

DEVELOPMENT OF DYED BANANA FIBRE SANDALS FROM AGRICULTURAL WASTE: A SUSTAINABLE FOOTWEAR INNOVATION

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Abstract

Synthetic materials are used in the making of shoes because of their durability, flexibility, low production cost and consistency in mass production. All of these benefits, however, come with their own drawbacks, such as their reliance on fossil-based resources and low biodegradability, necessitating a search for alternative sustainable footwear materials derived from renewable and waste sources. The goal of this study is to create an environmentally-friendly sandal prototype made of dyed banana fibre obtained from agricultural residues of banana pseudostem. The study proceeded in the following manner: the banana pseudostem fibres were handpicked, cleaned, dried, dyed and made into fibre yarn and the yarn was woven as a 2/2 twill fabric structure and used for the upper of the sandal. Fabric (woven banana fibre) was cut as per sandal upper pattern and then stitched and adhesive bonded with sole to make the sandal product. The fabric might be treated as an upper material during the assembly process and still be in the 2/2 twill weave. The sandal was light and presented a visible natural fibre surface after completed, which means that the banana pseudostem waste can be transformed to the upper of a sandal at the prototype stage. It is hoped that this study would give preliminary evidence for the development of handmade eco-friendly sandals using dyed banana fibre. But prototype assessment was only qualitatively done. Further experimental work is required to evaluate the material under practical footwear conditions, such as tensile, tear, abrasion, water, colour fastness, sole adhesion and in use durability. Cost analysis and consumer acceptance should also be reviewed prior to the consideration of using dyed banana fibre for wider footwear production.

1. Introduction

In recent years, the environmental impacts of synthetic materials have been a concern, prompting researchers and manufacturers to seek out renewable, biodegradable, and locally available alternatives to be used in product development. The use of synthetic rubber, polyurethane, polyester, polyvinyl chloride, ethylene-vinyl acetate, and other petroleum-based products is still critical in producing footwear due to their high durability, flexibility, low costs, and ease of mass production. Despite the benefits, fossil resource use, energy-intensive processing, lack of biodegradability, and disposal of post-consumer waste are major environmental issues of traditional footwear materials (Cheah et al., 2013; Quantis, 2018; Bodoga et al., 2024). This has reinforced the importance of sustainable materials to sustain the development of environmentally friendly footwear and fashion products.

Agricultural residues are an ideal material platform for the creation of sustainable products, since they are abundant, renewable and underutilized. The banana industry produces significant by-products following harvest such as leaves, peels and pseudostems. In many banana-producing regions the residues are either burned or left in the field, or processed with minimal value addition. Mohapatra et al. (2010) indicated that the banana by-products can be utilized in fibre extraction, food processing, animal feed, bioenergy, and development of industrial materials. One of such residues is the banana pseudostem which is of particular interest as it contains natural fibres which can be extracted and used in various applications such as textiles, crafts and composite. The banana fibre has been described to be biodegradable, lightweight, flexible and renewable material which can be used in developing sustainable products (Shinoj et al., 2011; Kumar et al., 2016).

Previous studies have investigated the banana fibre and other natural fibres for various material applications. Orndorff (1927) reported on the use of banana fibre and later, physical, mechanical and functional properties of the fibre were mentioned. According to Shinoj et al. (2011) and Kumar et al. (2016) banana is beneficial with properties like satisfactory tensile strength, lightweight, moisture absorbing, flexible and biodegradable. In addition to this, broader research on natural fibres has revealed that they can be employed to replace synthetic fibres as reinforcements in composites as well as for fabric, packaging, handicrafts, and other products because they are naturally renewable and have relatively low environmental impact (Faruk et al., 2012; Thyavihalli Girijappa et al., 2019). Sathishkumar et al (2014) also reported that the use of appropriate processing methods for natural and hybrid fibre-reinforced composites can allow the achievement of enhanced functional performance, strength, thermal stability and damping characteristics.

The appearance and tactile characteristics of materials are also significant in consumer products like shoes, bags and fashion accessories. The dyeing process can be used to increase the visual quality of natural fibres, and weaving can be used to increase structure, dimensional stability, flexibility and usability. Woven fabrics are a particularly important choice for sandal uppers as they can offer both functionality and surface design. The diagonal pattern of the twill weave can offer flexibility, textured surfaces and increased durability over plain weave, depending on the type of yarns used and fabric construction (Regnsteiner, 1986; Kadolph, 2010). So, banana fibre dyed and woven can be a viable way of producing eco-friendly footwear with high aesthetic and functional appeal.

