Chapter IV

RESULTS AND DISCUSSION

The study was conducted with the primary aim of exploring the potential of pineapple leaf fiber in the creation of traditional textiles for the Meitei community in Manipur. This comprehensive investigation encompassed a series of planned and executed steps, each contributing to the understanding of pineapple leaf fiber utilization in textile production. Beginning with an assessment of the availability of pineapple leaf fiber in India, the research proceeded to explore various extraction methods to obtain fibers efficiently and effectively. A pilot experiment was then undertaken to modify the produced pineapple leaf fiber, with the objective of enhancing its properties for textile applications. Subsequent phases involved rigorous testing of fiber properties, including tensile strength, elongation, moisture absorption, and color fastness, essential for determining the fiber's suitability for textile production. Following successful fiber modification and testing, the study transitioned to yarn preparation for weaving and surface ornamentation, which included the innovative fabrication of a motorized pineapple leaf fiber charkha to streamline the process. The prepared yarn underwent thorough testing to ensure its quality and performance before being utilized in the construction of traditional textiles on handlooms. Properties of the developed fabrics and Kawabata Analysis were conducted to evaluate the quality and characteristics of the textiles. Additionally, testing of dyed yarns, extraction of bromelain enzyme, cost calculations of the constructed fabric, feedback from consumers, and raising awareness about pineapple leaf fiber's potential for textile production were integral components of the study. This multidimensional approach aimed to provide a comprehensive understanding of the feasibility and viability of pineapple leaf fiber in the traditional textile-making process of the Meitei community in Manipur, contributing to both cultural preservation and sustainable development initiatives.

The results were provided, analyzed, and discussed within the following sections:

4. 1. Availability of Pineapple leaf fibre in India

4.2. Extraction of fiber

4.3. Pilot experiment on modification of produced Pineapple leaf fibre

4.4. Testing the properties of fibre

4.5. Preparation of yarn for weaving and surface ornamentation

4.5.1 Fabrication of motorized pineapple leaf fibre charkha

4.5.2. Yarn for weaving

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4.10. Cost Calculations of the constructed fabric

4.11. Feedback from the consumer

4.12. Awareness of pineapple leaf for making textiles

4.13. SWOC Analysis

4. 1. Availability of Pineapple leaf fibre in India

The availability of pineapple leaf fiber in India was explored through various organizations across different states. However, the majority of these organizations faced challenges that hindered the successful extraction and provision of the fiber for research purposes.

4.1.1. South India

1. **Vruksha Composites, Guntur, Andhra Pradesh:** Vruksha Composites, based in Guntur, Andhra Pradesh, engaged in seasonal work on natural fibers. However, the organization faced challenges in providing pineapple leaf fiber promptly. The process of extracting fiber from pineapple leaves demanded several labor-intensive steps, such as decortication and cleaning. These procedures consumed considerable time and necessitated skilled labor. The researcher approached Vruksha Composites with a request for the procurement of pineapple leaf fiber. Regrettably, despite a prolonged waiting period, the organization failed to fulfill the request as expected. Instead of receiving pineapple leaf fiber, the researcher was provided with raw sisal fiber, which was an unintended. This unexpected outcome resulted in a setback for the researcher's work, as sisal fiber did not align with the proposed focus on pineapple leaf fiber.

2. **Fiber Region, Chennai, Tamil Nadu:** Established in 2019, Fiber Region emerged as a notable wholesaler and trader specializing in a wide array of Synthetic and Natural Fiber products. Their offerings encompassed a broad spectrum, ranging from Natural Fibers to Synthetic Fibers and Fiber Mats. Operating as both a manufacturer and supplier, Fiber Region catered to diverse industries and applications, offering fibers like banana fiber, jute fiber, man-made fibers, polypropylene fiber, sisal fiber, and synthetic fibers.

   However, when approached by the researcher for procurement, Fiber Region was not engaged in dealing with pineapple leaf fiber. This could have been attributed to challenges such as difficulties in accessing pineapple farms, which may have hindered their involvement in this particular fiber.

3. **Shreekruti Agropower, Karnataka:** Shreekruti Agropower, based in Karnataka, faced challenges similar to other organizations in providing pineapple leaf fiber. The primary reason for their inability to supply the fiber was their difficulty in reaching farms and

procuring the necessary leaves for extraction. This difficulty in accessing pineapple farms could have been due to various factors such as geographical constraints, lack of established networks with pineapple growers, or logistical challenges in transportation.

Furthermore, the limited availability of raw materials posed a challenge for Shreekruti Agropower. Pineapple leaf fiber extraction requires a steady and sufficient supply of pineapple leaves, which had not been readily accessible in the quantities required by the organization.

4. **Akhil from Kerala:** Similar to other organizations, Akhil, an entrepreneur from Kerala, encountered difficulties in maintaining operations due to the labor-intensive process of pineapple leaf fiber extraction and potentially lower demand for the fiber. Despite initially engaging in work related to pineapple leaf fiber, Akhil discontinued operations by the time the researcher contacted him. He explained that it would require time to restart operations, which led to his inability to provide the fiber at that time. This suggests that Akhil faced challenges that hindered his ability to sustain ongoing work on pineapple leaf fiber, potentially due to factors such as resource constraints, market dynamics, or operational limitations.

5. **South Indian Textile Research Institute, Coimbatore, Tamil Nadu:** Although possessing expertise in textile research, this institute previously engaged in a project related to pineapple leaf fiber during the 1993. However, the institute had since discontinued its involvement in this project. This decision was likely influenced by the institute's primary focus on research rather than the extraction and supply of pineapple leaf fiber. Consequently, the institute has ceased activities related to pineapple leaf fiber, reflecting a shift in priorities and strategic direction towards other research endeavors.

4.1.2. West India

1. Meher International, Surat, Gujarat: Meher International's inability to provide pineapple leaf fiber was attributed to their procurement of pineapple yarn from another source, combined with their confidentiality policy that prevented them from disclosing any information regarding the fiber to the researcher when visited the company. Overall, Meher

International's inability to provide pineapple leaf fiber may have been influenced by a combination of factors, including their procurement of pineapple yarn from an alternate source, confidentiality policies regarding pineapple leaf fiber products, and their focus on synthetics and other natural fibre products. These factors could have led Meher International to prioritize other fibers over pineapple leaf fiber for their operations.

4.1.3. East India

1. **ICAR-National Institute of Natural Fiber Engineering and Technology, Kolkata, West Bengal:** ICAR-NINFET, a research institute focused on natural fibers, had conducted extensive research on pineapple leaf fiber extraction. However, due to their primary focus on machinery parts, supplying fiber to external researchers was not possible despite discussions via mail and calls. This could be due to resource allocation, specialization, and priority areas of research. Alternative sources for obtaining pineapple leaf fiber was needed to be explored by the researcher.

2. **Chandra Prakash & Co., Jaipur/Kolkata:** The Company supplied pineapple leaf fiber to the researcher; however, it was in an unfinished state, hindering its suitability for quality yarn production in traditional textiles of Manipur. The sample contained raw fiber intermixed with dried leaves, posing challenges in separating the fiber from the leaves. Moreover, despite being priced at Rs 3000 per kg plus GST and shipping charges, this composition rendered it unsuitable for yarn preparation. Furthermore, the fiber's quality did not meet the requisite standards for yarn production for the traditional textiles.

Fig. 4.1: Raw Pineapple leaf fiber

4.1.4. Northeast India

1. **Ramie Research Station, Sarbhog, Assam:** Ramie Research Station, located in Sarbhog, Assam, focused exclusively on research related to ramie and sisal fibers, despite being situated in a region known for its significant pineapple production.

Consequently, when contacted, the researcher was unable to obtain pineapple fiber from the personnel of the organization.

2. **Sherrard Wallang, Environmentalist, Shillong, Meghalaya:** Sherrard Wallang, an environmentalist based in Shillong, Meghalaya, possessed expertise in environmental matters. Despite this, challenges associated with pineapple leaf fiber extraction, including labor intensity, low demand, and limited technological availability, discouraged his participation in providing fiber for research purposes. The researcher reached out to him based on his prior provision of pineapple leaf fiber for a research work conducted by a Master's student from the Department of Clothing and Textiles at The Maharaja Sayajirao University of Baroda in 2019. However, by the time the researcher made contact, Wallang had already discontinued his involvement in such work. The researcher was advised to await the pineapple harvesting season. However, by the time the harvesting season arrived, the environmentalist was unable to fulfill the commitment.

3. **M/S Anchal, Teliamura bus stand, Agartala, West Tripura:** The organization declined to provide pineapple leaf fiber due to factors such as its lower demand relative to banana fiber and the labor-intensive nature of its extraction process. They had previously collaborated with ICAR on a fiber extraction program, which prompted them to list their company as a supplier of pineapple fiber on Indiamart where the researcher found the company name. Another potential reason for discontinuing work in this area could be a lack of prioritization of research on pineapple fiber by the organization. Additionally, the company was working on manufacturing of apparels.

4. **Assam Agricultural University, Jorhat:** Despite being an agricultural institution, Assam Agricultural University possessed a natural fiber extractor. Despite their extensive work on various natural fibers, the University was not actively involved in research on pineapple leaf fiber. A pilot experiment conducted by one of their students unfortunately yielded unsuccessful results until two students conducted successfully 2017.

5. **Emitex Export, Noida, Uttar Pradesh:** Emitex Export encountered difficulties in sourcing and transporting pineapple leaf fiber from distant regions such as Lower Assam and Nagaland. Despite these challenges, the researcher managed to obtain a small quantity of pineapple leaf fiber (approximately 23 g) from the company. Although the fiber was cleaner and free from accompanying dried leaves, it was coarse and exhibited low strength, making it susceptible to breakage. Additionally, there was a potential for high chemical usage in its production process.

Fig.4.2: Supplied Pineapple leaf fiber

Despite efforts from several organizations to provide pineapple leaf fiber for research, only two organizations were able to supply samples. Unfortunately, both samples had significant limitations. Given these constraints and the inadequacies of the provided samples, the researcher was compelled to undertake fiber extraction independently. This decision was necessitated by the inability of the sourced samples to meet the required standards for further research and experimentation.

Additionally, to supplement this endeavor, the researcher sought insights from individuals experienced in pineapple leaf fiber extraction, including former textile technologists, demonstrators, and staff who worked on pineapple leaf fiber project during the 1965-1970s in Manipur. These consultations provided valuable expertise and guidance, enhancing the researcher's ability to successfully extract and utilize pineapple leaf fiber for their research endeavors.

Details about the Pina Project in Manipur

Before the establishment of the Directorate of Handlooms and Textiles, Government of Manipur in 2017, the Design Extension Center and the Department of Handloom and Textiles were both part of the Department of Textiles, Commerce, and Industry. When the researcher visited the Directorate of Handloom and Textiles to investigate the current status of pineapple leaf fiber in Manipur, the researcher discovered that exploration of the fiber had previously

taken place during the period of 1965-1970s by the Design Extension Center within the Department of Textiles, Commerce, and Industry. Using the snowball technique, the researcher interviewed individuals who had been part of the project team working on pineapple leaf fiber. Unfortunately, the majority of the team members had passed away, and those who were interviewed had retired around a decade ago. The individual credited with introducing pineapple leaf fiber in 1965 was late K. Shantikumar of Nagamapal in Manipur, who had previously been an entrepreneur before working on the pineapple leaf fiber project under the Design Extension Center. The people interviewed by the researcher were-

1. Khangujam Shamu Singh, who previously served as an Assistant Director in the Design Extension Center, and had experience as a Textile Technologist. He retired in 2008.

2. Athokpam Ibetombi and Ingujam Binoychnadra, both former demonstrators involved in pineapple leaf fiber extraction processes. Both the former demonstrators retired in 2016.

3. Soibam Apanbi, one of the project staff members from the Design Extension Center. She retired in 2014.

Fig.4.3: Researcher with Kh. Shamu Singh

Fig.4.4: Researcher with the two former Demonstrators

In their project, two machines were utilized for extracting pineapple leaf fiber, referred to as 'crushing machines' because they crushed the pineapple leaves to extract the fiber. One machine was imported from Kolkata, while the other was a locally crafted replica of the imported one. The replica was created by a mechanic named Mohan from Khongman in Manipur, who unfortunately passed away. Consequently, there was no one available to explain the functioning of the machines, and the researcher was unable to locate any parts of the machines. Procurement of pineapple leaves after harvesting the fruits was done from different local farms in Waithou, Ngariyan and Angtha in Manipur.

Fig.4.5: Researcher with the former trainee

After the peak time, efforts related to pineapple leaf fiber declined due to various factors. These included insufficient profitability, inability to meet demands of larger markets, limited distribution of products (such as waistcoats, kurtas, and rugs) solely at exhibitions, decreased supply of leaves by farmers due to low charges, and disagreement between farmers' price demands and government acceptance. Consequently, due to lack of funding, the project transitioned to focus on handloom weaving. Since then, work on pineapple leaf fiber in Manipur has been discontinued.

Present personnel at the Design Extension Center and Directorate of Handlooms and Textiles had no knowledge regarding pineapple leaf fiber. However, they helped the researcher in providing the contact details of the personnel who worked on the Pina Project.

Fig.4.6: Researcher with the superintendent of Design Extension Center

The exploration of pineapple leaf fiber in India has been met with numerous challenges, hindering successful extraction and provision of the fiber for research purposes. Despite efforts from various organizations across different states, only limited samples of pineapple leaf fiber

were obtained, and these samples were often of insufficient quality. The discontinuation of pineapple leaf fiber projects in Manipur due to factors like profitability issues and disagreements over pricing further underscores the difficulties faced in this endeavor. Nevertheless, the researcher was able to gather valuable insights from individuals involved in past projects, enhancing their understanding of pineapple leaf fiber extraction. Moving forward, continued research and collaboration will be essential to overcome the obstacles and unlock the potential of pineapple leaf fiber in India's textile industry.

4.2. Extraction of fiber

Different extraction methods of pineapple leaf fiber were explored by the researcher. Mechanical extraction and manual extraction followed by water retting were the methods adopted.

Mechanical Extraction:

The mechanical extraction process, conducted at the CSIR-NEIST Laboratory in Lamphelpat, Manipur, proved to be efficient and reliable. Utilizing specialized machinery, this method ensured consistency in fiber quality and yielded satisfactory results. The machinery effectively removed the tough outer layer of the pineapple leaves, resulting in high-quality fibers suitable for various applications. However, it is worth observing that while mechanical extraction offers scalability and efficiency, it may require significant initial investment and maintenance costs.

Fig.4.7: Machine extracted pineapple leaf fibre

Manual Extraction with Hammering Technique:

Manual extraction, employing both hand scraping and the innovative hammering technique developed by the researcher, showed promising results. The hand scraping method, although labor-intensive, provided a baseline for comparison. However, concerns regarding

potential damage to fiber length and reduced yield prompted the exploration of alternative methods. The introduction of the hammering technique addressed these concerns by delicately breaking down the tough outer layer of the leaves, resulting in the production of long, smooth fibers. This approach significantly improved fiber yield and quality compared to hand scraping alone.

Fig.4.8: Hand extracted pineapple leaf fibre

Comparison of Methods:

A comparative analysis revealed distinct advantages and drawbacks of each extraction method. Mechanical extraction demonstrated efficiency and consistency in fiber quality, making it suitable for large-scale production. However, the initial investment and maintenance costs associated with machinery may pose financial challenges, particularly for small-scale operations. In contrast, manual extraction, despite being labor-intensive and time-consuming, offered flexibility and the potential for innovation, as demonstrated by the introduction of the hammering technique. While manual extraction may be feasible for smaller quantities of fiber, its scalability is limited.

This highlights the importance of exploring and comparing different extraction methods for pineapple leaf fiber. Mechanical extraction offers efficiency and consistency, while manual extraction with innovative techniques such as hammering shows promise in enhancing fiber yield and quality. By understanding the strengths and limitations of each method, stakeholders can make informed decisions to ensure sustainable and cost-effective fiber production. Further research and collaboration are essential to advance extraction technologies and support the growth of the pineapple leaf fiber industry.

4.3. Pilot experiment on modification of produced Pineapple leaf fibre

One of the inherent drawbacks of natural minor fibers, such as pineapple leaf fiber, is their stiffness and harshness. This characteristic makes them less suitable for certain applications, particularly those requiring softness. Traditionally, softening treatments are

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applied to improve the texture and handle of these fibers, enhancing their versatility and usability.

Scoured Pineapple Leaf Fiber:

Surprisingly, the researcher found that scoured pineapple leaf fiber, without any additional treatment, was sufficiently suitable for preparing stiff yarn for traditional weaving practices in Manipur. This observation contradicts the common practice of applying softening treatments to natural fibers. The decision to forgo further treatment of the scoured fiber was made based on its feasibility for yarn preparation, eliminating the need for enzyme or chemical treatments.

Minimization of Chemical Usage:

By opting to use scoured fiber without additional treatments, the researcher successfully minimized the use of chemicals and expensive enzymes typically employed in fiber softening processes. This reduction in chemical usage aligns with the growing emphasis on environmentally friendly and sustainable production practices.

However, it was observed that bleaching treatments led to deterioration of the fiber structure. This finding highlights a potential drawback of chemical treatments, as they may compromise the integrity of the fibers, affecting their quality and performance.

FESEM Analysis:

To further understand the impact of different treatments on fiber structure, longitudinal views of raw fiber, scoured fiber, enzyme-treated fiber, and bleached fiber were examined using Field Emission Scanning Electron Microscopy (FESEM). This analysis aimed to determine the structural parameters of the fibers for yarn spinning preparation.

The results suggest that scoured pineapple leaf fiber, without any additional treatment, is suitable for preparing stiff yarn for traditional weaving practices. This finding not only eliminates the need for softening treatments but also reduces the use of chemicals and expensive enzymes, contributing to a more sustainable production process. However, caution should be exercised when employing bleaching treatments, as they may adversely affect fiber structure

and quality. Further research is necessary to explore alternative methods for enhancing fiber properties without compromising their integrity.

4.4. Testing the properties of the pineapple leaf fibre

An in-depth analysis was conducted to assess various characteristics of pineapple leaf fiber. This examination covered aspects such as fiber length, diameter, denier, moisture content, and tensile strength, providing crucial insights into the fiber's physical and mechanical properties. Additionally, chemical properties were investigated, including water-soluble content, fat and wax content, as well as the presence of pectin, hemicellulose, and lignin. Cutting-edge FESEM analysis was employed to visualize surface structures and features of the fiber at the nano scale, offering a comprehensive understanding of its morphology and response to different treatments.

4.4.1. Physical Properties

Length and diameter of the fibre- the average length of the pineapple leaf fiber was observed by using steel ruler and determined to fall within the range of 65 to 92 centimeters. Furthermore, under the examination of a digital microscope, the diameter of the fiber was carefully measured and found to vary between 7 and 12 micrometers (µm).

Fig.4.9: Pineapple leaf fibre under microscope

Indices of the fiber- the WI value of the controlled fiber (raw fiber) was positive, indicating a relatively white appearance. The YI value indicated moderate yellowness, while the BI value suggested higher brightness compared to the scoured fiber.

The negative WI value of the scoured fiber suggested a non-white appearance, possibly due to discoloration or impurities. The higher YI value indicated increased yellowness, while the BI value suggests lower brightness.

The negative WI value of enzyme treated fiber indicated a non-white appearance, possibly due to discoloration. The higher YI value suggests increased yellowness, while the BI value indicates moderate brightness.

The bleached fiber sample exhibited a relatively low WI (Whiteness Index) I], indicating a less white appearance. The YI (Yellowness Index) and BI (Brightness Index) values suggested a moderate level of yellowness and brightness, respectively.

Table 4.1: Indices of pineapple leaf fibre

Sample	Whiteness Index (WI)	Yellowness Index (YI)	Brightness Index (BI)
BLEACHED PF	10.342	34.096	38.089
SCARRED PF	-6.410	48.145	23.789
CONTROLLED PF	0.755	40.857	32.101
ENZYMED PF	-2.924	46.313	27.054

Texture of the fiber- The analysis of the pineapple leaf fiber's texture entailed a thorough examination utilizing the high-resolution ZEISS Axio Imager 2 microscope. Through this process, the microscope screen revealed smooth, lustrous, and uniformly elongated strand of the pineapple leaf fiber, along with their corresponding diameter.

