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Sustainable Practices in Denim Fabric Production: A Comparative Analysis of Environmental Impact.

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Abstract

The environmental effect of producing denim fabric using sustainable methods is the focus of this study. The research examined the denim industry's current sustainability practises and suggests ways in which they might be improved. It also explored the environmental impacts of desizing procedures and offers greener options to address these issues. The results showed that the denim sector is becoming more conscious of sustainability challenges and is taking steps to lessen its negative effect on the environment. However, more teamwork and development are required. Desizing techniques were discussed, along with their negative effects on the environment, and environmentally friendly alternatives such enzymatic desizing and technology were proposed. The denim manufacturing process made more environmentally friendly by adopting these methods.

1.0 Introduction

1.1 Background

The constant rise in demand for the exploitation of sustainable denim is directly attributable to the exponential growth in information on the health and environmental risks associated with traditional denim processing. The environmental damage these businesses produce is significant; hence research is needed to identify potential solutions. Considering the challenges the denim industry is now experiencing in its search for alternatives to standard production practices, this analysis explores several sustainable methods of denim production (Periyasamy and Periyasami, 2023). Recent developments in eco-friendly denim dyeing processes have been studied at length. Denim indigo-foam-dyed using various techniques, including digital spray, microbially aided dying, and traditional indigo dyeing. This paper also discusses the numerous eco-friendly denim garment finishing processes, including ozone fading, e-flow, enzyme-based bleaching, water, laser fading, and so on. Finally, the potential impact of denim finishing techniques on microplastics and microfibers discharged from the garment during home washing is discussed (Álvarez *et al.* 2018). This analysis aims to shed light on the significance of eco-responsible solutions for enhanced environmental sustainability within the context of conventional denim processing, which can be rethought, reevaluated, renewed, and restructured as presented here.

1.2 Research aim

The research aim is to examine the relative effectiveness of several eco-friendly methods used in the manufacturing of denim.

1.3 Research objectives

- To analyse the sustainability practices within the denim supply chain and identify areas for improvement.
- To investigate the environmental concerns associated with desizing processes in denim production and propose eco-friendly alternatives.

1.4 Research question

- What sustainability practices are implemented within the denim supply chain, from raw material sourcing to retail?
- What are the specific environmental concerns related to several processes in denim production?

1.5 Problem statement

Denim is a product of the textile industry, one of several that have flourished since the Industrial Revolution. In order to get the right finish and get rid of any unwanted impurities or dyes, the denim industry uses a variety of chemical treatments. Greenhouse gases (GHG) were released throughout the colouring process, and large amounts of water and energy were used (Periyasamy and Militky, 2020). In the denim industry alone, azo dyes account for about half of the 600,000 tonnes of dyes generated annually and are utilised in the textile industry worldwide (Periyasamy and Periyasami, 2023). The denim industry has a major impact on the likelihood that the United Nations' sustainable development goals (SDG) will be met by 2030 (Periyasamy and Periyasami, 2023). The denim industry's massive outflow of polluted water, including harmful compounds, dyes, and other additives, has an effect on SDG6, as was previously mentioned. Denim production is a major contributor to greenhouse gas emissions and, hence, to the climate change highlighted in SDG13. Goal 14 of the Sustainable Development

Agenda, addresses the release of microfibers and microplastics into the ocean through domestic laundering (Álvarez *et al.* 2018). Cotton growing also has a major global influence on soil quality and highlights SDG15 (Periyasamy and Periyasami, 2023).

Because a broad variety of individuals can wear it, and it is appropriate for all seasons and events, denim has quickly become a fashion staple. Coarser cotton strands woven into a twill pattern are used to make denim (Sankarraj and Nallathambi, 2018). The denim jeans industry is projected to be worth around $87.4 billion by 2027, up from $63.5 billion in 2020 (Periyasamy and Periyasami, 2023). The rapidly growing e-commerce industry throughout the globe (point 6) boosts the demand for denim and other fabrics. The United States has the world's greatest per capita usage of denim and is the biggest market for denim worldwide. Apart from that, what drives the demand for denim is the increase in disposable money, the growing importance of fashion, and the trend towards more casual dress in the workplace.

1.6 Significance

Significant contributions to environmentally responsible denim fabric manufacture are found in this study. There is a pressing need to investigate and adopt eco-friendly alternatives to standard denim processing in light of growing awareness of the damage done to the environment by this method. This examines the whole scope of eco-friendly denim production practises, from dyeing procedures to garment finishing methods. The paper sheds light on the potential for these sustainable practices to reduce environmental harm by contrasting them with conventional approaches. In order to promote environmentally sustainable practices and solve the issues encountered by the denim sector, the results and suggestions offered in this paper might be a significant resource for denim producers, policymakers, and stakeholders.