The literature covering the field of sustainable fashion has highlighted the need to improve the reduction of material waste, the use of renewable

resources, the extension of the value chain of a product as well as the substitution of non-biodegradable materials with alternatives that would be more environmentally friendly (Muthu et al., 2012; Fletcher, 2014; Quantis, 2018). In-situ, banana fibre offers a chance to link agricultural waste management with the development of sustainable products. The application of banana fibre in sandal uppers, as dyed woven fabric is very limited and applications like textiles, handicrafts, ropes, paper, packaging and composites have been studied (Mohapatra et al., 2010; Shinoj et al., 2011; Kumar et al., 2016). This shows a gap in the development of the functional footwear product using banana pseudostem waste as the raw material in the footwear industry that is both aesthetically pleasing and environmentally friendly.

The problem that is the basis of this study is as follows. The first is that traditional shoe manufacturing relies heavily on synthetic materials and non-biodegradable. Secondly, despite the potential as a source of renewable fibre, banana pseudostems are not used extensively enough. While banana fibre has been used in textile and composite applications, its utilization for development of dyed woven sandals has not been well explored. This gap can be addressed to facilitate Waste to value, Sustainable Product Design and Small Scale Footwear manufacturing with locally available natural fibre resources. Hence, the objective of the current research was to create environment friendly footwear in the form of sandals by using dyed banana fibre obtained from the agricultural waste and also to evaluate the practical suitability of this material as footwear. The particular aims were:

To extract, process and dye banana fibre from agricultural waste for sustainable footwear development.

2. To make the sandal uppers by dyeing the woven banana fibre in a suitable weaving and tailoring method.

3. To evaluate the pre-production feasibility of the dyed banana fibre sandals regarding appearance, flexibility, comfort, usability and waste to value product development.

2. Literature Review and Conceptual Background

2.1 Banana Agricultural Waste as a Fibre Resource

There are several agricultural residues generated after banana harvests such as pseudostems, peels, leaves, sheaths, pith and male buds. These by-products are often overlooked, but they do also have valuable compounds like cellulose, hemicellulose, lignin, pectin, dietary fibre, and minerals. These components enable banana residues to be utilized for value added products like fibre extraction, biodegradable materials, food processing, animal feed, composite and industrial products (Mohapatra et al., 2010; Faruk et al., 2012; Thyavihalli Girijappa et al., 2019). The banana pseudostem is directly related to this study since it contains long fibres which can be extracted, dried and processed to make yarns, woven materials, ropes, mats and crafts. Some earlier work has been done with banana fibre in traditional, textile and composite applications (Orndorff, 1927; Shinoj et al., 2011; Kumar et al., 2016). Hence, the possibility of using banana pseudostem waste for the production of fibre is a practical approach for developing sustainable materials and it contributes to the waste to value approach. In the current work, the pseudostem was used as a renewable fibre source to produce a woven sandal upper.

2.2 Banana Fibre in Sustainable Product Development

Banana fibre is a natural fibre that has a renewable source, low density, biodegradability, flexibility and acceptable mechanical

characteristics, and is considered a lignocellulosic natural fibre. Banana fibre has been revealed to have the tensile strength, moisture absorption capacity, and lightweight structure that renders it suitable for its application in textile and composite industries, according to studies (Shinoj et al., 2011; Kumar et al., 2016). Natural fibres in general have been investigated as used in place of the synthetic fibres due to the fact that they are renewable, relatively cheap, light in weight and environmentally friendly (Bledzki & Gassan, 1999; Faruk et al., 2012; Pickering et al., 2016). The earlier works on banana fibre were mainly concentrated on the use of banana fibre as composite, textile, packaging and handicraft products. Sathishkumar et al., (2014) noted that when processed properly, natural and hybrid fibre-based materials can enhance strength, thermal stability, damping behaviour and durability. The present research, on the other hand, is using banana fibre as an exposed, dyed and woven upper for sandals. This transfers its use from material to Sustainable footwear design.

