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A Study on the Use of Orange Peels for Bio - Polishing of Denim Cotton Fabric

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Abstract: ***The textile industry is rapidly evolving to meet the growing demand for sustainability and high-performance fabrics. This study explores the potential of bio-polishing using enzymes derived from orange fruit peels as a sustainable finishing method for denim cotton fabrics. The enzymatic extracts obtained through controlled fermentation were applied to denim fabric samples using the pad-dry-cure method. Physical and aesthetic properties such as thickness, stiffness, fabric weight, and pilling resistance were evaluated before and after treatment. The results indicate that orange peel-derived bio-polish improved smoothness, reduced pilling, and maintained fabric strength while promoting circular economy practices by utilizing agro-waste. This research demonstrates the feasibility of citrus waste-based enzymatic finishes in the textile industry as an eco-friendly alternative to conventional synthetic enzymes.***

Keywords: Bio-polishing, orange peels, Denim cotton fabric, Enzymes, Sustainability, Textile finishing

1. Introduction

Textiles are integral to modern life, with applications spanning clothing, home furnishings, healthcare, and industrial products. They are primarily made from natural fibers (cotton, wool, silk), synthetic fibers (polyester, nylon), and regenerated fibers (viscose, lyocell), with increasing adoption of bio-based and recycled materials to enhance sustainability. However, the textile industry is associated with significant environmental impacts, including high water consumption, chemical use, and waste generation, prompting the need for eco-friendly innovations.

One such innovation is **bio-polishing,** an enzymatic finishing process that improves fabric quality by removing protruding fibers, reducing fuzziness and pilling, and enhancing smoothness and fabric appearance. Traditional bio-polishing relies on commercial cellulase enzymes, which are effective but expensive and can contribute to effluent treatment challenges. Enzymatic bio-polishing is particularly suitable for cellulosic fabrics such as cotton, including denim, improving softness, lustre, and overall textile performance while minimizing environmental impact.

Recent research highlights the potential of **orange peel waste**, an abundant agro-industrial byproduct, as a natural source of enzymes for bio-polishing. Orange peels contain bioactive compounds and cellulase enzymes that can effectively modify cotton surfaces, providing an eco-friendly alternative to conventional chemical processes. Utilizing citrus waste aligns with circular economy principles, promoting waste valorization and sustainable textile practices. Furthermore, citrus peel extracts have demonstrated additional benefits, such as natural antimicrobial activity, offering multifunctional improvements to textile products.

This study explores the application of orange peel-derived enzymes for **denim cotton biopolishing**, investigating their effects on fabric smoothness, pilling reduction, and overall quality enhancement. The work aims to provide an environmentally sustainable, cost-effective, and innovative approach to textile finishing, contributing to both industry sustainability and high-performance fabric production.

2. Review of Literature

Several researchers have highlighted the importance of enzymatic finishes in textiles as ecofriendly alternatives to conventional chemical treatments. Enzymes such as **cellulase, amylase, protease, and laccase** have been widely applied in desizing, scouring, bleaching, and finishing processes. Enzymatic bio-polishing, in particular, has been shown to improve cotton fabric quality by reducing surface fuzz, enhancing smoothness, softening fabric, and increasing durability (Cavaco-Paulo et al., 2003; Uddin, 2015). Shrimali & Dedhia (2016) emphasized that enzyme-based processing conserves water and energy, operates under mild conditions, and reduces chemical usage, though high enzyme costs remain a limiting factor.

Recent studies have explored the use of **agro-industrial waste**, particularly orange peels, as natural enzyme sources for textile applications. Orange peels are rich in bioactive compounds, including pectin, flavonoids, and cellulolytic enzymes, which can effectively hydrolyze cellulose and enhance bio-polishing efficiency (Kiron, 2014; Aishwariya, 2020). Utilizing these wastes not only improves fabric quality but also supports sustainable waste management and circular economy principles. Research by Norulaini (2012) and Hafiza Noreen et al. (2024) further demonstrates that enzymatic treatments reduce carbon footprints, minimize toxic effluent discharge, and promote eco-friendly textile manufacturing.