2.0 Literature review

2.1 Denim Supply chain

Warps in the 100-30 Tex range are often utilised in denim production because they are coarser than the weft. Indigo colours were applied to the warp but not the weft. The process of making denim is shown in Figure 1 (Periyasamy and Periyasami, 2023). However, denim's basic materials come from either natural or synthetic sources. Therefore, the first step of classification must be applied in order to grow or manufacture the fibres.

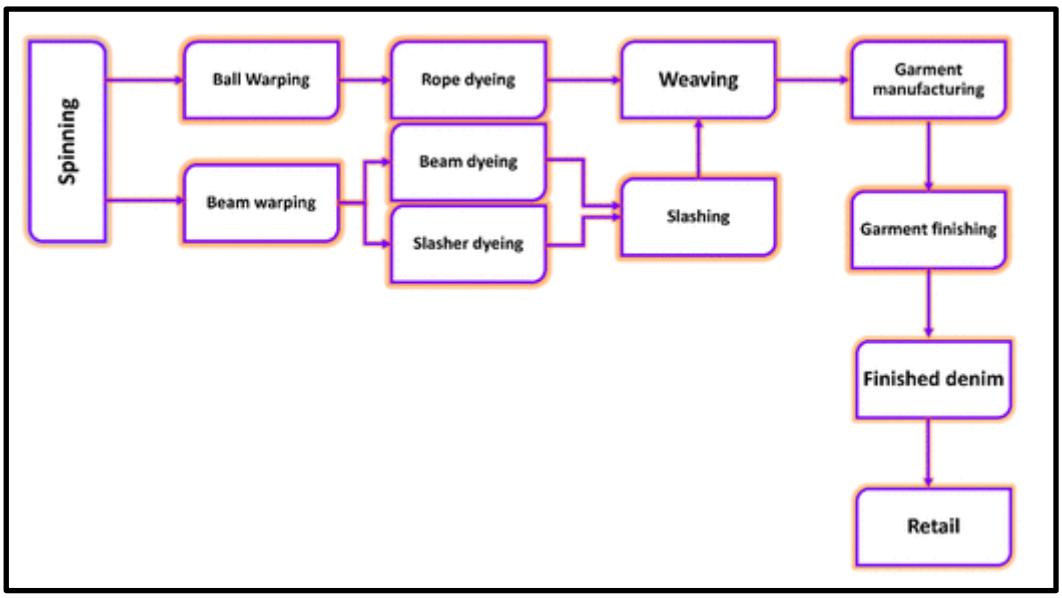


Figure 1. Denim production steps from starting with raw materials to the completed product.

(Source: Periyasamy and Periyasami, 2023)

The cotton fibres in a bale are opened and cleaned using a blow room and carding as the first stage in the spinning process (Sankarraj and Nallathambi, 2018). Yarns were then made using either a ring or open-end spinning technique, after which the fibres were carded and drawn into slivers. Fabric is made by warping threads that have been spun. Because of the stress placed on them during weaving, warp sheets benefit from being sized to enhance their durability. Since many chemicals are utilised in the sizing process at concentrations between 12% and 15%, the pollutant load is rising (Periyasamy and Periyasami, 2023).

2.2 Colaboration of denim

The use of indigo as a principal colourant in the dying process is commonplace in the creation of blue denim (Venkatraman and Liauw, 2019). Despite indigo's reputation for having low-quality vat dyes, it finds widespread use in the denim industry due to the authentic vintage look it imparts to denim. Indigo dyeing entails an oxidation-reduction process, as seen in Figure S1. The denim industry uses 50,000 metric tonnes of synthetic indigo even though indigo is naturally water-insoluble and must be transformed into a soluble state using alkali and a reducing agent before it can be applied to denim warps (Periyasamy and Periyasami, 2023). Therefore, denim dyeing annually requires 84,580 metric tonnes of sodium hydrosulfite and 53.580 metric tonnes of caustic soda (Periyasamy and Periyasami, 2023). Because it is seldom possible to completely cure all dyes, some of them end up in water streams where they are harmful to wildlife and the environment (in addition to being toxic, carcinogenic, or mutagenic).