2.3 Textile Structure and Twill Weave Considerations

The performance of a woven material is determined by the type of fibre, yarn preparation, weave pattern, fabric density and finishing method. Weave construction influences flexibility, strength, surface appearance, dimensional stability, drape and wear characteristics. Twill weave is a more flexible type of weave than plain weave and can create a weave diagonal surface effect, depending on the quality of the fabric and weave construction, and can be more flexible, textured and durable than plain weave (Regnsteiner, 1986; Kadolph, 2010). Sandal uppers require the material to be comfortable and give them structure. Therefore a 2/2 twill weave was chosen for this study so as to provide a balance between stability, flexibility

and appearance. This structure facilitated the transformation of the dyed banana fibre into a woven fabric that was able to be cut, moulded and glued to the sandal sole.

2.4 Sustainable Footwear and Conceptual Basis of the Study

Synthetic and petroleum-based technology still plays a significant role in the manufacture of footwear due to their durability, flexibility, low cost and suitability for mass production. But these advantages come with environmental issues related to fossil-resource dependency, energy-intensive processing, poor biodegradability and an accumulation of post-consumer waste (Cheah et al., 2013; Quantis, 2018; Bodoga et al., 2024). Studies in sustainable fashion and product design have since motivated the utilization of renewable materials, waste minimisation, biodegradable options, and the consideration of circular design strategies (Muthu et al., 2012; Fletcher, 2014; Quantis, 2018).

The study's conceptual model is an Input-Process-Output model as illustrated in Figure 1. The input stage comprises of banana pseudostem waste, textile dyes, sandal soles, adhesive, and weaving or crafting or stitching tools. The process stage involves fibre extraction, fibre cleaning, fibre drying, fibre dyeing, yarn preparation, 2/2 twill weaving, cutting, shaping, attaching to the sandal sole, finishing and simple quality checking. The product at the output stage is the prototype of dyed banana fibre sandal which includes the sustainability related outcomes like agricultural waste utilization, value added product generation and waste to value conversion. Banana fibre has been explored in the fields of textiles, composites, ropes, paper, packaging and handicrafts, but the use of banana fibre as an dyed woven material for sandal uppers is still limited (Mohapatra et al., 2010; Shinoj et al., 2011; Kumar et al., 2016).

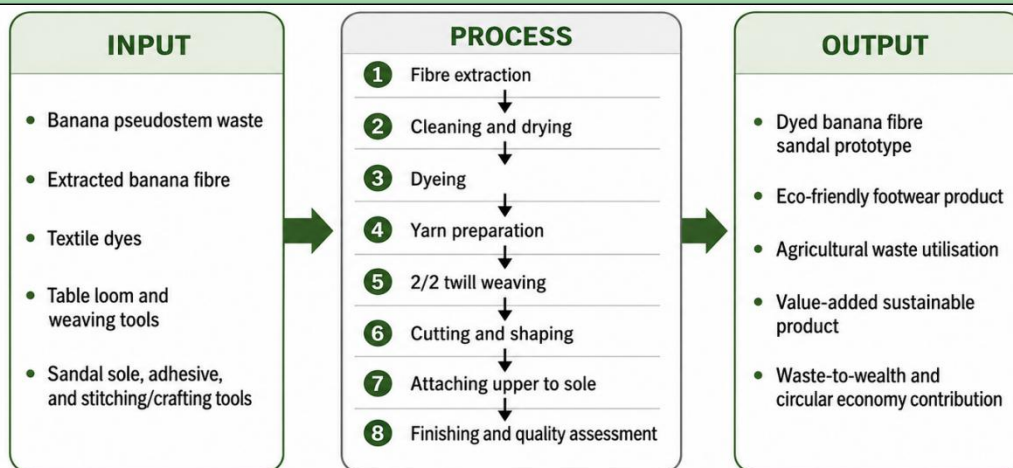


Figure 1. Input-Process-Output Conceptual Framework for Dyed Banana Fibre Sandal Development.

3. Materials and Methods

Feasibility of using dyed banana fibre as a sustainable material for sandal making was studied using prototype based product development approach. The work was practical and sequential in material collection and fabrication which involved the collection of

banana pseudostem, manual extraction of fibres, cleaning, drying, dyeing, yarn preparation, weaving, pattern cutting, attachment of woven upper to the sole, finishing and qualitative assessment of the prototype. The entire process is illustrated in Figure 2.

