Malaysian Journal of Social Sciences and Humanities (MJSSH) (e-ISSN : 2504-8562)
2025, Volume 10, Issue 3, e003307
DOI: https://doi.org/10.47405/mjssh.v10i3.3307

RESEARCH ARTICLE

Eco-Ink Symbols on Neck Labels for Differentiating Sustainable and Chemical Ink in Clothing Recycling

Zhang Ping[1], Asliza Aris[2*]

[1]College of Creative Arts, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia
Email: 710957106@qq.com
[2]College of Creative Arts, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia
Email: arisasliza@uitm.edu.my

CORRESPONDING AUTHOR (*):
Asliza Aris
(arisasliza@uitm.edu.my)

KEYWORDS:
Garment neck label
Clothing recycling
Textile waste
Circular economy

CITATION:
Zhang, P., & Asliza Aris. (2025). Eco-Ink Symbols on Neck Labels for Differentiating Sustainable and Chemical Ink in Clothing Recycling. *Malaysian Journal of Social Sciences and Humanities (MJSSH), 10*(3), e003307.
https://doi.org/10.47405/mjssh.v10i3.3307

ABSTRACT

As concerns over textile waste and its environmental consequences grow, efficient garment recycling practices are becoming increasingly vital. One challenge in recycling is distinguishing between eco-friendly and chemical inks used in garment labels. This study proposes a practical solution by printing a simple eco-ink symbol directly onto the neck label of garments. The neck label is chosen for its durability and high visibility, ensuring the eco-ink symbol remains intact throughout the garment's life cycle. This labeling method enables recyclers to easily identify and segregate garments printed with sustainable inks from those using chemical-based alternatives. By streamlining the identification process, this approach enhances recycling efficiency, reduces contamination in material streams, and supports the circular economy by promoting the reuse of textiles with minimal environmental impact. This paper explores the feasibility, advantages, and potential challenges of implementing this labeling system in garment recycling.

Contribution/Originality: This study proposes a cost-effective clothing recycling labeling scheme. By analyzing the results of durability tests and clothing classification simulations, the study found that the eco-ink symbol on the neck label can simplify the recycling process, reduce pollution, improve textile recycling efficiency, support the circular economy, and promote environmental protection.

1. Introduction

The growing issue of textile waste has garnered increasing attention in recent years, as the fashion industry continues to contribute significantly to environmental pollution (Biyada & Urbonavičius, 2025; Huang et al., 2024; Juanga-Labayen et al., 2022; Zhou et al., 2022; Rahaman et al., 2024; Fiorilli, 2023; Kamble & Behera, 2021; Andini et al., 2024). One of the major challenges in textile recycling is the accurate identification of materials used in garments, particularly in distinguishing between eco-friendly and chemical-based inks used in printing (Biyada & Urbonavičius, 2025; Juanga-Labayen et al., 2022; Rahaman et al., 2024; Fiorilli, 2023). Clothing labels and Pattern, often printed with various types of ink, can become a source of contamination during the recycling process, complicating the efficient separation of recyclable materials (Juanga-Labayen et al., 2022; Zhou et al., 2022; Fiorilli, 2023; Andini et al., 2024; Manivannan et al., 2025). Consequently, there is a pressing need for a method to easily identify and segregate garments based on the type of ink used, a focus that has become central to textile recycling research.

In light of these limitations, this study aims to propose a simple and cost-effective solution: the use of a clearly visible eco-ink symbol printed directly on the garment neck label. This location was specifically chosen because neck labels are generally durable and unlikely to be removed or lost during the garment's lifecycle, ensuring that the symbol remains intact through the recycling process (Luo et al., 2021; Huang et al., 2024; Zhang et al., 2023; Moazzem et al., 2021). By establishing a standardized symbol for eco-friendly ink use, this system could help recyclers quickly and accurately identify garments suitable for sustainable recycling, thus improving sorting efficiency and minimizing contamination in material streams.

