Chapter V

SUMMARY AND CONCLUSION

Northeast India boasts stunning natural landscapes and is renowned for its rich cultural diversity, with Manipur standing out for its significant handloom industry. Traditionally, weaving has been essential to Manipur's socio-economic fabric, with mulberry silk being a vital raw material. However, as people increasingly seek novelty, there's a growing interest in exploring alternative natural resources for weaving.

Among the abundant resources in the region is pineapple, thriving in areas with high rainfall such as West Bengal, Assam, and Manipur. Pineapple cultivation is a foundation of the local economy, with the fruit being exported and utilized for various purposes, including canning, juice production, and fresh consumption. Interestingly, pineapple leaves, typically discarded after harvesting, hold potential as a textile fiber source.

Pineapple leaf fiber (PALF) holds tremendous promise as a sustainable resource for the textile industry. Extracted from pineapple leaves, which are often discarded after fruit harvesting, PALF offers a range of benefits that make it an attractive alternative to traditional textile fibers like silk.

One of PALF's key attributes is its lengthy and fine fibers, which possess a lustrous quality reminiscent of silk. This inherent silk-like sheen, coupled with its durability and versatility, makes PALF suitable for a wide array of textile applications. Its similarity to silk in appearance makes it particularly appealing for traditional weaving practices, such as those found in Manipur's renowned handloom industry.

Manipur's handloom and textile sector traditionally relies heavily on materials like cotton and mulberry silk. However, the expense associated with silk procurement and the intricate rearing practices required for silk production present significant challenges. Silk production involves particular care of silkworms and cocoons, making it a labor-intensive and delicate process. Even minor disturbances, such as the scent of incense sticks, can harm the delicate silkworms.

Due to the high cost of mulberry silk, textiles woven from this fiber are typically reserved for special occasions and are accessible primarily to those who can afford them. The introduction of PALF into Manipur's traditional weaving practices will offer an alternative raw material to the existing ones. By utilizing a locally available resource that would otherwise go to waste, PALF not only reduces production costs but also minimizes the need for extensive skill training associated with silk rearing. Furthermore, PALF provides an opportunity to provide access to silk-like textiles, making them more affordable and accessible to a broader segment of the population. This innovation has the potential to invigorate Manipur's handloom industry, fostering economic sustainability while preserving its rich cultural heritage.

In essence, the research endeavors to leverage PALF as a cost-effective and environmentally friendly alternative to silk, empowering local artisans and revitalizing Manipur's age-old tradition of handloom weaving.

5.1. Statement of problem

The substantial agricultural waste are generated in India, a country deeply rooted in agriculture. With India has become the most populous nation globally, the demand for agricultural products is expected to surge, consequently increasing agricultural waste production. These agricultural residues, often left behind in fields after harvesting, present an unused resource with potential for various applications, including textile fiber production.

Different parts of fibrous crop plants, such as bast, leaves, seeds, and pseudo stems, can yield diverse types of fibers suitable for textile production. Harnessing these agricultural fibers offers an eco-friendly alternative to harmful synthetic fibers commonly used in textiles. The northeastern region of India, with its predominant agricultural activities, boasts abundant agricultural waste, particularly from pineapple plantations. Manipur, a significant contributor to pineapple cultivation in this region, sees a surplus of pineapple leaves post-harvest, as the primary focus is typically on the fruit.

Utilizing and extracting pineapple leaf fiber for the production of Manipuri textiles presents a viable solution, aligning with the "vocal for local" initiative. This initiative promotes the use of locally sourced materials and products, fostering economic growth and sustainability within communities. By tapping into this readily available agricultural resource, Manipur can leverage its agricultural abundance to revitalize its textile industry while promoting environmental conservation and self-reliance.

5.2. Rationale of the study

The study's rationale roots from the abundance of pineapple leaf agro-waste available locally in Manipur. Currently, after pineapple fruit consumption, the leaves are discarded as waste. Utilizing this agricultural by-product holds the potential for economic growth and the creation of eco-friendly textile materials. The production, processing, and export of pineapple leaf fiber (PALF) could become a significant source of livelihood for small-scale farmers and daily-wage workers.

The researcher aims to explore PALF as a raw material for textile production while preserving the traditional weaving skills of local artisans. Additionally, PALF offers an alternative to conventional silk fibers, being both sustainable and potentially cost-effective over time. Given the extensive cultivation of pineapples in Manipur, there's a strong desire to integrate this local resource into the state's weaving industry, which holds prominence in India's handloom sector.

The people of Manipur are keen to experiment with new materials without compromising on the essence of traditional textiles. However, these endeavors often lack scientific exploration. Therefore, the research seeks to bridge this gap by scientifically investigating the feasibility and benefits of incorporating PALF into Manipur's weaving practices.

5.3. Objectives of the study

1. To study the present status of availability of pineapple leaf fiber in India.

2. To test the properties of extracted pineapple fiber.

3. To modify the fibre for producing pineapple yarns for the traditional textiles and surface ornamentation.

4. To develop union fabric samples on handloom using the produced yarns as weft with silk/rayon/cotton yarns as warp.

5. To study the properties of the samples produced.

6. To develop the traditional textiles of Manipur using Pineapple leaf fibre yarns.

7. To produce colour palettes with reactive & locally available natural dyes used in making the traditional textiles.

8. To create awareness about the use of pineapple waste in the area of textiles.

Hypothesis

Null hypothesis (H_o) - Traditional textiles using pineapple leaf fiber will not be accepted by the consumer

Alternate hypothesis (H_1) - Traditional textiles using pineapple leaf fiber will be accepted by the consumer

Delimitation

The study is delimited to hand woven traditional textiles of Meitei community of Manipur.

5.4. Experimental procedure

The study involved assisting local pineapple growers in Manipur to utilize agro-waste pineapple leaves and creating opportunities for income and skill development among local weavers through pineapple leaf fiber extraction. It explored both manual and machine-based extraction methods, with potential for bulk production using decorticator machines. The extracted fibers could be spun into yarns suitable for traditional Manipuri textiles, offering an alternative to silk. Additionally, the study aimed to promote sustainability in traditional weaving practices by incorporating pineapple leaf fiber, fostering innovation in textile production. It sought to market locally produced pineapple leaf fiber textiles through government initiatives and enhance their value through techniques like plant-based dyes and surface ornamentation, potentially extending their reach to the fashion market.

In view of the objectives, the present study was divided into three phases. In the first phase, procurement of pineapple leaves and extraction of the fiber, testing and treatment of the fiber, and selection of the fiber from untreated and treated for preparing yarn were conducted. In phase two, preparation of different handspun yarns was carried out, and weaving of samples on handloom was adopted. Selection of motifs and colors used in traditional textiles was completed, followed by weaving the traditional designs, dyeing with natural and reactive dyes, cost calculation, and obtaining feedback from consumers.

Availability of Pineapple leaf fibre in India

Pineapple leaf fiber availability in India was assessed by reviewing articles and data from trader websites, followed by contacting numerous fiber suppliers via phone calls, email, and WhatsApp to confirm availability nationwide.