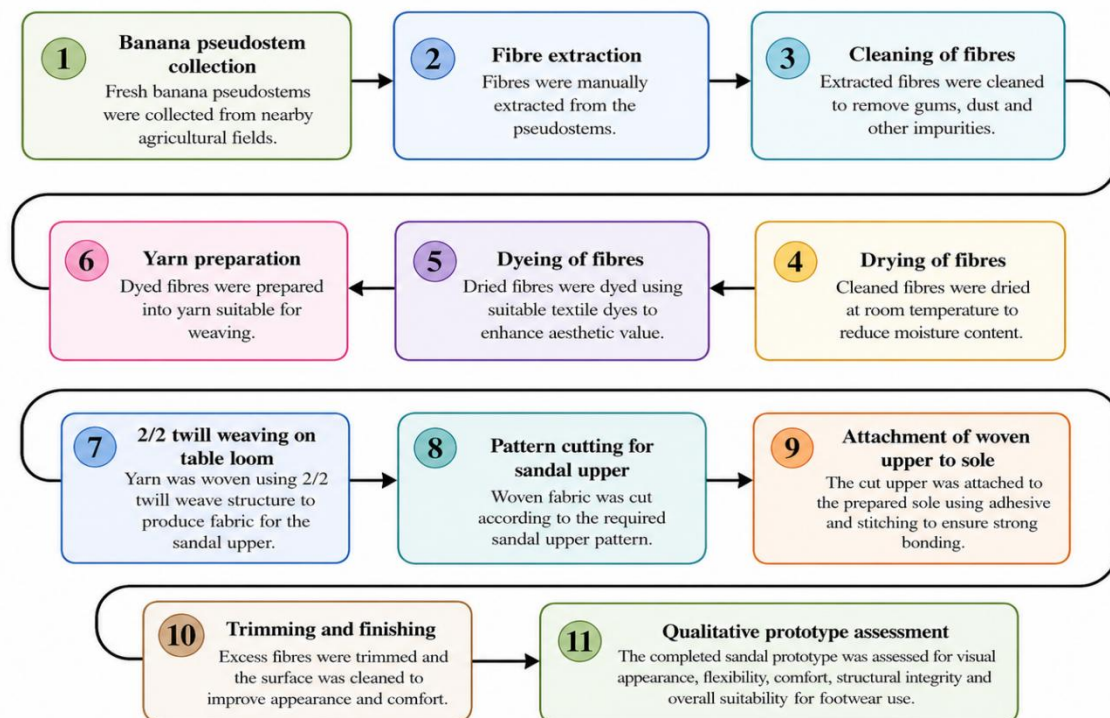


Figure 2. Prototype development workflow for dyed banana fibre sandals.

