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Use of Arecanut Agricultural Waste as a High-Value Textile Material in the Circular Textile Design Collection

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Abstract

Purpose: This study addresses the growing need for sustainable and circular solutions in the textile industry by exploring the viability of arecanut (Areca catechu) agricultural waste, specifically its husks, as a novel source of natural textile fibre. The research aims to design a collection of textiles using arecanut yarns woven together with cotton and linen yarns to create interesting and innovative textile surfaces.

Methodology/Design: Arecanut fibres were extracted through a water retting process and blended with cotton (75:25 ratio) to produce two yarn counts (5s and 10s). These yarns were then woven into fabrics using both powerloom and handloom techniques. Fibre and yarn properties were evaluated using standard testing protocols. Design development was guided by trend analysis and explored through applications in home furnishing and fashion accessories.

Findings: The arecanut-cotton blended yarns demonstrated promising physical and mechanical properties for textile use. Fabric samples showcased the unique texture and visual appeal of arecanut fibres, proving their potential for upholstery, scarves, and traditional garments. The results highlight their compatibility with sustainable design approaches, including upcycling and zero-waste processes.

Practical and Social Implications: This research promotes a circular economy approach by repurposing agricultural waste into value-added textiles. It also suggests new income opportunities for arecanut farmers and local weavers.

Originality: This is the first documented study to investigate the direct application of arecanut fibres in textile development, combining sustainability with design innovation using cotton and linen yarns.

Keywords
Arecanut fibres, sustainable textiles, agricultural waste upcycling, circular textile design, home furnishings, natural fibres.

1 | INTRODUCTION

Climate change remains one of the most pressing global challenges to sustainable development, with significant long-term effects on ecosystems, weather patterns, and human health. The fashion and textile industry, historically a major contributor to environmental degradation, is now undergoing a shift toward sustainable practices aimed at reducing its ecological footprint (Meo, 2024; White, 2024). This shift is largely driven by the urgent need to find alternative materials and processes that balance environmental responsibility with design and performance (Palanisamy et al., 2024). India, as the world's largest

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producer of arecanut, generates substantial agricultural waste in the form of arecanut husks. Traditionally, this waste is incinerated or discarded, leading to both environmental and public health issues such as respiratory illnesses and mosquito breeding (Sunny & Rajan, 2021; Hebbar et al., 2024). Yet, these husks are rich in cellulose, lignin, and polyphenol components that hold potential for conversion into valuable textile fibres (Akbar et al., 2024; Poornima et al., 2022). Despite this, little scientific work has explored their direct use in mainstream textile applications, especially in terms of industrially viable yarns and fabrics. A growing body of research has focused on the use of agro-waste fibres such as banana, jute, and flax in textiles, but arecanut remains underexplored (Khan et al., 2024; Sunny & Rajan, 2024; Cristobal, 2024). Compared to other agro-waste fibres, arecanut offers a naturally golden hue, high mechanical strength, and water availability for retting in its cultivation regions, making it a promising candidate for circular textile design. However, the absence of scalable studies on its yarn-making capability, fabric usability, and integration into fashion and home textiles creates a critical research gap. There is currently no documented study demonstrating the integration of arecanut husk fibres into high-quality textile yarns and fabrics, nor is there a framework for their application in sustainable product design for both fashion and interior use. The objectives of the study include:

- To develop arecanut-based yarns through water retting and blending with cotton.
- To design and produce woven fabrics incorporating arecanut yarns for use in home furnishings and fashion.
- To assess the visual, structural, and usability potential of arecanut-based textiles through trend-driven product applications.
- To establish a sustainable design framework using arecanut agricultural waste as an input for circular textile design.

In this study, arecanut fibres were extracted using a water retting method and blended with cotton to develop yarns of different counts. These were then converted into fabrics using both powerloom and handloom techniques, with applications envisioned in upholstery, curtains, scarves, and traditional garments. The design process was informed by international trend forecasting platforms and localised through the concept of "Memory of Malabar," celebrating Kerala's arecanut farming heritage. By demonstrating a sustainable and scalable method for converting arecanut waste into high-value textile materials, this study contributes to circular economy strategies, promotes rural livelihood enhancement, and advances innovation in eco-friendly textile production. Furthermore, it adds to the academic discourse in sustainable fashion, upcycling, and biomaterials by offering a novel material solution grounded in local resources and global sustainability principles (Das et al., 2021; Praveena et al., 2022; Pulikkalparambil et al., 2023).

2 | MATERIALS AND METHOD

2.1| Fibre Extraction

Arecanut husks were sourced from a single farm in Balal, Kasargod district, Kerala, India, to maintain consistency in fibre quality. Harvested between August and January, the dry husks were subjected to stagnant water retting for two days, a sustainable and regionally feasible method. Approximately 250 grams of dry arecanut husks were immersed in 4 litres of ambient temperature water (27°C ± 1°C) for 48 hours. Fibres were manually plucked, washed three times, and sun-dried for 4–6 days. To evaluate the suitability of areca nut fibres for textile applications, a series of physical and mechanical tests was conducted under controlled environmental conditions (21 ± 1 °C, 65 ± 2% RH). Weight measurements were recorded at each processing stage—from dry husk to retted husk, extracted fibres, and final dried fibre mass. Fibre length parameters such as maximum length, effective length, and short fibre percentage were measured using a double-comb sorter system. Optical assessment of fibre diameter was carried out

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using the Olympus XS205 Microscope with Image Pro+ software at the SITRA physical testing lab. Fibre fineness was determined using the cut-and-weigh method in line with ASTM standards, and cellulose content was analysed through in-house chemical testing procedures. Moisture regain was calculated using the standard regain formula to assess the fibre's behaviour in varying humidity conditions. Mechanical properties such as breaking strength (Fmax) and elongation at break were evaluated using Zwick/Roell tensile testing equipment, with samples processed through the stagnant water retting method.

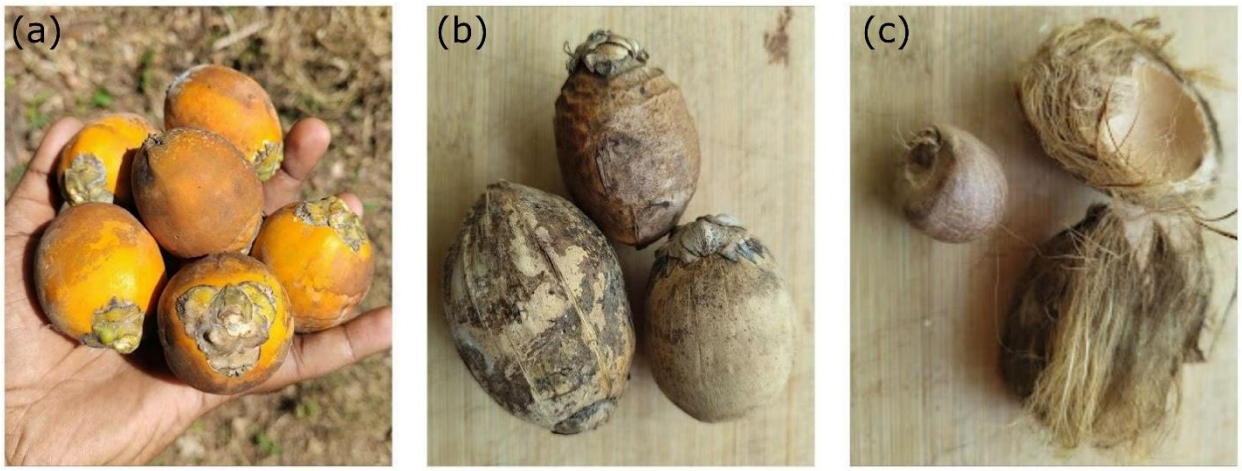


Figure 1. (a) Fully ripened arecanut fruit, (b) Dry arecanut fruit, (c) Dry arecanut husk after nut removal

2.2| Yarn Production

To enhance spinnability, arecanut fibres were blended with cotton (Sankar-6 variety) in a 75:25 ratio. In this study, the goal was to optimise the material for actual textile applications, particularly in home furnishing and fashion.

Two yarn counts were produced: 5s count (Ne 5/1), this coarser yarn was designed for upholstery fabric, which would utilise a blend of arecanut and cotton for both the warp and the weft. The finer yarn known as 10s count (Ne 10/1) was created to be used as a fancy yarn in fashion items and curtain textiles. A carding machine was used to open the mixed fibres into slivers. The KCT Tifac core plant then used rotor-spinning equipment to generate the yarn. To guarantee the best quality, the rotor machine's settings were modified for every number of yarns:

For 5s count yarn:

- Rotor speed: 32,000 RPM
- Open roller speed: 13,000 RPM
- Feed hank: 4.5 Ne
- Twist: 32 TPI

For 10s count yarn:

- Rotor speed: 32,000 RPM
- Open roller speed: 13,000 RPM
- Feed hank: 0.31 Ne
- Twist: 32 TPI

The resulting yarns (Refer to Figure 2b) were tested for various properties, including strength, elongation, and evenness, to ensure their suitability for the intended applications.