Fig.4.10: Pineapple leaf fibre under ZEISS microscope

Fibre fineness- The denier measurement of the pineapple leaf fiber was determined to be 47.57 denier. This value indicates that the fiber can be classified as both a long staple fiber and a very fine fiber. As a long staple fiber, it possesses lengthy and continuous filaments, which are desirable for textile applications as they contribute to strength and durability in finished products. Additionally, being classified as a very fine fiber suggests that it has a small diameter, making it suitable for use in delicate or lightweight fabrics.

Moisture content and regain- The moisture content of the pineapple leaf fiber was determined to be 10%, while the observed moisture regain was measured at 11.1%. Comparatively, this moisture regain value surpasses that of cotton, typically ranging from 9 to 10%, yet falls short of flax, which typically had a moisture regain of 12%, aligning with the standard moisture regain of textile fibers. These findings indicated the hydrophilic nature of the pineapple leaf fiber.

Tensile strength and bundle strength: Pineapple leaf fiber exhibited commendable tensile strength in comparison to various other natural fibers. Specifically, its tensile strength was measured at 4.278 grams-force per denier (gf/den), indicating its ability to withstand pulling forces. Additionally, the bundle strength of the pineapple leaf fiber was determined to be 27 grams per tex (g/tex), further underscoring its resilience and durability.

Table 4.2: Physical properties of pineapple leaf fibre

Properties	Results
Length of the fiber	65-92cm
Fineness of the fiber(denier)	47.57D single 90-100.8 Bundle
Moisture Content (%)	10%
Moisture Regain%	11.1%
Bundle strength	25-27 g/tex

Table 4.3: Tensile Strength -Speed- 500mm/min, ASTM D 885

Treatments	Max Load (gf)	Tenacity(gf/den)	Stress at break %
Raw fiber	126	4.278	0.9
Enzyme treated	116	4.048	0.6
Chemical treated	115.6	2.38	1.5

The raw fiber displayed the highest maximum load and tenacity among the three treatments, showcasing its superior strength and capacity to endure pulling forces. Nonetheless, it exhibited a relatively low stress at break percentage, implying limited elongation prior to fracturing. In contrast, the enzyme-treated fiber demonstrated slightly reduced maximum load and tenacity compared to the untreated fiber, with an even lower stress at break percentage, indicative of heightened elongation before failure. This suggests that the enzyme treatment may have influenced the fiber's strength and flexibility. Conversely, the chemically treated fiber presented the lowest maximum load and tenacity of the three treatments. Furthermore, it exhibited the highest stress at break percentage, suggesting increased elongation before rupture. This indicates that the chemical treatment may have compromised the fiber's overall strength and resilience.

4.4.2. Chemical Properties of the pineapple leaf fibre

The estimation of water-soluble, Fat and wax, pectin, hemicellulose and lignin content was conducted using soxhlet apparatus in the Department Clothing and Textiles laboratory, The Maharaja Sayajirao University of Baroda, the values obtained are as shown in the table:

Table 4.4: Chemical composition of the fibre

Properties	Results
Fats and Waxes	3.1%
Pectin	1.2%
Hemicellulose	2%
Lignin	1.3%
Cellulose	77.7%
Water soluble component	14.7%

The presence of fats and waxes at 3.1% indicated a natural lubrication and moisture resistance inherent in the fiber, potentially affecting its surface properties and processing behavior. Pectin, comprising 1.2% of the fiber, played a minor yet significant role in providing structural support and strength, contributing to the overall integrity of the fiber. Hemicellulose, constituting 2% of the fiber, contributed to its structural support and flexibility, enhancing its mechanical properties. Lignin, at 1.3%, reinforced the fiber's cell walls, imparting rigidity and durability. The predominance of cellulose at 77.7% underscored its role as the primary structural component, endowing the fiber with strength, stiffness, and suitability for textile applications. The presence of a water-soluble component at 14.7% suggested the inclusion of various organic compounds, influencing the fiber's solubility, moisture absorption, and behavior in wet conditions.

4.4.3. FESEM Analysis

FESEM analysis, which stands for Field Emission Scanning Electron Microscopy, was conducted to obtain exceptionally high-resolution images with a resolution of 1.5 nanometers.

Raw fiber

Scoured fiber
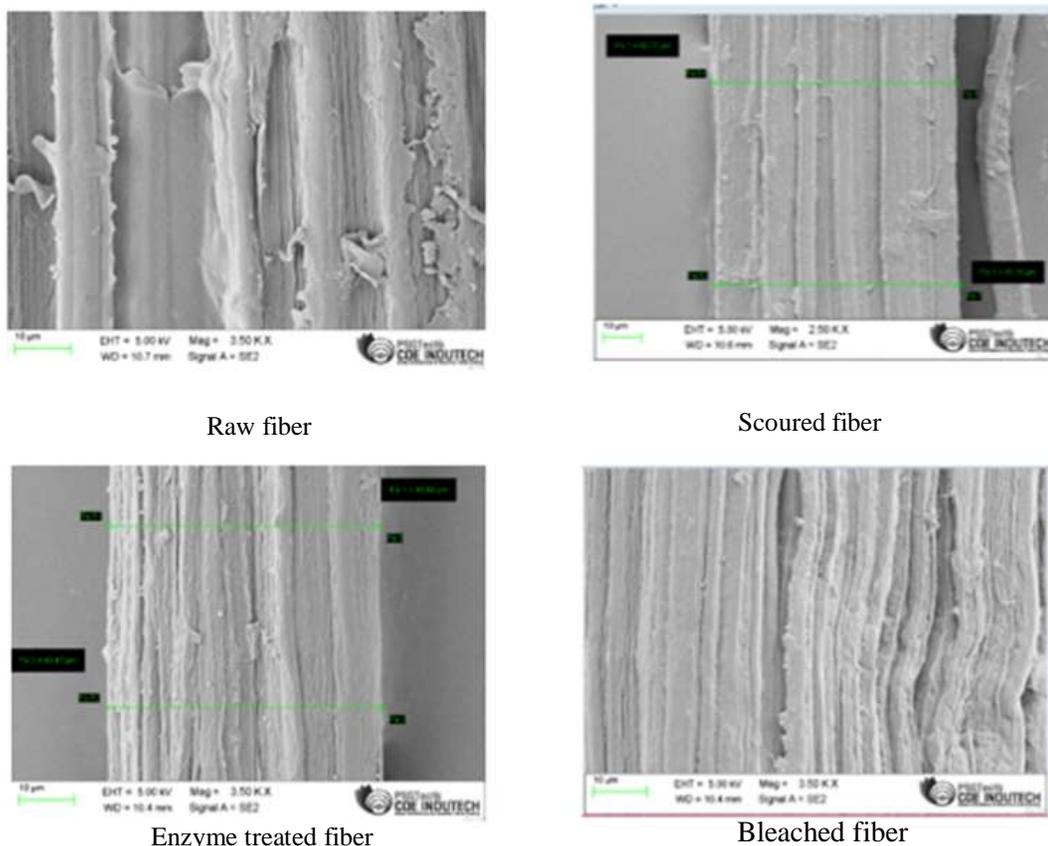
Enzyme treated fiber

Bleached fiber

Fig.4.11: Surface morphology of different pineapple leaf fibre under FESEM

This technique allowed for the visualization of surface structures and features at the nano scale. The objective of the analysis was to observe any physical and chemical changes occurring on the surface morphology of the fiber under different treatment conditions, providing insights into how the fiber responded to each treatment.

The results of the analysis revealed that the surface structure of the fiber became smoother after the scouring process, while it deteriorated after bleaching. Additionally, the enzyme-treated fiber exhibited a smoother fibrous surface compared to the untreated fiber.

4.5. Preparation of yarn for weaving and surface ornamentation

4.5.1. Fabrication of motorized pineapple leaf fibre charkha

A motorized spinning wheel inspired by the traditional phoenix charkha was developed specifically for producing yarn from pineapple leaf fibers. The motor incorporated into the spinning wheel has the capability to operate at 500 revolutions per minute (RPM). However, to ensure the creation of fine 100% pineapple leaf fiber yarn, the spinning wheel's speed was adjusted to approximately 200 RPM and maintained at this level by using foot paddle regulator.

This motorized spinning wheel comprises several essential components, each playing a crucial role in its seamless operation. The drive pulleys, positioned strategically within the mechanism, work in tandem with the motor to efficiently transfer rotational energy, ensuring smooth yarn production. The shafts provide structural support and enable the transmission of power

Fig.4.12: Diagram of the developed charkha

throughout the spinning wheel. Thread-making U-clamps and guide ways facilitate the precise positioning and movement of the fibers, ensuring uniformity in yarn production. Rope wires aid in maintaining tension, essential for the proper formation of yarn. The work table offers a stable platform for the spinning process, while tension screws allow for fine adjustments to ensure optimal tension levels. Belts and bobbins complete the intricate system, contributing to the overall functionality and efficiency of the spinning wheel.
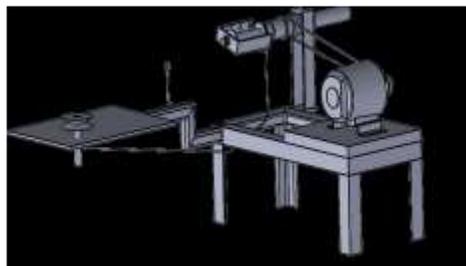
4.5.2. Yarn for weaving

The produced yarns were very fine, lustrous, even and stiff which were very compatible for making the traditional textiles of Manipur. Preparation of the similar fine texture of fabrics used in the textiles of the state was achieved with the help of the finely twisted yarn. Good tensile strength with low elongation was found.

The feasibility of utilizing very fine 100% pineapple leaf fiber yarn with a Z twist, for phee, and a higher count yarn with the same Z twist for phanek was observed. The yarns were found to be feasible for traditional textiles without undergoing any treatment, indicating the natural strength and durability of pineapple leaf fibers. This simplifies the production process, reduces costs, and maintains the authenticity of traditional textiles.

4.5.3. Yarns for surface ornamentation

1. Material Selection: Rayon and polyester were selected as blending materials for their compatibility with pineapple fiber and suitability for textile surface ornamentation.

2. **Charkha Selection**: Two types of charkhas, namely amber charkha and peti charkha, were employed for yarn production. These charkhas were chosen based on their traditional use and suitability for spinning various types of fibers.

3. **Yarn Production**: Yarns were spun using both amber charkha and peti charkha, incorporating pineapple fiber with rayon and polyester. Different twist levels were experimented with to determine the optimal twist for each blend.

4. **Observations**:

   - **Amber Charkha**: Pineapple/polyester yarn made with a medium twist using amber charkha resulted in the formation of snarls, likely due to the high twist causing tangling or knotting of fibers. This hindered the feasibility of using this particular blend for surface ornamentation.

   - **Peti Charkha**: Yarn produced with peti charkha had managed twist by keeping a constant speed manually.

5. **Adjustments and Further Trials**: To address the issues encountered with the amber charkha, adjustments were made, including:

- **Multiple Ply Yarns**: a total of five two-ply yarns were created, potentially reducing the occurrence of snarls and improving the feasibility for surface ornamentation.

- **Twist Variation**: Twist levels were adjusted to find the optimal twist for each blend, ensuring that the resulting yarns are suitable for use in fashion maker (sewing machine) for surface ornamentation.

6. **Feasibility Testing**: The five two-ply yarns produced were tested for their feasibility in surface ornamentation using a fashion maker (sewing machine- JUKI HZL 27Z) with the constant stitch length 3 stitches per cm using needle no. 18/110.

Table 4.5: Prepared Ply yarns

Yarn	Charkha	TPI (twist per inch)	Twist Direction	Denier	Count
Pineapple/Rayon–low twist(PRL)	Amber	6-8	Z+S - Z	354D	15's
Pinapple/Rayon-medium twist(PRM)	Amber	16-17	Z+S - Z	409D	13's
Pineapple/Rayon (PRP)	Peti	13-14	Z+S - Z	380D	14's
Pineapple/polyester-low twist(PPL)	Amber	6-8	Z+Z - Z	380D	14's
Pineapple/polyester(PPP)	Peti	14-16	Z+Z - Z	409D	13's

Yarn blends of pineapple yarn with rayon and polyester were spun using different charkhas, exhibiting distinct twist per inch (TPI) values. It highlighted the significance of twist levels in achieving desired yarn characteristics, with low twist yarns like Pineapple/Rayon–low twist (PRL) and Pineapple/Polyester-low twist (PPL) showcasing delicate flexibility, while higher twist yarns such as Pineapple/Rayon-medium twist (PRM) and Pineapple/Polyester(PPP) exhibited enhanced strength and resilience. The choice of charkha

also played a crucial role, with amber charkha consistently yielding lower TPI yarns compared to peti charkha.

Table 4.6: Combination of yarns for the trial of Surface

Lower thread	Upper thread	Lower thread	Upper thread
Pineapple/Rayon –low twist(PRL)	Polyester	Pineapple/Rayon –low twist(PRL)	Rayon
Pinapple/Rayon -medium twist(PRM)	Polyester	Pinapple/Rayon -medium twist(PRM)	Rayon
Pineapple/Rayon (PRP)	Polyester	Pineapple/Rayon (PRP)	Rayon
Pineapple/polyester- low twist(PPL)	Polyester	Pineapple/polyester- low twist(PPL)	Rayon
Pineapple/polyester(PPP)	Polyester	Pineapple/polyester(PPP)	Rayon

In the context of surface ornamentation, the utilization of multi-ply yarns encountered challenges when attempted as upper threads on the machine due to their higher count, leading to frequent breakage during operation. Consequently, a strategic adjustment was made, wherein these two-ply yarns were exclusively assigned to serve as lower threads, while combinations of polyester and rayon threads were designated as upper threads. This approach aimed to mitigate breakage issues and ensure smoother operation during the embellishment process. Moreover, to effectively showcase the visual impact of the ply yarns on the fabric, it was deemed necessary to conduct stitching on the fabric's wrong side. This method allowed for a better appreciation of the intricate details and texture imparted by the ply yarns on the fabric's right side, thus enhancing the overall aesthetic appeal of the surface ornamentation.

Samples of the surface ornamentation made with the prepared plied yarns and polyester as the upper thread
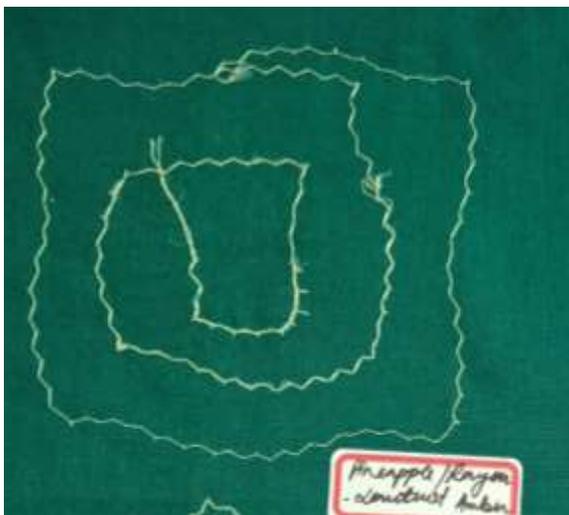

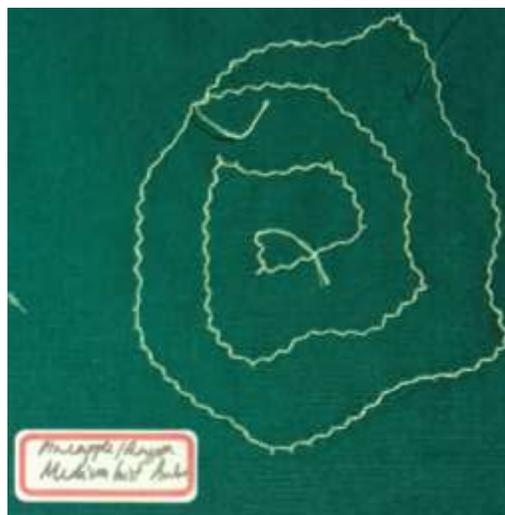Fig.4.13: Pineapple/Rayon
Low twist-Amber Charkha

Fig.4.14: Pineapple/Rayon
Medium twist-Amber Charkha
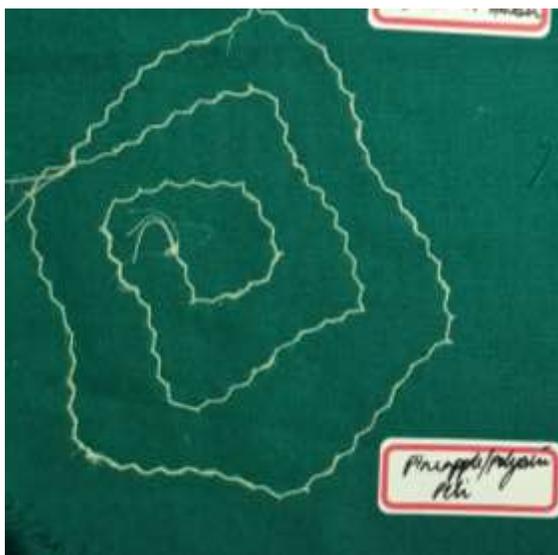

Fig.4.15: Pineapple/Polyester
Peti Charkha
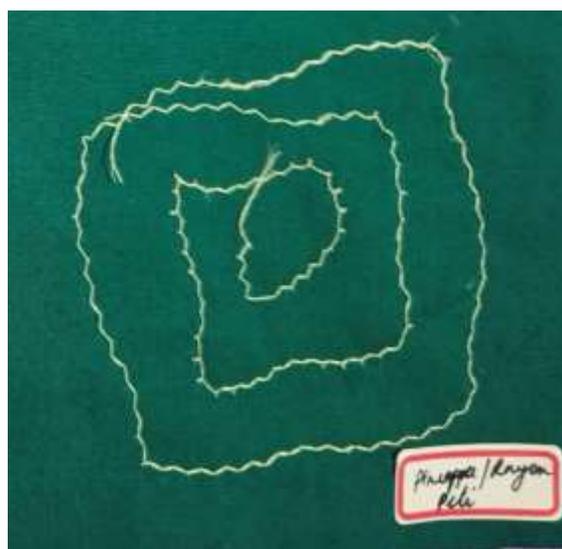
Fig.4.16: Pineapple/Rayon
Peti Charkha

Samples of the surface ornamentation made with the plied yarns and rayon as the upper thread