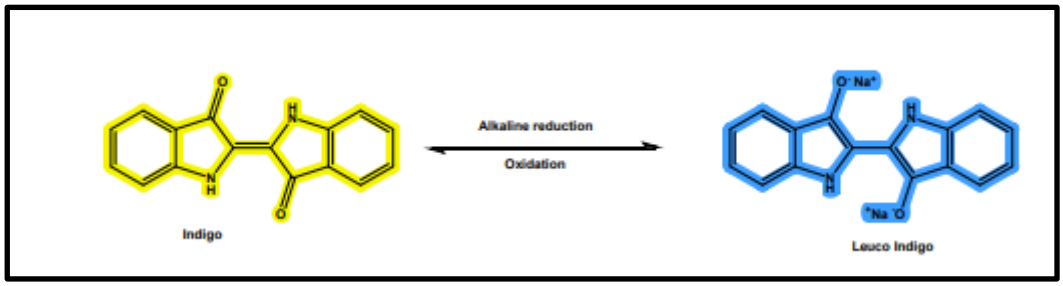


Figure S1. The oxidation-reduction reaction of indigo.

(Source: Periyasamy and Periyasami, 2023)

2.3 Desizing

Denim textiles often undergo deciding to get rid of sticky particles (Panda *et al.* 2023). This is accomplished using a wide variety of compounds, including detergents, Na2CO3, enzymes, and oxidative substances. Enzyme-based despising is widely employed in the industry since all other procedures lead to fabric degradation.

2.4 Sustainability of Denim

The production of one kilogramme of denim generates wastewater volumes of 40–65 litres. Greenpeace International estimates that the textile industry is the source of 20% of global water pollution (Periyasamy and Periyasami, 2023). The world's most populous nations—including China, India, and Bangladesh—are particularly hard hit by this issue (Scott, 2015). The denim industry's wastewaters need treatment before they can be discharged into the aquatic environment. Figure 2 depicts how wastewater from denim factories has contaminated the Noyal River in Tirupur, India, as well as the agricultural land in the region (Scott, 2015). Figure 2a depicts

the discharge of dyed wastewater from a denim factory, which subsequently contaminates the streams in Figure 2b and the river in Figures 2c and 2d. Photos show how it is influencing farming activities (Figure 2e), especially groundwater (Figures 2g and 2h).

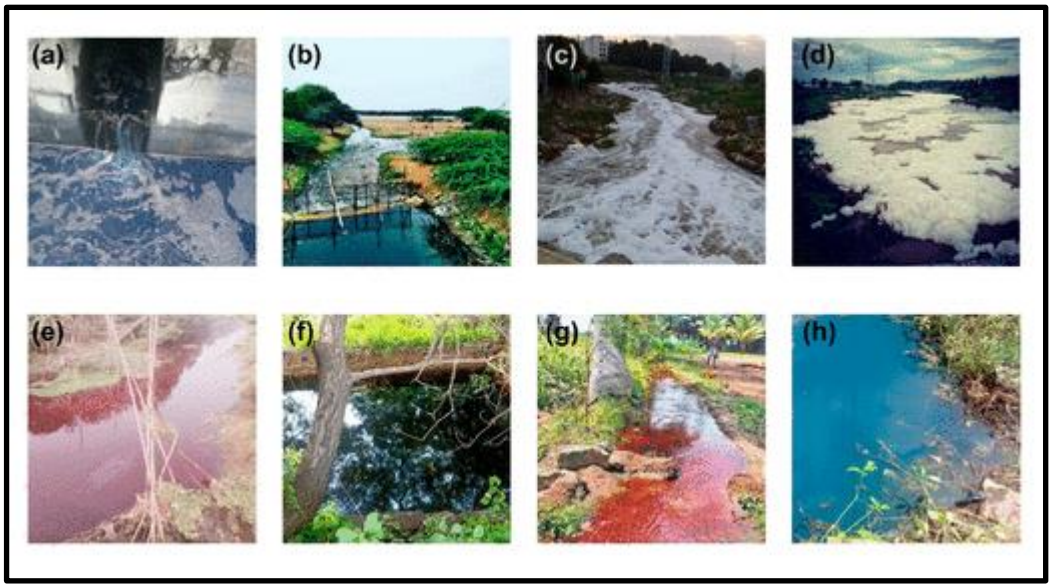


Figure 2. Denim effluent from industry (a) and in the water streams (b) that flow in the Noyal River (c–e), and the influence of these effluents on the agricultural land (f–h).

(Source: Periyasamy and Periyasami, 2023)

Every step of manufacturing involves the use of toxic chemicals, and as a consequence, a steady stream of potentially dangerous effluent is discharged into the environment. The principal polluters are the dyes, auxiliaries, and other chemicals used in the dyeing process (Saikhao *et al.* 2018). The heavy metals lead (Pb), copper (Cu), cadmium (Cd), chromium (Cr), and nickel (Ni) found in the dyes are known to be toxic and affect multiple organs, including the kidneys, the nervous system, the skin, the blood vessels, the immune system, and the foetus and the mother (Periyasamy and Militky, 2017). Denim production results in effluents with the characteristics shown in Figure 3, including elevated levels of chlorides, sulphates, and phenols; turbidity; total dissolved solids (TDS); suspended solids (SS); total dissolved solids (TDS); and dissolved oxygen (DO).