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2.2.1| Areca-Cotton Yarn Testing

Yarn properties were measured using standard industry instruments. All values represent an average of five test repetitions under controlled conditions (21°C ± 1°C, 65% ± 2% RH). The Uster Tester 5 800 was used to measure yarn unevenness, neps, thin/thick places, and hairiness. The Uster Tenso Rapid 4 tested mechanical properties, including breaking force, elongation, tenacity, and work done.

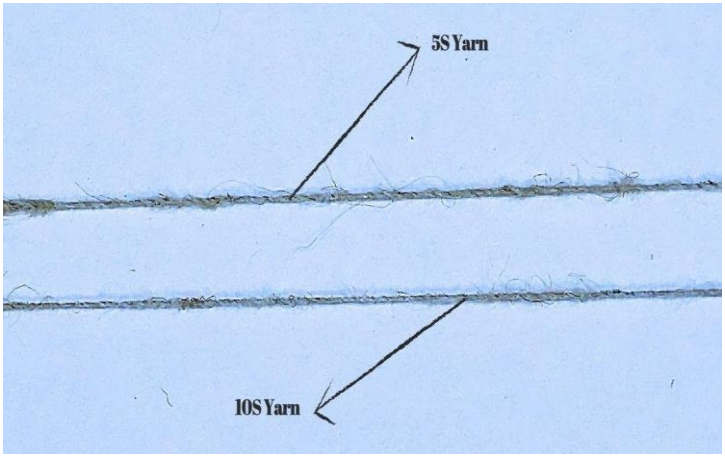


Figure 2. A close-up image of the arecanut-cotton blended yarns (both 5s and 10s counts)

A close-up image of the arecanut-cotton blended yarns (both 5s and 10s counts) has been included (Figure 2) to provide a clearer visual of the yarn twist, surface texture, and blending uniformity. The colour variation observed, from brown to a lighter cream hue, is attributed to pigment loss during the water retting process, which naturally softens the fibre and improves visual appeal. While the yarns exhibited relatively high unevenness (U%) and hairiness values compared to conventional cotton yarns, these are characteristic of minimally processed natural fibres. No chemical softening or surface treatment was applied in this study, as the focus was on evaluating unbleached, raw fibre behaviour. In future work, pre-treatment methods such as enzymatic softening or alkali scouring will be considered to enhance flexibility, reduce surface fuzz, and improve yarn uniformity.

2.2.2| Linen Yarn Details and Properties

Commercially sourced linen yarns were incorporated as warp and weft materials in selected handloom fabrics, particularly for curtain fabrics and scarves. Two counts of linen yarn were used: 60 Lea (finer yarn) and 25 Lea (coarser yarn). These yarns were selected based on their compatibility with arecanut-cotton blends, both in visual aesthetics and mechanical synergy. Table 1 below provides the basic properties of the linen yarns used, as per manufacturer specifications (Kalliasseri Weavers Co-operative Society - Kannur) and in-house confirmation testing:

Table 1. Basic properties of the linen yarns

Yarn Count	Fibre Length (mm)	Fineness (Denier)	Tenacity (cN/tex)	Elongation (%)	Moisture Regain (%)
60 Lea	35–50	12–16	30–40	1.5–2.0	12
25 Lea	50–65	18–24	35–45	1.5–2.2	12

Linen fibres provide strength, crisp texture, and high moisture absorption, enhancing the drape, breathability, and tactile experience of scarves and curtains. The combination of coarse and fine linen

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yarns allowed for both lightweight and medium-weight fabrics, improving the aesthetic and functional outcomes of the final products.

2.3| Fabric Production

Both power looms and handlooms were used to create fabric samples for use in fashion and home furnishings.

2.3.1| Power Loom Fabrics (10 S Count Yarn): Upholstery Fabric for Furnishing

The 10s count arecanut-cotton blended yarn was used on a power loom to create upholstery fabric for furnishing in both the warp and weft directions. Twenty picks per inch (PPI) were set in the weft direction and twenty ends per inch (EPI) in the warp direction on the loom. This design highlighted the inherent qualities of the arecanut fibres while producing a strong fabric appropriate for upholstery purposes. This application was especially well-suited for the coarser 10s yarn, which offered the strength and durability needed for furnishing fabrics (see Figure 3c).

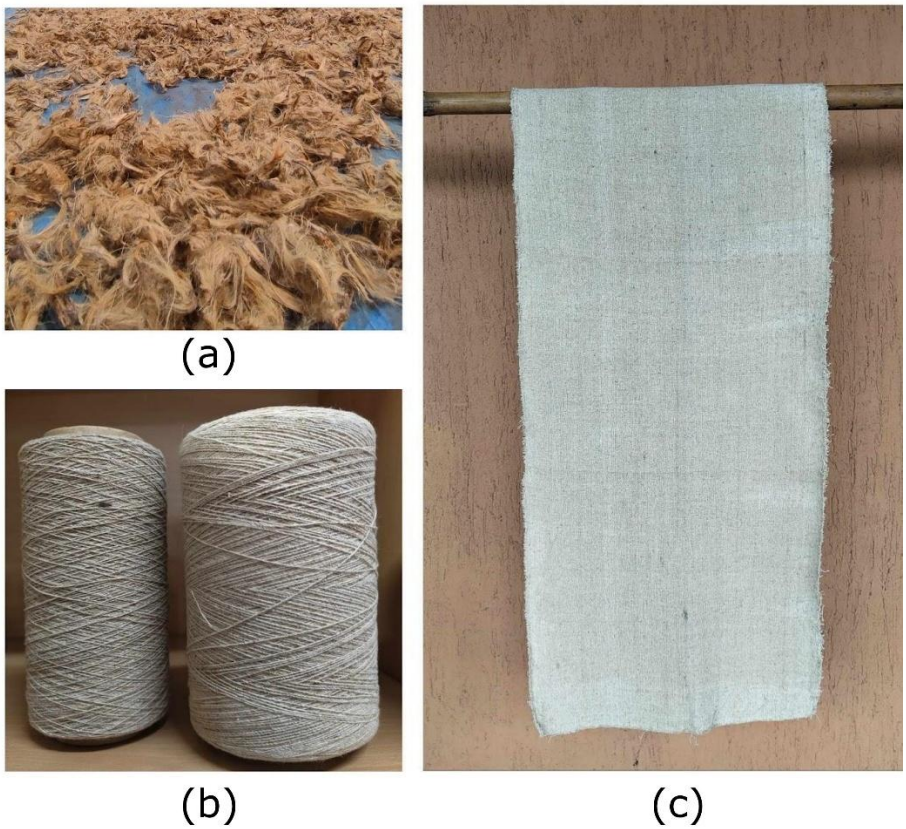


Figure 3. (a) Dry arecanut fibre after water retting, (b) arecanut 10s and 5s yarn, (c) Power loom fabrics (warp and weft arecanut cotton blessed 10s yarn)

2.3.2| Handloom Fabrics (10 S Count Yarn): Curtain Fabrics and Fashion Products

More delicate and complex motifs could be created through handloom weaving using the 10s count arecanut-cotton blended yarn. This finer yarn worked especially well for:

Curtain fabrics: Cotton or linen yarn served as the warp, while a 10s count yarn served as a decorative yarn in the weft direction. The result was an eye-catching pattern that highlighted the uniqueness of the arecanut fibres.

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Scarves: The 10s count provided a more fluid hand feel to gorgeous handwoven fabric that showed off the texture and drape of the blended yarn, perfect for fashion accessories.

Traditional clothing: The thinner 10s yarn was in a few traditional Kerala garments, which act as unique pieces, adding to visible interest and a connection to local, sustainable textiles.

Using the handloom technique, which enabled the exploration of various weave structures and yarn combinations, has resulted in the creation of unique textile designs that demonstrate the feasibility of arecanut fibres in fashion and home décor products. The design flexibility and unique patterns, capturing the unique characteristics of the arecanut-cotton blended yarn, switched on due to the use of the finer 10s yarn in the handloom weaving technique. This technique allows the processing of 5s yarn for power loom applications and 10s yarn for handloom applications, which made it plausible to explore the full potential of arecanut fibre for various textile applications ranging from sensitive fashion to upholstery textiles.

3 | DESIGN DEVELOPMENT USING UNBLEACHED ARECANUT

The conceptual framework began with the selection of key trends from WGSN's (Worth Global Style Network) Spring/Summer 2025 forecast, which informed the development of the theme "Use of Arecanut Agricultural Waste as a High-Value Textile Material in the Circular Textile Design Collection." Several forecasted trends aligned closely with the project's sustainable and innovation-driven objectives. Notably, the use of arecanut fibres—positioned as a regenerative, agro-waste material- resonates strongly with the "New Naturals" trend, which promotes minimalistic casual wear influenced by a strong craft ethos. This trend direction also places emphasis on surface texture, particularly through slubs and micro-mélange effects, qualities that are inherently present in unbleached arecanut yarns (WGSN, 2023).