Fig.4.17: Pineapple/Rayon
Low twist-Amber Charkha

Fig.4.18: Pineapple/Rayon
Medium twist-Amber Charkha

Fig.4.19: Pineapple/Rayon
Peti

Fig.4.20: Pineapple/Polyester
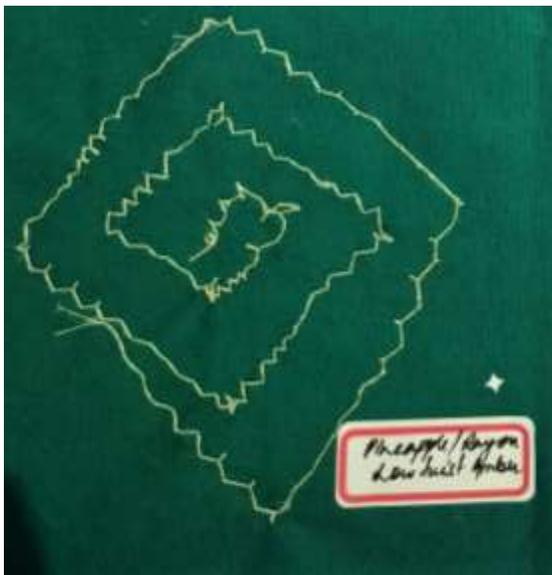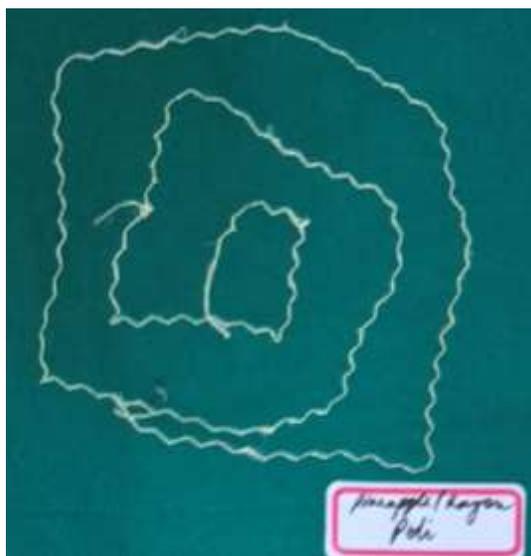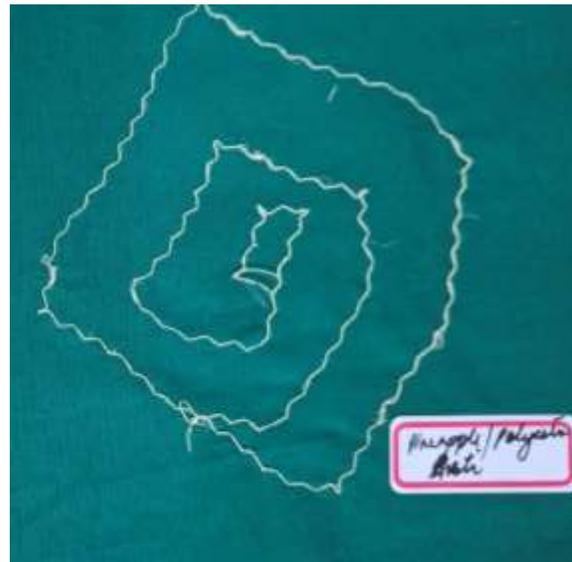Low twist-Amber Charkha

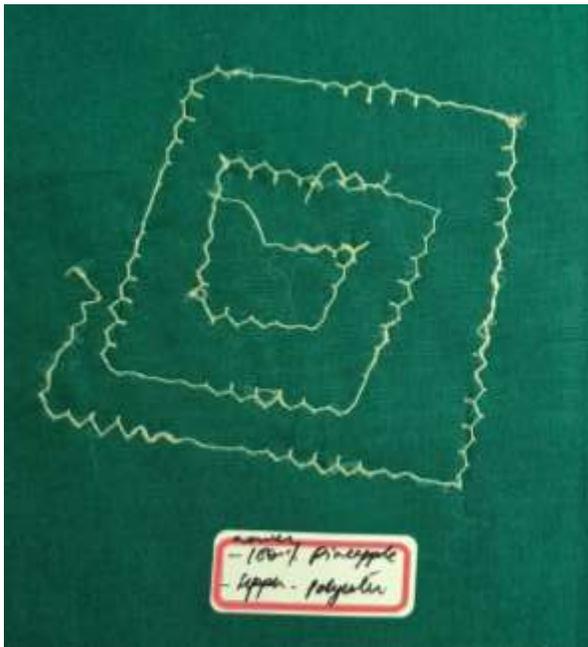**Samples of the surface ornamentation made with 100% pineapple yarn**

Fig.4.21: 100% Pineapple and Polyester as
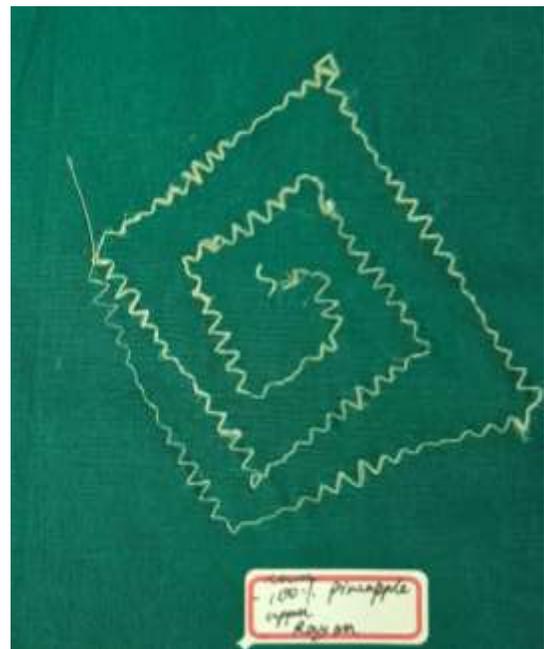upper thread
Motorized Charkha

Fig.4.22: 100% Pineapple and Rayon as upper
thread
Motorized Charkha

However, despite these efforts, observations from the results revealed a concerning issue with the ply of pineapple/polyester yarn, particularly when produced with a low twist using the Amber charkha. It was noted that this particular yarn exhibited a tendency to separate during operation, compromising its integrity and rendering it unsuitable for its intended use as surface ornamentation threads. Hundred percent 30's pineapple yarn was also explored in the trial to check the appearance.

This finding emphasizes the importance of testing and evaluation in the research and development process, highlighting the need for further refinement or exploration of alternative yarn options to ensure the successful execution of surface ornamentation techniques.

4.6. Testing of prepared yarn

The testing of prepared yarn involves the evaluation of various properties to assess its suitability for specific applications in textile production. These properties provide valuable insights into the thickness, strength, and twist characteristics of the yarns, which are crucial factors in determining their performance and usability in textile manufacturing processes. The denier value indicates the linear mass density of the yarn, while the yarn count specifies its thickness or fineness. The twist per inch (TPI) value denotes the spiral arrangement of the fibers around the yarn axis, influencing factors such as yarn strength, durability, and appearance.

Table 4.7: Properties of the Yarn for phee

Properties	Results
Denier of yarn	178D
Yarn Count	30's
Yarn Twist	Z twist 80-85 TPI

Table 4.8: Properties of the Yarn for phanek

Properties	Results
Denier of yarn	730D
Yarn Count	8's
Yarn Twist	Z twist 16 TPI

4.6.1. Determination of yarn fineness

Fine Yarn for Phee (30's): The fine yarn with a count of 30's indicates its relatively thin and delicate nature, making it suitable for intricate weaving patterns typical in phee, which is a

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traditional textile worn by Manipuri Meitei women. The denier of the yarn was measured at 177D. Denier served as a unit of measurement for the linear mass density of fibers, indicating the weight in grams of 9,000 meters of the yarn.

Fig.4.23: Fine Yarn for Phee (30's)

Fig.4.24: Yarn for Phanek (8's)

Higher Count Yarn for Phanek (8's): The denier of the yarn was measured at 730D. Denier is a unit of measurement for the linear mass density of fibers, indicating the weight in grams of 9,000 meters of the yarn. A higher denier value suggests a thicker yarn. The higher count yarn with a count of 8s suggested a thicker and more robust yarn suitable for weaving phanek, another traditional garment worn in Manipur.

4.6.2. Determination of yarn evenness

The utilization of long strands of fiber in the yarn-making process resulted in favorable evenness outcomes, as indicated by the findings presented in Graph 1. The analysis of the prepared yarn revealed that it exhibited a high degree of evenness, as evidenced by the mean value of 0.00925 grams per 100 centimeters. This mean value signified the average deviation in weight across the yarn length, with a lower value indicating more uniformity in the distribution of fiber mass. Additionally, the mean deviation of 2.3% further supported the conclusion of good evenness, as it represented the extent of variation from the mean value across the yarn length. A mean deviation of 0.0005g suggested a relatively small degree of fluctuation in fiber mass, further confirming the consistent quality of the yarn.
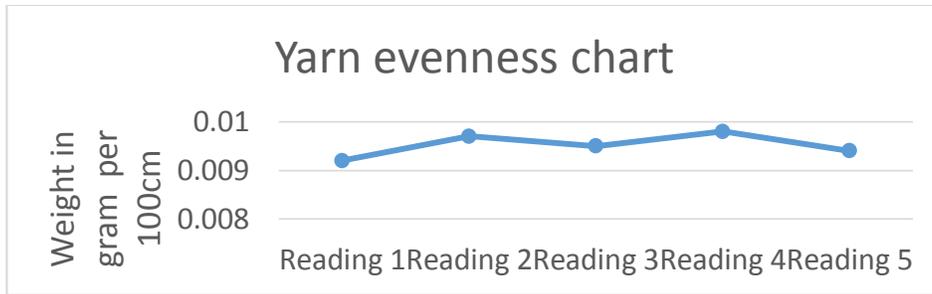
Graph 4. 1: Yarn evenness of 30's
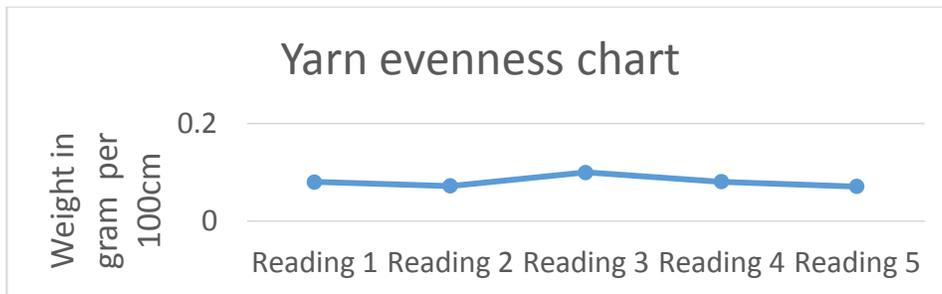
Graph 4. 2: Yarn evenness of 8's

The analysis of the 8s yarn revealed a mean value of 0.081 grams per 100 centimeters and a mean deviation of 0.00776g, as indicated in Graph 2. The mean value represented the average deviation in weight across the yarn length, with a higher value suggesting a greater deviation from uniformity. In this case, the mean value of 0.081 grams per 100 centimeters indicated a relatively small average deviation, implying a reasonable level of uniformity in the distribution of fiber mass along the yarn length. Additionally, the mean deviation of 9.62% reflected the extent of variation from the mean value across the yarn length. A higher mean deviation percentage indicated a greater dispersion or scatter of fiber mass, suggesting less uniformity. However, considering that the mean deviation was within an acceptable range and the mean value was relatively consistent, it can be inferred that the prepared yarn exhibited a reasonable level of evenness.

4.6.3. Determination of yarn strength and elongation

The testing of the strength and elongation characteristics of the different yarns -100% pineapple yarn and plied yarns was done. It highlights key properties such as maximum load, tenacity, stress, strain, and elongation, shedding light on the materials' ability to withstand

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external forces, their strength relative to linear density, and their deformation behavior under applied loads.

Table 4.9: Tensile strength of the 30's Yarn

Maximum load	128 g
Tenacity	0.72 g/den
Stress	0.021g/den
Strain	1.4%
Elongation	1.4 mm

Analyzing the given data, the maximum load refers to the maximum force applied to the material before it fails or breaks. In this case, the maximum load was given as 128 grams. Tenacity is a material property that represents the maximum force the material can withstand per unit linear density. It's typically measured in grams per denier (g/den). Here, the tenacity was given as 2.13 g/den, indicating the material's strength relative to its linear density. Stress is the force applied per unit area of the material. In this case, stress was given as 0.021 g/den. It indicated how much force is applied to each unit of the material's cross-sectional area. Strain measures the deformation of the material relative to its original size. It's typically expressed as a percentage. Here, the strain was given as 1.4%, indicating the percentage of elongation relative to the original length of the material. Elongation refers to the increase in length of the material under the applied load. In this case, the elongation was given as 1.4 mm, indicating how much the material stretched.

Table 4.10: Tensile strength of the 8's Yarn

Maximum load	2176.42g
Tenacity	2.98 g/den.
Elongation	2.62mm
Stress	2.98g/den
Strain	5.25%

The yarn (8's) endured a maximum load of 2176.42 grams at the speed of 100mm/min, showcasing its capacity to withstand external force. Tenacity was measured at 43.53 grams per denier (g/den), indicating the material's strength relative to its linear density. An elongation of 2.62 millimeters signified the extent to which the material stretched or deformed under the applied load. Stress was calculated as 2.98 grams per denier (g/den), reflecting the force applied per unit area of the material. Strain, reported as 5.25%, represented the percentage of elongation relative to the yarn's (8's) original length, indicating its ability to withstand external forces without permanent damage. (Table 4.11)

Table 4.11: Tensile strength of the developed plied yarns

*Sample	Speed (mm/min)	Maximum load (g)	Tenacity (g/den)	Elongation (mm)	Stress(g/den)	Strain (%)
PRL	100	673.49	1.90	2.62	1.90	5.24
PRM	100	786.41	1.92	3.48	1.92	6.97
PRP	100	784.81	2.07	2.80	2.07	5.61
PPL	100	747.27	1.97	2.23	1.97	4.46
PPP	100	646.91	1.58	3.88	1.58	7.76

*PRL- Pineapple Rayon, low twist (made with amber chrakha), PRM- Pineapple Rayon, medium twist (made with amber), RRP- Pineapple rayon (peti charkha), PPL- Pineapple polyester, low twist (amber charkha), PPP- pineapple/polyester (peti charkha).

Among the samples, PRM exhibited the highest maximum load at 786.41 g, indicating its superior strength compared to other samples. PRP demonstrated the highest tenacity at 2.07 g/den, followed closely by PRL and PPL. This indicates that PRP has the highest strength per unit linear density among the samples. PRM showed the highest elongation and strain values at 3.48 mm and 6.97%, respectively, indicating its ability to deform significantly before failure. PRP exhibited the highest stress value at 2.07 g/den, reflecting the force applied per unit area necessary to cause deformation.

Statistical analysis-The mean tenacity across the samples was 1.89 g/den, indicating the average strength of the yarns in the dataset. The standard deviation of tenacity (0.184 g/den) suggests that there is some degree of variability in tenacity values among the samples. Samples with tenacity values closer to the mean (1.89 g/den) exhibit relatively less variability in strength compared to those farther from the mean. The variance (0.0340) provided a measure of the

average squared deviation of data points from the mean. A lower variance indicated less variability in the dataset. SEM (Standard error of the mean) measured the precision of the estimate of the sample mean. It quantified the uncertainty or variability in the sample mean. The SEM was 0.0824.

The analysis reveals differences in strength, flexibility, and resilience among the samples. PRM stands out as the strongest sample with the ability to deform considerably before breaking. This makes it a promising choice for applications that demand both strength and flexibility. To better understand these properties and their potential uses, further research into the fiber compositions and manufacturing techniques of each sample is recommended.

4.6.4. Determination of yarn twists (TPI)

Very Fine Yarn for Phee (30's): Yarn for Phee (30s) featured exhibited a Z twist with a twist per inch (TPI) ranging between 80 to 85. This yarn could be called as crepe twist since it had 40-80 TPI (**Kadolph, S, J. 2017**). Z twist meant the fibers were twisted in a clockwise direction when viewed from one end of the yarn. The Z twist indicated that the fibers were twisted in a clockwise direction when viewed from one end of the yarn. This Z twist configuration ensured proper cohesion and strength in the yarn, mitigating the risk of unraveling during the weaving process and ultimately enhancing the durability of the resulting fabric.

Higher Count Yarn for Phanek (8s): The yarn exhibited a Z twist with a twist per inch (TPI) of 16. Yarn twist, which denotes the spiral arrangement of fibers around the yarn axis, was effectively employed in this yarn. Z twist meant the fibers were twisted in a clockwise direction when viewed from one end of the yarn. With a TPI value of 16, the yarn exhibited a moderate twist density (**Kadolph, S, J. 2017**).

PRL (Pineapple/Rayon–low twist): With a TPI range of 6-8, this yarn exhibited a relatively low twist density (**Kadolph, S, J. 2017**). Lower twist yarns often result in a softer, more pliable texture suitable for lightweight fabrics or delicate garments.

PRM (Pineapple/Rayon-medium twist): This variant featured a higher TPI range of 16-17, indicating a denser twist compared to PRL. The increased twist density imparts greater strength and stability to the yarn, making it suitable for applications requiring more durability, such as

upholstery or heavy-duty textiles. The medium twist also enhanced the yarn's resilience and overall performance.

PRP (Pineapple/Rayon): Falling between the low and medium twist variants, PRP showcased a TPI range of 13-14. This moderate twist density offered a balanced compromise between softness and strength, making it versatile for a wide range of textile applications. The inclusion of rayon in the blend likely contributes to the yarn's smooth texture and drape.

PPL (Pineapple/Polyester-low twist): Similar to PRL, PPL featured a low twist density with a TPI range of 6-8. The combination of pineapple and polyester fibers in a low twist yarn suggested a focus on achieving a softer, more flexible yarn suitable for lightweight fabrics or decorative applications.

PPP (Pineapple/Polyester): With a TPI range of 14-16, PPP stood out with a higher twist density compared to the other variants. This higher twist enhances the yarn's strength and resilience, making it suitable for applications requiring durability and stability. The blend of pineapple and polyester fibers offered a combination of natural and synthetic properties, contributing to the yarns overall performance and versatility.

4.7. Construction of traditional textiles on handloom

The experimentation involved the utilization of various yarn combinations and weaving techniques to replicate the essence of traditional Manipuri textiles, namely Rani phee, muga Innaphee, lengyan phee, and muga phanek. To ensure authenticity, the warp yarns were selected to match those traditionally used in Manipuri textiles, while undyed pineapple yarn was incorporated to preserve its natural color and integrity.

The fabric samples were woven using a throw shuttle loom, chosen for its precision in weaving intricate designs, particularly the temple stoop design, which adds depth and texture to the fabric. This manual weaving process facilitated the precise placement of weft yarns, allowing for the creation of complex motifs and patterns characteristic of Manipuri textiles. Evaluation of the produced samples revealed promising results in terms of suitability for each specific traditional textile. The plain weave union fabrics, incorporating silk/pineapple, Rayon/pineapple, cotton/pineapple, and Polyester/pineapple with extra weft traditional motifs and colors, successfully took the essence of Rani phee, muga Innaphee, lengyan phee, and muga

phanek, respectively. The choice of yarn counts for each fabric, including silk-50s, Rayon-22s, cotton-25s, and polyester-18s, contributed to the desired texture and drape characteristic of Manipuri textiles. Moreover, the incorporation of undyed pineapple yarn alongside undyed warp yarns preserved the natural color and aesthetic appeal of the pineapple fiber, enhancing the authenticity of the samples.

4.7.1. Types of Fabrics

The plain weave union fabrics, incorporating silk/pineapple, Rayon/pineapple, cotton/pineapple, and Polyester/pineapple with extra weft traditional motifs and colors, successfully took the essence of Rani phee, muga Innaphee, lengyan phee, and muga phanek, respectively. The choice of yarn counts for each fabric, including silk-50s, Rayon-22s, cotton-25s, and polyester-18s, contributed to the desired texture and drape characteristic of Manipuri textiles. Moreover, the incorporation of undyed pineapple yarn alongside undyed warp yarns preserved the natural color and aesthetic appeal of the pineapple fiber, enhancing the authenticity of the samples.

❖ Silk/Pineapple union fabric

Table 4.12: Rani Phee

Sr. No.	Attribute	
1	Size(mts)	2.4m x 1.2m (original), 1.2m x 0.51m (sample)
2	Yarn	Silk yarn in the warp and Pineapple yarn in the weft
3	Weave for base	Plain weave
	Ornamentation	Extra weft design motifs using rayon yarn.
4	Colour for base	Undyed warp yarn and Natural colour of weft (pineapple)
	Ornamentation	Red
5	Design: border Motifs	Extra weft design temple stoop Namthang khulat (floral) and kabok chaibi (Rice Puff)
6	Festival/Occasion	Marriage and special occasions

Fig.4.25: Rani Phee

The fabric samples produced for the traditional Rani phee, a cherished textile of the Meitei women in Manipur, were crafted to replicate its essence and significance, particularly for special occasions like weddings. The specifications of the fabric, including size, yarn composition, weave, ornamentation, color scheme, and design motifs, were carefully considered to ensure authenticity and cultural relevance.

Size: The original size of the Rani phee textile is 2.4 meters by 1.2 meters. However, for the purpose of sampling, a smaller size of 1.2 meters by 51 meters was used to create manageable fabric samples for experimentation and evaluation.