Additionally, studies have investigated enzymatic finishing in denim production, highlighting sustainable washing techniques and enzyme combinations (Mahmud et al., n.d.). The findings indicate that enzymes derived from natural or microbial sources can maintain fabric strength and color properties while reducing water consumption and

environmental impact. The literature collectively underscores the potential of **bio-polishing using natural enzyme** sources to improve fabric aesthetics, functionality, and sustainability, providing a strong rationale for the present study focused on orange peel-derived enzymes for denim cotton finishing.

3. Materials and Methods

Fresh orange peels were collected from local juice vendors, inspected, washed, and cut into small uniform pieces to remove impurities. The peels were then fermented with water, jaggery, and yeast in a standardized **10:3:1** ratio, allowing the process to continue for **4 to 12 weeks** under ambient conditions. This fermentation yielded a bioactive extract with a pH of **4–4.5**, rich in enzymes and natural compounds suitable for textile finishing.

The fermented extract was applied to **denim cotton fabrics** using the **pad-dry-cure method**. Fabric samples were treated at a **material-to-liquor ratio of 1:10 and a 3-dip, 3-nip technique**, followed by drying and curing at **55°C** to maintain enzyme activity. This process ensured uniform penetration of the bio-polish and consistent fabric treatment.

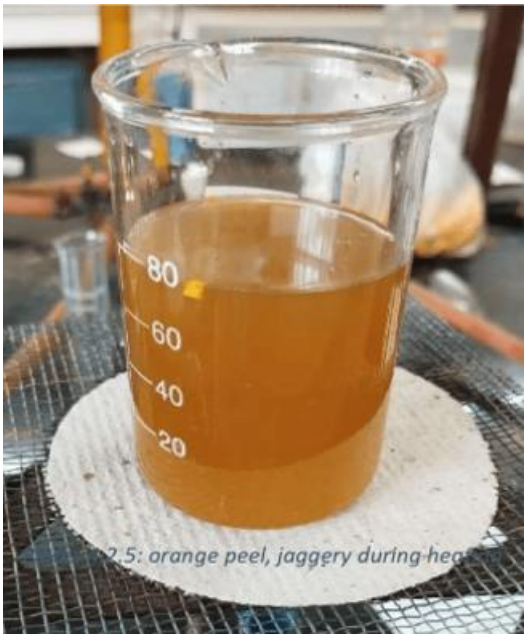
Fabric performance was evaluated using **standardized methods**: thickness (ISO 5084:1996), stiffness (ISO 4604), fabric weight (ISO 3801), and pilling resistance (ISO 12945-2). In addition, **visual and tactile assessments** were conducted through structured surveys to capture surface smoothness, appearance, softness, flexibility, and overall comfort. Combining instrumental and user-oriented evaluations provided a comprehensive understanding of the effectiveness of orange peel-derived bio-polish as an eco-friendly finishing agent for denim fabrics.

Plates 4.2.1: Orange fruit peel

Plates 4.2.2: Orange fruit peels a er shredding

Plates 4.2.3: Shredded orange peels and jaggery

Plates 4.2.4: One teaspoon yeast



Plates 4.2.5: Orange peels and jaggery while heating

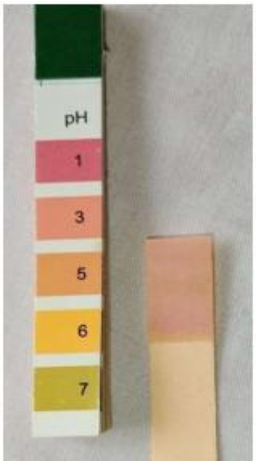
Plates 4.2.6: After adding orange peels and jaggery while heating

Plates 4.2.7: Poured in bottle for fermentation for 1 month

Plates 4.2.8: After 4 weeks of fermentation

Plates 4.2.9: pH. level 4 - 4.5 of finish

Plates 4.2.10: bio polish finish after 12 weeks



Plates 4.3.1: pH. level of finish before applica on of Finish

Plates 4.3.2: Bio Polish in liquor and kept for soaking in Bio Polish

Plates 4.3.3: Denim fabric added Finish bio polish on denim fabric

Plates 4.3.5: Hot Air Oven https://shorturl.at/0XryW

Plates 4.3.4: Paddling Mangle https://shorturl.at/Cxl.bw

4. Results and Discussion

4.1 Survey Responses

4.1.1 Ultra Lightweight Denim Fabric

- **Surface smoothness:** 47.1% rated smooth (4), 29.4% excellent (5), and indicating improved surface quality.
- **Comparison with untreated**: 80.4% found bio-polished denim smoother, confirming effectiveness.