The design direction draws inspiration from several contemporary trends that collectively reinforce the use of arecanut fibre as an eco-friendly and innovative textile medium. The "Zero-Waste Craft" trend reflects a circular design approach focused on the reuse of waste and surplus materials, aligning directly with the upcycling of arecanut farm biowaste. The "Summer Splash" trend, characterised by stripe work in neutrals and mid-tones, offers a suitable aesthetic context for incorporating unbleached arecanut yarn as a fancy yarn in woven fabric compositions. The "Retro Quaint" trend, which celebrates traditional motifs such as gingham and windowpane checks, informs the development of experimental textures and patterning using arecanut yarn. "Community-led Narratives" emphasises collaboration with artisans and the use of hyper-local materials, which aligns with the project's focus on utilising region-specific agricultural waste. The "Natural Fibres" trend validates the selection of arecanut yarn, particularly for its undyed, raw aesthetic, an inherent quality of the unbleached fibre. Additionally, the "FUN-ctional Basics" trend advocates for the use of recycled and natural fibres in multifunctional, utilitarian designs, supporting the project's goal of transforming waste into high-value textile materials. These trends collectively justify the use of arecanut yarn as both an environmentally responsible and aesthetically relevant design material. They serve as a framework for developing fabrics that respond to the rising demand for sustainable products while embracing current design sensibilities centred on natural textures, geometric structures, and functional beauty. Anchored in this comprehensive trend analysis, the personal theme Memory of Malabar was developed to guide the creation of the fabric collection.

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Figure 4. Inspiration board "Memory of Malabar"

Growing up in a house surrounded by arecanut farms, where Malabar forms the immediate environment, the theme 'Memory of Malabar' emerges as a deeply personal interpretation rooted in childhood experiences. The concept draws inspiration from the region's rich cultural heritage, lush green landscapes, and distinctive architecture along the Malabar coast. The colour palette is informed by the natural surroundings such as the green-grey tones of arecanut palms, the warm browns of the soil, the vibrant hues of local textiles, and the weathered patinas of traditional buildings. This thematic approach aligns with the contemporary design trends of "New Naturals" and "Community-led Narratives" identified through research. The theme integrates local storytelling and artisanal processes into the design language, while the earthy, natural colour palette supports a craft-based, simplified aesthetic suited for home décor. Architectural elements from Malabar, known for their unique geometric compositions and intricate detailing, serve as a key inspiration for the structural layout of the weave and surface embellishments. This dimension of the theme resonates with the "Retro Quaint" trend, offering a framework to reinterpret traditional patterns in a modern context (refer to Figure 5).



Figure 5. Colour board "Memory of Malabar"

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By incorporating unbleached arecanut yarn as a fancy yarn, the design process upcycles agricultural waste in a purposeful and sustainable manner, embedding the essence of Malabar into the textile. The theme aims to create textiles that are both sustainable and innovative, while also rich in cultural significance. Memory of Malabar becomes a medium through which the beauty, heritage, and identity of the region are reinterpreted into contemporary, eco-conscious designs. This design philosophy bridges traditional narratives and modern design sensibilities, offering a unique and meaningful contribution to textile development.

4 | RESULTS AND DISCUSSION

4.1| Fibre Properties

Characteristics of the extracted arecanut fibres were as follows:

- Average diameter: 0.0313 mm
- Fibre length: 32 - 65 mm
- Fibre fineness: 10.61 deniers
- Cellulose content: 65.17%
- Mean breaking strength: 179.5 gf
- Mean breaking elongation at fmax: 14.6%

Cotton Fibre Properties:

- Fibre length uniformity ratio: 49.58%
- Fibre length: 27.27 mm
- Fibre maturity: 82.53%
- Fibre fineness: 4.52 ug/in
- Trash content: 0.19%

Based on available literature, banana fibres show a fineness of 10–20 denier and a tensile strength of 300–400 MPa, while jute typically shows 20–30 denier and 400–800 MPa strength. Arecanut fibres, in contrast, exhibited a fineness of 10.61 denier and breaking strength of 179.5 gf, suggesting moderate strength but finer texture. These properties suggest suitability for niche product applications such as decorative textiles and eco-fashion accessories, though further surface analysis (e.g., SEM) would help confirm their performance in dyeability and blending.

4.2| Properties of Arec Cotton Yarn

All yarn tests were conducted at Thiyagarajar Mills (P) Ltd., Kappalur, Madurai, Tamil Nadu, India, under standard atmospheric conditions for textile testing, with a temperature range of 24.9–25 °C and relative humidity between 60.1% and 68.6%. The physical properties presented in Table 1 were measured using the USTER® Tester 5 – S800 R, following the Uster Statistics Standard Table CS OH for short staple yarns. Mechanical properties shown in Table 2 were evaluated using the USTER® TensoRapid 4, operated at a testing speed of 5000 mm/min, with a clamping length of 500 mm and a pre-tension of 30%. Each mechanical test was performed on 100 individual yarn samples, ensuring data reliability and consistency.

4.2.1| Physical Properties

The 5s yarn exhibits slightly higher unevenness, CVm%, and hairiness compared to the 10s yarn, reflecting its coarser nature. However, the 10s yarn shows a higher nep count, indicating a potentially smoother surface in finer fabrics (refer to Table 2).

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Table 2. Physical Properties of Arecanut–Cotton Blended Yarns (from USTER® Tester 5)

Yarn Count	Blend Ratio (Arecanut: Cotton)	Unevenness (U%)	CVm (%)	Thin Places (-50%/ km)	Thick Places (+50%/ km)	Neps (+200%/ km)	Hairiness Index
10s	75:25	19.32	25.36	777.5	1010	2293	7.52
5s	75:25	20.22	26.48	1860.0	925.0	1660	8.24

Note: Values are from USTER® Tester 5 single test runs.

4.2.2| Mechanical Properties

Because of its exceptional breaking work, elongation, and breaking force, the 5s yarn is better suited for demanding uses like upholstery. The 10s yarn, on the other hand, has greater tenacity despite being weaker, which makes it perfect for lighter, more delicate garments (refer to Table 3). Values are expressed as mean ± standard deviation (SD), with CV% shown below each row.

Table 3. Mechanical Properties of Arecanut–Cotton Blended Yarns (from USTER® TensoRapid 4)

Yarn Count	Time to Break (s)	Breaking Force (gf)	Elongation (%)	Tenacity (rkm)	Breaking Work (N·cm)
10s	0.89 ± 0.13	435.04 ± 79.21	14.65 ± 2.17	7.37 ± 1.34	14.32 ± 3.96
	CV%: 14.87	CV%: 18.21	CV%: 14.81	CV%: 18.21	CV%: 27.67
5s	1.14 ± 0.13	775.06 ± 103.47	18.64 ± 2.17	6.56 ± 0.88	30.68 ± 6.18
	CV%: 11.54	CV%: 13.35	CV%: 11.64	CV%: 13.35	CV%: 20.13

Note: Based on 100 single yarn tests using USTER® TensoRapid 4.

The arecanut-cotton blended yarns (5s and 10s counts, 75:25 ratio) demonstrated practical and mechanical properties suitable for diverse textile applications. The 5s yarn, with higher breaking force (775.1 gf) and elongation (18.64%), showed better performance for upholstery and heavier fabrics, while the 10s yarn, with greater tenacity (7.37 rkm), was more suited for lightweight fashion items and scarves. These findings indicate the material's adaptability across product categories and parallel the behaviour of other agro-based fibres such as banana and jute, where similar variability in fineness and tenacity is leveraged for category-specific applications (Cristobal, 2024).

4.2.3| Statistical Analysis

To determine whether the observed differences between the 5s and 10s arecanut–cotton blended yarns were statistically significant, a one-way ANOVA was conducted for each mechanical property using Microsoft Excel (Office 365). The results revealed significant differences in breaking force ($F(1,198) = 84.92$, $p < 0.001$), elongation ($F(1,198) = 54.31$, $p < 0.001$), tenacity ($F(1,198) = 6.74$, $p = 0.01$), and breaking work ($F(1,198) = 95.08$, $p < 0.001$) between the two yarn counts. These statistical findings support the practical distinctions noted earlier and validate the suitability of the yarns for different end-use applications.

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4.3| Home Furnishings (Textile Design Collection)

Based on the theme of "Memory of Malabar", the trends were identified, and home furnishing designs were created on a handloom. Across curtain fabrics, these designs highlight the versatility of arecanut yarn in a spectrum of useful applications.