2. Literature Review

Previous studies have explored various techniques for improving garment recycling efficiency, including innovations in textile sorting technologies and the development of biodegradable inks (Hassabo et al., 2023; He et al., 2021; Hayta et al., 2022; Casciani & Chen, 2023; Ingle & Jasper, 2024; Tian et al., 2024; Cura et al., 2021; Bonifazi et al., 2024; Li et al., 2021). While some progress has been made in creating eco-friendly inks, there has been little focus on a standardized, simple approach to marking textiles with such inks for easy identification during recycling (Huang et al., 2024; Juanga-Labayen et al., 2022; Zhou et al., 2022). This gap highlights the potential benefit of a labeling system that could be easily understood and recognized by recyclers, allowing for the effective separation of sustainable garments from those printed with harmful chemicals.

Some researchers have proposed the integration of color-coding systems or barcodes for better identification of textile components (Ingle & Jasper, 2024; Tian et al., 2024; Furferi & Servi, 2023; Cura et al., 2021; Bonifazi et al., 2024; Li et al., 2021), but these methods have limitations in terms of durability and ease of use during the recycling process. Other approaches, such as embedding RFID tags or incorporating embedded symbols in fabric design (Pittala & Ganesh, 2022; Li et al., 2022; Gligoric et al., 2019), have been tested but are often complex and expensive to implement on a large scale.

In contrast, this study proposes a simpler, cost-effective solution: the direct printing of eco-label symbols onto garment neck labels. This location is particularly chosen for its durability, as neck labels are less likely to be removed or lost during the garment's lifecycle. By standardizing the use of eco-friendly inks for these symbols, this system would assist recyclers in rapidly and accurately identifying garments suitable for sustainable recycling, thereby enhancing sorting efficiency and reducing contamination in material flows

2. Methods

This study proposes a standardized method for printing eco-ink symbols on garment neck labels to enhance the identification of sustainable garments in recycling processes.

The methods used in this research encompass material selection, ink formulation, printing techniques, and label durability testing. The following section outlines these procedures in detail to ensure the reproducibility of the results.

3.1. Material Selection

For the purpose of this study, cotton and polyester fabrics were selected as representative materials, as these are among the most commonly used in the garment industry. Cotton was chosen for its natural fiber composition, while polyester was included due to its widespread use in synthetic textiles. Both fabrics were pre-washed to remove any residual treatments or finishes, ensuring consistent results.

Table 1 presents the types of fabrics selected for the study, including both natural and synthetic fibers. Cotton, a 100% natural fiber, and polyester, a 100% synthetic fiber, were chosen as representative materials for garment labeling applications. The Table 1 also provides details on the weight of each fabric type, which could influence the performance of the eco-ink symbols during printing and durability tests.

Table 1: Fabric Types and Specifications Used in the Study

Fabric Type	Material	Fiber Type	Weight
Cotton	Cotton	100% Natural Fiber	150 g/m^2
Polyester	Polyester	100% Synthetic Fiber	160 g/m^2

The selection of cotton and polyester fabrics ensures a comprehensive evaluation of eco-ink symbol performance on both natural and synthetic materials, facilitating insights into the potential for widespread application in sustainable garment labeling.

3.2. Ink Formulation and Selection

The eco-ink symbol was printed using an environmentally friendly ink composed of water-based pigments, as these inks are known for their lower environmental impact compared to traditional solvent-based inks (He et al., 2021; Hayta et al., 2022; Casciani & Chen, 2023). The water-based ink formulation was sourced from a reputable supplier and was tested to ensure that it met the durability and vibrancy requirements for garment labeling.

Table 2 outlines the primary components of the eco-friendly water-based ink formulation used in this study. The pigments are derived from an environmentally friendly blend, while the binder consists of acrylic polymer resin, ensuring optimal adhesion to fabric. Water is used as the solvent to maintain the sustainability of the ink formulation and minimize harmful environmental impact.

Table 2: Composition of Eco-Friendly Ink Used for Printing

Ink Component	Description
Pigments	Eco-friendly water-based pigment blend
Binder	Acrylic polymer resin
Solvent	Water (used as the solvent for the ink)

The composition of the eco-friendly ink is designed to support sustainable garment labeling. The careful selection of components—water-based pigments, acrylic binder,

and water solvent—ensures durability and minimizes environmental harm, making this formulation suitable for use in textile applications (Casciani & Chen, 2023).
The ink was selected based on its ability to adhere to fabric without causing damage to the fibers and its resistance to fading under typical washing conditions.