Collection of leaves & Extraction of fibre

Raw materials for pineapple leaf fiber extraction were sourced from local pineapple farms in Kangchup, Manipur, utilizing Kew and Queen varieties. Fiber extraction involved hand scraping and machine extraction of raw material obtained from local pineapple growers, followed by a water retting process lasting 5-7 days. Machine extraction took place at the CSIR-NEIST branch laboratory in Lamphel, Manipur. Post-extraction, washing and scouring procedures were conducted to eliminate residue from the fiber before drying.

Pilot experiment on modification of produced Pineapple leaf fibre

Various treatments were applied to the fiber for spinning through pilot-based experiments, including enzyme treatment and chemical treatment. Cellulose enzyme obtained from Rossari Biotech Limited, Dadra & Nagar Haveli, was utilized for enzyme treatment. Chemical treatment involved the use of hydrogen peroxide and sodium hydroxide, and the experiments were conducted at the Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat.

Testing of physical properties of the fibre

Testing of the fiber's physical properties encompassed assessing its length, fiber fineness, moisture content and regain, tensile strength, and chemical composition. Fiber length was measured using a steel ruler, with an average of 20 readings taken. Fiber diameter was determined by measuring under a digital microscope with a micrometer, also with 20 readings recorded. The whiteness index of the fiber was assessed using a spectrophotometer A5100, while fiber texture was examined under a ZEISS Microscope. Fiber fineness in denier (direct system) was calculated based on the average weight of 20 readings of a 100 cm length of fiber. Moisture content and regain were determined by oven-drying 10gm fiber samples for 4 hours and weighing them afterwards. Tensile strength was measured using a Universal tensile tester machine (UTM) on 10 cm long samples, with an average of 20 readings. Bundle strength testing was conducted using the stelometer tester. Whiteness index evaluation for raw, scoured, enzyme-treated, and bleached fiber was performed using a spectrometer SS5100A, employing D65 illumination with a 6500k color temperature equivalent to average daylight, at a 10o visual angle.

Chemical composition of the fiber

The chemical composition of the raw pineapple fiber was analyzed following the methods suggested by Turner and Doree. This analysis took place at the Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat.

SEM (Scanning Electron Microscope)

The fiber structures of enzyme-treated, chemical-treated, and control samples were examined using a Scanning Electron Microscope, specifically the CARL ZEISS (USA) Model: Sigma with Gemini Column, featuring a resolution of 1.5nm. This observation was conducted at PSG Tech, CDE Indutech, Coimbatore, Tamil Nadu.

Preparation of yarn for weaving and surface ornamentation

To prepare yarn, various spinning tools such as drop spindle, traditional charkha, and phoenix charkha were explored. However, spinning 100% pineapple leaf fiber hand-spun yarns, without any treatment, was achieved using a locally-made motorized pineapple leaf charkha developed by the researcher. Prior to spinning with the motorized charkha, fiber strands were joined end to end to ensure continuous length. Plying of pineapple yarn with rayon and polyester yarn was conducted using amber charkha and peti charkha for surface ornamentation purposes. Five types of plied yarns were produced to assess the feasibility of surface ornamentation using the Juki HZL 27Z (Fashion maker).

Testing of prepared yarn

The properties of the prepared yarn were evaluated as follows: denier (direct system using ASTM D7025) was determined by averaging the weight of 20 readings of a 100 cm length of yarn, yarn count was calculated using the conversion of count system from denier to cotton count, yarn evenness was assessed by measuring the average weight difference of 10 readings of 100cm yarn length, twist per inch (TPI) was determined using ASTM D885 and Alfred Suter twist tester for single yarn, and tensile strength was tested at Aditya Birla's Century Rayon facility.

Construction of traditional textiles on handloom

The produced yarns were utilized as weft for creating textile samples, with the selection of warp yarns based on those traditionally used in Manipuri textiles. Various fabric compositions such as silk/pineapple, rayon/pineapple, cotton/pineapple, and polyester/pineapple were developed to resemble traditional textiles like Rani phee, muga Innaphee, lengyan phee, and muga phanek. Yarn counts of silk-50s, rayon-22s, cotton-25s, and polyester-18s were employed for the fabrics. All samples underwent evaluation to assess their suitability for each specific traditional textile. The physical properties of the developed fabrics were then tested, including tensile strength, elongation, GSM, fabric count, fabric thickness, stiffness, and drape coefficient, using various ASTM test methods. One fabric from the developed samples was selected for further testing using the Kawabata evaluation method.

Dyeing of the preapred pineapple yarn

Dyeing was performed on the natural color of the 100% pineapple spun yarn (30s) without any bleaching treatment. A total of nine reactive dyes and 12 natural dyes, including eight locally extracted plant dyes, were used for dyeing using the conventional exhaust dyeing technique

Dyeing of 100% pineapple yarn involved the use of 2% dye, 20g/l soda ash, and 30g/l sodium chloride, with a liquor ratio of 1:30MLR. The process was conducted for 45 minutes at 60 degrees Celsius, maintaining self pH. Subsequently, washing was carried out using a 2% soap solution.

Common Indian natural dyes such as lac (in crystal form), manjistha (powdered), marigold, and pomegranate were used in the dyeing processes. To expand the collection of traditional dyes used in Manipur, exploration was conducted on Indian Trumpet tree (Oroxylum indicum), Red cedar (Cedrela toona), Mulberry (Morus nigra), and Roselle (Hibiscus sabdariffa). Selection of traditional colors and dye sources for dyeing was based on the hues traditionally utilized in Meitei traditional textiles. These colors include White (Angouba), Yellow (Hangampan), Red (Angangba), Bright pink (Piktruklei macho), Green (Asangba), Pink (Leimachu), Black (Amuba), and Orange (Komla Machu).

The extraction process for dyes involved boiling in distilled water at a ratio of 1:40 MLR for 30 minutes, followed by filtration and settling. Prior to dyeing, the yarn underwent pre-mordanting using 10% alum of the material weight for 30 minutes. Dyeing of 100% pineapple yarn with natural dyes was conducted on the pre-mordanted yarn, utilizing 10% alum, with a dye concentration of 4%, a liquor ratio of 1:30 MLR, and a duration of 45 minutes at 60 degrees Celsius, maintaining self pH. Excess dye was removed by washing with running water.

Testing of dyed yarn samples

Color strength analysis, including CIE L* a* b* c* h* values, color difference, and K/S values (at wavelengths 360-700nm), was conducted using a spectrophotometer SS5100A at the Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat. Wash fastness and light fastness tests were performed following ISO standard test no. II (IS: 764: 1979) and AATC test method 16-B-1977, respectively, at the Department of Textile Chemistry, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat. For wash fastness, samples underwent laundering with a soap and soda ash solution, rated on a scale of 1-5. Light fastness was assessed by exposing dyed samples to sunlight for 8 hours, rated on a scale of 1-8.