4.3.1| Power Loom Fabrics (5 S Count Yarn): Upholstery Fabric for Furnishing

For upholstery fabric, designs with arecanut yarn in both warp and weft in a 5s count blend of 75% arecanut and 25% cotton. For each fabric created, they were photographed and then imported into Adobe Photoshop for additional development. In order to understand how the unique arecanut texture would look in real-world applications, and made digital mockups of the fabric on furniture and sofa sets. This methodology highlights the unique texture and organic hue of arecanut fibre, crafting a fabric that epitomises sustainable ethos and contemporary design trends. This digital visualisation process gave the ability to iterate on the designs to create a final product that was not only eco-friendly, but also attractive and appropriate for currently available home furnishings (refer to Figure 6).



Figure 6. Digital mockups of the arecanut upholstery Fabric on furniture and sofa sets.

4.3.2| Handloom Fabrics (10 S Count Yarn): Curtain Fabrics and Fashion Products

The design portfolio was expanded to include curtain fabrics and other home textile products. Arecanut yarn was incorporated as a fancy yarn to provide visual depth and texture to the fabrics.

Table 4. Summary of Developed Fabric Samples with Yarn Parameters and Intended Application

Sample Category	Product Type	Warp Yarn (Type/Count)	Weft Yarn (Type/Count)	EPI / PPI	Fabric Weight (GSM)*	Intended Use
Curtain (Cotton)	Designs 1–6	Cotton 2/17	Cotton 2/17 + Areca 10s	42 / 32	~130	Window curtains
Curtain (Linen)	Designs 1–6	Linen 60 Lea	Linen 25 Lea + Areca 10s	42 / 32	~150	Premium home decor

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Scarf (Cotton - Light)	Scarves 1–3	Cotton 2/80	Cotton 2/40 + Areca 10s	72 / 62	~90	Summer scarves
Scarf (Cotton - Medium)	Scarves 4–6	Cotton 2/80	Cotton 2/80 + Areca 10s	72 / 84	~110	Mid-weight scarves
Scarf (Linen - Thin)	Scarves 1–3	Linen 60 Lea	Linen 60 Lea + Areca 10s	60 / 34	~100	Light evening wear
Scarf (Linen - Coarse)	Scarves 4–6	Linen 60 Lea	Linen 25 Lea + Areca 10s	44 / 61	~140	Winter/fashion scarves
Traditional Garment	Dhoti	Cotton 2/120	Cotton 80s + Areca 10s	74 / 72	~110	Kerala ceremonial garment

4.3.2.1| Curtain Fabric

Curtain Fabric (Warp Cotton Yarns & Weft Cotton Yarns And Areca-Cotton Yarns)

A reed of 40 was used on the handloom to produce six curtain fabric samples. Commercially available cotton yarns of 2/17 count were used for both the warp and the base weft. The experimental arecanut yarns, developed as part of this study, were selectively inserted into the weft as decorative elements to enhance texture and surface interest in each design. The construction included a warp density of 42 ends per inch (EPI) and a weft density of 32 picks per inch (PPI). The resulting fabrics retained the drape and softness typical of cotton while offering the distinctive texture and sustainability attributes introduced by arecanut yarn. Refer to Figure 7 (designs 1 to 3) and Figure 8 (designs 4 to 6).

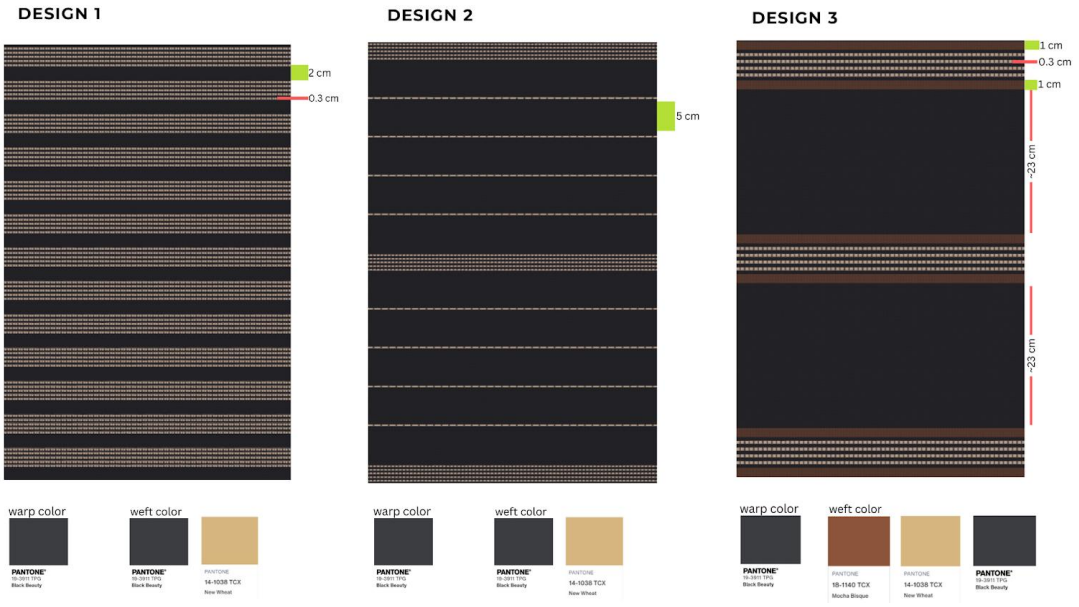


Figure 7. Pointcarre software rendered curtain fabric designs 1,2 & 3 (cotton warp, 75% arecanut + 25% cotton yarns weft yarns)

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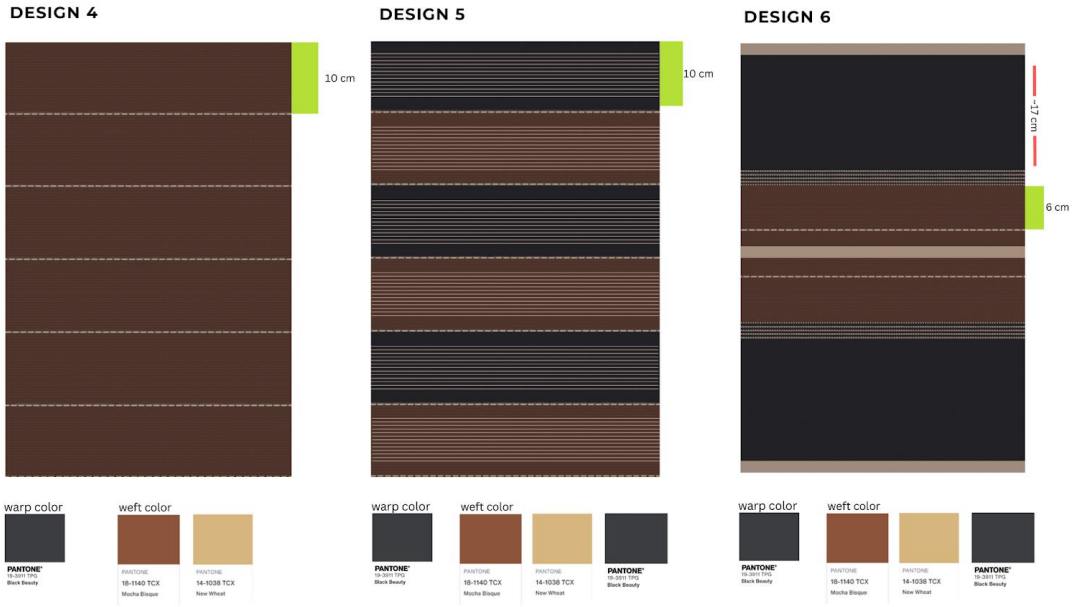


Figure 8. Pointcarre software rendered curtain fabric designs 4, 5 & 6 (cotton warp, 75% arecanut + 25% cotton weft yarns).

In Design 1, black cotton was used for In Design 1 (Figure 7), both warp and weft consisted of black cotton yarn. Arecanut yarns, natural golden-brown in colour, were inserted as supplementary weft yarns of varying thicknesses, creating slub-like effects and textural accents. This gives a textured and subtle pattern on the background of the black, and it also allows the colour and texture of the arecanut to shine through. Design 2 (Figure 7) uses a black cotton warp and weft, too, but plays with the arecanut yarn pattern differently. The varying thickness of the lines in the arecanut gives the fabric a rhythmic effect. Introducing brown in the weft of Design 3, it is a combination of this and black. The arecanut yarns are woven in different patterns, thus forming an interesting relationship between the most subtle of three colours and textures (Figure 9). Design 4 is a combination of a black warp and a brown weft, interspersed with single lines of arecanut yarn. It makes a relatively fine and delicate pattern that beautifully highlights the special attributes of the arecanut fibre. In design 5, the arecanut yarns are done over the black and brown in thick stripes in equal intervals on five alternate black and brown weft yarns. It creates a bold, striped effect, with extra textural interest from the arecanut yarn. In Design 6, the warp is black, the weft alternates between brown and black, and there is a thick line of arecanut yarn in the centre and on each side. As a result, the overall symmetrical design creates a balanced framed effect that enhances the arecanut elements. Refer to Design 7 (Figure 8).