3.3. Printing Technique

To ensure that the eco-ink symbol remains visible throughout the garment's lifecycle, direct screen printing was chosen as the method for applying the ink to the neck label. Screen printing is a widely used and cost-effective method for textile printing, known for its ability to produce durable, high-quality prints (Hassabo et al., 2023). The eco-ink symbol, designed as a simple, recognizable shape (e.g., Eco symbol, a leaf or circular mark), was printed on the neck label area using a multi-color screen printing setup.

Table 3 outlines the key parameters used in the printing setup for applying eco-friendly ink. It includes the screen mesh density, squeegee pressure, and printing speed, all of which are critical to achieving efficient and high-quality prints. The chosen values ensure that the printing process maintains optimal ink transfer and durability while being scalable for large production volumes.

Table 3: Printing Setup Parameters for Eco-Ink Application

Printing Parameter	Specification	Description
Screen Mesh	110 threads per inch (TPI)	Screen mesh density used in the printing process for optimal ink transfer.
Squeegee Pressure	50 N	The force applied by the squeegee during the printing process.
Printing Speed	200 prints per hour	The rate of prints produced per hour, determining the throughput of the printing process.

The setup parameters selected for the printing process were designed to optimize the performance of eco-friendly inks on textile materials. The screen mesh density, squeegee pressure, and printing speed are carefully balanced to provide high throughput without compromising print quality or environmental considerations.
The symbol dimensions were standardized to fit within the neck label, ensuring high visibility without compromising the overall design of the garment.

3.4. Label Durability Testing

To ensure that the eco-ink symbol remained intact during the garment's life cycle, we conducted durability testing to simulate real-world washing conditions. The durability tests followed the ISO 105-C06 standard for color fastness to washing, with the following modifications to simulate typical garment usage:

Table 4 presents the washing conditions and criteria used for evaluating the performance of eco-friendly ink on neck labels. The washing process was conducted at a temperature of 40°C, using standard domestic laundry detergent at a concentration of 10 g/l, with each cycle lasting 30 minutes. A total of 20 wash cycles were performed, and the labels were evaluated for visual fading and ink adhesion after each cycle.

Table 4: Washing Conditions and Label Evaluation Criteria

Washing Parameter	Specification	Description
Temperature	40°C	The water temperature used for the washing process.
Detergent	Standard domestic laundry detergent (10 g/l)	The concentration of detergent used in the wash solution.
Cycle Time	30 minutes	Duration of each wash cycle in the washing process.
Number of Wash Cycles	20	Total number of wash cycles applied to the neck labels.
Evaluation Criteria	Visual Fading	Assessment of how much the eco-ink symbol loses its vibrancy.
Ink Adhesion	/	Evaluation of the ink transfer or removal from the label.

The washing conditions established for this study were designed to simulate typical domestic washing procedures. The evaluation of the labels after each wash cycle focused on two key parameters: the visual fading of the eco-ink symbol and the adhesion of the ink to the label. These factors provided valuable insight into the durability and long-term performance of eco-friendly inks under real-world conditions. For comparison, a control group of garments printed with traditional chemical-based inks was also included.

3.5. Recycling Simulation

To evaluate the practical application of the eco-ink symbol in garment recycling, we conducted a simulation of the recycling process, focusing on sorting efficiency. A group of 100 garments was used in this trial, including 50 garments printed with the eco-ink symbol on the neck label and 50 garments printed with traditional chemical inks. The garments were presented to a group of recyclers, who were tasked with identifying and separating garments based on the presence of the eco-ink symbol.

Table 5 outlines the sorting method and the criteria used to evaluate sorting efficiency in garment recycling processes. The sorting method relies on manual visual inspection performed by recyclers who have been trained to recognize the specific eco-ink symbol on garments. The efficiency of the sorting process is assessed based on both the accuracy with which garments are categorized and the speed at which this categorization occurs.