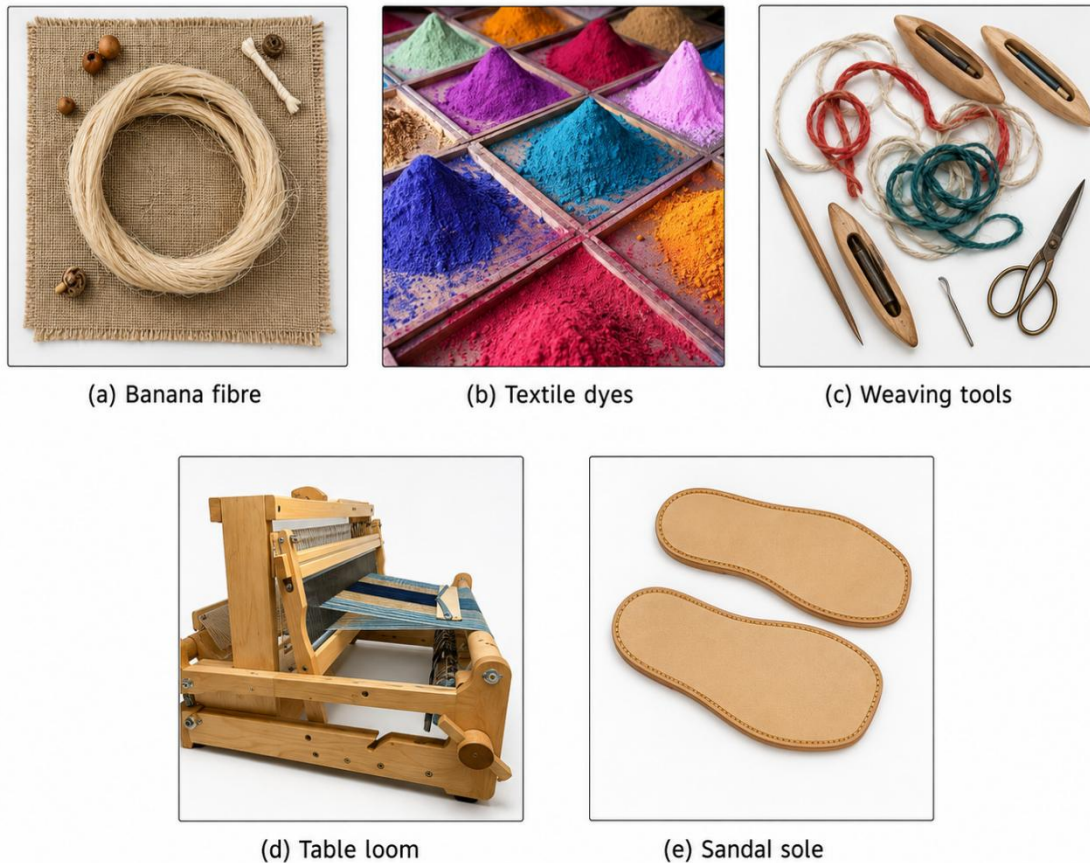
3.1 Materials and Equipment

The banana fibre was obtained from the fresh banana pseudostem and was the major raw material used in making the sandal upper. Support materials such as powdered textile dyes

for colouring, sandal soles to form the base of the sandal, adhesive, stitching or crafting materials and cotton/banana fibre yarn support was provided where necessary for weaving stability.

The prototype was made using the common textile and craft machines. The banana fibre fabric was woven with a table loom and various other implements including small craft tools, scissors, measuring tools, yarn support and

shuttle for yarn handling, and for preparing the fabric were used in the cutting and sandal assembly processes. Main materials and selected equipment used in the prototype developing process are presented in figure 3.



(a) Banana fibre

(b) Textile dyes

(c) Weaving tools

(d) Table loom

(e) Sandal sole

Figure 3. Materials and equipment used for developing dyed banana fibre sandals.

3.2 Prototype Development Process

The fresh banana stem was picked from the nearby agricultural field and processed for fibre extraction. Fibres were manually separated from the pseudostems, cleaned, and free of gums, dust and other impurities. The fibres were dried at room-temperature after cleaning prior to dyeing. The dried fibres were dyed with appropriate textile dyes to enhance their appearance for the use in footwear. The fibres were dried once more following the dyeing process and were then ready to be made into yarns for weaving. A 2/2 twill weave pattern was created on a table loom as it was important to have diagonal surface lines, flexibility, and durability, all of which are applicable to sandal uppers. The woven fabric

was then cut into the upper pattern that was needed and then glued and stitched onto the prepared sole. Excess fibres were cut off and surface was cleaned for appearance, comfort and finishing.

3.3 Prototype Assessment

The finished prototype sandals were evaluated qualitatively for aspect, flexibility, comfort, structural strength, finishing and overall usability. Given that study was exploratory, product feasibility was assessed only. At this stage there was no laboratory testing for mechanical strength, abrasion resistance, water resistance and colour fastness.

4. Results and Discussion

4.1 Development of the Dyed Banana Fibre Sandal Prototype

The prototype development process led to the process of making sandals from dyed banana fibre as the major woven material for the upper part of the sandals. The pseudo stem waste was used as banana fibre which was dyed, converted into yarn, woven into cloth, cut to the sandal upper shape and joined to the sole prepared by adhesive and stitching. This prototype was

successfully developed and showed that the banana pseudostem waste had the potential to be used for footwear material by using the basic fibre to product development process.

Figure 4 shows prototype views and illustrates the process of weaving banana fibre into the upper of a sandal and the close-up view of the woven surface in the upper part. The dyed banana fibre displayed a light weight and craft like look, indicating the feasibility of handmade and eco-friendly shoe application.



Figure 4. Prototype views of dyed banana fibre sandals developed from agricultural waste.

4.2 Woven Upper and Surface Characteristics

The upper of the dyed banana fibre was woven and the surface texture and the interlacement pattern could be seen. The fibre was then woven into an upper as a 2/2 twill as shown in Figure 5. The twill weave' diagonal pattern enhanced the upper look and provided a handmade look to the sandal. The weave surface was also shown to be cohesive enough to cut, shape and adhere onto the sole. Figure 5 shows that the woven banana

fibre material could be processed during manufacturing without considerable fibre separation, based on the edge finish and area of attachment. This is essential, as the upper of sandals should be made from a material that is able to retain the shape in the cutting and assembly process, but will also be flexible during use. Based on the results it is concluded that the dyed banana fibre is apt to be used for prototype footwear in twill weave.