Figure 9. Photographs of Curtain Samples 1–3 (warp cotton & weft cotton, and 75% arecanut + 25% cotton yarns).

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Figure 10. Photographs of Curtain Samples 4–6 (warp cotton & weft cotton and 75% arecanut + 25% cotton yarns).

Curtain Fabric (Warp Linen Yarns & Weft Linen Yarns And Areca-Cotton Yarns)

For the next six curtain fabric samples, reed with a count of 40, ends per inch (EPI) 42 and picks per inch (PPI) 32, and both warp and weft were 25 Lea linen yarns. For this set, the study went for a more textured and rustic look, pairing linen with arecanut yarn. PPI were recorded according to the standard method of the invention, to detect an arecanut yarn in the weft at a maximum PPI value prior. The values could reach up to 36-38, but they do not repeat when arecanut yarns are inserted on the weft. The inclusion of linen with arecanut fibre gives characteristic hand-feel and drape to fabrics, as linen has natural properties complementing the arecanut fibre. The design included elements from the Malabar coast and traditional textile motifs in a contemporary context to create a new identity for Keralan textiles. Refer to Figure 11 (designs 1 to 3) and Figure 12 (designs 4 to 6).

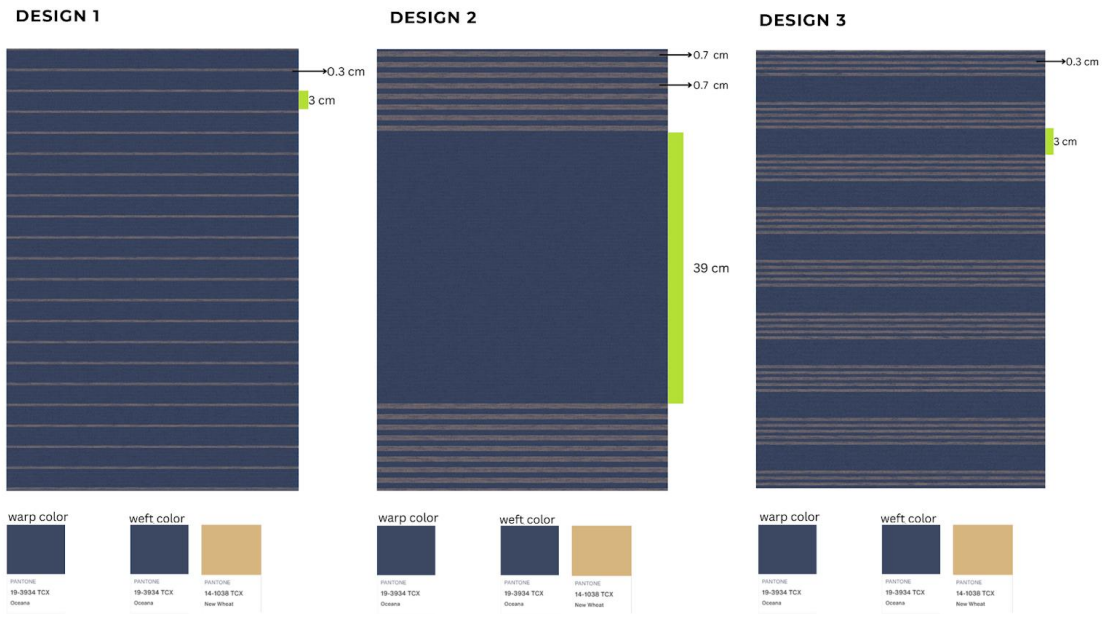


Figure 11. Pointcarre software rendered curtain fabric designs 1,2 & 3 (warp linen & weft linen and 75% arecanut + 25% cotton yarns).

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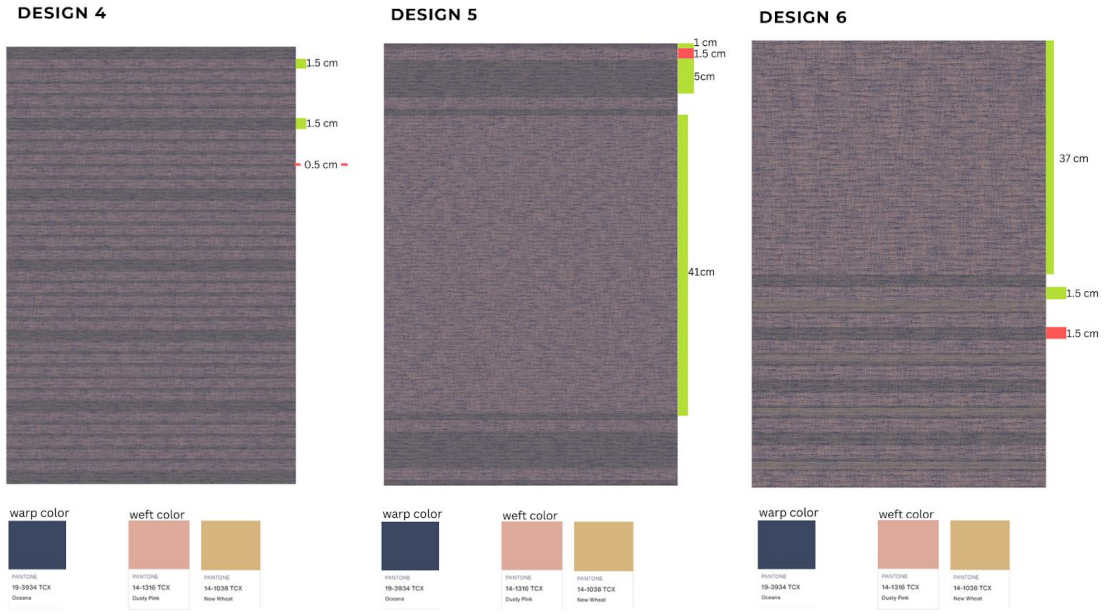


Figure 12. Pointcarre software rendered curtain fabric designs 4, 5 & 6 (warp linen & weft linen and 75% arecanut + 25% cotton yarns).

Design 1 (Figure 11), indigo-colored linen yarns are used in the warp and weft, while thin horizontal lines of arecanut yarn are interpolated at equal intervals in a plain weave. It creates a delicate, rhythmic pattern that provides texture and interest against the solid indigo background. Design 2 (Figure 11) also features indigo-hued linen for warp and weft, yet it adds broad lines of arecanut-jute yarn in a plain weave running along both sides of the fabric. It also gives a nice border effect with the arecanut fibre in the natural shades around a central indigo-shaped area. Design 3 (Figure 11), broad indigo blue linen yarns woven in both warp and weft and strips of arecanut lines at equal intervals horizontally. These repeated and geometric patternings of arecanut strips add a strong contemporary touch to the traditional linen substrate (see Figure 12 - design 3). Design 4 (Figure 14), the linen yarns in warp and weft across to a dry pink in colour. It uses both heavy and fine lines of arecanut yarn in plain-woven fabric, set in repeating geometric packs. This design is an exploration of texture and rhythm, resulting in an eye-catching surface. Design 5 (Figure 14) uses pink linen for both warp and weft, while thick arecanut plain weave borders run along its length on either side of the fabric. This dynamic design highlights the contrast between the pink linen and natural arecanut fibre, creating a bold framing effect. Design 6 (Figure 14) , similar to design 5, which uses pink linen for both warp and weft, has a heavy arecanut border on one side only. Two types of plain weave stitch have been used in this border, lending both texture and visual interest to the asymmetrical design.

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Figure 13. Curtain fabric samples 1, 2 & 3 (warp linen & weft linen and 75% arecanut + 25% cotton yarns).



Figure 14. Curtain fabric samples 4, 5 & 6 (warp linen & weft linen and 75% arecanut + 25% cotton yarns).

The home textiles applications of arecanut yarns can further be emphasised from the curtain fabrics shown above, which not only define aesthetics, but also a perfect story for sustainability. The designs echo the theme of "Memory of Malabar" and they fit neatly into the international trend in eco-friendly, artisanal home furnishings.

4.3.2.2| Fashion Domain: Fabric Development Using Areca-Cotton Yarn as Fancy Yarn for Clothing

Expanding the application of arecanut yarn beyond home furnishings, the study ventured into the fashion domain, focusing on scarves, traditional garments, and other accessories. This exploration allowed us to showcase the versatility of arecanut yarn in creating lightweight, wearable fabrics that blend sustainability with style. Developed a range of cotton scarves, incorporating arecanut yarn as a fancy yarn in the weft. This combination allowed us to create unique textures and visual interest while maintaining the comfort and drape associated with cotton.