- **Appearance:** 56.9% rated good (4), 27.5% excellent (5); treatment enhanced brightness and evenness.
- **Fabric improvement perception**: 68.7% rated moderate to high (4–5), showing a noticeable upgrade.
- **Touch/feel:** Most rated average to good (3–4), suggesting moderate improvement.
- **Daily wear comfort**: 47.1% comfortable (4), 31.4% highly comfortable (5).
- **Flexibility/stretch:** 39.2% good, 35.3% very good, 13.7% excellent.
- **Overall handle:** Average rating 4.25; treated denim exhibited very good drape and tactile feel.

4.1.2 Lightweight Denim Fabric

- **Surface smoothness:** 70.6% rated 4–5; smoothness improved significantly.
- **Comparison with untreated**: 78% preferred treated fabric.
- **Appearance:** 72.5% rated 4–5; visual appeal enhanced.
- **Improvement perception:** 71% agreed treated fabric looks improved.
- **Touch/feel:** Moderate improvement, majority rated 3–4.
- **Daily wear comfort:** 67% rated 4–5; strong approval of wear ability.
- **Flexibility/stretch:** 72.6% rated good–very good.
- **Overall handle:** Average rating 4.08; 76.5% rated 4–5.

4.1.3 Medium Weight Denim Fabric

- **Surface smoothness:** 39.2% rated 4, 31.4% rated 5; smooth feel noted.
- **Comparison with untreated:** 68% preferred treated denim.
- **Appearance and improvement:** 49% rated 4, 21.6% rated 5; noticeable enhancement.
- **Touch/feel:** Mostly moderate (3–4), some excellent (5).
- **Comfort:** 39.2% rated 4, 27.5% rated 5.
- **Flexibility/stretch:** 45.1% very good, 27.5% good, 9.8% excellent.
- **Overall handle**: Average 4.08; strong positive feedback.

4.1.4 Heavy Weight Denim Fabric

- **Surface smoothness**: 33.3% rated 3, 35.3% rated 4, 19.6% rated 5; moderate to high smoothness.
- **Comparison with untreated:** 60.8% preferred treated fabric.
- **Appearance & improvement:** 45.1% rated 4, 29.4% rated 5; visual enhancement confirmed.
- **Touch/feel:** Majority rated neutral to good (3–4).
- **Daily wear comfort:** 41.2% rated 4, 19.6% rated 5.
- **Flexibility/stretch:** 33.3% good, 33.3% very good, 20.8% fair.
- **Overall handle:** Average 4.06; high approval for drape and flexibility. 5.2 Readings of Tests

Fabric Type	Test	Control Sample	After Bio-Polish Treatment	Observation
Ultra Lightweight	Thickness (mm)	0.32	0.31	Slight decrease in thickness
	Stiffness (Warp/Weft, L/2)	1.07 / 1.2	1.15 / 1.13	Increased handle flexibility
	Fabric Weight (GSM)	146.8	147.6	Slight increase
	Pilling	2	5	No pilling after treatment
Lightweight	Thickness (mm)	0.58	0.59	Slight increase
	Stiffness (Warp/Weft, L/2)	1.32 / 1.1	1.37 / 1.05	Warp more flexible, weft slightly stiffer
	Fabric Weight (GSM)	224	240	Increase in fabric density
	Pilling	3	4	Slight improvement
Medium Weight	Thickness (mm)	0.71	0.68	Reduced thickness, smoother hand
	Stiffness (Warp/Weft, L/2)	1.32 / 1.1	1.37 / 1.05	Improved flexibility
	Fabric Weight (GSM)	304	316	Increased weight
	Pilling	2	3	Moderate pilling
Heavy Weight Thickness	Thickness (mm)	0.81	0.80	Negligible change
	Stiffness (Warp/Weft, L/2)	1.91 / 1.3	2.5 / 1.51	Improved warp flexibility
	Fabric Weight (GSM)	400	404	Slightly higher weight
	Pilling	3	4	Slight pilling improvement