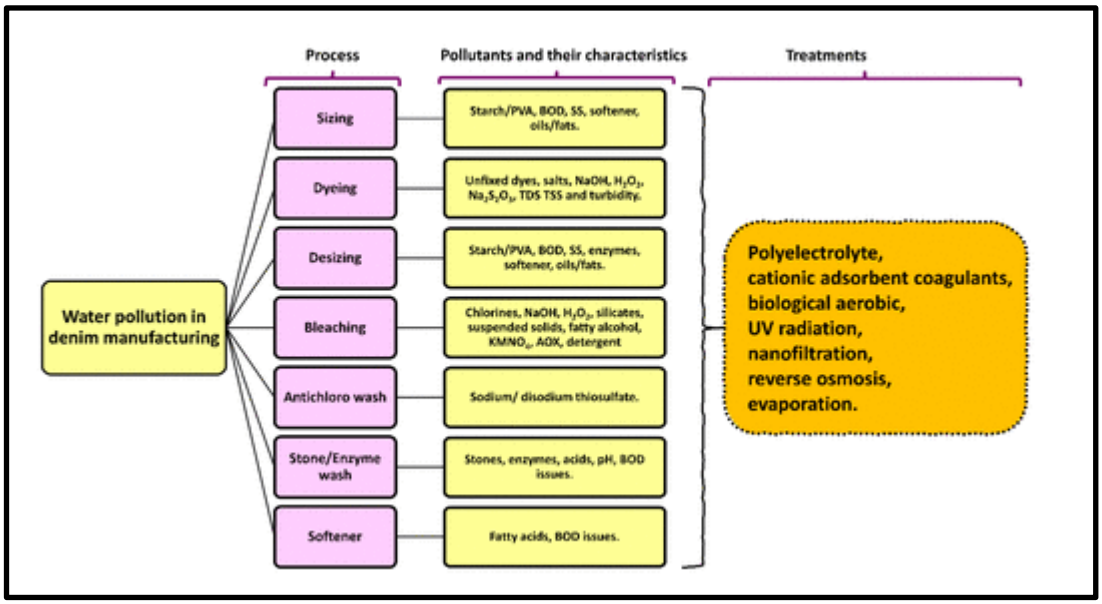


Figure 3. Water pollution during denim processing stages.

(Source: Periyasamy and Periyasami, 2023)

The agricultural sector and industrial usage are particularly vulnerable to the effects of these effluents, which in turn have a ripple effect on people's daily lives. Toxic elements from the dyeing process, such as salts, ionic metals, surfactants, and their complexes, toxic organic chemicals, formaldehyde, biocides, emulsifiers, detergents, and dispersants, are released into the environment when clothes are washed at home (Saikhao *et al.* 2018).

2.5 Raw Materials and Environmental Concerns

Cotton, which comes from cotton plants, is one of the most valuable natural fibres. The Cotton Incorporation report estimates that denim accounts for around 12% of all cotton used (Periyasamy and Periyasami, 2023). Cotton is very soft and comfortable on the skin and wicks away moisture quite well. Cotton is a fast-decomposing fibre that is convenient for landfills but also pollutes the soil and water when too much fertiliser and pesticides are used (Sankarraj and Nallathambi, 2018). To lessen its environmental impact, organic cotton is grown using less water and fewer fertilisers and pesticides.

Lyocell is a sustainable fibre made by dissolving wood pulp in amine oxide, a non-toxic solvent. Producing it doesn't need chemical fertilisers or insecticides since it comes from well-managed forests (Jabbar *et al.* 2020). Due to its superior wet strength and lustre, lyocell has the potential to replace cotton in the denim industry. Polyester is a more affordable alternative to natural fibres; therefore, it has replaced cotton in many fabrics, including denim (Sankarraj and Nallathambi, 2018). In addition, it has many of the same qualities as natural fibres, with the exception of absorbency. To produce polyester fibres/films and resins, almost 70 million barrels of crude oil are used annually (Periyasamy and Periyasami, 2023). Polyester is not biodegradable, and so stays in the ecosystem for a very long time, which has serious consequences for the environment. The majority of microplastics in water come from polyester clothing, especially denim.