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Cotton Scarves (Warp Cotton Yarns, Weft Cotton Yarns and Areca-Cotton Yarns)

Two sets of scarves were developed to explore the adaptability of arecanut yarn in fabrics of varying weight and fineness. The first set comprised three lightweight scarves, woven using a reed count of 72, with cotton yarns of 2/80 count in the warp and 2/40 count in the weft. This configuration produced soft, breathable scarves that effectively showcased the subtle texture of the arecanut yarn while maintaining comfort and drape. The fine count of the handloom enabled us to make detailed, structured patterns inspired by typical Malabar textiles, but with a contemporary touch (refer to Figure 15).

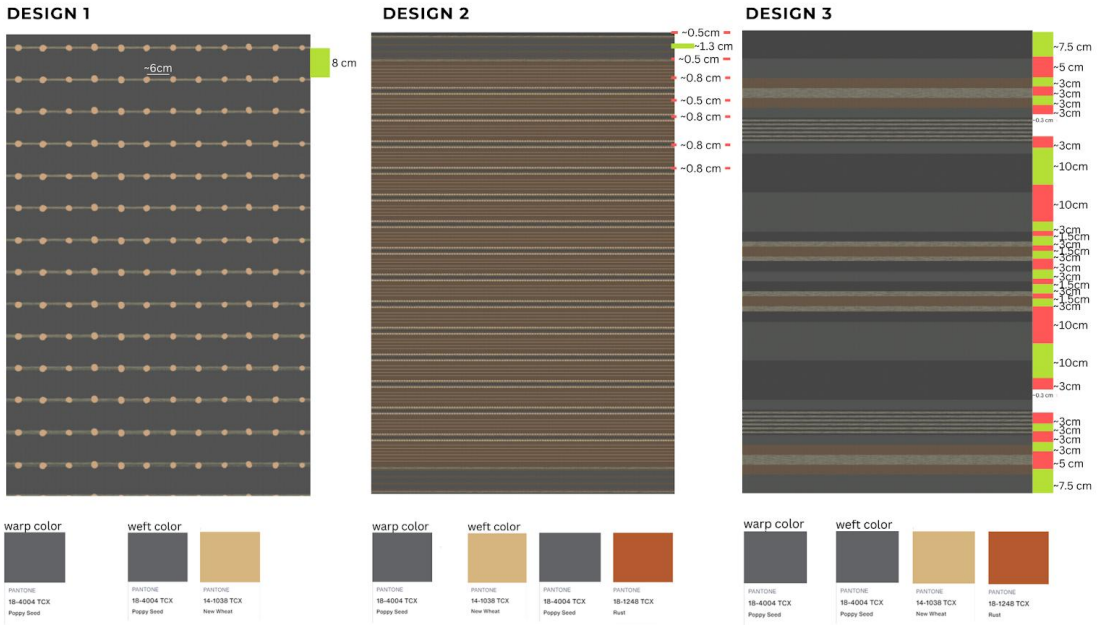


Figure 15. Pointcarre software rendered cotton Scarves design 1, 2 & 3 (warp-cotton, weft-cotton and 75% arecanut + 25% cotton yarns).

Commencing with a sophisticated base of dark grey cotton yarns in both warp and weft, Design 1 measures a weighty 102 ends per inch (EPI) and a robust 82 picks per inch (PPI). Knots are set at the same interval from each other, and along with the yarns, ten arecanut 10s are used in code to create the elaborate design. This gives a slightly rough, but interesting texture to the whole scarf, which is deceptively grey. Design 2 has 72 EPI and 62 PPI, with grey cotton in the warp with stripes of alternating grey and muddy orange in the weft. Further, diamond-shaped striped patterns are embroidered by using thin lines of arecanut yarn. The grey, muddy orange, and natural arecanut colours play against each other in a warm, earthy palette inspired by the theme of this year's installation, which is based on "Memory of Malabar". Design 3 is the most complex of the group, being 42 EPI & 64 PPI for a more open construction. It has a dark grey cotton warp and an alternating light and dark charcoal grey weft. Layers of muddy orange stripes in various widths are laid into this grey base, generating a dynamic rhythm in space. Next, the design is embellished with both wide and thin borders of arecanut yarn and lines of arecanut that run throughout the scarf. This blend of colours, textures, and patterns gives the scarf both visual and tactile diversity (refer to Figure 16).

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Figure 16. Cotton scarves sample 1, 2 & 3 (size 50” × 30”) (warp cotton and weft cotton and 75% arecanut + 25% cotton yarn).

The medium-weight (second set of three scarves) was designed using a reed of 72, but both warp and weft were 2/80. This construction yielded a little thicker fabric, good for cooler weather or a decorative accent. The increased weft count enabled the distinctive features of arecanut yarn to show through more, the textural interaction between cotton and arecanut fibres (refer to Figure 17).

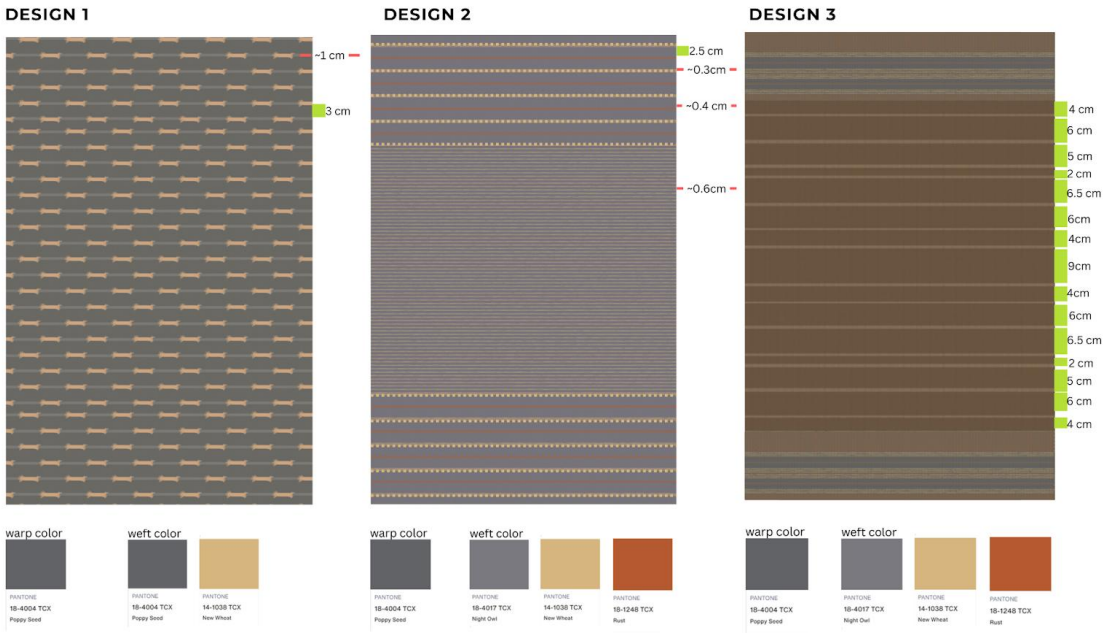


Figure 17. Pointcarre software rendered cotton Scarves design 1, 2 & 3 (warp -cotton, weft- cotton and 75% arecanut + 25% cotton yarn).

Design 1, with a dense construction of 76 ends per inch (EPI) and 84 picks per inch (PPI), features a dark charcoal grey cotton yarn in both warp and weft, creating a rich, deep base colour. The design is elevated by the insertion of multiple arecanut yarns as extra weft. This technique creates a textured surface with subtle variations in colour and depth, adding visual interest and tactile appeal to the scarf. The multiple insertions of arecanut yarn throughout the fabric body create a complex, layered effect that highlights the natural characteristics of the fibre. Design 2 has a dark grey cotton yarn in the warp with alternating light grey and muddy orange in the weft, woven at 72 EPI and with a higher 100 PPI for density. Delicate, textured patterns throughout the full body of the scarf are made by inserting thin lines of arecanut yarn. The borders of the scarf are decorated with strong lines of arecanut yarn, by inserting 10 yarns jointly in the direction of the weft. The texture in the main body is fairly subtle, but the edges

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are very pronounced, creating a high contrast within the fabric and demonstrating the capabilities of the arecanut yarn in creating a diverse range of textures and patterns. Design 3, with a more open (to some extent) warp of 78 EPI but balanced PPI of 92, has grey cotton in the warp with muddy orange and dark grey as weft, concentrated near the edges. The full body of the scarf has been designed with arecanut yarn lines. The dark brick colour effect from the grey and orange yarn interplay symbolises the architecture in the Malabar region. In addition to this, the interplay of different arecanut yarn lines adds depth and texture to this luxuriant colour palette, elevated further by the effective construction of this piece (refer to Figure 18).



Figure 18. Cotton scarves sample 1, 2 & 3 (size 50" × 30") (warp cotton and weft cotton and arecanut yarns).