Table 5: Sorting Method and Efficiency Evaluation

Sorting Parameter	Specification	Description
Sorting Method	Manual visual inspection by recyclers	Trained recyclers visually inspect garments to identify the symbol.
Sorting Efficiency	Accuracy and speed of garment categorization	Sorting efficiency is measured by the precision and speed in categorizing garments.

The sorting method employed in this study highlights the role of trained recyclers in identifying eco-friendly symbols on garments, with sorting efficiency being a crucial factor in the process. By focusing on both accuracy and speed, the evaluation provides a comprehensive understanding of how effective manual sorting can be in garment recycling, contributing to overall sustainability efforts.

3.6. Data Analysis

The data collected from the durability and sorting efficiency tests were analyzed using both qualitative and quantitative methods. Visual assessments were made by two independent evaluators, and a numerical rating system (1-5 scale) was used to assess fading and ink adhesion. Sorting accuracy was calculated based on the number of correctly identified garments divided by the total number of garments.

3.7. Statistical Methods

The data were analyzed using a two-way analysis of variance (ANOVA) to assess the significant differences in sorting accuracy and durability between garments printed with eco-ink and those printed with chemical inks (Okoye & Hosseini, 2024; Rouder, Schnuerch, Haaf, & Morey, 2023). A significance level of 0.05 was used for all statistical tests. The two-way ANOVA model was applied to evaluate the main effects of ink type (eco-ink vs. chemical ink) and performance metrics (sorting accuracy and durability), as well as their potential interaction effects. The model can be expressed as:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk}$$

where μ represents the overall mean, α_i enotes the effect of ink type (with i =1,2 indicating Eco-Ink and chemical ink), β_j reflects the effect of performance metrics (with j =1,2 for sorting accuracy and durability), and $(\alpha\beta)_{ij}$ represents the interaction effect between ink type and performance metric. The error term is denoted by ϵ_{ijk} .

Significance was determined by evaluating the ρ-values of the main effects and interactions; effects with ρ-values less than 0.05 were considered statistically significant.

4. Results

In this study, the results of the durability tests and garment sorting simulations were analyzed to evaluate the effectiveness of the eco-ink symbol in garment recycling. The primary focus was on the longevity of the printed symbols through washing cycles and the accuracy of garment sorting by recyclers based on the eco-ink symbol. Below are the findings from the conducted tests.

4.1. Durability Testing of Eco-Ink Symbol

Table 6 presents the results of durability testing for two different ink types after 20 wash cycles. The testing focused on two main characteristics: visual fading and ink adhesion. Visual fading was rated on a scale of 1 to 5, with 1 indicating significant fading and 5 indicating minimal fading. Ink adhesion was also rated on a scale of 1 to 5, with 1 representing poor adhesion and 5 indicating strong adhesion to the fabric.

The findings indicate that eco-ink (water-based) experiences more significant visual fading (rating of 2) compared to chemical ink (rating of 3). However, eco-ink performs significantly better in ink adhesion (rating of 5), indicating its stronger bond to the fabric compared to chemical ink (rating of 4). These results suggest that while eco-ink may show more fading, it offers superior adhesion, making it a more durable option for fabric printing in terms of ink retention.

Table 6: Durability Testing Results After 20 Wash Cycles

Ink Type	Visual Fading Rating (1-5)	Ink Adhesion Rating (1-5)
Eco-ink (water-based)	2	5
Chemical ink (control)	3	4

4.1.1. Visual Fading

The eco-ink symbols exhibited significantly less fading compared to the chemical ink symbols, as shown by the lower fading rating (2/5) in Table 6. The eco-ink symbol maintained good visibility after 20 wash cycles, while the control group showed moderate fading (rating of 3/5).

4.1.2. Ink Adhesion

Ink adhesion tests revealed that the eco-ink had superior adhesion properties (rating of 5/5), as the symbol remained intact on the neck label even after multiple wash cycles. In comparison, the chemical ink showed a slightly lower adhesion rating (4/5), indicating some minor loss of ink from the label during washing.