Yarn: The warp yarn consisted of luxurious silk, chosen for its lustrous sheen and smooth texture, while the weft yarn comprised pineapple fiber, adding a unique natural element to the fabric.

Weave for Base and Ornamentation: The base fabric utilized a plain weave, providing a simple yet sturdy foundation for the textile. Ornamentation was achieved through the incorporation of extra weft designs using rayon yarn, allowing for the creation of intricate motifs and patterns typical of Rani phee.

Color: The base fabric maintained the authenticity of the traditional Rani phee by employing undyed warp yarns (white), while the weft yarn retained its natural color (cremish), imparting an original aesthetic to the fabric. Additionally, red (angangba machu in Manipuri) a Traditional colour of Meitei Community, was used for the ornamentation, enhancing the richness of the textile.

Fig.4.26: Placement of motifs

Moirang phijan
(Temple stoop motif)

Namthang Khulat
(Floral motif)

Kheiroithek mayek
(Squirrels motifs)

Kabok chaibi
(Rice puff motif)
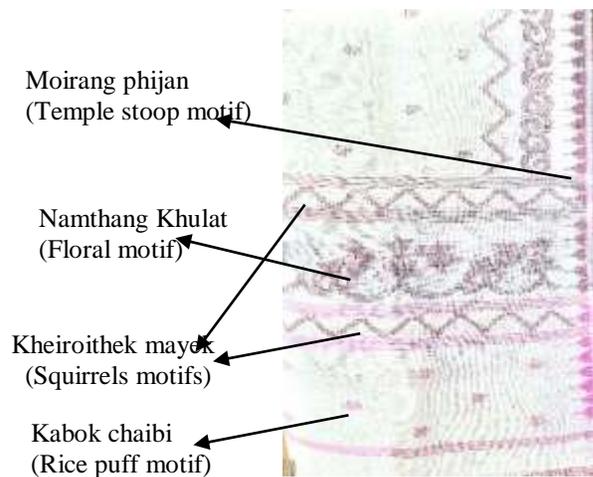
Fig.4.27: Traditional motifs used

Design: The border motifs featured the iconic traditional Moirang phijan (temple stoops) design along the length, which adds depth and texture to the fabric, along with traditional floral motifs known as Namthang khulat and Kheiroithek mayek (Squirrels motif) across the border and kabok chaibi (Rice Puff) throughout the body. Mayek is a local term of motif in Manipuri.

Festival/Occasion: Rani phee was a traditional upper garment which hold special significance during marriages and other auspicious occasions in Manipuri culture, symbolizing tradition, heritage, and the cultural identity of the Meitei community.

Weaver: The construction of a fabric resembling Rani-Phi had been accomplished through the expertise of   Khwairakpam Roma Devi, a 55 years old skilled Rani-Phi weaver from Awang Sekmai, Mayai Leikai, in the Imphal West District of Manipur. She worked on this craft as her active income.

Fig.4.28: Khwairakpam Roma Devi

By adhering to these specifications and design elements, the fabric samples successfully captured the essence of Rani phee, inducing its cultural significance and serving as a authentication to the rich textile heritage of Manipur. Through experimentation and innovation, traditional textiles like Rani phee could to be made.

❖ Union of Cotton/Pineapple Fabric

Table 4.13: Lengyan Phee

Fig.4.29: Lengyan Phee

Sr. No.	Attribute	
1	Size(mts)	2.2m x 1m (original)
2	Yarn	Cotton yarn in the warp and Pineapple yarn in the weft
3	Weave for base Ornamentation	Plain weave Extra weft design motifs using rayon yarn.
4	Colour for base Ornamentation	Undyed warp yarn and Natural colour of weft (pineapple) Orange
5	Design: border motifs	Extra weft design temple stoop Pangantem (geometrical) and kabok chaibi (Rice Puff)
6	Festival/Occasion	Marriage and special occasions

Lengyan phee, a traditional textile of Manipur, grabbed cultural significance as attire worn by both men and women during special occasions, particularly marriages. The fabric samples created to replicate Lengyan phee were designed to honor its heritage and relevance in Manipuri culture, ensuring authenticity and functionality.

Size: The original size of Lengyan phee is 2.2 meters by 1 meter, providing ample fabric for draping over the shoulder and creating an elegant silhouette. This size was maintained in the fabric samples to preserve the traditional dimensions of the textile.

Yarn: The warp yarn consisted of durable cotton, chosen for its strength and versatility, while the weft yarn comprised pineapple fiber, adding a natural element to the fabric and enhancing its texture.

Weave for Base and Ornamentation: A plain weave was utilized for the base fabric, providing a sturdy foundation for the textile. Ornamentation was achieved through the incorporation of extra weft designs using rayon yarn, allowing for the creation of intricate motifs and patterns typical of Lengyan phee.

Color: The base fabric maintained the authenticity of Lengyan phee by employing undyed warp yarns, while the weft yarn retained its natural color, imparting a subtle and earthy aesthetic to the fabric. Additionally, orange (komla macho in local term) a vibrant and traditional color in Manipuri culture, was used for the ornamentation.

Design: The border motifs featured the iconic temple stoop design, adding depth and texture to the fabric, along with traditional geometrical motifs known as Pangantem and kabok chaibi (Rice Puff), symbolizing harmony and abundance.
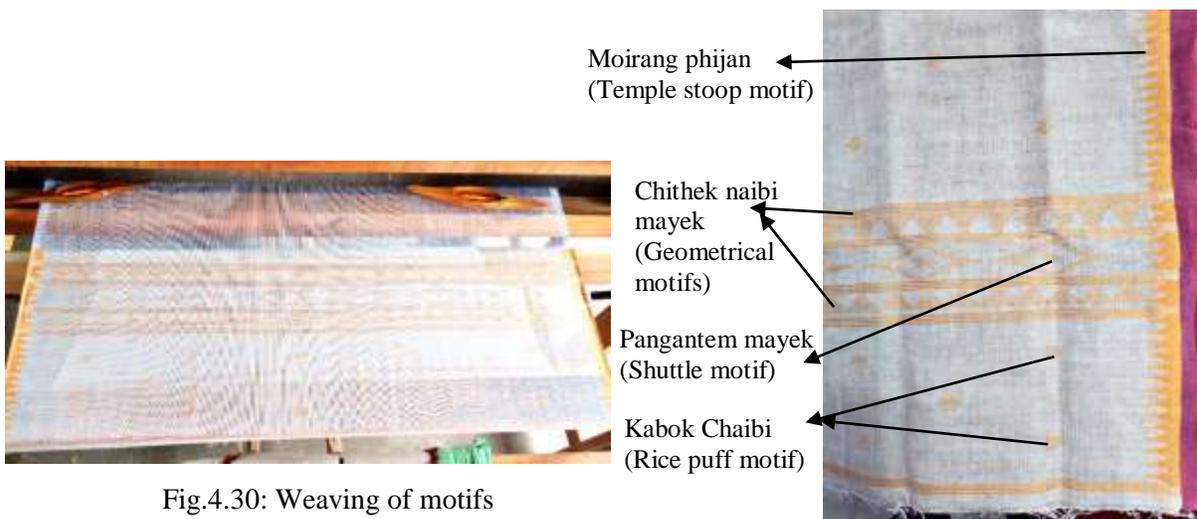
Fig.4.30: Weaving of motifs

Moirang phijan (Temple stoop motif)

Chithek naibi mayek (Geometrical motifs)

Pangantem mayek (Shuttle motif)

Kabok Chaibi (Rice puff motif)

Fig.4.31: Traditional motifs used

Festival/Occasion: Lengyan phee holds special significance during marriages and other auspicious occasions in Manipuri culture, serving as a symbol of tradition, elegance, and cultural identity. Its versatility allowed it to be worn by both men and women, draped over the shoulder in a graceful manner.

Weaver: An assessment was conducted to evaluate the viability of employing a Cotton/Pineapple union fabric to replicate the Lengyan phee. A sample was crafted by skilled weaver Phuritshabam Shanti Devi, aged 46, hailing from Khurkhul, Mayai Leikai, in Imphal West district, Manipur. With her expertise in weaving, she earns a supplementary income through her craft.

Fig.4.32: Phuritshabam Shanti Devi

Through attention to detail and adherence to traditional design elements, the fabric samples successfully captured the essence of Lengyan phee ensuring its continued relevance and appreciation in Manipuri society.

❖ Rayon/Pineapple union fabric

Table 4.14: Khurkhul muga Innaphee

Fig.4.33: Khurkhul muga Innaphee

Sr. No.	Attribute	
1	Size(mts)	2.2m x 1m (original)
2	Yarn	Rayon Yarn in the warp and Pineapple yarn in the weft
3	Weave for base	Plain weave
	Ornamentation	Extra weft design motifs using rayon yarn.
4	Colour for base	Undyed warp yarn and Natural colour of weft (pineapple)
	Ornamentation	Yellow
5	Design: border motifs	Extra weft design temple stoop Waikhu mayek (Crab motif) and kabok chaibi (Rice Puff)
6	Festival/Occasion	Marriage and special occasions

The traditional textile of muga innaphee held significant cultural value among Meitei women in Manipur and was frequently put on on various auspicious occasions and festivities. Among the diverse range of muga innaphee textiles, the Khurkhul variant stood out as the most revered and widely acclaimed indigenous muga innaphee textile.

The fabric sample was crafted to emulate the essence of a traditional textile that was often worn during significant events like marriages and special occasions among the Meitei community in Manipur.

Size: The original size of the textile was 2.2 meters by 1 meter, providing ample coverage for traditional draping styles and ensuring suitability for various occasions.

Yarn: The warp yarn consisted of rayon, chosen for its durability and versatility, while the weft yarn comprised pineapple fiber, adding a unique and natural element to the fabric.

Weave for Base and Ornamentation: A plain weave was employed for the base fabric, ensuring an even foundation for the textile. Ornamentation was achieved through the incorporation of extra weft design motifs using rayon yarn, allowing for the creation of intricate patterns and designs.

Color: The base fabric maintained a subtle elegance with undyed warp yarn (white), while the natural color of the weft yarn, yellow (Hangam mapan machu in local term), added vibrancy and charm to the textile.

Fig.4.34: Placement of motifs

Khoijao Mayek
(Fishing hook motif)

Moirang phijan
(Temple stoop motif)

Waikhu Mayek
(Crab motif)

Kheiroithek mayek
(Squirrels motifs)

Kabok chaibi
(Rice puff motif)
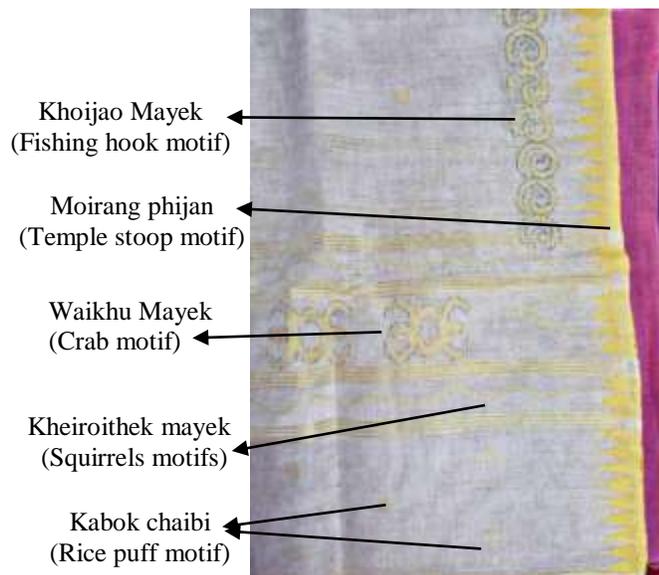
Fig.4.35: Traditional motifs
used

Design - Motifs: The border motifs featured a combination of traditional designs, including the iconic temple stoop design for added depth and texture. Additionally, traditional motifs such as Waikhu mayek (Crab motif) and kabok chaibi (Rice Puff) adorned the borders, symbolizing elements of nature and prosperity.

Festival/Occasion: This textile held cultural significance, particularly during marriages and special occasions, where it served as a symbol of tradition, elegance, and cultural identity within the Meitei community in Manipur.

Weaver: To assess the practicality of utilizing a Rayon/Pineapple combination fabric to imitate the Khurkhul muga (Mulberry silk) Innaphee. A fabric prototype was created by the skilled artisan Phuritshabam Shanti Devi, aged 46, who was expertise in weaving the Innaphee. She

resided in Khurkhul, Mayai Leikai, in the Imphal West district of Manipur, and supplements her income through her weaving skills.

The fabric sample captured the characteristic of traditional Meitei textiles, craftsmanship, cultural designs, and lively color. This made it a perfect option for wearing on special occasions and celebrations.

❖ Union of Polyester/ Pineapple fabric

Table 4.15: Muga Phanek

Sr. No.	Attribute	
1	Size(mts)	1.7m x 1.2m (original)
2	Yarn	Polyester yarn in the warp and Pineapple yarn in the weft
3	Weave for base Ornamentation	Plain weave Extra weft design motifs using polyester yarn.
4	Colour for base Ornamentation	Orange warp yarn and Natural colour of weft (pineapple) Red
5	Design: border motifs	Extra weft design temple stoop No motif on the body
6	Festival/Occasion	Any special occasions

Fig.4.36: Muga Phanek

The traditional attire known as muga phanek was commonly observed worn by Meitei women during various occasions. Among the diverse range of muga phanek textiles, the variant originating from Khurkhul was particularly renowned and widely favored. Another textile, known as muga phanek, served as the lower garment, akin to a sarong. Phanek held significant cultural significance among Meitei women, traditionally crafted from materials such as cotton and silk, notably the mulberry muga sourced from Khurkhul.

Size: The original dimensions of the fabric measured 1.7 meters in length and 1.2 meter in width, providing sarong draping styles.

Yarn: Polyester yarn constituted the warp, lending durability and structure to the fabric, while pineapple yarn was employed in the weft, introducing a natural and distinctive element.

Weave for Base and Ornamentation: A plain weave served as the foundational structure of the fabric, ensuring stability and versatility. For ornamentation, extra weft design motifs were incorporated using polyester yarn, enhancing the aesthetic appeal of the fabric.

Color: The base of the fabric featured an intriguing contrast, with orange warp yarn adding vibrancy and warmth, complemented by the natural color of the weft, resulting in a visually striking combination. Additionally, the ornamentation was highlighted with red hues, adding further depth and richness to the overall color scheme.

Moirang phijan
(Temple stoop motif)

Fig.4.37: Weaving of motifs

Fig4.38: Traditional motif used

Design - Border Motif: The border of the fabric was adorned with extra weft design motifs, notably the temple stoop pattern, adding intricate detail and texture. However, the body of the fabric remained devoid of motifs, allowing for a clean and versatile suitable for various occasions.

Festival/Occasion: Designed for versatility, the fabric was suitable for any special occasion, offering a blend of elegance, sophistication, and contemporary appeal that transcended specific cultural or ceremonial contexts.

Weaver: To assess the practicality of utilizing a Polyester/Pineapple combination fabric to imitate the muga phanek, a fabric prototype was created by the young and skilled artisan Thengujam Anjita, aged 19. At the time, Anjita was a student pursuing a diploma in electronics and communication engineering, demonstrating expertise in weaving phanek. She resided in

Khurkhul, Makha Leikai, in the Imphal West district of Manipur, and supplemented her income for her education.

Fig.4.39: Thengujam Anjita

The exploration of various fabric unions, such as silk/pineapple, cotton/pineapple, rayon/pineapple, and polyester/pineapple, yielded promising results in replicating traditional Manipuri textiles like Rani phee, Lengyan phee, and muga innaphee. Attention to detail was applied in yarn selection, weaving techniques, ornamentation, and color schemes, resulting in fabric samples that successfully captured the essence and cultural significance of these traditional textiles. Additionally, the incorporation of undyed pineapple yarn alongside warp yarns preserved the natural aesthetic appeal of the pineapple fiber, enhancing the authenticity of the samples. The stiffness achieved from the fiber structure closely resembled existing traditional textiles, making them highly feasible for production. Moreover, the fabrics exhibited desirable characteristics such as lightweight, strength, and suitability for various occasions, suggesting their potential for widespread adoption in both traditional and contemporary settings. Overall, this exploration represented a significant step forward in preserving and revitalizing Manipuri textile heritage while also opening avenues for innovation and sustainability in the textile industry.

Traditional Motifs used in the developed traditional textiles

Namthang Khulat (floral motif)

Kheiroithek mayek (Squirrel inspired motif)

Kwaklei Mayek (Orchid motifs)

Pangantem mayek (Shuttle motif)

Waikhu mayek (crab motif)

Khoijao mayek (Fishing hook motif)

Fig.4.40: Sketches of the traditional motifs
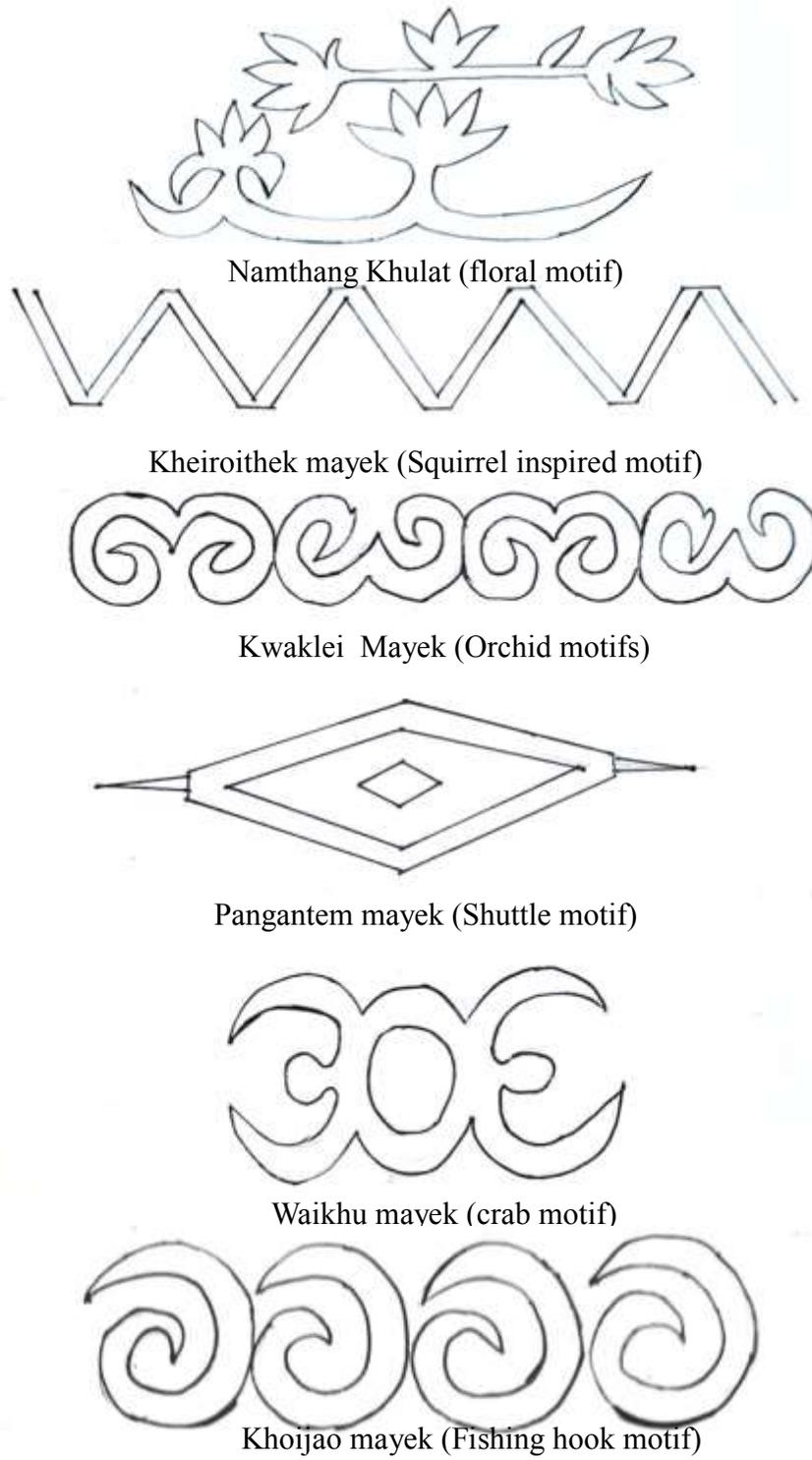
Samples of four different developed textiles

Fig.4.41: Silk/pineapple fabric

Fig.4.42: Silk/pineapple fabric with extra weft motif

Fig.4.43: Cotton/pineapple fabric

Fig.4.44: Rayon/pineapple fabric

Samples of different developed textiles

Fig.4.45: Rayon/pineapple fabric
with extra weft motifs-Rice puff
and temple stoop

Fig.4.46: Polyester/pineapple fabric

4.7.2. Properties of the developed Fabrics

The physical properties of the developed fabrics underwent extensive testing according to standardized procedures. Tensile strength and elongation were assessed, as well as GSM (grams per square meter), fabric count, fabric thickness, stiffness, and drape coefficient. Additionally, one fabric sample was chosen for further analysis using the Kawabata test method.