5. Discussion

The bio-polishing treatment consistently improved surface smoothness, tactile handle, visual appearance, and pilling resistance across all denim weights. Lightweight and ultra-lightweight fabrics showed greater perceived improvements in comfort and handle, likely due to their lower initial stiffness. Medium and heavy-weight fabrics exhibited moderate enhancement, with improvements mainly in handle and pilling resistance. Fabric weight and thickness changes were minimal, indicating that bio-polishing preserves structural integrity while enhancing surface and tactile properties. Overall, bio-polishing with citrus peel extract proves effective in upgrading denim fabric quality, particularly in enhancing softness, smoothness, and daily wear comfort.

6. Summary and Conclusion

This study demonstrates that natural enzyme-based extracts derived from orange peels are an effective, eco-friendly solution for bio-polishing denim fabrics across various weight categories- ultra-lightweight, lightweight, medium-weight, and heavyweight. The treatment consistently enhanced both physical and aesthetic properties while preserving the structural integrity of the fabrics. Minor changes in thickness and GSM across all categories indicate controlled fiber removal and minimal impact on fabric strength. Stiffness showed slight variations along warp and weft directions, yet overall flexibility, drape, and wear comfort were maintained.

A major outcome of the study was the significant improvement in pilling resistance. Across all fabric weights, pilling grades increased (from 2–3 to 4–5), reflecting smoother surfaces, reduced fuzz formation, and enhanced

durability. Survey feedback strongly corroborated these findings, with respondents rating the bio-polished denim higher in smoothness, appearance, flexibility, comfort, and overall handle. Average survey scores ranged from 4.06 to 4.25 out of 5, highlighting clear consumer preference for treated fabrics, especially in surface smoothness, aesthetics, and suitability for daily wear.

Fabric-specific findings:

- **Ultra-lightweight denim:** Thickness slightly decreased (0.32 → 0.31 mm), stiffness remained balanced (warp: 1.07 → 1.15; weft: 1.20 → 1.13), and GSM showed negligible change (146.8 → 147.6 g/m²). Pilling resistance improved from grade 2 to 5, confirming enhanced surface smoothness, durability, and overall aesthetic quality. Respondents rated surface smoothness and appearance very positively (76.5–84.4%), with comfort and flexibility also scoring high (78.5–88.2%).
- **Lightweight denim**: Thickness remained stable, warp stiffness slightly increased (1.32 → 1.37), and weft stiffness decreased (1.10 → 1.05), while GSM increased moderately (224 → 240 g/m²). Pilling improved from grade 3 to 4. Survey scores averaged 4.08, with 70–78% of respondents confirming noticeable improvements in smoothness, appearance, and comfort.
- **Medium-weight denim:** Slight decrease in thickness (0.71 → 0.68 mm) and minor stiffness changes were observed, with GSM rising from 304 → 316 g/m². Pilling resistance increased from grade 2 to 3. Surveys revealed strong preference for treated fabric, with 70–78% rating surface smoothness and appearance positively, and overall handle scoring an average of 4.08.
- **Heavyweight denim:** Thickness remained nearly unchanged (0.81 → 0.80 mm), with minor increases in stiffness (warp: 1.91 → 2.5; weft: 1.3 → 1.51) and slight GSM increase (400 → 404 g/m²). Pilling grades improved from 3 to 4. Respondents consistently rated the fabric as smoother and more appealing, with average overall handle scoring 4.06/5.

Demographic data indicated that the majority of respondents were young adults (21–30 years, 62%), with females forming the largest group (70%). Feedback across all age and gender groups consistently favoured the bio-polished denim over untreated fabrics.