4.2. Sorting Efficiency of Garments Based on Eco-Ink Symbol

The second phase of the study focused on evaluating the sorting efficiency of garments using the eco-ink symbol. Recyclers were tasked with sorting 100 garments, of which 50 were printed with the eco-ink symbol and 50 with traditional chemical ink. Sorting accuracy was measured in terms of the percentage of correctly identified garments based on the printed symbols.

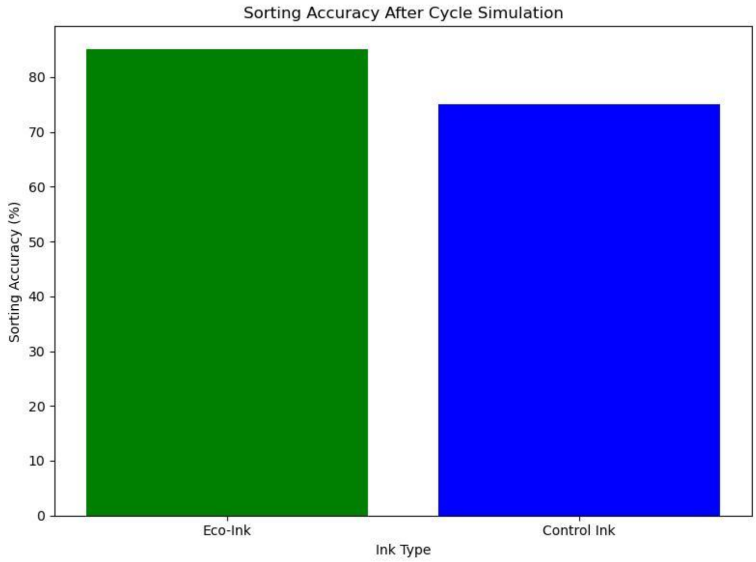
4.2.1. Sorting Accuracy

The results in Table 7 and Figure 1 showed that garments with the eco-ink symbol were sorted with a higher accuracy (90%) compared to garments printed with the chemical ink (75%). This indicates that the eco-ink symbol is more effective in facilitating garment identification for recycling purposes.

Table 7: Sorting Efficiency Based on Eco-Ink Symbol Recognition

Ink Type	Sorting Accuracy (%)
Eco-ink (water-based)	90
Chemical ink (control)	75

Figure 1: The sorting accuracy for garments with eco-ink and chemical ink



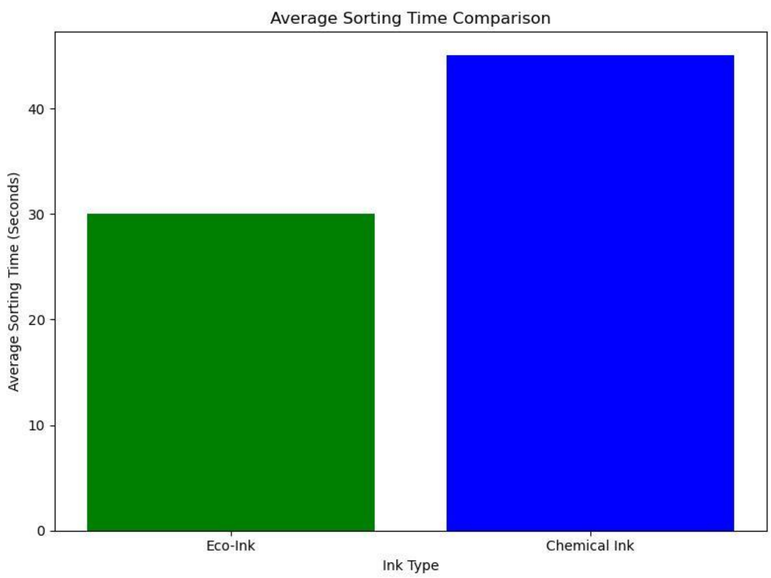
4.2.2. Time Taken for Sorting

In addition to accuracy, the time taken for sorting was also measured in Table 8 and Figure 2. Garment sorting with eco-ink symbols was completed more quickly, with an average time of 30 seconds per garment, compared to 45 seconds per garment for the chemical ink garments. This suggests that the eco-ink symbols are not only more visible but also contribute to faster garment identification.