Table 4.16: Properties of the developed Fabrics

Fabric	Yarn count (Ne)	Fabric count(Thread per inch)	Cover factor (Kc)	GSM (g/m^2)	Thickness (mm)
Rani phee (Silk/Pineapple)	Warp-50's weft-30's	Warp-66 weft-44	15.55	56	0.24
Khurkhul muga Phee(Rayon/Pineapple)	Warp-21's weft-30's	Warp-16 weft 36	9.95	77.48	0.26
Lengyan Phee (Cotton/Pineapple)	Warp-25's weft-30's	Warp-16 weft 44	10.80	75.96	0.30
Muga Phanek (polyester/pineapple	Warp -18's Weft-8's	Warp- 39 Weft-32	17.60	184.4	0.57

Effect of Union blends on Fabric Properties: The fabric compositions varied, with blends including silk, rayon, cotton, and polyester yarns with pineapple yarn. This blending influenced properties such as texture, strength, and appearance.

Impact of Yarn Count and Fabric Count: Yarn count referred to the thickness of the yarn, while fabric count indicated the number of threads per inch in the fabric. These parameters influenced fabric characteristics such as weight, thickness, and durability. Fabrics with higher yarn counts and fabric counts generally tended to have higher cover factors, indicating better coverage of threads in the fabric structure. Muga Phanek had the highest yarn count and the fabric count since the textile was used as lower garment while the others fabrics were used as lightweight traditional textiles (used as upper garments).

Cover Factor and Fabric Performance: The cover factor represented the extent of interlacing and coverage of threads in the fabric structure. Higher cover factors generally implied denser

fabrics with better coverage and potentially higher durability. Fabrics with higher cover factors, such as the Muga Phanek and Rani Phee, had exhibited better resistance to wear and tear due to the tighter interlacing of fibers.

GSM and Thickness: GSM (grams per square meter) indicated the weight of the fabric per unit area, while thickness reflected the fabric's bulkiness. Fabrics with higher GSM values and thicknesses, like the Muga Phanek (GSM- 184.4 g/m^2) and Thickness (0.57mm), had offered better insulation and protection against the elements but it could be heavier and less breathable compared to fabrics with lower GSM values. The Rani phee had a GSM of 56 g/m2 and a thickness of 0.24 mm. These values indicated a relatively lightweight fabric with a moderate thickness. Khurkhul Muga Phee (Rayon/Pineapple) exhibited a GSM of 77.48 g/m2 and a thickness of 0.26 mm. These values suggested a slightly higher weight and thickness compared to the Rani Phee fabric. The GSM for Lengyan Phee (Cotton/Pineapple) was measured at 75.96 g/m2 with a thickness of 0.30 mm. Despite having a similar GSM to the Khurkhul Muga Phee, the Lengyan Phee fabric appeared to be slightly thicker.Muga phanek demonstrated significantly higher GSM and thickness values, measuring at 184.4 g/m2 and 0.57 mm, respectively. These values indicated a much denser and thicker fabric compared to the others in the analysis.

Table. 4.17: One way ANOVA (between groups' variants) of the developed Fabrics – Cover factor

Fabric	Cover factor mean(Kc)	Sum of Squares SS	Mean Square MS	F-Stat	P-Value (0.05)
Rani phee (Silk/Pineapple)	15.55				
Khurkhul muga Phee(Rayon/Pineapple)	9.95				
Lengyan Phee (Cotton/Pineapple)	10.80	130.9299	43.64	1010.22	0.00
Muga Phanek (polyester/pineapple	17.60				

The one-way Analysis of Variance of Cover factor of fabrics was conducted to analyze the differences in the cover factor among four textiles: Rani Phee, Khurkhul Muga Phee, Lengyan Phee, and Muga Phanek. The analysis revealed the following results:

The sum of squares, approximately 130.9299, quantified the total variability observed in the cover factor among the four textiles. The mean square, calculated as 43.64, represented the average variability observed in the cover factor between the textiles. It was obtained by dividing the sum of squares by the degrees of freedom. The F-statistic, computed as 1010.22, was utilized to assess the significance of differences in the mean cover factor among the textiles. It compared the variability between groups (textiles) to the variability within groups. The associated p-value, observed to be 0.00, a low p-value suggested strong evidence that there are differences in cover factor between the textiles. The ANOVA within variables (within each textile) could not be calculated directly due to the cover factor being obtained from the mean of fabric count, which was a limitation in the analysis.

Table 4.18: One way ANOVA (Within group's Variants) of the developed Fabrics – GSM

Fabric	GSM mean (g/m^2)	Std. Dev.	Std. Error	Sum of Squares SS	Mean Square MS
Rani phee (Silk/Pineapple)	56	1.2	0.6928		
Khurkhul muga Phee(Rayon/Pineapple)	77.48	0.0153	0.0088		
Lengyan Phee (Cotton/Pineapple)	75.96	0.3175	0.1833	3.15	0.39
Muga Phanek (polyester/pineapple	184.4	0.1833	0.1058		

The one-way ANOVA (Within variables) was conducted to analyze the developed fabrics in terms of GSM (grams per square meter). Four fabrics were examined: Rani phee (Silk/Pineapple), Khurkhul muga Phee (Rayon/Pineapple), Lengyan Phee (Cotton/Pineapple), and Muga Phanek (Polyester/Pineapple). The standard deviation for Rani phee was found to be 1.2, with a standard error of 0.6928. For Khurkhul muga Phee, the GSM was recorded at 77.48 g/m^2, with a minimal standard error of 0.0088 and a standard deviation of 0.0153. Lengyan Phee exhibited a GSM of 75.96 g/m^2, accompanied by a standard error of 0.1833 and a standard deviation of 0.3175. Lastly, Muga Phanek demonstrated a GSM of 184.4 g/m^2, with a standard error of 0.1058 and a standard deviation of 0.1833.These findings provided insight into the

variation in GSM among the different fabric compositions. The sum of squares (SS) was 3.15 and a mean square (MS) was 0.39.

Table 4.19: One way ANOVA (Between groups' variants) of the developed Fabrics – GSM

Fabric	GSM mean (g/m^2)	Sum of Squares SS	Mean Square MS	F-Stat	P-Value (0.05)
Rani phee (Silk/Pineapple)	56				
Khurkhul muga Phee(Rayon/Pineapple)	77.48				
Lengyan Phee (Cotton/Pineapple)	75.96	30404.42	10134.81	25745.09	0
Muga Phanek (polyester/pineapple	184.4				

The provided data encompasses the GSM (grams per square meter) measurements for four distinct fabrics: Rani phee (Silk/Pineapple), Khurkhul muga Phee (Rayon/Pineapple), Lengyan Phee (Cotton/Pineapple), and Muga Phanek (Polyester/Pineapple).

The analysis was conducted with yielding a sum of squares (SS) of 30404.42 and a mean square (MS) of 10134.81. The resulting F-statistic was 25745.09, with a corresponding p-value of 0.00. The analysis revealed significant differences in GSM among the fabrics, evidenced by the calculated F-statistic and the associated p-value. The GSM values indicated considerable variability among the fabrics. While Rani phee exhibited the lowest GSM value at 56 g/m^2, Muga Phanek showed the highest at 184.4 g/m^2.

Table 4.20: One way ANOVA (Within group's variants) of the developed Fabrics – Thickness

Fabric	Thickness mean(mm)	Std. Dev.	Std. Error	Sum of Squares SS	Mean Square MS
Rani phee (Silk/Pineapple)	0.24	0.0303	0.0136		
Khurkhul muga Phee(Rayon/Pineapple)	0.26	0.0065	0.0029	0.0071	0.0004
Lengyan Phee (Cotton/Pineapple)	0.30	0.0152	0.0068		
Muga Phanek (polyester/pineapple	0.57	0.0239	0.0107		

Each fabric exhibited specific characteristics, with Rani phee having a thickness of 0.24 mm and a standard deviation of 0.0303, indicating moderate variability around its mean thickness. Khurkhul Muga Phee showed a slightly higher thickness of 0.26 mm with a lower standard deviation of 0.0065, suggesting less variability compared to Rani phee. Lengyan Phee demonstrated a thickness of 0.30 mm with a standard deviation of 0.0152, indicating moderate variability similar to Rani phee. In contrast, Muga Phanek displayed a notably higher thickness of 0.57 mm with a standard deviation of 0.0239, signifying relatively higher variability. The provided Sum of Squares (SS) and Mean Square (MS) values further elucidated the variability within the fabrics, aiding in the comprehensive understanding of their thickness characteristics.

In the provided data (table: 4.21), a one-way ANOVA (Analysis of Variance) test was conducted to analyze the thickness measurements (in millimeters) of all the textiles. This analysis aimed to compare the thicknesses of these fabrics. Each fabric exhibited specific characteristics, with Rani phee having a thickness of 0.24 mm and a standard deviation of 0.0303, indicating moderate variability around its mean thickness. Khurkhul muga Phee showed a slightly higher thickness of 0.26 mm with a lower standard deviation of 0.0065, suggesting less variability compared to Rani phee. Lengyan Phee demonstrated a thickness of 0.30 mm with a standard deviation of 0.0152, indicating moderate variability similar to Rani

phee. In contrast, Muga Phanek displayed a notably higher thickness of 0.57 mm with a standard deviation of 0.0239, signifying relatively higher variability.

Table 4.21: One way ANOVA (Between groups' variants) of the developed Fabrics – Thickness

Fabric	Thickness mean (mm)	Sum of Squares SS	Mean Square MS	F-Stat	P-Value (0.05)
Rani phee (Silk/Pineapple)	0.24				
Khurkhul muga Phee(Rayon/Pineapple)	0.26				
Lengyan Phee (Cotton/Pineapple)	0.30	0.3532	0.1177	267.1627	0
Muga Phanek (polyester/pineapple	0.57				

Subsequently, a notably high F-statistic of 267.1627 was calculated, with a corresponding p-value of 0, suggesting that the observed differences in thickness among the fabrics were statistically significant at a significance level of 0.05. The Sum of Squares (SS) was determined to be 0.3532, resulting in a Mean Square (MS) of 0.1177.

Table 4.22: Tensile strength

Fabric	Speed (mm/min)	Tenacity (Kgf/mm)	Elongation (mm)	Maximum load(Kgf)	Percentage strain maximum load
Rani phee (Silk/Pineapple)	Warp- 100	0.20	9.85	10.21	19.70
	Weft- 100	0.30	2.75	14.76	5.50
Khurkhul muga Phee (Rayon/Pineapple)	Warp-100	0.32	9.67	15.91	19.34
	Weft- 100	0.27	3.18	13.46	6.36

Lengyan Phee (Cotton/Pineapple)	Warp-100	0.20	11.05	9.90	22.11
	Weft -100	0.24	3.75	12.15	7.50
Muga Phanek (Polyester/Pineapple)	Warp-100	0.51	24.3	25.52	48.60
	Weft-100	0.45	2.71	22.70	5.421

Note- Gauge length for all= 50mm

In the dataset provided, the mechanical properties of four different fabrics were examined: Rani phee (Silk/Pineapple), Khurkhul muga Phee (Rayon/Pineapple), Lengyan Phee (Cotton/Pineapple), and Muga Phanek (Polyester/Pineapple). The analysis encompassed parameters such as tenacity (in Kgf/mm), gauge length (in mm), maximum load (in Kgf), elongation (mm) and the percentage strain at maximum load, with evaluations conducted for both warp and weft directions at a constant speed of 100 mm/min. For Rani phee, the warp direction exhibited a tenacity of 0.20 Kgf/mm, with a maximum load of 10.21 Kgf, resulting in a percentage strain of 19.70% at maximum load. Conversely, the weft direction demonstrated a higher tenacity of 0.30 Kgf/mm, accompanying a maximum load of 14.76 Kgf, and a lower percentage strain of 5.50% at maximum load. Similarly, Khurkhul muga Phee displayed varying mechanical properties between warp and weft orientations. The warp direction showcased a tenacity of 0.32 Kgf/mm, with a maximum load of 15.91 Kgf, corresponding to a percentage strain of 19.34% at maximum load. In contrast, the weft direction exhibited a slightly lower tenacity of 0.27 Kgf/mm, a maximum load of 13.46 Kgf, and a percentage strain of 6.36% at maximum load. Lengyan Phee showcased comparable mechanical characteristics across warp and weft directions, with tenacity values of 0.20 Kgf/mm (warp) and 0.24 Kgf/mm (weft), accompanied by maximum loads of 9.90 Kgf (warp) and 12.15 Kgf (weft), respectively. These parameters resulted in varying percentage strains at maximum load: 22.11% (warp) and 7.50% (weft). Lastly, Muga Phanek demonstrated notable differences in mechanical behavior between warp and weft orientations. The warp direction exhibited a tenacity of 0.51 Kgf/mm, with a maximum load of 25.52 Kgf with elongation 24.3 mm resulting in a percentage strain of 48.60% at maximum load. On the other hand, the weft direction showed a lower tenacity of 0.45 Kgf/mm, a maximum load of 22.70 Kgf, and a percentage strain of 5.421% at maximum

load. These comprehensive analyses provide valuable insights into the mechanical performance of each fabric.

Table 4.23: One way ANOVA (Within group's variants) of the developed Fabrics – Tensile strength

Fabric	Maximum load mean (kgf)	Std. Dev.	Std. Error	Sum of Squares SS	Mean Square MS
Rani phee (Silk/Pineapple)	Warp-10.21	0.36	0.21		
	Weft- 14.76	1.06	0.61		
Khurkhul muga Phee(Rayon/Pineapple)	Warp-15.91	0.39	0.22		
	Weft-13.46	0.39	0.22		
Lengyan Phee (Cotton/Pineapple)	Warp-9.90	0.40	0.23	6.94	0.43
	Weft-12.15	0.68	0.39		
Muga Phanek (polyester/pineapple	Warp-25.52	0.6	0.35		
	Weft-22.70	0.96	0.55		

An extensive investigation delved into the intricate mechanical properties of several traditional fabrics, including Rani Phee (Silk/Pineapple), Khurkhul Muga Phee (Rayon/Pineapple), Lengyan Phee (Cotton/Pineapple), and Muga Phanek (Polyester/Pineapple). The primary focus of this analysis was to understand how these fabrics responded to tensile forces, particularly along their warp and weft directions. For Rani Phee, the mean maximum load in the warp direction was recorded at 10.21 kgf, exhibiting a standard deviation of 0.36 kgf and a standard error of 0.21 kgf, signifying the average force required to induce failure or deformation when pulled along the warp direction. Meanwhile, in the weft direction, a mean maximum load of 14.76 kgf was observed, with a standard deviation of 1.06 kgf with the standard error 0.61. For Khurkhul Muga Phee, a robust mean maximum load of 15.91 kgf was noted in the warp direction, accompanied by a standard deviation of 0.39 kgf and a standard error of 0.22 kgf, suggesting notable resistance to stretching along this axis. In the

weft direction, a mean maximum load of 13.46 kgf was observed, with identical standard deviation and standard error values to those in the warp direction, indicating consistent strength characteristics in both orientations. Similarly, Lengyan Phee showcased distinct properties, with a mean maximum load of 9.90 kgf in the warp direction, accompanied by a standard deviation of 0.40 kgf and a standard error of 0.23 kgf. Conversely, in the weft direction, a slightly higher mean maximum load of 12.15 kgf was recorded, accompanied by a standard deviation of 0.68 kgf and a standard error of 0.39 kgf, indicating variations in strength profiles between the warp and weft directions. Finally, Muga Phanek exhibited remarkable strength characteristics, displaying a robust mean maximum load of 25.52 kgf in the warp direction, with a standard deviation of 0.6 kgf and a standard error of 0.35 kgf, and 22.70 kgf in the weft direction, albeit with a higher standard deviation of 0.96 kgf and a standard error of 0.55 kgf, indicating substantial strength profiles in both directions.

Table 4.24: One way ANOVA (Between group's variants) of the developed Fabrics – Tensile strength

Fabric	Maximum load mean (kgf)	Sum of Squares SS	Mean Square MS	F-Stat	P-Value (0.05)
Rani phee (Silk/Pineapple)	Warp-10.21				
	Weft- 14.76				
Khurkhul muga Phee(Rayon/Pineapple)	Warp-15.91				
	Weft-13.46	684.30	97.76	225.43	0
Lengyan Phee (Cotton/Pineapple)	Warp-9.90				
	Weft-12.15				
Muga Phanek (polyester/pineapple	Warp-25.52				
	Weft-22.70				

The one-way ANOVA, which examines the variation between groups, was conducted to analyze the tensile strength of the developed fabrics. Sum of Squares (SS), Mean Square (MS), F-Statistic, and P-Value (0.05), was utilized to assess and compare the mechanical

properties of the given textiles. The Sum of Squares (SS) was employed to quantify the total variation in the maximum load mean observed across all fabric samples, elucidating the dispersion of data points around the mean. With an SS value of 684.30, the overall variability in maximum load mean among the fabrics was delineated. Furthermore, Mean Square (MS), calculated by dividing the Sum of Squares by the degrees of freedom, provided an average measure of variability within the dataset. The MS value, standing at 97.76, depicted the average variation in maximum load mean observed among the fabric samples. Meanwhile, the F-Statistic was employed to gauge the significance of differences in mean maximum load among the fabric samples. With an F-Statistic of 225.43, a substantial difference in mean maximum load among the fabrics was indicated, suggesting notable variations in their mechanical properties. Finally, the P-Value (0.05), serving as a critical threshold for determining statistical significance, was found to be 0, denoting a highly significant difference in mean maximum load among the fabrics.

Table 4.25: Average fabric stiffness/bending length

Sample	Warp (cm)		Weft (cm)	
	Face to Face	Back to Back	Face to Face	Back to Back
Rani phee (Silk/Pineapple)	3.12	3.38	9.68	9.32
Khurkhul muga Phee(Rayon/Pineapple)	3.68	3.42	6.41	6.7
Lengyan Phee (Cotton/Pineapple)	3.12	3.1	8.76	8.86
Muga Phanek (polyester/pineapple)	2.98	2.99	7.9	8

The analysis focused on measuring the warp and weft dimensions of each fabric in both face-to-face and back-to-back orientations. For Rani phee, the warp dimensions ranged from 3.12 cm (face-to-face) to 3.38 cm (back-to-back), while the weft dimensions ranged from 9.68 cm (face-to-face) to 9.32 cm (back-to-back). Similarly, Khurkhul muga Innaphee exhibited warp dimensions ranging from 3.68 cm (face-to-face) to 3.42 cm (back-to-back), and weft dimensions ranging from 6.41 cm (face-to-face) to 6.7 cm (back-to-back). Lengyan Phee

showcased warp dimensions of 3.12 cm (face-to-face) and 3.1 cm (back-to-back), along with weft dimensions of 8.76 cm (face-to-face) and 8.86 cm (back-to-back). Lastly, Muga Phanek displayed warp dimensions of 2.98 cm (face-to-face) and 2.99 cm (back-to-back), accompanied by weft dimensions of 7.9 cm (face-to-face) and 8 cm (back-to-back). Khurkhul muga Innaphee had the highest warp dimension value, and Rani phee had the highest weft dimension value. Muga Phanek had the lowest warp dimension value, and Rani phee had the lowest weft dimension value. These comprehensive analyses provide valuable insights into the dimensional characteristics of each fabric.