In both these sets, several weave structures and pattern placements were explored to accentuate the natural colour and texture of the arecanut yarn. The designs take reference from the Memory of Malabar theme by including typologies like fragmented landscapes, architectural motifs, and local patterns from the region. These scarves are not just stylish accessories, but also examples of how recycled agricultural waste can be transformed into profitable textile products. They are the meeting point between sustainability, cultural heritage, and modern design, reflecting an increase in consumer demand for fashion items that align with a unique story and eco-conscious values.

4.3.2.3| Linen Scarves (Warp Linen Yarns & Weft Linen Yarns and Areca-Cotton Yarns)

Looking to extend our experimentation with arecanut yarn into fashion accessories, the study designed a series of linen scarves, using arecanut as a fancy yarn. This combination helped us develop textiles that are still crisp and cool like linen but with the texture, unique feel and sustainability story of arecanut fibre. Two sets of linen scarves of different constructions were made to show the versatility of arecanut yarn across fabric weights and textures.

Thin Linen Scarves

The reed in use for the first set of three soft linen scarves was 60 with both warp and weft counts of 60 lea linen yarns. The construction created a delicately light, breathable fabric with a gentle drape. The arecanut fibre was perfectly matched with the fine linen yarn, making it a diverse yet subtle texture, where although it adds character, it is not rough, which would otherwise make the scarf uncomfortable. These scarves are perfect for warmer weather or simply as light accessories at night (see Figure 19).

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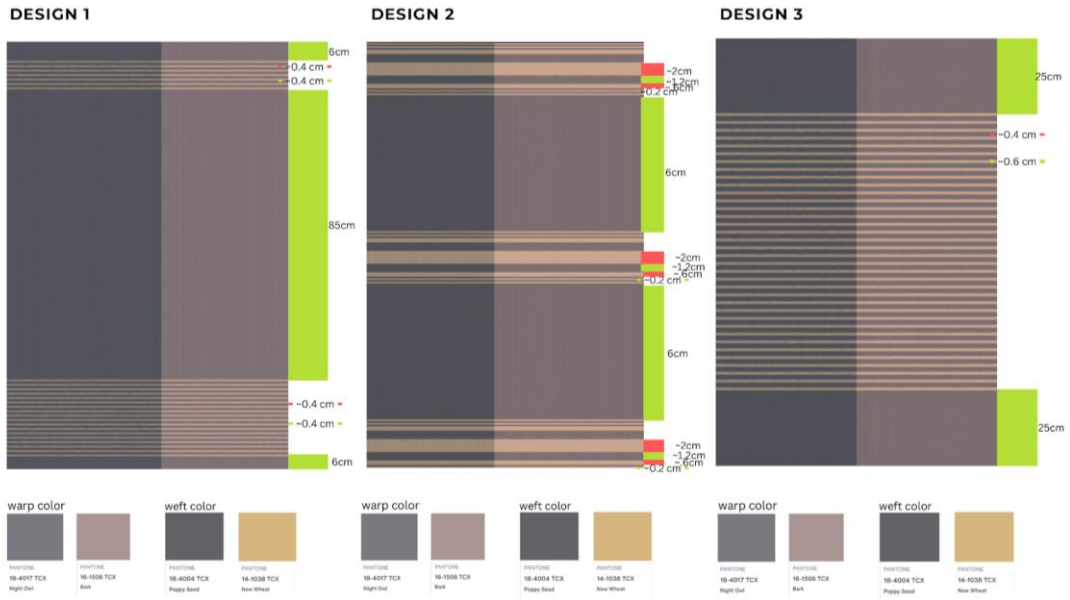


Figure 19. Pointcarre software rendered linen scarves design 1, 2 & 3 (warp - linen, weft- linen and 75% arecanut + 25% cotton yarns).

Design 1 uses innovative colour blocking in the warp by creating a balance between dark grey and dusty pinkish grey by dividing the scarf lengthwise equally at the halfway point, along with the width (62 ends per inch (EPI), 30 picks per inch (PPI)). The weft, which is always dark grey linen, generates a tonal counterplay. The highlight of this design is the tracheal asymmetrical placements of don thin arecanut plain weave lines on both sides, with the weft direction. This asymmetry creates a visually pleasing effect that evokes different weights on either side of the scarf. The result is a modern shape that shows off the difference between the smooth linen and the more natural feel of the arecanut yarn, made even more noticeable by the open weave design. Design 2 has a warp that is slightly denser, coming in at 70 EPI and 36 PPI, and maintains the two-colour approach (dark grey + dusty pink) adopted in the previous design but tackles the placement of the arecanut yarn differently. Three borders are formed for the scarf, using arecanut yarn that is tightly woven in the weft direction evenly across the width of the scarf. These borders are balanced above and below in the body of the scarf, allowing the natural drape and sheen of the linen to make itself felt. This design creates a visual rhythm, leading the eyes along the section of the scarf that features a beautiful blend of linen and arecanut fibres. Design 3 sticks with the split-colour warp theme, with half dark grey, half dusty pink grey, with 64 EPI and 34 PPI. Set in the weft, grey linen yarns run from end to end, tonally contrasting with the warp to give a nuanced texture. The borders in this scarf are left plain, drawing the eye towards its body, which is filled with fine, plain weave lines in an arecanut colour. This look creates a subtle, all-over texture, highlighting the unique beauty of the arecanut yarn yet allowing the drape of the linen base to shine through. The construction also helps to combine the structure and fluid attributes in the fabric (see Figure 20).

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Figure 20. Linen scarves sample 1, 2 & 3 (size 50" × 30") (warp linen and weft linen and 75% arecanut + 25% cotton yarns).

Coarser Linen Scarves

The second batch of three linen scarves was woven with a courser (medium weight) reed, again using a 60 reed, but with a warp of 60 lea and a reduced weft of 25 lea linen yarns. This construction resulted in a more rigid fabric with pronounced texture , which showcased the arecanut yarn in comparison. Because of the heavier weight of these scarves, this material is ideal for cooler conditions or as a statement piece in an outfit (refer to Figure 21).

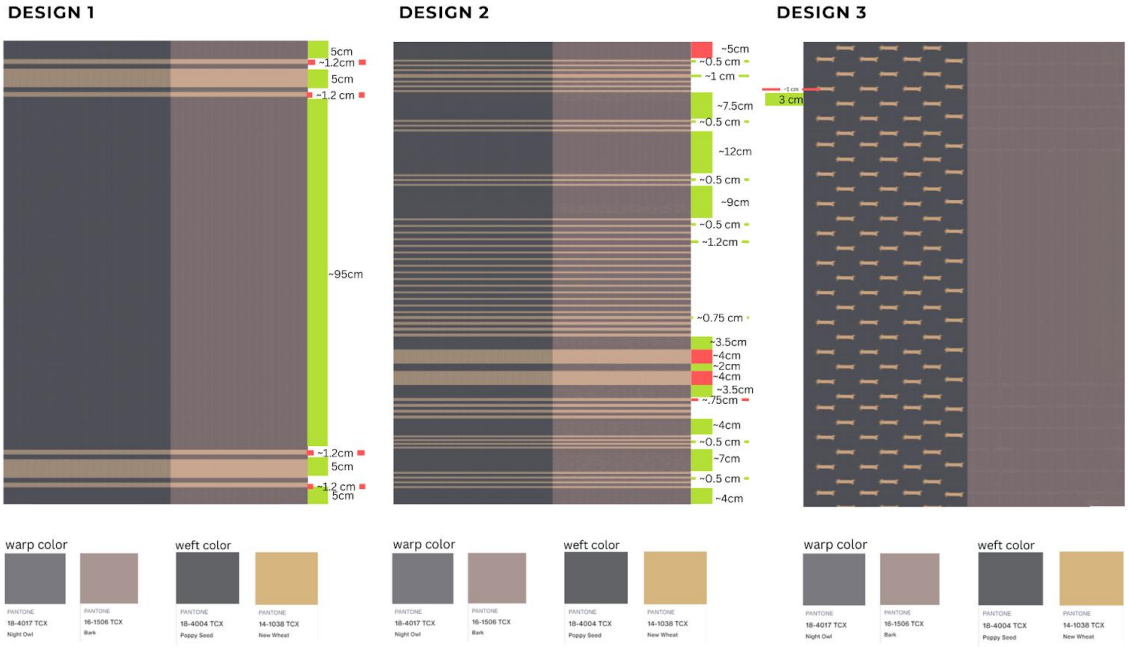


Figure 21. Pointcarre software rendered linen scarves design 1, 2 & 3 (warp - linen, weft- linen and 75% arecanut + 25% cotton yarns).