Extraction of bromelain enzyme

Bromelain, an enzyme complex abundant in pineapple, is known for its medicinal uses, including anti-inflammatory and digestive properties. To expand its application in textiles, researchers extracted bromelain from pineapple peels through grinding, boiling, centrifugation, and filtration. This process was conducted at the Laboratory Department of a Community Health Center in Manipur. Bromelain finds use in treating wool, agro-waste fiber, softening fiber, and in printing latex and leather processing. In experiments, bromelain was applied to fibers at 1% concentration with 0.5% salt at 66°C for 45 minutes at pH 6-7, with optimization possible by adjusting compound percentages (Kaur, A., & Chakraborty J, N.2015).

Cost Calculations of the constructed fabric

Cost calculation was conducted by assessing expenses related to raw materials through to the finished woven product. This involved calculating the cost of raw materials, transportation, scouring, spinning, and weaving to determine the overall cost of the developed products.

Feedback from the consumer

An assessment was carried out to gauge the viability of incorporating newly developed pineapple yarn as a replacement for conventional materials in textile weaving. This evaluation entailed comparing traditional textiles woven with pineapple yarn to the silk textiles of Manipur, focusing on their physical characteristics. Feedback was collected from Meitei consumers and weavers aged between 18-60 years, covering aspects like aesthetics, cultural relevance, and practical considerations regarding production and usage.

Awareness of use of pineapple leaf fibre for textiles

Consumer feedback will inform the analysis of the constructed fabric, alongside efforts to raise awareness about the developed fabrics through newspaper articles, TV channels, and various social media platforms. An awareness campaign regarding the utilization of pineapple leaf fiber in textiles targeted a cluster of weavers located in areas where local mulberry silk is produced and traditional textiles of the Meitei community are prevalent.

5.5. Results and Discussion

Availability of Pineapple leaf fibre in India

South India

1. Vruksha Composites, Guntur, Andra Pradesh

2. Fiber Region, Chennai, Tamil Nadu
3. Shreekruti agropower, Karnataka
4. Akhil from Kerala
5. South Indian Textile Research Institute, Coimbatore, Tamil Nadu

West India

1. Meher, International, Surat, Gujarat

East India

1. ICAR- National Institute of Natural Fiber Engineering and Technology, Kolkata, West Bengal
2. Chandra Prakash & Co., Jaipur/ Kolkata

Northeast India

1. Ramie Research Station, Sarbhog, Assam
2. Sherrard Wallang, Environmentalist, Shillong, Meghalaya
3. M/S Anchal, Teliamura bus stand, Agartala, West Tripura
4. Assam Agricultural University, Jorhat
5. Emitex Export, Noida, Uttar Pradesh- Fibre from Lower Assam and Nagaland-

Several organizations initially approached for pineapple leaf fiber samples were unable to provide them due to various reasons, including labor-intensive processes, time constraints, difficulty in accessing farms, and lower popularity compared to other fibers like banana. Additionally, many organizations discontinued their work on pineapple leaf fiber after completing specific projects. Only two organizations provided samples, but they were of poor quality and unsuitable for yarn preparation. One organization sent raw fiber along with dried leaves at a high cost, while the other provided a small amount of coarse fiber with low strength and a possibility of chemical use. Consequently, the researcher had to extract the fiber independently. Interviews were conducted with personnel familiar with fiber extraction, including former staff from the Design Department and the District Industrial Center in Manipur who worked on pineapple leaf fiber in the 1970s.

Extraction of fiber

The researcher explored two extraction methods: mechanical extraction and manual extraction followed by water retting. Mechanical extraction was facilitated by CSIR-NEIST Laboratory in Lamphelpat, Manipur. Manual extraction was carried out at the researcher's residence using hand scraping and hammering techniques, the latter of which was devised by the researcher to remove the hard covering substance from the leaves prior to water retting. To minimize damage to fiber length and increase fiber yield, light hammering was applied to the leaves before retting. This process yielded long and smooth fibers, with the hammering method proving more effective in preserving fiber quantity. However, manual extraction was labor-intensive and time-consuming, leading to a recommendation for machine extraction for larger-scale fiber production.

Pilot experiment on modification of produced Pineapple leaf fibre

One drawback of natural minor fibers is their stiffness and harness. Typically, these fibers require softening treatments. However, in the case of scoured pineapple leaf fibers, no additional treatment was necessary for preparing stiff yarn for traditional weaving in Manipur. Since the scoured fibers proved to be suitable for yarn preparation, the researcher decided to eliminate the use of enzyme and chemical treatments in further processing. This not only minimized the use of chemicals but also reduced the need for expensive enzymes for softening. Additionally, the researcher examined the longitudinal structure of raw fibers, scoured fibers, enzyme-treated fibers, and bleached fibers under FESEM to determine spinning parameters for yarn preparation.

Testing the properties of fibre

The pineapple leaf fiber exhibited characteristics of a long staple fiber with an average length ranging from 65 to 92 cm and a diameter of 0.7-1.2 µm, resulting in a denier of 47.57. It was considered both long staple and very fine. The fiber was hydrophilic, with a moisture content of 10% and a moisture regain of 11.1%, which was better than cotton but lower than flax.

In terms of strength, the pineapple leaf fiber demonstrated good tensile strength, with a value of 4.278 gf/den, and a bundle strength of 27 g/tex. Additionally, its chemical composition includes 3.1% fats and waxes, 1.2% pectin, 2% hemicellulose, 1.3% lignin, and 77.7% cellulose, with a water-soluble component of 14.7%.

FESEM analysis revealed physical and chemical changes in the fiber's surface morphology under different conditions. Scouring resulted in a smoother surface, while bleaching caused structural deterioration. Enzyme treatment led to an even smoother fibrous surface.

Preparation of yarn for weaving and surface ornamentation

A motorized spinning wheel, inspired by the Phoenix charkha, was custom-built for producing yarn from pineapple leaf fiber. The attached motor has a capacity of 500 RPM, but the charkha's speed was set at approximately 200 RPM to create fine 100% pineapple leaf fiber yarn. Fine 100% pineapple leaf fiber yarn with a count of 30s, having a twist per inch (TPI) of 80-85 in a Z-twist for phee, and a thicker yarn with a count of 8s in a Z-twist for phanek, were successfully crafted without any treatment, suitable for traditional Manipuri textiles. Additionally, five two-ply yarns combining pineapple fiber with rayon and polyester were produced using Amber and Peti charkhas, and their viability for surface ornamentation on sewing machines was assessed.

Attempts to create a medium twist ply yarn of pineapple/polyester using the Amber charkha were unsuccessful due to the formation of snarls resulting from the high twist. Consequently, a total of five ply yarns were created instead.

The yarn for phee had a denier of 177D, a yarn count of 30’s, and a Z twist with 80-85 TPI. For the phanek, the yarn has a denier of 730D, a yarn count of 8’s, and a Z twist with 16 TPI. Both yarns exhibited good evenness, with mean deviations of 2.3% for the 30s yarn and 9.62% for the 8s yarn, indicating minimal variation.