2.6 Theory

The Sustainable Development theory is suitable for analysing the research topic of sustainable practices in denim fabric production. The idea behind this notion is that it must provide for the demands of the present without jeopardising the capacity of future generations to do the same. The Theory of Sustainable Development encourages the adoption of policies and procedures that lessen the rate of resource depletion, cut down on pollution, and advance ecological balance in the denim manufacturing process (Shi *et al.* 2019). This concept is applied to the creation of denim fabric by using environmentally responsible methods, including growing organic cotton, reusing water, and using low-impact dyes. Sustainable resource management and environmental conservation are the goals of these methods, which try to reduce water use, energy output, and the discharge of toxic substances (Suárez-Eiroa *et al.* 2019). In addition, the Theory of Sustainable Development stresses the significance of economic and social sustainability. Fair salaries, safe working conditions, and an emphasis on social responsibility in the workplace are all crucial components of a sustainable denim manufacturing process (Sankarraj and Nallathambi, 2018).

3.0 Methodology

3.1 Philosophy

Interpretivism

Interpretivism is a philosophical approach which emphasises the objectives of interpretation of social phenomena and also the importance of context (Van Leeuwen and Janssen, 2019). The researcher used interpretivism research philosophy in this research. The interpretivist method was appropriate for this study because it allowed the researcher to gain insight into the dynamics and decision-making processes of the denim fabric industry by interpreting and comprehending the social and contextual factors that affect the adoption and effectiveness of sustainable practices in denim fabric production.

3.2 Design

Explanatory

Explanatory research design identifies causation and elaborates on a phenomenon (Sileyew, 2019). The researcher used an explanatory research design in this research. The explanatory research design was appropriate for this study because it facilitates the recognition of causal relationships and provides a more in-depth understanding of the occurrence of sustainable practices in the manufacturing of denim fabric, thereby revealing the factors that contribute to their efficacy or limitations.

3.3 Approaches

Deductive

Research using the deductive method involves formulating a broad theory or hypothesis, testing using targeted experiments and gathering evidence (Mainde *et al.* 2021). The researcher used deductive research in this research. The deductive method was appropriate for the study since it enabled one to theorise about the effects of eco-friendly manufacturing processes on denim. This allowed for the systematic collection and analysis of data to verify and evaluate these assumptions, which helped the researcher learn more about their success in mitigating environmental problems.

3.4 Data collection

Information or data is collected with the help of a systematic procedure called data collection to answer research questions or achieve research goals (Van Leeuwen and Janssen, 2019). The researcher used secondary data collection in this research. Secondary data were drawn and analysed insights from data already gathered by other organisations or academics, such as publications, scholarly studies, or accessible databases (Newman *et al.* 2020). Additionally, the researcher employed thematic data analysis to examine information from various sources.

4.0 Data analysing and Findings

The worldwide market for synthetic indigo dyes is forecast to grow significantly, reaching a value of $1,639,000,000 by 2028 (Periyasamy and Periyasami, 2023). Synthetic indigo is predicted to outpace natural indigo in the future due to its propensity to induce high-contrast fading on jeans. Consequently, there is a much higher need for indigo chemical production, which is a serious environmental problem (Venkatraman and Liauw, 2019). Because aniline is generated from benzene, another chemical often regarded as harmful, it was employed as a feedstock in the production of indigo. Formaldehyde, hydrogen cyanide, sodamide, and alkalis were also used in the synthesis.

The biosynthesis of indigo is one method being explored as the demand for eco-friendly practices grows. Bioindigo has acquired popularity due to its biodegradability and low toxicity, both of which might have positive effects on the environment if more people use it (Periyasamy and Periyasami, 2023). Natural colours are restricted in variety when compared to synthetic ones made from microorganisms or plants. They are more costly because they need a lot of water and land to grow, and they must be harvested. In addition to their colour, these compounds also possess useful qualities such as antibacterial action against a wide range of diseases, anticancer activity, antioxidative activity, and resistance to UV light (Sajjad *et al.* 2020). These pigments are used as functional dyes for denim and other textile fabrics (Figure 4) due to their broad range of possible uses and desirable aesthetic and functional features.