Figure 5. Close-up view of the dyed banana fibre woven upper used in the sandal prototype, showing the 2/2 twill weave structure, texture, and edge finish.

4.3 Qualitative Functional Assessment

The final prototype was evaluated by a qualitative evaluation to determine its suitability in the field of footwear. The evaluation has considered the appearance, flexibility, usability, comfort, finishing and structural integrity. These observations were used to assess the feasibility of the study, which was exploratory and prototype, and not laboratory verified performance. The qualitative assessment showed that the dyed

banana fibre upper had an attractive natural texture and could be formed into a sandal upper. The woven structure was relatively stable during cutting and attachment, and the assembled sandal exhibited good flexibility and comfort in the preliminary observation. Further improvement and testing, however, would be required for commercial applications to improve finishing quality and durability.

Table 1: Qualitative assessment of the dyed banana fibre sandal prototype.

Assessment parameter	Observation	Interpretation
Visual appearance	Dyed banana fibre produced a natural and textured surface	Suitable for handmade and eco-friendly footwear design
Flexibility	Woven upper showed flexibility during handling	Indicates preliminary suitability for sandal upper movement
Comfort	Prototype appeared lightweight and wearable during preliminary observation	Shows potential for basic footwear use
Structural integrity	Woven upper remained attached after assembly using adhesive and stitching	Attachment method was workable at prototype level
Surface texture	2/2 twill weave produced a visible diagonal pattern	Improved aesthetic quality and material identity
Finishing quality	Trimming and surface cleaning improved	Further refinement is needed for

	the final appearance	market-ready production
Usability	Prototype achieved complete sandal form	Demonstrates feasibility of converting banana fibre into footwear

5. Implications of the Study

The study is relevant to the environment as it shows the potential of banana pseudostem waste to be transformed to a value added footwear material. Banana fibre application helps the utilisation of agricultural waste, the use of renewable material, the development of biodegradable products, and waste-to-value conversion. The method could also help to diminish partially the dependence on synthetic materials in handmade shoes' manufacture, but comprehensive environmental performance would have to be confirmed by additional evaluation. Socio-economic relevance of the study is also achieved as it relates to banana cultivation areas where the pseudostem residues are locally available. Similar products can be developed with local artisans and small enterprises with appropriate training in fibre extraction, dyeing, weaving and sandal making. The concept can apply to craft livelihoods, women-led small enterprises, rural livelihoods, tourism products, sustainable lifestyle markets.

6. Limitations and Future Research

The results are to be considered as preliminary prototype-level results. Assessment was done through visual inspection, handling, comfort observation and overall usability and not through the use of standardised laboratory testing. So, the study concludes that the dyed banana fibre sandals can be developed but not the level of performance for industrial production and durability. Further study is required to perform mechanical and durability test and to assess dyed banana fibre sandals for their performance during usage. Key tests can include tensile, tear, abrasion, flex, moisture absorbency, colour fastness, adhesion of soles, and long-term wearing. The consumer acceptance and production cost, and the standardisation and scalability of the

design, and the market potential for the product should also be explored in further studies prior to commercialisation.

7. Conclusion

This study demonstrated the feasibility of developing eco-friendly sandals using dyed banana fibre extracted from agricultural waste. The Banana pseudostem fibre was extracted, cleaned, dried, dyed, spun into yarns, woven into 2/2 twills and fabricated into sandals. The final prototype has revealed the feasibility of banana fibre as a usable upper material which can be adhered to the sandal sole and be stitched. The sandal prototype developed showed a natural woven pattern and lightweight, flexible, and aesthetically appropriate for handmade and eco-friendly sandal applications. The 2/2 twill weave helped to create the surface of the upper and the aesthetic appearance of the fibre was enhanced by dyeing. Based on the results, it can be inferred that the banana pseudostem waste can be converted into a value added footwear product by using simple and practical product development process. The study significantly contributes to product innovations towards sustainability by connecting the dots of agricultural waste utilisation, natural fibre processing, textile structure, and eco-footwear development. It also showcases possibilities of banana fibre sandals for small scale production and sustainable life style markets. The results, however, are preliminary since it was a qualitative and prototype evaluation. Standard laboratory testing procedures for strength, abrasion resistance, colour fastness, water resistance, sole adhesion and long-term durability should be done prior to more widespread use.

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