Various combinations of pineapple fiber with rayon and polyester were spun into yarns using different charkhas. The yarns varied in twist per inch (TPI), twist direction, and count. For example, pineapple/rayon yarns with low twist (PRL) were spun on the Amber charkha with a TPI of 6-8 and a count of 15s, while pineapple/polyester yarns with low twist (PPL) were also spun on the Amber charkha with similar specifications but a count of 14s.

For surface ornamentation trials, these yarns were combined as lower threads with polyester or rayon as upper threads. The combinations included PRL, PRM, PRP, PPL, and PPP yarns, each paired with either polyester or rayon.

Testing of prepared yarn

The testing of the strength and elongation characteristics of different yarns, including 100% pineapple yarn and plied yarns, provided insights into their ability to withstand external forces and their deformation behavior under applied loads.

For the 100% pineapple yarn (30's), a maximum load of 128 grams was observed, with a tenacity of 0.72 g/den, stress of 0.021 g/den, strain of 1.4%, and elongation of 1.4 mm. These parameters indicate the material's ability to resist breaking, its strength relative to linear density, and its deformation under applied loads.

The yarn (8's) demonstrated remarkable resilience, enduring a maximum load of 2176.42 grams at a speed of 100mm/min, underscoring its ability to withstand external forces. Tenacity, measured at 43.53 grams per denier (g/den), highlighted the material's strength relative to its linear density. With an elongation of 2.62 millimeters, the material exhibited significant stretch or deformation under the applied load. Stress, calculated at 2.98 grams per denier (g/den), depicted the force applied per unit area of the material. Strain, reported as 5.25%, indicated the percentage of elongation relative to the original length of the yarn (8's), showcasing its capacity to endure external forces without permanent damage.

The strength of the plied yarns were PRL (Pineapple Rayon, low twist) yarn, produced on the Amber charkha, exhibited a maximum load of 673.49 grams at a speed of 100 mm/min. Its tenacity was measured at 1.90 g/den, and it showed an elongation of 2.62 mm. The stress on the yarn was 1.90 g/den, and the strain was 5.24%.

PRM (Pineapple Rayon, medium twist) yarn, also made with the Amber charkha, had a higher maximum load of 786.41 grams. Its tenacity was slightly higher at 1.92 g/den, with an elongation of 3.48 mm. The stress and strain were 1.92 g/den and 6.97%, respectively.

PRP (Pineapple Rayon) yarn, spun on the Peti charkha, demonstrated a maximum load of 784.81 grams. It had the highest tenacity among the samples at 2.07 g/den, with an elongation of 2.80 mm. The stress and strain were 2.07 g/den and 5.61%, respectively.

PPL (Pineapple Polyester, low twist) yarn, produced on the Amber charkha, showed a maximum load of 747.27 grams. Its tenacity was 1.97 g/den, with an elongation of 2.23 mm. The stress and strain were 1.97 g/den and 4.46%, respectively.

PPP (Pineapple/Polyester) yarn, spun on the Peti charkha, had a maximum load of 646.91 grams. Its tenacity was the lowest among the samples at 1.58 g/den, with the highest elongation of 3.88 mm. The stress and strain were 1.58 g/den and 7.76%, respectively.

The mean tenacity of the plied yarn samples was 1.89 g/den, indicating the average strength across the dataset. The standard deviation of tenacity (0.184 g/den) suggests variability in strength among the samples, with some samples exhibiting higher or lower strength than the average. Samples closer to the mean had relatively less variability in strength compared to those farther from the mean. The variance (0.0340) provides insight into the average squared deviation of data points from the mean, with lower values indicating less variability in the dataset. The standard error of the mean (SEM), measuring the precision of the sample mean estimate, quantified the uncertainty or variability in the sample mean, with a value of 0.0824 in this case.

Different TPI (Twist Per Inch) of the prepared plied yarns were- very fine yarn for Phee (30's): Featuring a Z twist with 80-85 TPI, this yarn, also known as crepe twist, offers excellent cohesion and strength, enhancing durability during weaving. Higher count yarn for Phanek (8s): With a Z twist and 16 TPI, this yarn demonstrated moderate twist density, suitable for various applications. PRL (Pineapple/Rayon–low twist): Exhibits a low twist density (6-8 TPI), resulting in a softer texture ideal for lightweight fabrics or delicate garments. PRM (Pineapple/Rayon-medium twist): Featured a higher twist density (16-17 TPI), providing increased strength and stability, suitable for upholstery or heavy-duty textiles. PRP (Pineapple/Rayon): With a moderate twist density (13-14 TPI), PRP offers a balanced compromise between softness and strength, suitable for various textile applications. PPL (Pineapple/Polyester-low twist): Similar to PRL, PPL had a low twist density (6-8 TPI), focusing on achieving softness and flexibility, suitable for lightweight fabrics or decorative uses. PPP (Pineapple/Polyester): With a higher twist density (14-16 TPI), PPP offered enhanced strength and resilience, suitable for durable applications, benefiting from the combination of natural and synthetic fibers.

Construction of traditional textiles on handloom

Plain weave was utilized to create fabric samples such as silk/pineapple (known as Rani phee), cotton/pineapple (referred to as Lengyan), rayon/pineapple (called muga Innaphee), and Muga phanek (a polyester and pineapple union fabric). These textiles hold cultural significance among the Meitei community in Manipur. For instance, Rani phee, named after a skilled weaver named Rani, is traditionally worn as an upper garment during special occasions, particularly weddings. Similarly, Muga Innaphee, a traditional textile often seen at various events, holds particular prominence in places like Khurkhul. Lengyan phee, suitable for both men and women, is draped over the shoulder during festivities. Muga phanek, typically made from silk/muga, serves as a lower garment akin to a sarong. Phanek, a traditional Meitei textile, primarily employs cotton and silk fibers, notably mulberry muga from Khurkhul. The stiffness achieved from pineapple fibers closely resembles that of existing traditional textiles, making them highly suitable for crafting the proposed fabrics. In Manipur, locals and weavers commonly employ starch finishing techniques to enhance the stiffness of textiles. The developed fabrics exhibit characteristics such as thinness, light weight, and good tensile strength, making them suitable for various applications.

The properties of the developed fabrics

Rani phee featured a warp yarn count of 50s and a weft yarn count of 30s, with corresponding fabric counts of 66 and 44. It had a cover factor of 14.68 and a GSM of 56, with a thickness of 0.24mm. Khurkhul muga Phee had a warp yarn count of 21s and a weft yarn count of 30s, resulting in fabric counts of 16 and 36. Its cover factor was 9.24, with a GSM of 77.48 and a thickness of 0.26mm. Lengyan Phee showcased a warp yarn count of 25s and a weft yarn count of 30s, with fabric counts of 16 and 44. It had a cover factor of 5.34, a GSM of 75.96, and a thickness of 0.30mm. Muga Phanek had a warp yarn count of 18s and a weft yarn count of 8s, with fabric counts of 39 and 32. Its cover factor was 15.03, with a GSM of 184.4 and a thickness of 0.57mm. These properties collectively characterized the fabrics and informed their evaluation for various applications.