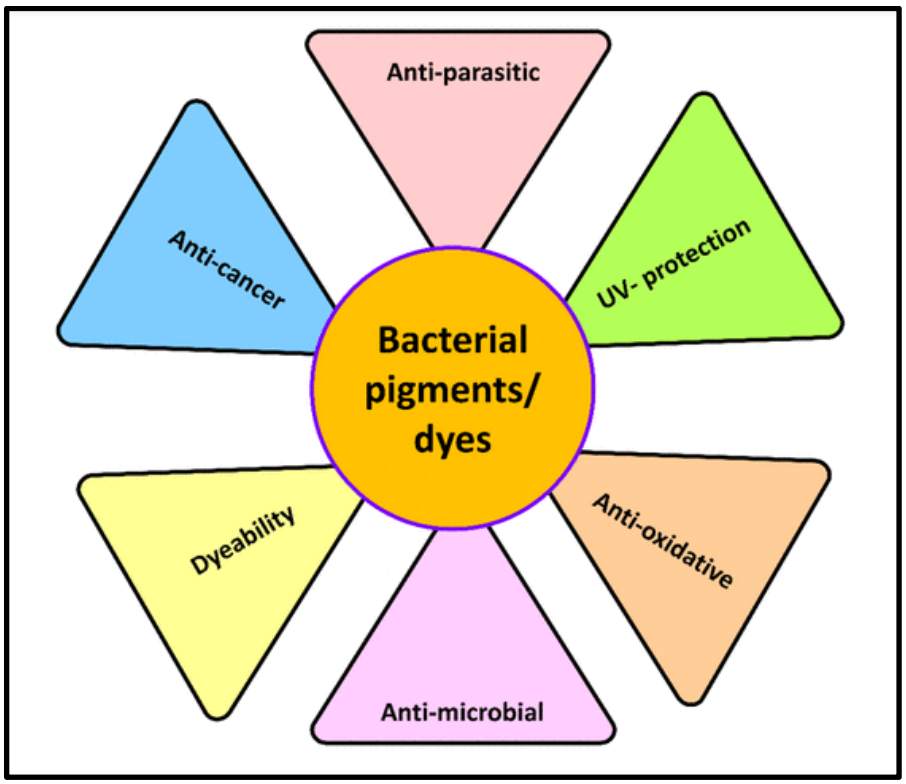


Figure 4. Multifunctional properties of bacterial pigments.

(Source: Periyasamy and Periyasami, 2023)

Bacteria have been identified to have a plethora of indigo-producing enzymes in recent decades. All of these enzymes rely on oxygen to complete the indole conversion pathway. The medium might be supplemented with tryptophan or indole to boost indigo production. Indigo is synthesised using a variety of enzyme pathways, as shown in (Figures 5a and 5b), which illustrate natural and microbial synthesis, respectively (Periyasamy and Periyasami, 2023).

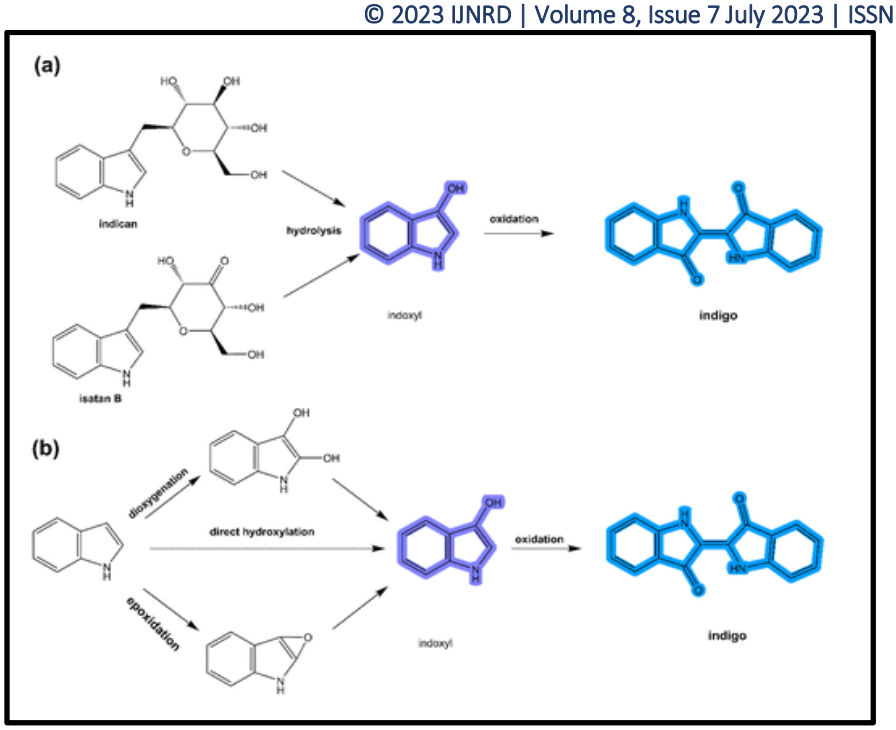


Figure 5. Natural (a) and microbial (b) synthesis of indigo.

(Source: Periyasamy and Periyasami, 2023)

Bacterial tryptophan is extracted for use in the manufacture of bio indigo (Figure 6). The ring structure necessary to create indigo molecules is already present in tryptophan. When compared to manufacturing techniques based on synthetic chemistry, this biological procedure is quick and easy to carry out. Concentrated fermentation broth containing 3.2 g/L indican was used to colour the cotton clothes and oxidised in the air (Sankarraj and Nallathambi, 2018). Dye penetration and adsorption on the fibre were also investigated using synthetic indigo (i.e. unreduced indigo) at an equimolar ratio, with the same results (Venkatraman and Liauw, 2019). Therefore, indican has superior colouring qualities and shows complete environmental friendliness from synthesis to its use in cotton textiles.