Table 4.26: One way ANOVA (Within group's variants) of the developed Fabrics-Stiffness (Warp direction)

Sample	Warp (cm)		Std. Dev.		Std. Error	
	Face to Face	Back to Back	Face to Face	Back to Back	Face to Face	Back to Back
Rani phee (Silk/Pineapple)	3.12	3.38	0.18	0.13	0.08	0.05
Khurkhul muga Phee(Rayon/Pineapple)	3.68	3.42	0.23	0.28	0.11	0.12
Lengyan Phee (Cotton/Pineapple)	3.12	3.1	0.17	0.20	0.08	0.09
Muga Phanek (polyester/pineapple)	2.98	2.99	0.19	0.19	0.08	0.08

A detailed analysis was conducted to examine the warp measurements, standard deviation, and standard error of various traditional fabrics, including Rani Phee (Silk/Pineapple), Khurkhul Muga Phee (Rayon/Pineapple), Lengyan Phee (Cotton/Pineapple), and Muga Phanek (Polyester/Pineapple). The warp measurements for each fabric type were recorded both face to face and back to back. For Rani Phee, the warp measurements face to face were found to be 3.12 cm with a standard deviation of 0.18 cm and a standard error of 0.08 cm, while back to back measurements were 3.38 cm with a standard deviation of 0.13 cm and a standard error of 0.05 cm. Similarly, Khurkhul Muga Phee exhibited face to face warp measurements of 3.68 cm with a standard deviation of 0.23 cm and a standard error of 0.11 cm,

and back to back measurements of 3.42 cm with a standard deviation of 0.28 cm and a standard error of 0.12 cm. Lengyan Phee and Muga Phanek also displayed similar patterns with slight variations in their warp measurements, standard deviations, and standard errors. This analysis provided valuable insights into the dimensional characteristics and consistency of warp measurements among the different traditional fabrics. The sum of squares and Mean squares within the groups were found to be 1.34 and 0.04 respectively.

Table 4.27: One way ANOVA (Between group's variants) of the developed Fabrics-Stiffness (Warp direction)

Sample	Warp (cm)		F-Stat	P- value
	Face to Face	Back to Back		
Rani phee (Silk/Pineapple)	3.12	3.38	7.3	0
Khurkhul muga Phee(Rayon/Pineapple)	3.68	3.42		
Lengyan Phee (Cotton/Pineapple)	3.12	3.1		
Muga Phanek (polyester/pineapple)	2.98	2.99		

The one-way ANOVA conducted to analyze the stiffness of the developed fabrics in the warp direction revealed a significant difference among the fabric samples. The stiffness, measured in centimeters, was assessed both face to face and back to back for each fabric sample. Results indicated that the mean stiffness values varied across the different fabric compositions. Specifically, Rani Phee (Silk/Pineapple) exhibited a mean stiffness of 3.12 cm face to face and 3.38 cm back to back. Khurkhul Muga Phee (Rayon/Pineapple) displayed a mean stiffness of 3.68 cm face to face and 3.42 cm back to back. Lengyan Phee (Cotton/Pineapple) showed mean stiffness values of 3.12 cm face to face and 3.1 cm back to back. Lastly, Muga Phanek (Polyester/Pineapple) demonstrated mean stiffness values of 2.98 cm face to face and 3.0 cm back to back.

The sum of squares and mean squares among the fabrics were found to be 1.23 and 0.30 respectively. The computed F-Statistic of 7.3 indicated a significant difference in stiffness among the fabric samples. Moreover, the P-value associated with this F-Statistic was found to be 0, indicating strong evidence against the null hypothesis that there is no difference in stiffness among the fabric samples.

Table 4.28: One way ANOVA (Within group's variants) of the developed Fabrics-Stiffness (Weft direction)

Sample	Weft (cm)		Std. Dev.		Std. Error	
	Face to Face	Back to Back	Face to Face	Back to Back	Face to Face	Back to Back
Rani phee (Silk/Pineapple)	9.68	9.32	0.32	0.37	0.14	0.17
Khurkhul muga Phee(Rayon/Pineapple)	6.41	6.7	0.13	0.16	0.06	0.74
Lengyan Phee (Cotton/Pineapple)	8.76	8.86	0.26	0.22	0.11	0.10
Muga Phanek (polyester/pineapple)	7.9	8	0.25	0.38	0.11	0.17

The provided data presents measurements of ANOVA (Analysis of Variance) of the weft direction to provide standard deviation and standard error, for various traditional fabrics, namely Rani Phee (Silk/Pineapple), Khurkhul Muga Phee (Rayon/Pineapple), Lengyan Phee (Cotton/Pineapple), and Muga Phanek (Polyester/Pineapple). These measurements were taken for both face to face and back to back orientations, offering insights into the dimensional characteristics of the fabrics.

For Rani Phee, the weft measurements face to face were recorded at 9.68 cm with a standard deviation of 0.32 cm and a standard error of 0.14 cm, while back to back measurements were 9.32 cm with a standard deviation of 0.37 cm and a standard error of 0.17 cm. Khurkhul Muga Phee displayed face to face weft measurements of 6.41 cm with a standard deviation of 0.13 cm and a standard error of 0.06 cm, and back to back measurements of 6.7 cm with a standard deviation of 0.16 cm and a standard error of 0.74 cm. Lengyan Phee exhibited face to

face weft measurements of 8.76 cm with a standard deviation of 0.26 cm and a standard error of 0.11 cm, and back to back measurements of 8.86 cm with a standard deviation of 0.22 cm and a standard error of 0.10 cm. Finally, Muga Phanek displayed face to face weft measurements of 7.9 cm with a standard deviation of 0.25 cm and a standard error of 0.11 cm, and back to back measurements of 8 cm with a standard deviation of 0.38 cm and a standard error of 0.17 cm. The value of the SS (Sum of Squares) and MS (Mean squares) were obtained as 2.49 and 0.078 respectively.

Table 4.29: One way ANOVA (Between group's variants) of the developed Fabrics-Stiffness (Weft direction)

Sample	Weft (cm)		F-Stat	P- value
	Face to Face	Back to Back		
Rani phee (Silk/Pineapple)	9.68	9.32	89.49	0
Khurkhul muga Phee(Rayon/Pineapple)	6.41	6.7		
Lengyan Phee (Cotton/Pineapple)	8.76	8.86		
Muga Phanek (polyester/pineapple)	7.9	8		

In the analysis conducted using the F-Stat and P-value, in addition to the provided SS (Sum of Squares) value of 48.71 and MS (Mean Square) value of 6.95, it was found that the F-Stat value was 89.49, with a corresponding P-value of 0. This indicateed a significant difference among the given fabrics in terms of their weft measurements. The SS value 48.71 represented the total variation in the weft measurements among the fabrics, while the MS value 6.95 represented the average variation within the dataset. This significant difference suggested that the fabric compositions influence the dimensional characteristics of the weft direction.

Table 4.30: Drape coefficient of developed and existing textile

Developed Fabric	Drape coefficient	Fabric (existing textile)	Drape coefficient (Starched)	Drape coefficient (De-starched)
Rani phee Silk/Pineapple (S/P)	67.57%	Rani phee Silk/Silk(S/S)	60.61%	18.85%
Muga Innaphee Rayon/Pineapple(R/P)	57.13%	Muga Innaphee Rayon/Silk(R/S)	53.65%	15.38%
Lengyan phee Cotton/Pineapple(C/P)	64%	Lengyan phee Cotton/Silk(C/S)	64.09%	46.66%

The drape coefficient values obtained for the developed fabrics, composed of Silk/Pineapple (S/P), Rayon/Pineapple (R/P), and Cotton/Pineapple (C/P), were significantly higher compared to those of existing textiles such as Silk/Silk (S/S), Rayon/Silk (R/S), and Cotton/Silk (C/S), both starched and de-starched.

For instance, the S/P fabric exhibited a drape coefficient of 67.57%, while the S/S fabric had a lower coefficient of 60.61%. This indicates that the S/P fabric possesses superior drapability compared to traditional Silk/Silk textiles. Similarly, the R/P fabric showed a drape coefficient of 57.13%, whereas the R/S fabric had a lower coefficient of 53.65%. Again, this suggests that the R/P fabric offers better draping qualities compared to conventional Rayon/Silk textiles. Furthermore, the C/P fabric displayed a drape coefficient of 64%, whereas the C/S fabric had a slightly higher coefficient of 64.09%. However, it's important to note that even though the C/S fabric had a marginally higher coefficient, the C/P fabric outperformed in terms of drapability when compared to both starched and de-starched Cotton/Silk textiles, which showed coefficients of 64.09% and 46.66% respectively.

Overall, the results indicate that the developed fabrics incorporating pineapple yarns alongside silk, rayon, and cotton possess comparable drapability compared to traditional textiles commonly used in the Meitei community. This suggests potential benefits of pineapple leaf fibre in making traditional textiles of Meitei community.

Table 4.31: One way ANOVA (Between group's variants) of the developed Fabrics- Drape-coefficient comparison

Developed Fabric	Drape coefficient	Fabric (existing textile)	Drape coefficient (Starched)
Silk/Pineapple (S/P)	67.57%	Silk/Silk(S/S)	60.61%
Rayon/Pineapple(R/P)	57.13%	Rayon/Silk(R/S)	53.65%
Cotton/Pineapple(C/P)	64%	Cotton/Silk(C/S)	64.09%

ANOVA Results

Sum of Squares SS	Mean Square MS	F-Stat	P-Value (0.05)
17.85	17.85	0.63	0.47

The one-way ANOVA conducted to compare the drape coefficients of the developed fabrics revealed interesting findings. The drape coefficients, representing the ability of a fabric to conform to the shape of a draped surface, were compared between different fabric compositions: Silk/Pineapple (S/P), Rayon/Pineapple (R/P), and Cotton/Pineapple (C/P), alongside their respective existing textile resemblance: Silk/Silk (S/S), Rayon/Silk (R/S), and Cotton/Silk (C/S).

The analysis resulted in a Sum of Squares (SS) value of 17.85 and a Mean Square (MS) value of 17.85. The F-Statistic, calculated to assess the significance of differences in drape coefficients among the fabric groups, was found to be 0.63. Additionally, the corresponding P-Value (0.05) was calculated as 0.47. These statistical values indicated that there were no significant differences observed in the drape coefficients among the different fabric compositions. Despite variations in fabric composition and the incorporation of pineapple yarns, the drape coefficients remained relatively consistent across the developed fabrics and their existing traditional textile equivalents. This suggested that the addition of pineapple yarn

did not significantly different the drape characteristics compared to traditional textiles (which are starched).

The traditional textiles of the Meitei community in the state were known for their stiffness in draping, a notable feature. Researcher had successfully developed stiff fabrics without requiring any finishing treatment. During drapability tests, these fabrics had exhibited high drape coefficients, making them suitable for use as drapes around the upper body. Remarkably, the obtained drape coefficient values had been comparable to those of the traditional starched textiles, known as "phee," used in Manipur.

4.7.3. Kawabata Analysis

The Kawabata Evaluation System (KES) comprises a set of tools utilized to measure the mechanical properties of textile materials that influence the tactile qualities perceived by human touch. These instruments enable the objective assessment of garment material properties, offering insights into comfort perception. By applying minimal forces, akin to those experienced during fabric manipulation or touch, Kawabata instruments evaluate various mechanical properties such as tensile (stretch), shear stiffness (drape), bending rigidity (flexing), compression (thickness, softness), and surface friction and roughness (proximity to the skin), which directly impact tactile sensations.

Through the analysis of energy loss during mechanical deformation and recovery processes, KES provides a comprehensive tool for fabric hand assessment. This analytical capability not only allows for the prediction of human response to textiles but also facilitates an understanding of how factors such as fiber type, yarn structure, fabric construction, and finishing techniques contribute to perceptions of comfort.

In the evaluation utilizing the Kawabata Evaluation System, the chosen fabric, the cotton/pineapple fabric, was assessed for its suitability as a fabric for women's thin dresses. The analysis focused on obtaining low stress mechanical properties across various parameters including compression, fabric weight and thickness, tensile strength, shear stiffness, surface characteristics, and bending rigidity. (https://textiles.ncsu.edu/tpacc/comfort-performance/kawabata-evaluation-system/)

The reason for the choice of cotton/pineapple fabric as the test material was that cotton common in textile manufacturing, owing to its versatility and widespread use in clothing production. By blending cotton with pineapple yarn, a sustainable and potentially innovative fabric composition is achieved, which warrants thorough evaluation to determine its performance in garment applications.

The evaluation process involved testing using the Kawabata instruments to measure the fabric's mechanical properties under low stress conditions. These properties are crucial in determining the fabric's suitability for thin dresses, as they directly impact comfort, aesthetics, and overall wearability. Compression properties were assessed to determine the fabric's ability to maintain its shape under pressure, crucial for close-fitting garments and transportation. Fabric weight and thickness measurements were conducted to ensure lightweight yet adequately covering dresses for comfort and style. Tensile properties were evaluated to ascertain the fabric's strength and elasticity, essential for enduring stretching forces during wear. Shear properties were examined to gauge the fabric's drape and fluidity, contributing to aesthetic appeal and ease of movement. Surface properties such as friction and roughness were analyzed to assess tactile feel and comfort against the skin. Bending properties were assessed to understand how the fabric flexes and conforms to the body, affecting overall drape and fit.

The results for each test are given below:

Table 4.32: Primary and Total Hand value (Women's Thin dress Fabric)

	Koshi (Stiffness)	Numeri (smoothness)	Fukurami (Fullness & softness)	THV KN-302 Winter
Cotton/pineapple	8.17	6.42	9.63	3.05

In the evaluation of THV KN-302 Winter fabric, Cotton/pineapple fabric, key parameters including Koshi (stiffness), Numeri (smoothness), and Fukurami (fullness & softness) were analyzed (scale 0-10) using the Kawabata Evaluation System (KES).
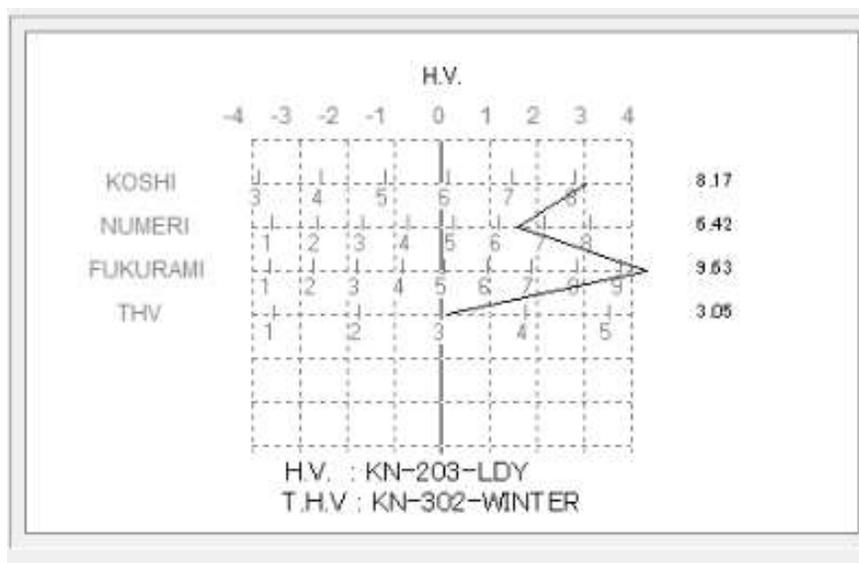
Graph 4.3: Primary and Total Hand value (Women's Thin dress Fabric)

The fabric exhibited a moderate level of stiffness, with a Koshi value of 8.17. This stiffness provided structure and stability to garments, ensuring they maintained their shape during wear. The fabric displayed a relatively smooth surface texture, with a Numeri value of 6.42. Smoothness was desirable for clothing, as it enhanced comfort and reduced friction against the skin. With a Fukurami value of 9.63, the fabric demonstrated a high degree of fullness and softness. This attribute was particularly desirable in thin dresses. The THV Total Hand Value, which encompasses multiple fabric properties, including Koshi, Numeri, and Fukurami, was 3.05 out of 5. This comprehensive assessment indicated that the fabric possessed a favorable combination of stiffness, smoothness, and fullness & softness, making it suitable for use in women's thin dresses.

The analysis of Koshi, Numeri, and Fukurami values using the Kawabata Evaluation System underscored the suitability of THV KN-302 Winter fabric for use in women's thin dresses. Its combination of mechanical properties, along with the overall THV Total Hand Value, indicated that the fabric met the requirements for style, comfort, and quality in garment construction.

Table 4.33: Low compression properties (KES-FB3A)

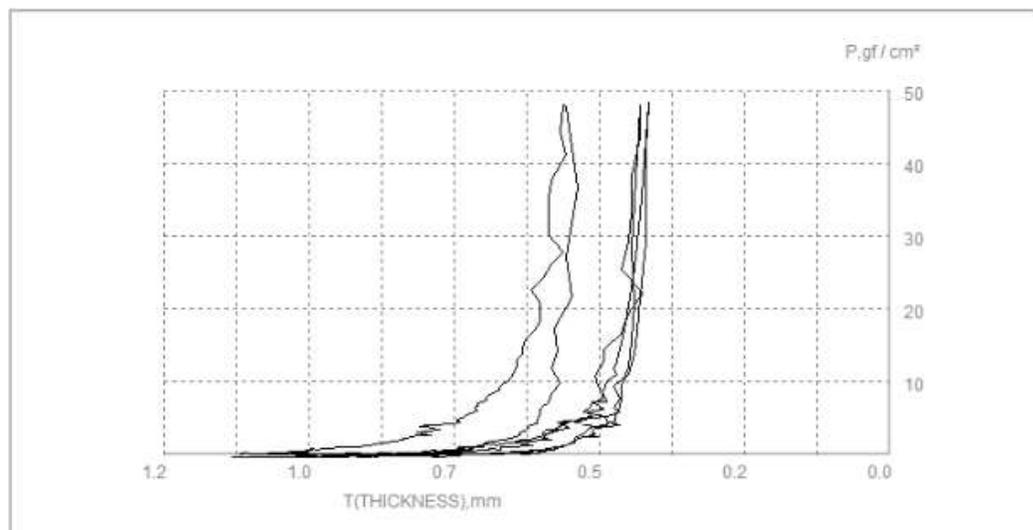| Cotton/pineapple Fabric	LC	WC g.cm/cm²	RC %
	0.303	0.283	37.56

Parameters

LC: Linearity of Compression-thickness curve
WC: Compressional energy
RC: Compressional resilience

The Kawabata Evaluation System (KES-FB3A) analysis of the compression properties of the Cotton/pineapple Fabric revealed significant insights into its behavior under compressional forces. Three key parameters were measured: Linearity of Compression-thickness curve (LC), Compressional energy (WC), and Compressional resilience (RC).

Graph 4.4: Low compression properties (KES-FB3A) of Cotton/pineapple fabric (3 samples)

The LC value obtained for the fabric was 0.303 g.cm/cm². This parameter assesses the linearity of the relationship between compression force and fabric thickness. A higher LC value indicates a more linear compression-thickness curve, suggesting that the fabric exhibits uniform compression behavior across different levels of applied force. The fabric demonstrated a compressional energy value (WC) of 0.283 g.cm/cm². This parameter quantifies the energy

absorbed by the fabric during compression. A lower WC value indicates that the fabric requires less energy to compress, suggesting that it is relatively soft and pliable. In the context of women's thin dresses, a fabric with low compressional energy would offer enhanced comfort and ease of movement, contributing to a pleasant wearing experience. The compressional resilience (RC) of the fabric was measured at 37.56%. RC represents the ability of the fabric to recover its original thickness after compression. A higher RC value indicates greater resilience, implying that the fabric can bounce back to its original shape more effectively after being compressed.