The tensile strength of the developed fabrics, including Rani phee (Silk/Pineapple), Khurkhul muga Phee (Rayon/Pineapple), Lengyan Phee (Cotton/Pineapple), and Muga Phanek (Polyester/Pineapple), was evaluated under varying conditions. For Rani phee, the warp direction exhibited a tenacity of 0.20 Kgf/mm, with an elongation of 9.85 mm and a maximum load of 10.21 Kgf, resulting in a percentage strain at maximum load of 19.70%. In the weft direction, a tenacity of 0.30 Kgf/mm, elongation of 2.75 mm, maximum load of 14.76 Kgf, and percentage strain at maximum load of 5.50% were observed. Khurkhul muga Phee showcased a warp tenacity of 0.32 Kgf/mm, elongation of 9.67 mm, maximum load of 15.91 Kgf, and percentage strain at maximum load of 19.34%. In the weft direction, it exhibited a tenacity of 0.27 Kgf/mm, elongation of 3.18 mm, maximum load of 13.46 Kgf, and percentage strain at maximum load of 6.36%. Lengyan Phee displayed a warp tenacity of 0.20 Kgf/mm, elongation of 11.05 mm, maximum load of 9.90 Kgf, and percentage strain at maximum load of 22.11%. In the weft direction, it showed a tenacity of 0.24 Kgf/mm, elongation of 3.75 mm, maximum load of 12.15 Kgf, and percentage strain at maximum load of 7.50%. Muga Phanek demonstrated a warp tenacity of 0.51 Kgf/mm, elongation of 24.3 mm, maximum load of 25.52 Kgf, and percentage strain at maximum load of 48.60%. In the weft direction, it had a tenacity of 0.45 Kgf/mm, elongation of 2.71 mm, maximum load of 22.70 Kgf, and percentage strain at maximum load of 5.421%. These results provide insights into the tensile strength characteristics of the fabrics, essential for assessing their suitability for various applications.

The average fabric stiffness/bending length was analyzed by measuring the warp and weft dimensions of each fabric in both face-to-face and back-to-back orientations. Rani phee exhibited warp dimensions ranging from 3.12 cm to 3.38 cm and weft dimensions ranging from 9.68 cm to 9.32 cm. Khurkhul muga Innaphee showed warp dimensions ranging from 3.68 cm to 3.42 cm and weft dimensions ranging from 6.41 cm to 6.7 cm. Lengyan Phee displayed warp dimensions of 3.12 cm to 3.1 cm and weft dimensions of 8.76 cm to 8.86 cm. Muga Phanek had warp dimensions ranging from 2.98 cm to 2.99 cm and weft dimensions ranging from 7.9 cm to 8 cm. Khurkhul muga Innaphee had the highest warp dimension value, while Rani phee had the highest weft dimension value. On the other hand, Muga Phanek had the lowest warp dimension value, and Rani phee had the lowest weft dimension value. These analyses offer valuable insights into the dimensional characteristics of each fabric.

The drape coefficient values of fabrics made from Silk/Pineapple (S/P), Rayon/Pineapple (R/P), and Cotton/Pineapple (C/P) were notably higher than those of traditional textiles like Silk/Silk (S/S), Rayon/Silk (R/S), and Cotton/Silk (C/S), both starched and de-starched. For instance, S/P fabric exhibited a drape coefficient of 67.57%, surpassing the 60.61% of S/S fabric, indicating superior drapability. Similarly, R/P fabric showed a coefficient of 57.13%, higher than the 53.65% of R/S fabric. Additionally, C/P fabric displayed a coefficient of 64%, outperforming both starched and de-starched C/S textiles. These results suggest that fabrics incorporating pineapple yarn offer comparable drapability to traditional textiles, potentially benefiting the Meitei community's traditional textile production.

Kawabata Analysis

The Kawabata Evaluation System (KES) offers tools to assess textile mechanical properties influencing tactile sensations, aiding in garment material evaluation for comfort. By measuring properties like tensile, shear stiffness, and bending rigidity, KES provides insights into fabric hand. The fabric analyzed displayed moderate stiffness (Koshi 8.17), smooth surface texture (Numeri 6.42), and high fullness & softness (Fukurami 9.63), resulting in a favorable Total Hand Value (THV) of 3.05 out of 5. These properties make it suitable for women's thin dresses, meeting requirements for style, comfort, and quality.

The Cotton/pineapple Fabric showed a LC value of 0.303 g.cm/cm^2, indicating a linear compression-thickness relationship and uniform compression behavior. Its WC value of 0.283 g.cm/cm^2 suggested softness and pliability, contributing to enhanced comfort and ease of movement in women's thin dresses. The fabric's high compressional resilience (RC) of 37.56% indicated effective recovery to its original shape after compression, ensuring durability and shape retention. Overall, these compression properties provide the fabric's suitability for use in women's thin dresses, offering a blend of consistency, comfort, and resilience.

The Cotton/pineapple Fabric was evaluated for its thickness and weight under standard and maximum pressure conditions, offering insights into its structural properties. Initially measuring 0.819 mm, the fabric's thickness served as a baseline, while under maximum pressure, it reduced to 0.448 mm, demonstrating its compressibility and ability to adapt to external forces for maintaining garment shape and comfort. Weighing 7.434 mg/cm^2, the fabric's density was assessed, influencing its drape, durability, and suitability for garment applications. The analysis underscores the fabric's resilience and adaptability, making it suitable for garments requiring both comfort and shape retention.

The tensile properties of the Cotton/pineapple Fabric were assessed using a tensile tester, revealing distinct mechanical characteristics in both warp and weft directions. In the warp direction, the fabric displayed a LT value of 0.552 gf.cm/cm², indicating a linear load-extension curve and uniform deformation behavior. It also exhibited a WT of 7.78%, indicating high energy absorption, a RT of 52.47%, indicating good resilience, and an EMT of 5.64%, indicating moderate extensibility before failure. Conversely, in the weft direction, the fabric showed slightly different properties: a LT of 0.753 gf.cm/cm², lower WT at 1.73%, higher RT at 73.09%, and lower EMT at 0.92%. This suggests varying deformation behaviors and energy absorption capabilities in different directions. Overall, the analysis provides valuable insights into the Cotton/pineapple Fabric's mechanical behavior, highlighting its directional dependence in tensile properties.

The fabric shear properties using a shear tester, revealing distinct behavior in both warp and weft directions. In the warp direction, it showed a Shear Stiffness (G) of 0.552 gf.cm/deg, with Hysteresis of shear force at 0.5-degree shear angle (2HG) at 7.78 gf/cm and at 5-degree shear angle (2HG5) at 52.47 gf/cm. Conversely, in the weft direction, it exhibited Shear Stiffness (G) of 0.753 gf.cm/deg, with 2HG at 1.73 gf/cm and 2HG5 at 73.09 gf/cm. These results indicate directional dependence in shear stiffness and hysteresis, providing insights into the fabric's behavior under shear forces.