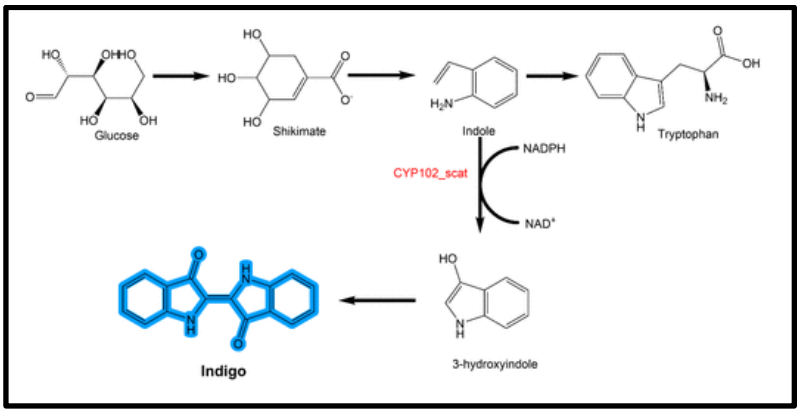


Figure 6. Biosynthesis of indigo from *E. coli* cells.

(Source: Periyasamy and Periyasami, 2023)

Alternative methods of colouring have emerged as of late, such as alkali/salt-free reactive dyeing on cotton (Saikhao *et al.* 2018). The alternatives to hazardous materials are listed in Table 1. Natural indigo's stability, who discovered that the leuco form of indigo stabilised on a nanocellulose matrix carrier without the need for chemical agents, making the dye safer for the environment when applied to cellulosic materials (Venkatraman and Liauw, 2019).

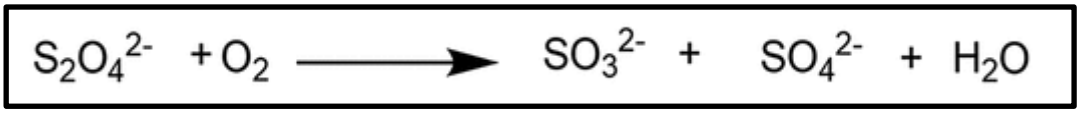
dyes	traditional	alternatives
sulfur dyes	Na_2SO_3	$C_6H_{12}O_6$, $HSCH_2CH_2OH$
vat dyes	$Na_2S_2O_4$, NaOH	electrochemical method
vat and sulfur dyes	$K_2Cr_2O_7$	H_2O_2, $[Na^+]_2{\cdot}[B_2O_4(OH)_4]^{2-}$
sulfur, vat dyes		solubilized dyes
hydrotropic agents	CH_4N_2O	$NaN(CN)_2$
neutralizing agents	CH_3COOH	HCOOH

Table 1. Environmentally Friendly Alternative Chemicals for the Denim Dyeing Process

Sustainable Dyeing of Denim

(Source: Periyasamy and Periyasami, 2023)

A wide variety of substances and techniques have been employed in the indigo reduction process (Mohan and Shukla, 2022). Sodium dithionite (i.e., hydrosulfite: Na2S2O4) is the most often used reducing agent because of its effective reducing power, ability to reduce indigo at room temperature, shorter time, availability, convenience of handling, and inexpensive cost (Venkatraman and Liauw, 2019). Since sodium hydrosulfite (Na2S2O4) affects aerobic processes and has the potential to anaerobically create toxic hydrogen sulphide (SO32-) from the sulphate (SO42-) that is present in the dye wastewater, and it was used in greater quantities for the reduction of synthetic indigo; the formation of byproducts is depicted in Scheme 1 (Periyasamy and Periyasami, 2023).



Scheme 1. Byproduct Formation of Na2S2O4 during Indigo Dyeing

(Source: Periyasamy and Periyasami, 2023)

5.0 Conclusion

This paper has shown how crucial it is to use environmentally friendly methods when manufacturing denim. The research analysed the denim industry's sustainable practices and highlighted room for development. It also looked at the environmental impacts of denim desizing methods and suggested greener options. The examination of the denim supply chain showed that many stakeholders are becoming more conscious of sustainability concerns and putting in place procedures to lessen the industry's negative effects on the environment. Improvements might be made in raw material sources, production methods, and distribution. Improving sustainable practices requires teamwork from many participants throughout the supply chain. Clearly, traditional desizing operations, such as chemical waste and water contamination, contribute to environmental issues. Investigating greener options, such as enzymatic desizing and cutting-edge technology, has shown encouraging answers to these issues. If these solutions are implemented, denim manufacturing have less negative effects on the environment and become more sustainable.