The analysis of the compression properties of the Cotton/pineapple Fabric highlighted its suitability for use in women's thin dresses. The fabric exhibited a relatively linear compression-thickness curve, indicating consistent thickness under compression. Additionally, its low compressional energy suggested softness and comfort, while the high compressional resilience ensures durability and shape retention over time.

Table 4.34: Fabric weight and Thickness

Cotton/pineapple Fabric	Fabric Thickness (mm)	Fabric Thickness at max. pressure (mm)	Fabric weight (mg/cm^2)
	0.819	0.448	7.434

In the evaluation of the Cotton/pineapple Fabric, several key parameters related to fabric thickness and weight were assessed, providing valuable insights into its structural properties. The fabric thickness and weight were measured both in their standard state and under maximum pressure conditions.

Initially, the fabric exhibited a thickness of 0.819 mm. This standard measurement provides a baseline for understanding the fabric's inherent thickness characteristics. Under maximum pressure conditions, the fabric thickness was reduced to 0.448 mm. This reduction indicated the fabric's compressibility and its ability to adapt to external forces, which is essential for maintaining garment shape and comfort during wear. The fabric weight, expressed as milligrams per square centimeter (mg/cm²), was determined to be 7.434 mg/cm². This

measurement quantifies the mass of fabric per unit area, providing insights into its density and overall feel. A higher fabric weight suggests a denser material, which may influence its drape, durability, and suitability for specific garment applications. The analysis of fabric thickness and weight highlights the Cotton/pineapple Fabric's structural characteristics and its suitability for various applications. The fabric's ability to maintain a relatively consistent thickness under pressure indicated its resilience and adaptability, essential qualities for garments that require both comfort and shape retention.

Table 4.35: Tensile Properties using tensile tester (KES-FB1A)

|	Direction	LT	WT gf.cm/cm^2	RT %	EMT %
Cotton/pineapple	Warp	0.552	7.78	52.47	5.64
	Weft	0.753	1.73	73.09	0.92
	Average	0.635	4.67	62.78	3.28

Parameter
LT: Linearity of load- extension curve
WT: Tensile Energy
RT: Tensile resilience
EMT: Extensibilty

The tensile properties of the Cotton/pineapple Fabric were evaluated using a tensile tester (KES-FB1A), providing valuable insights into its mechanical characteristics in both warp and weft directions. Several key parameters, including Linearity of load-extension curve (LT), Tensile Energy (WT), Tensile Resilience (RT), and Extensibility (EMT), were measured and analyzed.

Warp Direction: In the warp direction, the fabric exhibited a LT value of 0.552 gf.cm/cm². This parameter assesses the linearity of the relationship between load and extension during tensile testing. A higher LT value indicates a more linear load-extension curve, suggesting uniform deformation behavior under increasing load.

F gf/cm
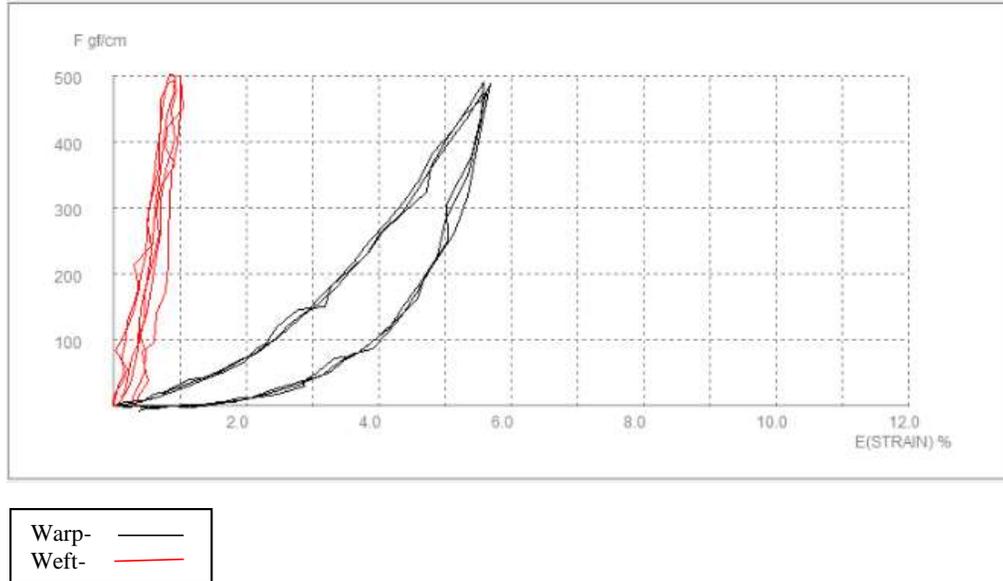
Warp- ———
Weft- ———

Graph 4.5: Tensile Properties using tensile tester (KES-FB1A)

The Tensile Energy (WT) measured in the warp direction was 7.78%. WT quantifies the energy absorbed by the fabric during tensile deformation. A higher WT value indicates greater energy absorption, suggesting a fabric's ability to withstand stretching forces without rupturing or tearing.

The Tensile Resilience (RT) in the warp direction was 52.47%. RT represents the fabric's ability to recover its original dimensions after tensile deformation. A higher RT value indicates greater resilience, suggesting that the fabric can return to its original state after being stretched.

The Extensibility (EMT) measured in the warp direction was 5.64%. EMT quantifies the percentage of elongation the fabric can undergo before reaching its breaking point. A higher EMT value indicates greater extensibility, suggesting that the fabric can stretch more before failing.

Weft Direction: In the weft direction, the fabric exhibited different tensile properties compared to the warp direction. The LT value was 0.753 gf.cm/cm², indicating a slightly different deformation behavior compared to the warp direction.

The Tensile Energy (WT) measured in the weft direction was 1.73%, lower than that in the warp direction. This suggests that the fabric may have different energy absorption capabilities in different directions.

The Tensile Resilience (RT) in the weft direction was 73.09%, higher than that in the warp direction. This indicates that the fabric has excellent resilience in the weft direction, bouncing back to its original state more effectively after being stretched.

The Extensibility (EMT) measured in the weft direction was 0.92%, indicating lower extensibility compared to the warp direction.

The analysis of tensile properties in both warp and weft directions provides valuable insights into the mechanical behavior of the Cotton/pineapple Fabric. The fabric demonstrates different characteristics depending on the direction of tensile force.

Table 4.36: Shear properties using shear tester (KES-FB1)

	Direction	G Gf.cm.deg	2HG gf/cm	2HG5 gf/cm
Cotton/pineapple	Warp	0.552	7.78	52.47
	Weft	0.753	1.73	73.09
	Average	0.635	4.67	62.78

Parameters
G: Shear Stiffness
2HG: Hysteresis of shear force at 0.5 deg shear angle
2HG5: Hysteresis of shear force at 5 deg shear angle

The shear properties of the Cotton/pineapple Fabric were assessed using a shear tester (KES-FB1), providing insights into its behavior under shear forces in both warp and weft directions. Three key parameters were measured and analyzed: Shear Stiffness (G), Hysteresis of shear force at 0.5-degree shear angle (2HG), and Hysteresis of shear force at 5-degree shear angle (2HG5).
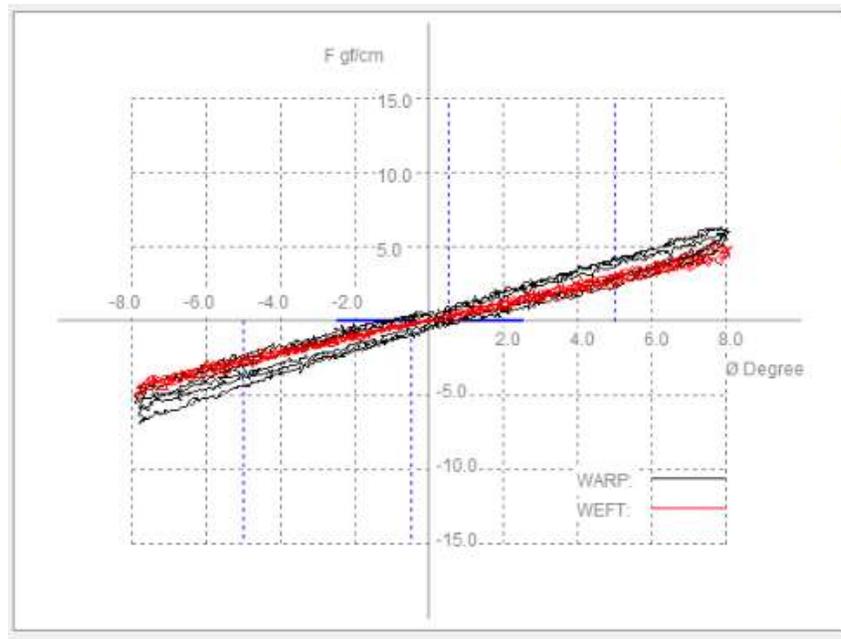
Graph 4.6: Shear properties using shear tester (KES-FB1)

Warp Direction: In the warp direction, the fabric exhibited a Shear Stiffness (G) of 0.552 gf.cm/deg. This parameter quantifies the fabric's resistance to shear deformation, with a higher G value indicating greater stiffness.

The Hysteresis of shear force at 0.5-degree shear angle (2HG) measured in the warp direction was 7.78 gf/cm. 2HG represents the energy dissipated during shear deformation, with a lower 2HG value indicating less energy loss and higher efficiency in shear resistance.

The Hysteresis of shear force at 5-degree shear angle (2HG5) in the warp direction was 52.47 gf/cm. This parameter provides additional information on the fabric's behavior under higher shear angles, with a higher 2HG5 value indicating increased energy dissipation.

Weft Direction: In the weft direction, the fabric exhibited different shear properties compared to the warp direction. The Shear Stiffness (G) was measured at 0.753 gf.cm/deg, indicating slightly different resistance to shear deformation compared to the warp direction.

The Hysteresis of shear force at 0.5-degree shear angle (2HG) measured in the weft direction was 1.73 gf/cm, lower than that in the warp direction. This suggested lower energy dissipation during shear deformation in the weft direction.

The Hysteresis of shear force at 5-degree shear angle (2HG5) in the weft direction was 73.09 gf/cm, indicating higher energy dissipation compared to the warp direction.

The analysis of shear properties in both warp and weft directions provides valuable insights into the fabric's behavior under shear forces. The fabric exhibited different shear stiffness and hysteresis characteristics depending on the direction of shear.

Table 4.37: Surface properties using Surface tester (FES-FB4)

	Direction	MIU	MMD	SMD (µm)
Cotton/pineapple	Warp	0.121	0.0263	7.770
	Weft	0.252	0.0279	12.740
	Average	0.186	0.0271	10.255

Parameters
MIU: Coefficient of friction
MMD: Mean Deviation of MIU
SMD: Geometrical Roughness

The surface properties of the Cotton/pineapple Fabric were analyzed using a Surface Tester (FES-FB4), providing insights into its surface characteristics in both warp and weft directions. Three key parameters were measured and analyzed: Coefficient of friction (MIU), Mean Deviation of MIU (MMD), and Geometrical Roughness (SMD).

Warp Direction: In the warp direction, the fabric exhibited a Coefficient of Friction (MIU) of 0.121. MIU represents the resistance to sliding between two surfaces, with lower values indicating smoother surfaces and reduced friction.

The Mean Deviation of MIU (MMD) measured in the warp direction was 0.0263, indicating the variability of the coefficient of friction across the fabric surface. A lower MMD value suggests more consistent surface properties.
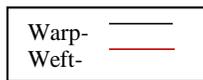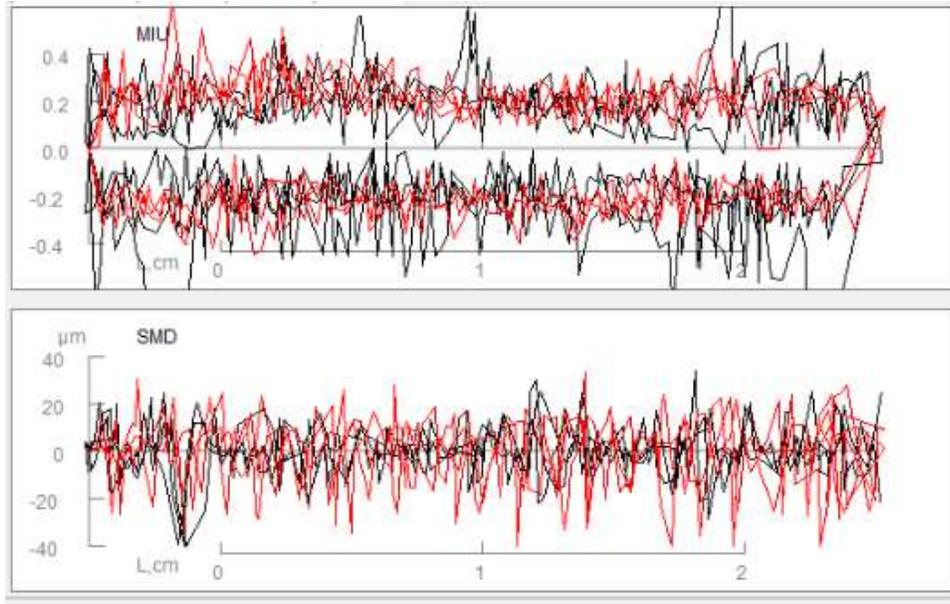
| Warp- | ———— |
| Weft- | ———— |

Graph 4.7: Surface properties using Surface tester (FES-FB4)

The Geometrical Roughness (SMD) in the warp direction was measured at 7.770 µm. SMD quantifies the surface roughness of the fabric, with higher values indicating a rougher surface texture.

Weft Direction: In the weft direction, the fabric exhibited different surface properties compared to the warp direction. The Coefficient of Friction (MIU) was measured at 0.252, indicating a higher resistance to sliding compared to the warp direction.

The Mean Deviation of MIU (MMD) in the weft direction was 0.0279, suggesting variability in surface properties across the fabric surface. The Geometrical Roughness (SMD) in the weft direction was 12.740 µm, indicating a rougher surface texture compared to the warp direction.

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Table 4.38: Bending Properties using pure bending tester (KES-FB2)

	Direction	B gf.cm^2/cm	2HB gf.cm^2/cm
Cotton/pineapple	Warp	0.0359	0.0348
	Weft	1.9740	0.9651
	Average	1.0049	0.4999

Parameters
B: Bending Rigidity
2HB: Hysteresis of Bending Moment

The bending properties of the Cotton/pineapple Fabric were analyzed using a pure bending tester (KES-FB2), providing insights into its behavior under bending forces in both warp and weft directions. Two key parameters were measured and analyzed: Bending Rigidity (B) and Hysteresis of Bending Moment (2HB).
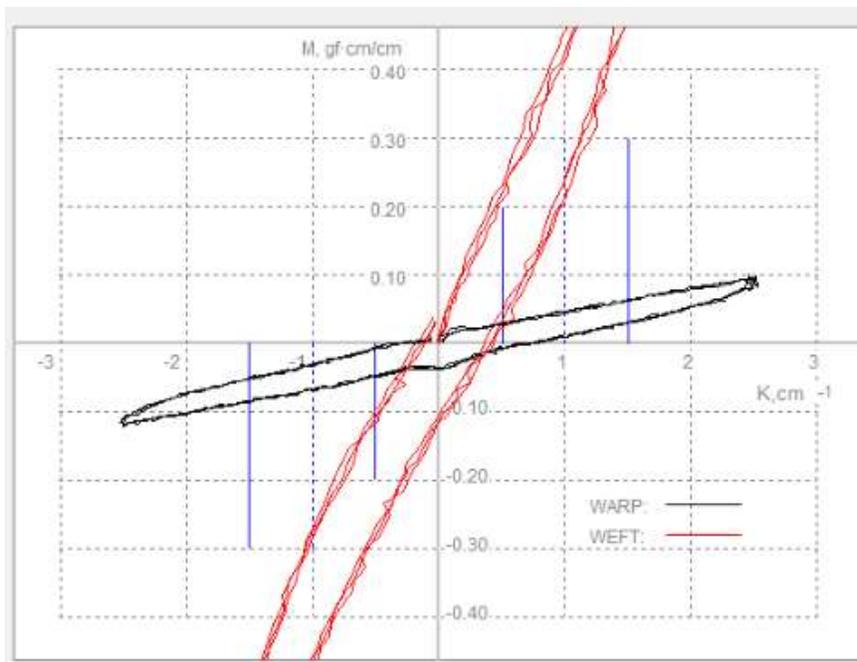
Graph 4.8: Bending Properties using pure bending tester (KES-FB2)

Warp Direction: In the warp direction, the fabric exhibited a Bending Rigidity (B) of 0.0359 gf.cm²/cm. B represents the resistance of the fabric to bending deformation, with lower values indicating greater flexibility.

The Hysteresis of Bending Moment (2HB) measured in the warp direction was 0.0348 gf.cm²/cm. 2HB represents the energy loss during bending deformation, with lower values indicating higher efficiency in energy transmission.

Weft Direction: In the weft direction, the fabric exhibited different bending properties compared to the warp direction. The Bending Rigidity (B) was measured at 1.9740 gf.cm²/cm, indicating higher resistance to bending compared to the warp direction.

The Hysteresis of Bending Moment (2HB) in the weft direction was 0.9651 gf.cm²/cm, indicating energy loss during bending deformation.

The analysis of bending properties in both warp and weft directions provided details about the fabric's flexibility and energy transmission characteristics. The fabric exhibited different bending rigidity and hysteresis properties depending on the direction of measurement.

This comprehensive analysis using the Kawabata Evaluation System provided valuable insights into the performance of the cotton/pineapple fabric, informing designers and manufacturers in optimizing fabric selection and enhancing garment quality and comfort.

4.8. Dyeing of Pineapple yarn

The dyeing process was executed on 100% pineapple spun yarn (30's) in its natural color, without undergoing any prior treatments such as bleaching. Both reactive dyes and natural dyes were utilized to achieve a wide range of colors and effects.

4.8.1. Dyeing with reactive and natural dyes

The selection of traditional colors and the sourcing of dyes for the dyeing process were determined by referencing the traditional colors utilized in the weaving of Meitei traditional textiles. These colors were chosen to align with the cultural significance and aesthetic preferences associated with Meitei textiles.

The traditional colors used in Meitei traditional textiles, along with their corresponding Meitei names, include:

- White: Angouba

- Yellow: Hangampan

- Red: Angangba

- Bright Pink: Piktruklei Macho

- Green: Asangba

- Pink: Leimachu

- Black: Amuba

- Orange: Komla Machu

The selection of these traditional colors for dyeing ensures the preservation of cultural authenticity and the continuation of traditional practices in textile production.

By incorporating these traditional colors into the dyeing process, the resulting dyed yarns or fabrics not only capture the essence of Meitei traditional textiles but also contribute to the preservation and promotion of Meitei cultural heritage. Additionally, the utilization of natural dyes or dyeing methods inspired by traditional practices further enhances the authenticity and sustainability of the dyeing process.

Reactive Dyes: Nine different reactive dyes were employed in the dyeing process. Reactive dyes are preferred for cellulosic fibers like pineapple yarn due to their ability to form covalent bonds with the fiber, resulting in excellent colorfastness and wash resistance.

The conventional exhaust dyeing technique was employed for dyeing, wherein the reactive dyes were dissolved in a suitable dye bath, and the yarn was submerged in the dye liquor. The dye bath was heated to the recommended temperature for reactive dyes, typically between 40-60 degrees Celsius, and maintained for a specific duration to ensure proper dye absorption and fixation onto the yarn fibers.

The reactive dyes used in the process were as follows:

- RP: Reactofix dark pink

- RO: Procion brilliant orange M-2R

- RBY: Procion brilliant yellow M-4G

- RY: Procion yellow M-3R

- RR: Procion brilliant Red M-5B

- RB: Procion black

- RG: Procion green

- RBP: Procion pink

- RBR: Procion brown

The choice of reactive dyes allowed for a diverse color palette, ranging from vibrant shades like dark pink, orange, and red to subtler tones such as yellow, green, and brown. Additionally, the covalent bonding of reactive dyes with the pineapple yarn ensured long-lasting color retention and resistance to fading, enhancing the overall quality and durability of the dyed yarn.