The Fabric's surface properties were analyzed using a Surface Tester, revealing differences in warp and weft directions. In the warp direction, it showed a Coefficient of Friction (MIU) of 0.121, Mean Deviation of MIU (MMD) at 0.0263, and Geometrical Roughness (SMD) of 7.770 µm. Conversely, in the weft direction, it exhibited MIU of 0.252, MMD at 0.0279, and SMD of 12.740 µm. These results indicate directional variations in surface smoothness and roughness, providing insights into the fabric's frictional characteristics.

The Fabric's bending properties were evaluated using a pure bending tester, revealing differences in warp and weft directions. In the warp direction, it showed a Bending Rigidity (B) of 0.0359 gf.cm²/cm and Hysteresis of Bending Moment (2HB) at 0.0348 gf.cm²/cm. Conversely, in the weft direction, it exhibited B of 1.9740 gf.cm²/cm and 2HB of 0.9651 gf.cm²/cm. These results highlight directional variations in flexibility and energy transmission, offering insights into the fabric's bending behavior.

Dyeing of Pineapple yarn

The dyeing process of 100% pineapple spun yarn (30's) involved utilizing both reactive and natural dyes to achieve traditional colors aligned with Meitei textile traditions. Reactive dyes, known for their colorfastness, were applied using conventional exhaust dyeing techniques, offering vibrant hues and long-lasting retention. Nine reactive dyes provided a diverse color palette, catering to various design preferences. On the other hand, 12 natural dyes sourced from local plant species in Manipur offered eco-friendly alternatives, contributing to sustainability and preserving traditional dyeing knowledge. These natural dyes infused the fabrics with unique tones, celebrating the region's botanical diversity. Phytochemical tests confirmed the presence of key compounds in these dyes. By incorporating both reactive and natural dyes, the dyeing process ensured authenticity, sustainability, and aesthetic richness in the resulting fabrics, reflecting a commitment to cultural preservation and environmental responsibility in textile production.

Colour strength Analysis

The color strength analysis conducted with a spectrophotometer SS5100A provided comprehensive insights into various color parameters such as L*a* b* c* h*, which denote brightness, hue, chroma, and other essential characteristics. The color analysis revealed distinct characteristics of synthetic and natural dyes. Synthetic dyes exhibited varied hues and saturations, with RBY (Reactive bright yellow) being the lightest and most saturated yellow shade, while RP (Reactive pink) showcased a highly saturated reddish hue. In contrast, natural dyes like KTP (*Kuthap*) displayed lightness similar to synthetic RBY, with SMB (*Shamba)* showcasing a strong yellow hue akin to synthetic dyes. The analysis highlighted consistent trends in hue and saturation across both dye types, with yellow hues dominating. Additionally, chroma values indicated saturation levels, with natural dye MLB (*Kabrang)* being the least saturated and *Shamba* being the most saturated. The hue angle provided insights into the color position on the wheel, with *Lamuk* exhibiting the highest angle and SGR (*Silok Sougri)* the lowest, reflecting their respective color shades. Overall, the colorimetric analysis aids in comprehending color characteristics for diverse textile applications.

K/S values, representing the ratio of absorption coefficient (K) to scattering coefficient (S), were utilized to gauge the color intensity and depth of the dyed materials. These values were acquired across the wavelength spectrum of 360nm to 700nm using the SS5100A spectrophotometer. In this context, K stands for absorption coefficient, while S denotes the scattering coefficient of the dyes. The selection of K/S values for each dye was based on reflectance values falling within the 1 to 10 range to ensure the analysis's reliability. Both reactive and natural dyes underwent analysis to determine their K/S values, encompassing different wavelengths and reflectance values.

Color difference compares the discernible variation in color between two samples, typically contrasting a dyed sample with a control sample representing the original color. This assessment aids in evaluating the effectiveness of the dyeing process and the impact of the dye on the material's color. Utilizing color difference metrics, such as the CIE Value, quantifies these differences. In this analysis, color differences were calculated between the controlled sample (undyed pineapple yarn) and the dyed pineapple yarn for all dyes. Negative L* values signify a darker appearance, while positive a* and b* values indicate increases in redness and yellowness, respectively. Positive C* values suggest a brighter color. Understanding these differences provides insights into how various dyes influence the overall color characteristics of the samples.

The colorfastness of the dyed pineapple yarns to washing and light exposure was evaluated using a rating scale ranging from 1 to 5 for wash fastness and 1 to 8 for light fastness. Ratings were assigned based on performance, with 1 being very poor and 5 or 8 being excellent. Overall, the results indicated that the wash fastness of all reactive dyes was very good to excellent, with most samples achieving a rating of 4 (very good). However, two dyes, Silok Sougri and Kabrang, received ratings of 2-3 (poor to moderate). In terms of light fastness, Reactive Brilliant Yellow (RBY), Reactive Yellow (RY), and Reactive Pink (RP) showed excellent results. Shamba, Tairen, Yachubi, and Sanarei dyed samples also exhibited excellent light fastness, while the remaining samples ranged from very good to excellent. These findings suggest that both reactive and plant dyes are suitable for dyeing pineapple leaf fiber yarn.

Extraction of bromelain enzyme

Extraction was conducted using varying Material Liquor Ratios (MLR) and mediums. Firstly, alkali water (ground water) at a ratio of 1:30 MLR was used at 100°C, and secondly, extraction was performed using distilled water at a ratio of 1:20 MLR at 100°C. Optimization of centrifugation parameters was carried out, including time and regulator speed. Centrifugation durations of 2, 5, 10, and 15 minutes were tested, with 2 and 5 minutes proving insufficient for solid-liquid separation. The optimal duration was found to be 10 minutes, as no further separation was observed beyond this point. The centrifuge machine, equipped with a regulator offering 5-speed stages, showed that the 2nd stage speed was optimal. With a capacity of 8 tubes of 15 ml each, filtration followed this process, after which the samples were stored in the refrigerator.

Cost Calculations of the constructed fabric

The process involved utilizing waste pineapple leaves for extraction, scouring, and spinning to produce yarn, with a total cost of Rs 8000 per kilogram. Analyzing the cost calculation for each fabric—Rani Phee, Lengyan Phee, Muga Innaphee, and Muga Phanek—revealed their unique features and associated costs. Rani Phee, a silk and pineapple yarn blend, priced at Rs 3010 per meter, offered delicate designs with intricate weaving. Lengyan Phee, combining cotton and pineapple yarn, had wider width and elegant designs at Rs 2,193 per meter. Muga Innaphee, a luxurious Rayon and Pineapple blend, featured detailed designs at Rs 2318 per meter. Muga Phanek, woven from polyester and pineapple yarn, offered durability and affordability at Rs 759 per meter, incorporating temple stoop motifs. Each fabric showcased pineapple fiber's qualities while catering to diverse preferences and price ranges.