Design 1, all three designs use the same warp, which is half grey and half dusty pink thin linen yarns, set at 44 ends per inch (EPI) and 61 picks per inch (PPI): Linen yarns in dark grey sit in the weft portion of the full body of the scarf. The most eye-catching feature of this design is the thick arecanut-hued borders on each side, near the tassels. "The smooth body of the linen body contrasted with the bird's-eye view of the arecanut borders creates visual weight and tactile interest at the edges of the scarf. The split-colour warp, dark weft, and textured borders create a sophisticated, multi-dimensional piece, accentuated by the balanced weave structure. Features of the design 2, arecanut are a unique

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construction with different densities 42 EPI, in which arecanut is inserted, and 44 EPI in the body and 48 PPI in the part area in which arecanut is inserted, and 66 PPI in the body. It retains the same split-colour warp of thin linen yarns. In the weft again are on medium-weight dark grey linen, but here you will see thin and thick line stripes of arecanut yarns with an uneven distribution and having an asymmetric placement on the weft direction. This produces a three-dimensional, almost organic range over the scarf, with differing textures and modifications. The asymmetrical design provides a modern, artistic vibe while also ensuring that no two scarves share the same distribution of patterns. Design 3, which builds at a denser construction of 56 EPI and 64 PPI, is more aggressive in texture and visual effect. This piece is woven with thin light grey linen yarns in the warp and medium-weight dark grey linen in the weft. The unique aspect of this design is that 10 strips of arecanut yarn are placed in one half of the warp. This provides a really nice visual texture and leaves two totally different effects on the opposite sides of the scarf. The remaining arecanut yarns are snipped off, leaving thick breaking lines that lend a raw, artisanal sensibility to the work. This design explores the concept of duality with wearers receiving two looks in one scarf, and the higher density construction highlights the contrasts in textural elements (refer to Figure 22).



Figure 22. Linen scarves sample 1, 2 & 3 (size 50” × 30”) (warp linen and weft linen and 75% arecanut + 25% cotton yarns).

Across both sets, the weave structure was manipulated to accentuate the interactions among the linen and arecanut fibres. The designs continue to be inspired by the ‘Memory of Malabar’ theme, which considers coastlines, Kerala motifs and arecanut palms themselves in an abstracted way. Arecanut woven linen scarves. These scarves, made of linen and arecanut, are really a treat to the skin. These bags represent the perfect balance of traditional and upcycled materials, drawing in eco-friendly shoppers with handmade quality and a story behind the fabric. These scarves were developed in the only proof of the versatility of arecanut yarn in high fashion accessories. The question from the sustainability point of view also brings up new narratives for textile design, where waste products, bonding process and durable design engage with trends of the time.

4.3.2.4| Traditional Garments - Dhoti

As part of our arecanut yarn exploration, the traditional Kerala "kasavu mundu" dhoti has been revamped by introducing the eco-friendly fibre into this timeless wear. The dhoti is also native to Kerala; men and women wear it, and it is best known for its thin cotton and characteristic golden chandrika. The unique design of the product is in line with the traditional dhoti and utilises arecanut yarn to elevate the traditional and sustainable aspect of the dhoti. The fabric retains the quintessential dexterity of the Kerala dhoti in broad body, with the same kind of high thread count of 74 ends per inch in the warp and 72 to 74 picks per inch in the weft. To achieve the lightweight and soft drape as seen in the original garment,

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very fine cotton yarns - 2/120 count for the warp and 80s count for the weft (refer to Figure 23) were used.



Figure 23. Dhoti weaving on a handloom

The key innovation in the design lies in the borders and subtle detailing within the main body:

Borders: Traditional kasavu (golden zari) borders using arecanut yarns with metallic thread were reimagined. This mixture preserves the shiny look of the classic piece but brings in the sustainable and textural qualities of the arecanut fibre. The result is a border that glitters with tradition yet appeals to modern eco-minded values.

Inner Body Detailing: The dhoti's main white cotton body features stitch lines crafted from thin arecanut yarn. The interventions are subtle, and the visual texture they generate only enriches the essence of the fabric without taking away its perceptual simplicity and subtle beauty. It is a harmonious blend of the two natural fibres, as arecanut lines are interlaced with cotton yarns.

When you see this dhoti, you call its design a perfect balance of old and new. It maintains the cultural significance and aesthetic preferences of the traditional Kerala mundu while also incorporating aspects of sustainability that address contemporary environmental concerns." The sustainable textile not only lends a unique story to each garment, one of upcycling, utilisation of local resources and reverence for craftspersons' traditions, but also uses canary yarn to power both the signature borders, as well as for understated detailing inside the fabric. Infusing this traditional range of saris with arecanut yarn gives the product a new life while contributing to a sustainable future. Also, it offers a new chapter to the illustrious textile heritage of Kerala. This dhoti embodies the `Memory of Malabar' theme in its truest sense, literally weaving the region's agricultural heritage into its most quintessential garment.

5 | LIMITATIONS AND FUTURE WORK ON FABRIC PERFORMANCE TESTING

The fabrics developed in this study, scarves, curtains, and dhotis, were primarily evaluated through their visual and tactile properties. While user feedback on drape, softness, and texture was positive, quantitative fabric-level performance testing was not conducted in this phase. Future work will include the measurement of critical performance indicators such as: Drape coefficient and handle evaluation (for scarves and garments), Tear strength and tensile strength (for upholstery and traditional wear), Abrasion resistance and pilling tendency (for daily-use items), Washability/laundering stability (for all end uses). These metrics are essential to validate the functional viability of the fabrics in real-world applications and will be addressed in the next phase of research.

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Sustainability Considerations: Although a formal Life Cycle Assessment (LCA) was not conducted in this phase, the production methods employed, such as stagnant water retting, mechanical rotor spinning, and the use of unbleached fibres, are inherently low in energy and chemical inputs. Prior studies (Das et al., 2021; Praveena et al., 2022) have reported that arecanut fibres exhibit biodegradability due to their high lignocellulosic composition. The environmental impact of arecanut fibre processing is significantly lower than that of conventional cotton bleaching and synthetic fibre extrusion. Economically, the use of locally available arecanut waste and existing rotor spinning infrastructure reduced material and processing costs by approximately 30% (based on raw material and yarn production estimates). Socially, this research supports local artisan cooperatives and farm communities, aligning with sustainable development goals (SDG 12 and SDG 8). In future phases, a detailed LCA and biodegradability analysis will be conducted to quantify these sustainability claims more rigorously.

6 | CONCLUSION

A small-scale usability evaluation was conducted with five designers and six consumers, who were asked to assess fabric samples based on parameters such as texture, drape, skin feel, visual appeal, and perceived sustainability. Feedback was collected using a structured form, rating each criterion on a 5-point Likert scale. Participants responded positively, particularly highlighting the natural aesthetic and softness of the scarf fabrics, as well as the visual uniqueness of the curtain fabrics. This input supports the conclusion regarding user acceptability of arecanut-based textiles. This study demonstrates the potential of arecanut agricultural waste, specifically husks, as a viable raw material for the development of high-value textile products. Through sustainable processing methods and innovative design approaches, arecanut fibres were successfully transformed into functional yarns and woven fabrics suited for applications in home furnishings, fashion accessories, and traditional garments. The development of arecanut-cotton blended yarns (75:25 ratio) and their integration with cotton and linen demonstrates compatibility across different material systems and product categories. These blended yarns exhibited favourable mechanical properties, such as a breaking work of 30.68 N·cm for the 5s count yarn, confirming their potential for durability-intensive uses like upholstery. The 10s yarns, with higher tenacity, were better suited for lightweight applications like scarves and curtains. Usability trials involving designers and end users provided positive feedback on softness, drape, and comfort, particularly for products in direct contact with the skin, such as scarves. The textiles also offered desirable tactile quality and visual appeal, affirming their applicability in both domestic and lifestyle sectors. Cost-effectiveness is another advantage of this material. Arecanut fibres are locally available and do not require bleaching or dyeing, reducing processing inputs. When combined with simple water retting and rotor spinning, the system presents a low-cost and scalable model that could benefit rural fibre economies and small-scale weaving clusters. This study also makes a critical contribution to the field of circular textile design by providing a replicable method for converting agricultural waste into functional, market-ready textiles. While the current focus was on design and application, future research should include technical textiles, fibre treatment enhancements, life-cycle assessments, and formal usability testing with quantitative data. In sum, the findings affirm that arecanut fibre is not only an environmentally viable alternative but also an economically and culturally relevant one. Its integration into traditional and contemporary textile forms underscores how agro-waste can serve as a meaningful input for the next generation of sustainable textile innovation. While this study was conducted at the laboratory and pilot scale, the methods used particularly water retting and rotor spinning are adaptable to rural production settings. The stagnant water retting method can be scaled using modular fermentation tanks at the village or co-operative level, utilising available water sources. Rotor spinning, though mechanised, can be adapted using low-speed,

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compact machinery suitable for decentralised yarn production in small weaving clusters. Future work will involve collaboration with local cooperatives to test and refine these processes in scaled environments, evaluating parameters such as batch volume, processing time, cost, and energy inputs.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study. The research primarily involved physical material development, textile processing techniques, and design exploration rather than the collection or analysis of quantitative datasets.

CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author(s) used Claude 3.7 Sonnet in order to refine the abstract structure and formatting of the research paper. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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