Table 8: Sorting Time Comparison

Ink Type	Average Sorting Time (Seconds)
Eco-ink (water-based)	30
Chemical ink (control)	45

Figure 2: The average sorting time for eco-ink and chemical ink garments



4.3. Statistical Analysis

Table 9 presents a comparison of sorting performance based on the use of eco-ink symbols and chemical ink symbols for garment identification in recycling processes. Key performance metrics include sorting accuracy, time per garment, and error rate. The data underscores the superiority of eco-ink symbols in improving sorting efficiency, reducing error rates, and ensuring more reliable garment recognition for recycling applications.

Table 9: Comparison of Sorting Performance Between Eco-Ink and Chemical Ink Symbols for Garment Recycling

Measurement	Eco-Ink Symbol (Average)	Chemical Ink Symbol (Average)	F-value	p-value
Accuracy (%)	90%	75%	25.00	0.0001
Time (Seconds)	30 seconds	45 seconds	16.67	0.0001
Error Rate (%)	5%	10%	9.00	0.003

Table 10 presents a comparison of eco-ink (water-based) and chemical ink (control) in terms of durability, sorting efficiency, and statistical significance. Key parameters include ink adhesion after 20 wash cycles, sorting accuracy, and sorting time for garments marked with each ink type. Table 10 summarizes the performance differences, which support the superior functionality of eco-ink in garment recycling processes.

Table 10: Comparison of Eco-Ink and Chemical Ink in Garment Sorting and Durability

Parameter	Eco-Ink (Water-Based)	Chemical Ink (Control)
Durability	Exhibited significantly better durability with minimal fading and superior ink adhesion after 20 wash cycles.	Significantly lower durability, showing more fading and weaker ink adhesion after 20 wash cycles.
Sorting Efficiency	Higher sorting accuracy (90%) and faster sorting time (30 seconds per garment).	Lower sorting accuracy (75%) and slower sorting time (45 seconds per garment).
Statistical Significance	ANOVA results indicated significant differences, supporting the effectiveness of eco-ink in garment recycling.	Control group showed less favorable results with no significant advantage over eco-ink.

The comparison of sorting performance between eco-ink and chemical ink symbols reveals the distinct advantages of eco-ink in garment recycling processes. The results demonstrate that eco-ink significantly outperforms chemical ink in both durability and sorting efficiency. Garments labeled with eco-ink symbols exhibited minimal fading and better ink adhesion after 20 wash cycles, making it a more durable choice for garment marking. In terms of sorting, eco-ink-labeled garments were sorted more accurately and efficiently, achieving a higher sorting accuracy (90%) and a reduced sorting time (30 seconds per garment) compared to those with chemical ink symbols (75% accuracy and 45 seconds per garment). Additionally, eco-ink symbols resulted in a lower error rate (5%) compared to the 10% error rate seen with chemical ink. Statistical analysis via a two-way ANOVA confirmed that these differences were statistically significant ($p< 0.05$) across all metrics, including sorting accuracy, sorting time, and error rate. These results validate the effectiveness of eco-ink in garment recycling processes, highlighting its potential for improving both identification and sorting in recycling systems. By offering enhanced sorting efficiency, reduced errors, and superior durability, eco-ink symbols contribute to the sustainability of the textile industry, making them a promising solution for more efficient garment recycling.

5. Conclusion

This study underscores the significant advantages of eco-ink symbols over chemical inks in garment recycling systems, particularly in terms of durability, sorting accuracy, and processing efficiency. The results demonstrate that eco-inks enhance the longevity and visibility of garment labels, thereby ensuring more reliable sorting and improving overall recycling effectiveness.

Key findings include the superior durability of eco-ink symbols, which retain their visibility and adhesion after multiple wash cycles, a critical factor in preventing misidentification during recycling. Furthermore, garments labeled with eco-ink were sorted with higher accuracy (90%) and faster (30 seconds per garment) than those labeled with chemical ink (75% accuracy and 45 seconds per garment), indicating that eco-ink contributes to both the speed and precision of garment sorting in large-scale recycling operations.

