion industry's reliance on synthetic, non-renewable materials.

The qualitative insights gathered from stakeholders in Pune, Maharashtra, emphasize a growing interest in sustainability and a willingness to adopt eco-friendly solutions. However, challenges such as cost concerns and limited awareness highlight the need for continued advocacy and capacity-building initiatives to facilitate broader adoption. This research contributes to the broader discourse on sustainable fashion by demonstrating how waste repurposing can drive innovation, resource efficiency, and social impact. The adoption of such practices not only reduces organic waste but also supports the Sustainable Development Goals (SDGs) by promoting responsible production and consumption patterns.

Moving forward, the scalability of fruit-waste-based fasteners presents an exciting opportunity for the fashion industry to integrate sustainable practices at all levels of production. By fostering collaborations between industry stakeholders, policymakers, and local communities, this approach can serve as a blueprint for systemic change in material use and waste management, ultimately advancing the global shift toward a more sustainable future.

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