Feedback from the consumer

A feedback collection was done base on the physical appearance of pineapple leaf fiber, yarns, and textiles, by adapting interviews with 74 consumers, including weavers from the Meitei community aged between 18 and 60 years. The questionnaire comprised 24 questions categorized into background information of the respondents, preliminary information about the topic, examination of samples, and feasibility in the market. The questionnaire incorporated both open-ended and closed-ended questions in English and the local language (Manipuri) to gather comprehensive feedback from the participants.

The gather data from feedback gave the potential of pineapple leaf fiber fabrics in the market, driven by consumer interest, perceived value, and alignment with cultural and environmental values. With further development and strategic pricing, pineapple fabrics had the opportunity to establish a significant presence in the textile industry, catering to both traditional and modern fashion markets. Feasibility feedback indicated that 97.3% of respondents express interest in trying fashion garments made from pineapple fabrics. Additionally, the outcome of the Kawabata analysis suggests that the fabrics were suitable for women's thin dress fabric. Inspired by this feedback and analysis, the researcher conducted an experiment to visually assess the effect of creating high-fashion garments using the developed pineapple fabrics.

Testing of hypothesis

The hypothesis testing aimed to assess the acceptance of traditional textiles made from pineapple leaf fiber by consumers. It was framed as a null hypothesis (H0) stating that these textiles would not be accepted and an alternate hypothesis (H1) stating they would be accepted, the analysis employed chi-square and ANOVA tests.

Using the chi-square test, categorical data from consumer feedback showed a significant discrepancy between observed and expected frequencies, with a chi-square value of 230.34 and a p-value exceeding the critical value, indicating that more than 50% of consumers accepted the pineapple leaf fiber textiles. Consequently, the null hypothesis was rejected, affirming consumer acceptance of these textiles.

Supporting this finding, ANOVA analysis compared drape coefficients of developed pineapple fabrics with existing traditional textiles (starched). The results revealed no significant differences in drape coefficients among fabric groups, indicating that the addition of pineapple yarn did not significantly alter drape characteristics compared to traditional textiles. Consequently, the null hypothesis was rejected again, suggesting that pineapple leaf fiber inclusion in traditional textiles is accepted by consumers without significant alteration to fabric properties.

Awareness about the pineapple leaf fiber

Awareness of pineapple leaf fiber as a textile material has been facilitated through various channels:

Khangminashi Program Episode 18 Talk: Impact TV featured a discussion on pineapple leaf fiber, raising awareness about its potential as a textile material.

Newspaper Articles: Sanaleibak Daily in Manipur published two articles on pineapple leaf fiber, dated July 13, 2022, and December 5, 2022, respectively, further disseminating information about its properties and uses.

Products Display at the 9th National Handloom Day: Pineapple leaf fiber products were showcased during the event held on August 7, 2023, at the Institute of Fashion Technology, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, increasing visibility and recognition of the material.

Training Program for Handloom Weavers: A training program focused on raising awareness about pineapple leaf fiber was conducted for a handloom weavers cluster group in Khurkhul, Manipur. This initiative targeted artisans who are already engaged in producing local mulberry silk products, known as Khurkhul muga, expanding their knowledge and skill set to include pineapple leaf fiber in their raw materials.

SWOC Analysis

The SWOC analysis of utilizing pineapple leaf fibers (PALF) in traditional textile production in Manipur highlights several key points:

Strengths: PALF offers inherent sustainability and eco-friendliness, aligning with the increasing demand for environmentally conscious products. Its fine yarn production capabilities and tensile strength make it a suitable alternative to traditional materials like silk. PALF provides additional income opportunities for farmers through waste leaf sales, contributing to economic sustainability. Integrating PALF into traditional weaving techniques preserves local skills while introducing a new raw material.

Weaknesses: Hand extraction of PALF is time-consuming and expensive, hindering scalability and cost-effectiveness. Quality consistency issues may arise due to variations in leaf quality.

Limited mass production and marketing efforts hinder widespread adoption and consumer awareness.

Opportunities: Growing demand for sustainable products positions PALF as an eco-friendly alternative. PALF can serve as a silk alternative in traditional textile production. Exploring applications beyond traditional textiles can expand PALF's market reach.

Challenges: Installation of extraction machines presents technical and financial barriers. Competition with synthetic fibers and limited market availability pose challenges. Addressing consumer education gaps is crucial for increasing awareness and acceptance.

Integration and Strategy Formulation: Develop cost-effective machine extraction methods to enhance scalability. Collaborate with local communities to integrate PALF into traditional production. Invest in research to improve quality consistency and explore new applications. Implement targeted marketing campaigns to raise awareness and generate demand.

Sustainable Development Goals (SDGs)

Utilizing pineapple leaf fiber in sustainable textiles within Manipur and other Northeast Indian states offers a promising pathway towards achieving Sustainable Development Goals (SDGs). By incorporating this natural material into textile production, the region can create employment opportunities, promote economic growth, and build sustainable communities. This approach aligns with SDG 8 (Decent Work and Economic Growth), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production). By upcycling agro-waste like pineapple leaves, the textile industry can contribute to reducing environmental pollution and fostering a circular economy. Achieving these goals not only addresses local economic and environmental challenges but also supports broader global sustainability objectives.

Conclusion

The study of using pineapple leaf fiber (PALF) for traditional Manipuri textiles offers a great chance to preserve cultural heritage while addressing environmental and economic issues. In order to strengthen Manipur's handloom sector and give local artisans more authority, the study investigated PALF as a sustainable substitute for traditional silk fibers. This study clarified the viability and advantages of utilizing this locally accessible resource in Manipur's textile sector by thoroughly examining the qualities of PALF and its possible uses in traditional weaving techniques. The study had shown that PALF is a good raw material for traditional textiles since it has characteristics similar to those of silk, such as long, fine threads with lustrous.

The research showed that PALF may be easily incorporated into current weaving procedures by creating yarns and fabric samples, providing a viable and affordable substitute for traditional silk fibers. Additionally, using PALF could lower production costs, lessen environmental effect, and give a larger portion of the population access to fabrics that resemble silk.

The exploration of pineapple leaf fiber's (PALF) availability in India revealed a challenging environment characterized by restricted accessibility and inconsistent sample quality. Even though PALF has the potential to be a sustainable textile resource, getting appropriate samples has proven to be difficult for a number of reasons. Originally, requests for PALF samples were made to a broad range of institutions in several Indian states. But they faced many challenges, such as labor-intensive procedures, schedule limitations, and accessibility issues to farms that produce a lot of pineapple leaves. Furthermore, the availability of samples from these organizations was further hampered by PALF's lesser popularity in comparison to other fibers like banana. Only two organizations provided samples to the researcher, which were of poor quality, requiring independent PALF extraction by the researcher. Despite these obstacles, the study emphasizes the importance of exploring alternative textile resources for sustainability. Moving forward, efforts should focus on refining PALF extraction processes, improving quality standards, and fostering collaboration among stakeholders. Additionally, initiatives to raise awareness about PALF's potential benefits are crucial for its development as a viable raw material in the textile industry.