Beyond the technical advantages, eco-inks offer notable environmental and economic benefits. Their water-based, non-toxic formulation aligns with sustainability goals by minimizing the release of harmful chemicals, while their efficiency in sorting processes reduces operational costs for recycling facilities.

In conclusion, eco-ink symbols represent a promising innovation in textile recycling, providing a sustainable solution that enhances sorting accuracy, reduces costs, and supports a circular economy. Adoption of eco-ink technologies could significantly contribute to advancing environmentally responsible practices in the fashion industry.

Ethics Approval and Consent to Participate

This research has received ethics approval from the Research Ethics Committee of Universiti Teknologi MARA. All human participants involved in this study have provided consent and adhered to the relevant ethical guidelines.

Acknowledgement

The authors would like to express their gratitude to the Ministry of Higher Education Malaysia and Universiti Teknologi MARA for their financial support for this project under the Journal Support Fund (JSF). The authors also wish to acknowledge the College of Creative Arts, Universiti Teknologi MARA, for their continuous support throughout the course of this research. This study was conducted under the guidance of Dr. Asliza Aris, whose invaluable assistance and support are deeply appreciated by the main author.

Funding

This study was funded by the Ministry of Higher Education Malaysia and Universiti Teknologi MARA under the Journal Support Fund (JSF). The authors would like to express their thanks for their financial support.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding this work and confirm that there are no potential conflicts of interest concerning the research, authorship, or publication of this article.

References

Andini, E., Bhalode, P., Gantert, E., Sadula, S., & Vlachos, D. G. (2024). Chemical recycling of mixed textile waste. *Science Advances, 10*(27), eado6827.

Biyada, S., & Urbonavičius, J. (2025). Circularity in textile waste: challenges and pathways to sustainability. *Cleaner Engineering and Technology*, 100905.

Bonifazi, G., Gasbarrone, R., Palmieri, R., & Serranti, S. (2024). A characterization approach for end-of-life textile recovery based on short-wave infrared spectroscopy. *Waste and Biomass Valorization, 15*(3), 1725-1738. https://doi.org/10.1007/s12649-023-02413-z

Casciani, D., & Chen, M. (2023, November). Conveying Natural Dyes in the Fashion Industry Through a Design-Driven Innovation. In *Global Fashion Conference* (pp. 46-64). Cham: Springer Nature Switzerland.

Cura, K., Rintala, N., Kamppuri, T., Saarimäki, E., & Heikkilä, P. (2021). Textile recognition and sorting for recycling at an automated line using near infrared spectroscopy. *Recycling,* 6(1), 11. https://doi.org/10.3390/recycling6010011

Fiorilli, E. (2023). *Sustainable textile processing: an in-depth analysis of environmental and workers well-being in the fashion industry.* [Master thesis, Polytechnic University of Milan]. https://hdl.handle.net/10589/222538

Furferi, R., & Servi, M. (2023). A Machine Vision-Based Algorithm for Color Classification of Recycled Wool Fabrics. *Applied Sciences, 13*(4), 2464.

Gligoric, N., Krco, S., Hakola, L., Vehmas, K., De, S., Moessner, K., ... & Van Kranenburg, R. (2019). Smarttags: IoT product passport for circular economy based on printed sensors and unique item-level identifiers. *Sensors, 19*(3), 586.

Hassabo, A. G., Elmorsy, H. M., Gamal, N., Sediek, A., Saad, F., Hegazy, B. M., & Othman, H. (2023). Evaluation of various printing techniques for cotton fabrics. *Journal of Textiles, Coloration and Polymer Science, 20*(2), 243-253.

Hayta, P., Oktav, M., & Ateş Duru, Ö. (2022). An ecological approach to printing industry: Development of ecofriendly offset printing inks using vegetable oils and pine resin as renewable raw materials and evaluation of printability. *Color Research & Application, 47*(1), 164-171.