References

Álvarez, G., Barros, Á. and Velando, A., 2018. The use of European shag pellets as indicators of microplastic fibers in the marine environment. *Marine pollution bulletin*, *137*, pp.444-448. DOI: 10.1016/j.marpolbul.2018.10.050

Jabbar, A., Tausif, M., Tahir, H.R., Basit, A., Bhatti, M.R.A. and Abbas, G., 2020. Polylactic acid/lyocell fibre as an eco-friendly alternative to polyethylene terephthalate/cotton fibre blended yarns and knitted fabrics. *The Journal of The Textile Institute*, *111*(1), pp.129-138.

Mainde, D., Chola, D.K. and Mpolomoka, D.L., 2021. Interrogating Civic Education Pedagogies that Stimulate Political Participation in Selected Secondary Schools in Zambia. *International Journal of Research and Innovation in Social Science (IJRISS)*, *5*(2), pp.269-279.

Mohan, D. and Shukla, S.P., 2022. Hazardous consequences of textile mill effluents on soil and their remediation approaches. *Cleaner Engineering and Technology*, *7*, p.100434.

Newman, M. and Gough, D., 2020. Systematic reviews in educational research: Methodology, perspectives and application. *Systematic reviews in educational research: Methodology, perspectives and application*, pp.3-22.

Panda, S.K.B.C., Sen, K. and Mukhopadhyay, S., 2023. Sustainable Photocatalytic Desizing Process for the Starch-Based Size. *ACS omega*.

Periyasamy, A.P. and Militky, J., 2017. Denim processing and health hazards. In *Sustainability in denim* (pp. 161-196). Woodhead Publishing.

Periyasamy, A.P. and Militky, J., 2020. Sustainability in textile dyeing: recent developments. *Sustainability in the textile and apparel industries: Production Process Sustainability*, pp.37-79.

Periyasamy, A.P. and Periyasami, S., 2023. Critical Review on Sustainability in Denim: A Step toward Sustainable Production and Consumption of Denim. *ACS omega*, *8*(5), pp.4472-4490.

Periyasamy, A.P. and Periyasami, S., 2023. Critical Review on Sustainability in Denim: A Step toward Sustainable Production and Consumption of Denim. *ACS omega*, *8*(5), pp.4472-4490.

Periyasamy, A.P., Rwahwire, S. and Zhao, Y., 2019. Environmental friendly textile processing. DOI: 10.1007/978-3-319-48281-1_176-1

Saikhao, L., Setthayanond, J., Karpkird, T., Bechtold, T. and Suwanruji, P., 2018. Green reducing agents for indigo dyeing on cotton fabrics. *Journal of Cleaner Production*, *197*, pp.106-113. DOI: 10.1016/j.jclepro.2018.06.199

Sajjad, W., Din, G., Rafiq, M., Iqbal, A., Khan, S., Zada, S., Ali, B. and Kang, S., 2020. Pigment production by cold-adapted bacteria and fungi: colorful tale of cryosphere with wide range applications. *Extremophiles*, *24*, pp.447-473.

Sankarraj, N. and Nallathambi, G., 2018. Enzymatic biopolishing of cotton fabric with free/immobilised cellulase. *Carbohydrate polymers*, *191*, pp.95-102. DOI: 10.1016/j.carbpol.2018.02.067

Scott, A., 2015. Cutting out textile pollution. *Chemical & Engineering News*, *93*(41), pp.18-19. DOI: 10.1021/cen-09341-bus1

Shi, L., Han, L., Yang, F. and Gao, L., 2019. The evolution of sustainable development theory: Types, goals, and research prospects. *Sustainability*, *11*(24), p.7158.

Sileyew, K.J., 2019. *Research design and methodology* (pp. 1-12). Rijeka: IntechOpen.

Suárez-Eiroa, B., Fernández, E., Méndez-Martínez, G. and Soto-Oñate, D., 2019. Operational principles of circular economy for sustainable development: Linking theory and practice. *Journal of cleaner production*, *214*, pp.952-961.

Van Leeuwen, A. and Janssen, J., 2019. A systematic review of teacher guidance during collaborative learning in primary and secondary education. *Educational Research Review*, *27*, pp.71-89.

Venkatraman, P.D. and Liauw, C.M., 2019. Use of a carbon dioxide laser for environmentally beneficial generation of distressed/faded effects on indigo dyed denim fabric: Evaluation of colour change, fibre morphology, degradation and textile properties. *Optics & Laser Technology*, *111*, pp.701-713.