7. Conclusion

Orange peel-based enzymatic extracts provide a viable, sustainable alternative for denim biopolishing. The treatment improves surface smoothness, reduces pilling, and enhances aesthetic appeal without compromising essential physical properties such as thickness, stiffness, and GSM. By repurposing agro-industrial waste, this process supports circular economy principles and demonstrates the potential of natural, eco-friendly solutions in textile finishing.

Future research could focus on optimizing enzyme activity and fermentation duration, improving enzyme stability, and scaling the process for industrial applications. Additionally, integrating this bio-polishing technique with other sustainable textile processes, such as natural dyeing or waterless finishing, may further reduce environmental impact while improving product quality.

8. Industrial Relevance and Applications

The study highlights significant industrial potential for using orange peel waste as a biopolishing agent. By leveraging agro-waste, this enzymatic finishing method offers a cost effective and sustainable alternative, making it particularly suitable for small and medium textile enterprises (SMEs), especially in developing countries. Beyond denim finishing, orange peel extracts can be applied in scouring, antimicrobial treatments, and natural dyeing processes. Sustainable fashion brands producing organic or recycled textiles could adopt this technique to enhance product quality while promoting eco-friendly credentials. Moreover, the approach supports waste valorisation by reducing citrus peel disposal, addressing environmental concerns in urban areas.

9. Future Scope

While the results are promising, further research is needed to optimize the process for industrial implementation. Key directions include:

1) Scaling up fermentation in bioreactors to ensure consistent enzyme production.
2) Profiling enzyme activity to quantify cellulase and pectinase concentrations accurately.
3) Combining orange peel extracts with other agro-wastes, such as banana or pineapple peels, to develop multi-enzymatic finishes with broader applications.
4) Evaluating the durability of the bio-polish finish under repeated washing and wear cycles.
5) Integrating orange peel-based treatments into other sustainable textile processes, such as waterless dyeing or nanofinishes, to further reduce environmental impact.

10. Limitations

The orange peel-based bio-polishing process has certain limitations. Enzyme activity is highly sensitive to factors such as concentration, pH, and treatment duration; deviations can result in inconsistent outcomes, particularly in large-scale applications. Raw material variability due to seasonal differences and extraction methods can affect enzyme quality and efficiency, making standardization and reproducibility challenging. These factors limit the reliability of the process across different batches of fabric.

11. Drawbacks

Despite its eco-friendly benefits, the method also presents drawbacks. Overexposure to enzymatic treatment can cause slight variations in GSM, stiffness, or even tensile strength, potentially affecting fabric durability. Compared to conventional chemical finishing, orange peel enzyme treatments may require longer processing times, specialized handling, and optimization, which could limit immediate adoption for large-scale industrial use. Nevertheless, with proper process control and standardization, these challenges can be mitigated to enable sustainable textile finishing.

12. Background of the Study

The global textile industry contributes significantly to environmental degradation due to its high-water consumption, excessive use of synthetic chemicals, and generation of hazardous effluents. Conventional finishing processes often rely on harsh chemicals that compromise environmental safety and fabric quality. With the growing emphasis on sustainable development goals (SDGs), there has been a shift towards green technologies. Enzymatic processing offers advantages such as lower energy requirements, reduced water usage, and biodegradability. Orange peel waste, which is often discarded in massive quantities, has potential to serve as a renewable raw material for bio-polishing applications. This makes the study relevant not only in textiles but also in waste management and sustainable product design.

13. Detailed Methodology

The methodology was carefully designed to ensure reproducibility and accuracy. The fermentation process was carried out at room temperature, and the pH was monitored weekly. Physical changes such as color, odor, and viscosity were documented to track fermentation progress. Post-fermentation, the extract was filtered through muslin cloth to remove solid residues and then stored under refrigerated conditions to maintain enzyme activity. Before application, the solution was analyzed for enzymatic activity using simple substrate assays for cellulase and pectinase presence. The denim fabrics were prewashed to remove finishing chemicals before applying the bio-polish solution. Multiple denim weights (ultra-light, light, medium, and heavy) were tested to evaluate the finish across a wide spectrum of fabric types. This comprehensive methodology ensures that the findings can be generalized across different denim categories.

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