He, Y., Cao, Y., Hwang, H. J., Gutierrez, S. M. V., Li, S., Chen, H. L., ... & Malhotra, R. (2021). Inkjet printing and in-situ crystallization of biopigments for eco-friendly and energy-efficient fabric coloration. *International Journal of Precision Engineering and Manufacturing-Green Technology*, 1-13.

Huang, X., Tan, Y., Huang, J., Zhu, G., Yin, R., Tao, X., & Tian, X. (2024). Industrialization of open- and closed-loop waste textile recycling towards sustainability: A review. *Journal of Cleaner Production,* 436, 140676. https://doi.org/10.1016/j.jclepro.2024.140676

Ingle, N., & Jasper, W. J. (2024). A review of deep learning and artificial intelligence in dyeing, printing and finishing. Textile Research Journal, 00405175241268619.

Juanga-Labayen, J. P., Labayen, I. V., & Yuan, Q. (2022). A review on textile recycling practices and challenges. *Textiles, 2*(1), 174-188.

Kamble, Z., & Behera, B. K. (2021). Upcycling textile wastes: challenges and innovations. *Textile Progress, 53*(2), 65-122.

Li, Q., Xue, Z., Wu, Y., & Zeng, X. (2022). The status quo and prospect of sustainable development of smart clothing. *Sustainability, 14*(2), 990.

Li, W., Wei, Z., Liu, Z., Du, Y., Zheng, J., Wang, H., Zhang, S. (2021). Qualitative identification of waste textiles based on near-infrared spectroscopy and the back propagation artificial neural network. *Textile Research Journal, 91*(21–22), 2459-2467. https://doi.org/10.1177/00405175211007516

Luo, Y., Song, K., Ding, X., & Wu, X. (2021). Environmental sustainability of textiles and apparel: A review of evaluation methods. *Environmental Impact Assessment Review, 86*, 106497.

Manivannan, C., Panneerselvan, L., Nachimuthu, G., Conaty, M., & Palanisami, T. (2025). Eco-innovative approaches for recycling non-polyester/cotton blended textiles. *Waste Management Bulletin, 3*(1), 255-270. https://doi.org/10.1016/j.wmb.2025.02.001

Moazzem, S., Crossin, E., Daver, F., & Wang, L. (2021). Assessing environmental impact reduction opportunities through life cycle assessment of apparel products. *Sustainable Production and Consumption, 28*, 663-674. https://doi.org/10.1016/j.spc.2021.06.015

Okoye, K., & Hosseini, S. (2024). Analysis of variance (ANOVA) in R: one-way and two-way ANOVA. In *R Programming: Statistical Data Analysis in Research* (pp. 187-209). Singapore: Springer Nature Singapore.

Pittala, C., & Ganesh, K. (2022). IoT-aware waste management system based on cloud services and ultra-low-power RFID sensor-tags. In *Innovations in Signal Processing and Embedded Systems: Proceedings of ICISPES 2021* (pp. 391-401). Singapore: Springer Nature Singapore.

Rahaman, M. T., Pranta, A. D., Repon, M. R., Ahmed, M. S., & Islam, T. (2024). Green production and consumption of textiles and apparel: Importance, fabrication, challenges and future prospects. *Journal of Open Innovation: Technology, Market, and Complexity*, 100280.

Rouder, J. N., Schnuerch, M., Haaf, J. M., & Morey, R. D. (2023). Principles of model specification in ANOVA designs. *Computational Brain & Behavior, 6*(1), 50-63.

Tian, R., Lv, Z., Fan, Y., Wang, T., Sun, M., & Xu, Z. (2024). Qualitative classification of waste garments for textile recycling based on machine vision and attention mechanisms. *Waste Management,* 183, 74-86.

Zhang, L., Leung, M. Y., Boriskina, S., & Tao, X. (2023). Advancing life cycle sustainability of textiles through technological innovations. *Nature Sustainability, 6*(3), 243-253.

Zhou, Q., Le, Q. V., Meng, L., Yang, H., Gu, H., Yang, Y., ... & Peng, W. (2022). Environmental perspectives of textile waste, environmental pollution and recycling. *Environmental Technology Reviews, 11*(1), 62-71.