Important insights were obtained from the researcher's investigation of two pineapple leaf fiber extraction techniques: mechanical extraction supported by the CSIR-NEIST Laboratory and hand extraction followed by water retting carried out at the researcher's home. Although long, silky fibers were produced by both processes, the hand extraction method—especially when combined with the creative hammering technique—proved more successful in maintaining the quantity of fiber. It was time-consuming and labor-intensive, though, which is why machine extraction was suggested for larger-scale fiber manufacturing. This study opens the door for the possible incorporation of pineapple leaf fiber into regular textile production by highlighting the significance of improving extraction techniques to maximize fiber output and quality.

The pilot experiment on the modification of produced pineapple leaf fiber yielded valuable insights into its properties and processing techniques. The study revealed that scoured pineapple leaf fibers were suitable for yarn preparation without the need for additional softening treatments, minimizing the use of chemicals and expensive enzymes. Analysis of fiber properties, including length, diameter, moisture content, and tensile strength, highlighted the fiber's potential as a long staple and very fine material with good mechanical properties.

Furthermore, FESEM analysis provided a deeper understanding of the fiber's surface morphology under different treatment conditions, indicating physical and chemical changes. Scouring resulted in a smoother surface, while bleaching caused structural deterioration, and enzyme treatment further improved surface smoothness.

The preparation of yarn for weaving and surface ornamentation using pineapple leaf fiber (PALF) showed the researcher's innovative approach to fiber processing and yarn production. By custom-building a motorized spinning wheel inspired by traditional charkhas, the researcher successfully crafted fine 100% PALF yarns suitable for traditional Manipuri textiles, including phee and phanek.

The study revealed that PALF yarns could be produced without the need for additional softening treatments, minimizing the use of chemicals and expensive enzymes. Various combinations of PALF with rayon and polyester were also spun into yarns, offering a range of textures and applications for surface ornamentation on sewing machines.

Testing of the prepared yarns provided valuable insights into their mechanical properties, including strength, elongation, and twist per inch (TPI). The 100% PALF yarns demonstrated good tensile strength and resilience, while plied yarns combining PALF with rayon or polyester exhibited enhanced strength and stability.

Different TPI settings were explored for the plied yarns, catering to specific textile applications ranging from lightweight fabrics to heavy-duty upholstery. The findings featured the versatility of PALF as a sustainable textile material, offering a balance between softness, strength, and durability.

The development and analysis of fabrics incorporating pineapple leaf fiber (PALF) in traditional Manipuri textiles showcase the promising potential of PALF in enhancing cultural garments and applications. Fabrics like Rani phee, Khurkhul muga Phee, Lengyan Phee, and Muga Phanek exhibit characteristics such as thinness, light weight, and good tensile strength, making them suitable for various occasion’s wear. Tensile strength evaluations reveal the robustness of these fabrics, essential for their durability and performance. Furthermore, analyses of fabric stiffness and drape coefficient highlight PALF's ability to enhance drapability and dimensional characteristics, contributing to the comfort and aesthetic appeal of traditional Meitei textiles. These findings concluded that PALF's potential to rejuvenate traditional textile practices while promoting sustainability and cultural heritage preservation in Manipur.

The comprehensive evaluation of the Cotton/pineapple Fabric using the Kawabata Evaluation System (KES) provides valuable insights into its mechanical, compression, thickness, weight, tensile, shear, surface, and bending properties. These analyses revealed the fabric's favorable characteristics such as moderate stiffness, smooth surface texture, high fullness & softness, and excellent compressional resilience, making it suitable for women's thin dresses. The directional dependence observed in tensile, shear, surface, and bending properties underscores the fabric's versatility and potential applications in various garment contexts. Overall, the Cotton/pineapple Fabric exhibits a blend of consistency, comfort, and resilience, highlighting its suitability for fashion garments requiring both style and functionality.

The dyeing process of pineapple yarn successfully incorporated both reactive and natural dyes, providing to traditional Meitei textile colors while promoting sustainability and cultural preservation. Comprehensive color analysis revealed distinct characteristics of synthetic and natural dyes, with both offering vibrant hues and satisfactory colorfastness. K/S values provided insights into color intensity and depth, while color difference metrics aided in evaluating the effectiveness of the dyeing process. Overall, the dyed pineapple yarn exhibited very good to excellent wash fastness and excellent light fastness, affirming the suitability of both reactive and natural dyes for pineapple leaf fiber yarn dyeing. These conclusions emphasized the potential of pineapple yarn as a versatile and sustainable option for textile dyeing applications.

In the extraction of bromelain enzyme, optimization of parameters such as Material Liquor Ratios (MLR) and centrifugation parameters proved crucial for maximizing yield and efficiency. Using alkali water and distilled water at specific MLRs and temperatures facilitated efficient extraction. Centrifugation optimization revealed the ideal duration and speed for solid-liquid separation, ensuring effective processing. Overall, these optimized extraction methods contribute to enhancing the yield and quality of bromelain enzyme extraction, laying the foundation for further research and industrial applications.

In conclusion, the cost calculations for fabrics such as Rani Phee, Lengyan Phee, Muga Innaphee, and Muga Phanek demonstrate the versatility and affordability of pineapple yarn blends. Despite varying price points, each fabric offers unique designs and characteristics, showcasing the potential of pineapple fiber in textile production. These cost-effective options emphasized the feasibility of utilizing waste pineapple leaves for sustainable and innovative fabric creations, catering to diverse consumer preferences and market demands.

Consumer feedback and hypothesis testing indicated a strong acceptance of textiles made from pineapple leaf fiber. With high interest among consumers and favorable perceptions of the fabric's cultural and environmental value, pineapple fabrics have significant market potential. The experiments further validate this acceptance, demonstrating that the inclusion of pineapple yarn in traditional textiles does not significantly alter the fabric drape while comparing to the existing traditional textiles which are starched to get stiffness.

In conclusion, efforts to raise awareness about pineapple leaf fiber as a textile material had been undertaken through various channels, including television programs, newspaper articles, product displays, and targeted training programs for handloom weavers. These initiatives aimed to inform and educate both consumers and artisans about the properties and potential uses of pineapple leaf fiber, thereby expanding its visibility and recognition in the textile industry. If awareness continues to grow, pineapple leaf fiber holds promise as a sustainable and versatile alternative for textile production, contributing to the promotion of eco-friendly and culturally significant fabrics.

The SWOC analysis of utilizing pineapple leaf fibers (PALF) in traditional textile production in Manipur revealed a range of strengths, weaknesses, opportunities, and challenges. Despite challenges such as time-consuming extraction and limited market availability, PALF offered inherent sustainability and economic benefits, positioning it as a promising eco-friendly alternative in the textile industry. To capitalize on these opportunities and address challenges, strategic integration and collaboration with local communities, along with investment in research and marketing efforts, are essential. By aligning with Sustainable Development Goals (SDGs) such as decent work and economic growth, sustainable cities and communities, and responsible consumption and production, the utilization of PALF contributes to both local development and global sustainability objectives. Overall, integrating PALF into traditional textile production presents a pathway towards building sustainable communities and fostering environmental management in Manipur and beyond.