The utilization of a variety of reactive dyes not only provided a wide spectrum of colors but also offered the flexibility to achieve different effects and finishes, providing diverse preferences and required designs. This versatility in color and effect options enhances the applicability of the dyed pineapple yarn in various textile applications, including apparel, home textiles, and accessories.

Natural Dyes: The utilization of 12 natural dyes including the 8 local plant sources aligned with sustainable and environmentally conscious practices in textile production. These natural dyes not only offered a renewable and eco-friendly alternative to synthetic dyes but also contributed to the preservation of traditional dyeing knowledge and cultural heritage associated with natural dye extraction.

Details (with local names) of the 8 dyes collected from Manipur:

1. **Indian Trumpet Tree (*Oroxylum indicum*) - Shamba:** The bark of this plant yielded orange color, derived from flavonoids and anthraquinone compounds.

2. **Red Cedar (*Toona Ciliata*) - Tairen:** The bark of the red cedar tree produced a rich brown color, enhancing the earthy tones of the dyed samples.

3. **Mulberry (*Morus nigra*) - Kabrang:** The fruits of the mulberry tree yielded a subtle greyish color, adding a soft and muted tone to the dyed fabrics.

4. **Roselle (*Hibiscus sabdariffa*) - Silok Sougri:** The fruits of the roselle plant imparted a delicate pink hue, lending a touch of femininity to the dyed textiles.

5. **Hill Glory Bower (*Clerodendrum infortunatum*) - Kuthap:** The fresh leaves of the hill glory bower plant provided a pale green dye because of the presence of chlorophyll a and chlorophyll b (By Saikhom, J, 2013), introducing a refreshing and naturalistic shade to the dyed samples.

6. **Koda Tree (*Ehratia acuminate*) - Lamuk:** The bark of the koda tree contributed to a blackish color, adding depth and richness to the dyed fabrics.

7. **Malabar Melastome (*Melastoma malabathricum*) - Yachubi:** The leaves of the Malabar melastome plant yielded a yellowish dye, infusing warmth and brightness into the dyed textiles.

8. **Kamala or Kumkum Tree (*Mallotus philippensis*) - Ureirom Laba:** The bark of the kamala or kumkum tree contained tannins that produced a reddish-brown color, adding warmth and depth to the dyed fabrics.

Lac (*Kerria lacca*) in its crystal form, powdered manjistha (*Rubia cordifolia*), marigold *(Tagetes erecta)*, and pomegranate (*Punica granatum*) are commonly used as natural dyes in India. Among the plant dyes collected for this study, Indian Trumpet tree (*Oroxylum indicum*), Red cedar (*Cedrela toona*), Mulberry (*Morus nigra*), and Roselle (*Hibiscus sabdariffa*) were explored to expand the range of traditional dyes in Manipur.

Phytochemical tests can identify chemical groups like Flavonoid, Anthocyanin, Chlorophyll, Tannins, and Carotenoids in the local plant dyes. Tests involve specific reactions or observations, such as color changes or precipitate formation, to confirm the presence of these compounds.

The utilization of these local plants for dye extraction not only provided a sustainable and eco-friendly dyeing solution but also celebrated the rich botanical diversity of the region. Furthermore, the unique color tones obtained from natural dyes added depth and character to

the dyed yarns or fabrics, enhancing their aesthetic appeal and value. By incorporating natural dyes into the dyeing process, textile artisans had the opportunity to create value-added textiles, reflecting the natural resources. The utilization of natural dyes in the dyeing process highlighted a commitment to sustainability, craftsmanship, and cultural preservation in textile manufacture. By taking up natural dyeing techniques and materials, textile weavers were able to create textiles that not only captivated with their traditional but also contributed to a more sustainable and environmentally friendly textile industry.

The dyed samples' color palettes were generated using a Premier Colour Scan SS5100A spectrophotometer in the Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat. (Page no.)

4.8.2. Analysis of the dyed yarns

Colour strength test

The color strength analysis, encompassing parameters such as CIE L* a* b* c* h*, color difference, and K/S values, was conducted using a spectrophotometer SS5100A. The measurements were performed under D65 illumination, which replicates average daylight conditions, with a color temperature of 6500K. The observations were made at a 10-degree angle of visual observation, ensuring standardized conditions for accurate data acquisition.

Daniel R. Witt, https://www.researchgate.net/publication/259245149
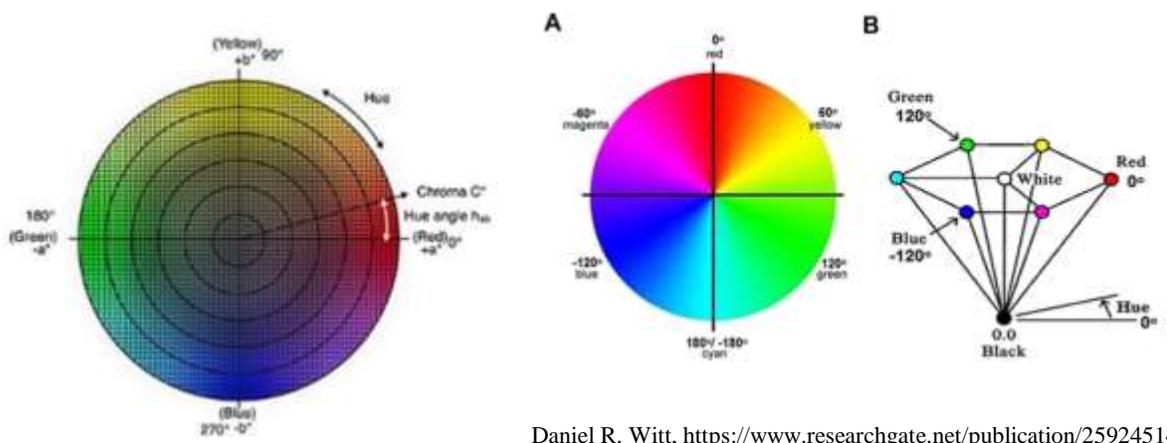
https://r.search.yahoo.com/ sensing.konicaminolta.asia. What-is-lch-color-space -

Fig.4.47: L*a*b*c*h* values on colour spectrum

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Colour Palettes of pineapple yarn dyed with natural dyes and reactive dyes- created using Spectrophotometer

Fig.4.48: Colour palettes of Pineapple yarn dyed with reactive dyes

RP- Reactofix dark pink, RO- Procion brilliant orange M-2R, RBY-Procion brilliant yellow M-4G, RY- Procion yellow M-3R, RR-Procion brilliant Red M-5B, RB-Procion black, RG- Procion green, RBP-Procion pink and RBR- Procion brown

URR: Ureirom YCB: Yachubi, LMK: Lamuk, KTHP: Kuthap, SGR: Silok sougri, MLB: Kabrang, TRN: Tairen, SMB: Shamba , Sanarei (MRG), PMG: Kaphoi, LAC: Lac, MJT: Manjistha

Fig.4.49: Colour palettes of Pineapple yarn dyed with natural dyes

Colour Palettes created using pineapple yarn with natural dyes and reactive dyes
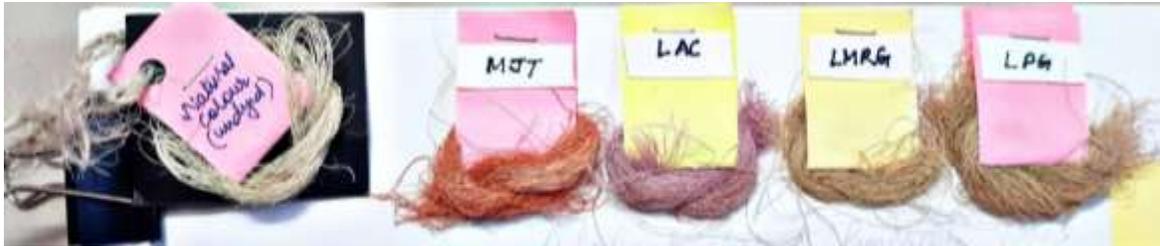
Fig.4.50: Pineapple yarn dyed with natural dyes

Fig.4.51: Pineapple yarn dyed with natural dyes

Fig.4.52: Pineapple yarn dyed with Reactive dyes
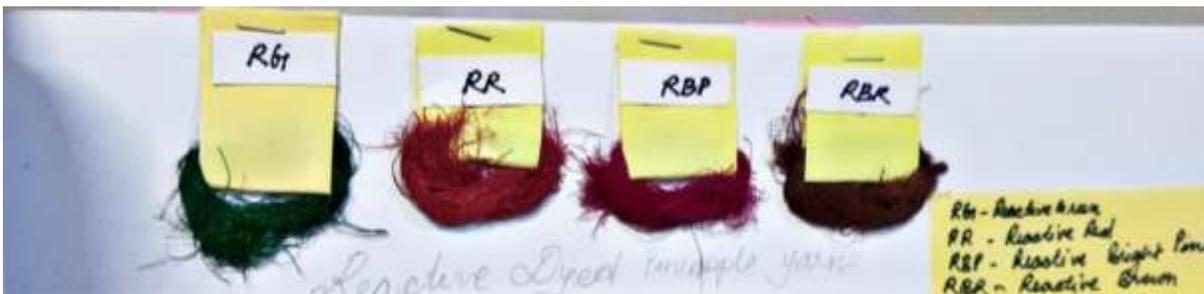
Fig.4.53: Pineapple yarn dyed with natural dyes

Developed samples using the dyed pineapple leaf yarn with reactive and natural dyes

Fig.4.54: Rayon/pineapple fabric with extra weft motifs using pineapple yarn dyed with reactive dyes

Fig.4.55: Rayon/pineapple fabric with extra weft motifs using pineapple yarn dyed with natural dyes

The *a value serves as an indicator of the presence of red or green tones within a color spectrum. If the value is positive, it signifies a red hue, while a negative value indicates the presence of green. Similarly, the *b value is utilized to determine whether a dye tends towards yellow or blue. A positive *b value suggests a yellow tint, whereas a negative *b value suggests the presence of blue tones. Moreover, the c value represents the chroma, which essentially measures the saturation or intensity of a color. It signifies the distance from the L axis, which represents lightness in the color space. A higher *c value implies a more intense color saturation. In addition, the *h value denotes the hue angle from the center, representing the specific color shade. This angle provides insight into the exact hue or color of a sample.

In the examination of natural dyes, the analysis of the L*a*b*c*h* values was done while maintaining a controlled sample. This controlled environment ensures consistency and accuracy in the assessment, enabling researchers to determine variations and shades in color characteristics among different dye samples.

Table 4.39: L*a*b*c*h* values of the dyed samples with Reactive dyes

(*)Sample	L*	a*	b*	c*	h*
Controlled	68.10	2.77	20.74	**20.93**	82.35
RP	18.87	**49.53**	12.623	51.11	**14.86**
RO	32.674	45.071	56.30	74.03	49.49
RBY	**57.54**	9.75	**90.70**	91.23	83.83
RY	**56.31**	14.86	90.38	**91.59**	80.63
RB	0.000	0.000	0.000	0.000	0.000
RG	15.75	**-37.61**	25.47	45.42	145.92
RBP	19.13	52.17	**-2.40**	52.22	**357.36**
RR	19.10	47.36	32.73	57.57	34.63
RBR	**9.65**	29.90	16.62	34.21	29.05

(*)reactive colours with the code- RP- Reactofix dark pink, RO-Procion brilliant orange M-2R, RBY-Procion brilliant yellow M-4G, RY- Procion yellow M-3R, RR-Procion brilliant Red M-5B, RB-Procion black, RG-Procion green, RBP-Procion pink and RBR- Procion brown.

L* values indicated the brightness of the color, with 0 being black and 100 being white. RBY had the highest L* value (57.54), indicating it's the lightest shade among the samples. Controlled had a relatively high L* value (68.10), which suggested it's closer to white.

RP had the highest positive value of **a*** (49.53), indicating a reddish hue. Meanwhile, RG had the highest negative value (-37.61), indicating a greenish hue. RBY and RY had the highest positive values of **b***, indicating yellowness. Chroma (c*) represented the colorfulness or saturation of a color. RY showed the highest chroma (90.38), indicating it's the most saturated among the samples. Controlled had the lowest chroma, which was expected since it didn't represent a specific color. Hue angle (h*) represented the color's position on the color wheel, with 0° being red, 120° being green, and 240° being blue. RBP had the highest hue angle (357.36°), indicating it's closer to magenta on the color wheel. RBY and RY were both yellow shades, with RBY being the lightest and most saturated. RP and RR were reddish shades, with RP being the most saturated. RG was a green shade, being the most saturated and greenest among the samples. RBP was a pink shade, with a high hue angle indicating it was closer to magenta. RB had all values as 0, indicating it had an absence of color, as black isn't in the visible spectrum of colors and cannot exist in any light.

Table 4.40: L*a*b*c*h* values of the dyed samples with natural dyes

Sample	L*	a*	b*	c*	h*
Controlled	68.10	2.77	20.74	20.93	82.35
URR	**22.54**	**29.05**	39.77	48.45	53.130
YCB	46.30	8.83	33.03	34.19	74.99
LMK	41.33	3.82	34.03	34.24	**83.55**
KTHP	**56.88**	3.90	29.40	29.65	82.39
SGR	36.66	25.45	4.79	25.89	**10.66**
MLB	38.52	**3.12**	**4.50**	**5.48**	55.25
TRN	36.60	24.61	30.91	39.51	51.45
SMB	43.30	24.86	**66.02**	**70.54**	69.33
MRG)	55.53	6.77	40.83	41.38	80.56

PMG	49.51	8.28	28.59	29.77	73.80
LAC	45.69	18.21	10.91	21.23	30.92
MJT	42.68	37.20	35.04	51.10	43.272

URR: Ureirom YCB: Yachubi, LMK: Lamuk, KTHP: Kuthap, SGR: Silok sougri, MLB: Kabrang, TRN: Tairen, SMB: Shamba , Sanarei (MRG), PMG: Kaphoi, LAC: Lac, MJT: Manjistha

In the natural dye, the highest L* value was observed in Kuthap (56.88), indicating it was the lightest shade among the natural dye samples. This is consistent with the trend observed in the synthetic dye dataset, where RBY had the highest L* value. Following Kuthap, Sanarei (marigold) had the second highest L* value, suggesting it was also relatively light in color. The highest b* value was observed in Shamba (Indian Trumpet tree) (66.02), indicating a strong yellow hue. This is in line with the synthetic dye dataset where RBY had the highest b* value, signifying a strong yellow color. While not directly comparable, the value in the natural dye data align with those in the synthetic dye dataset, showcasing the dominance of yellow hues in both. The lowest chroma (c*) value was found in Kabrang, pale green shade (5.48), indicating it was the least saturated among the natural dye samples. This value was similar to the synthetic dye data, where Controlled had the lowest chroma value (0), representing a neutral control sample with no specific color. Conversely, the highest chroma value was observed in Shamba, indicating it was the most saturated color among the natural dye samples. The hue angle was highest in Lamuk and lowest in Silok Sougri. The low hue angle in Silok Sougri may be attributed to its pink shade, which is near red (0°) on the color space.

The colorimetric analysis provides insights into the lightness, hue, chroma, and other characteristics of the color samples, aiding in understanding their properties and applications in various textiles.

K/S values were determined to represent the ratio of absorption coefficient (K) to scattering coefficient (S) of the dyed samples. These values served as indicators of the color intensity and depth of the dyed material. The K/S values were obtained across the wavelength range of 360nm to 700nm using a spectrophotometer SS5100A. Here, K denotes the absorption

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coefficient, while S represents the scattering coefficient of the dyes. Various K/S values were collected across wavelengths ranging from 400nm to 700nm for each dye. However, to ensure the reliability of the analysis, the selection of K/S values for each dye was based on the reflectance value falling within the range of 1 to 10. Analysis of K/S value of every dye (both reactive and natural dyes) along with its range of wavelength and different reflectance values was done.

Wavelength vs Reflectance vs K/S value of dyed yarns (reactive dyes)

The table provided details the analysis conducted on Reactofix Dark Pink (RP) dye, focusing on its reflectance and corresponding K/S values across various wavelengths:

At a wavelength of 410nm, the reflectance was observed to be 1.06, yielding a K/S value of 46.00. As the wavelength increased to 420nm, the reflectance slightly increased to 1.65, resulting in a lower K/S value of 29.22. Continuing the movement, at 430nm, the reflectance further increased to 2.17, with a corresponding decrease in

Table4.41: Reactofix Dark Pink (RP)		
Wavelength (nm)	Reflectance	K/S
410	1.06	46.00
420	1.65	29.22
430	2.17	22.01
440	2.41	19.72
450	2.17	22.09
460	1.51	32.033
590	2.23	21.41
600	6.039	7.31

the K/S value to 22.01. Similarly, at 440nm and 450nm, the reflectance remained relatively stable around 2.41 and 2.17, respectively, resulting in similar K/S values of 19.72 and 22.09.

The reflectance experienced a notable decrease at 460nm, dropping to 1.51, which led to an increase in the K/S value to 32.033. Towards the higher end of the spectrum, at 590nm, the reflectance was measured at 2.23, resulting in a K/S value of 21.41. Finally, at 600nm, there was a significant increase in reflectance to 6.039, causing a substantial decrease in the K/S value to 7.31.

The table provided data on the analysis conducted on Procion Bright Yellow (RBY) dye, detailing its reflectance and corresponding K/S values across different wavelengths:

At a wavelength of 490nm, the reflectance was measured at 3.00, resulting in a K/S value of 15.70. As the wavelength increased to 500nm, there was a noticeable increase in reflectance to 7.01, leading to a decrease in the K/S value to 6.17. Continuing this observation pattern, at 510nm, the reflectance further increased to 12.6, resulting in a lower K/S value of 3.17.

Table 4.42: Procion Bright Yellow (RBY)

Wavelength (nm)	Reflectance	K/S
490	3.00	15.70
500	7.01	6.17
510	12.6	3.17

In the analysis of Procion Brilliant Orange (RO) dye, at a wavelength of 550nm, the reflectance was measured at 2.05, resulting in a K/S value of 23.42. As the wavelength increased to 560nm, there was a notable increase in reflectance to 4.13, leading to a decrease in the K/S value to 11.13. In the observation at 570nm, the reflectance further increased to 6.74, resulting in a lower K/S value of 6.45. Similarly, at 580nm, the reflectance experienced another significant increase to 10.29, causing a decrease in the K/S value to 3.91.

Table 4.43: Procion Brilliant Orange (RO)

Wavelength (nm)	Reflectance	K/S
550	2.05	23.42
560	4.13	11.13
570	6.74	6.45
580	10.29	3.91

In the analysis of Procion Yellow (RY) dye, the data in Table 4.44 provided information regarding its reflectance and corresponding K/S values across different wavelengths:

At 490nm wavelength, the reflectance was recorded as 2.07, resulting in a K/S value of 23.18. As the wavelength increased to 500nm, there was a

Table 4.44 Procion Yellow (RY)

Wavelength (nm)	Reflectance	K/S
490	2.07	23.18
500	3.70	12.54
510	7.00	6.177
520	13.81	2.69

noticeable rise in reflectance to 3.70, leading to a decrease in the K/S value to 12.54. This continued as the analysis progressed to 510nm, where the reflectance further increased to 7.00, resulting in a lower K/S value of 6.177. Subsequently, at 520nm, the reflectance experienced another significant surge, reaching 13.81, causing a decrease in the K/S value to 2.69.

In Table 4.45, concerning Procion Black (RB) dye, the data indicated a nil reflectance and subsequently a nil K/S value across the entire spectrum from 360nm to 700nm. This observation aligned with the nature of black coloration, which absorbs all wavelengths of light without reflecting

Table 4.45: Procion Black (RB)		
Wavelength (nm)	Reflectance	K/S
360 to 700	Nil	nil
-	-	-

any back, resulting in a complete absence of color. Therefore, the absence of reflectance and K/S values for Procion Black (RB) in the provided data table indicated that no light was reflected or scattered, confirming its expected property as a color that absorbs all light and does not contribute any spectral reflectance.

In the analysis of Procion Red (RR) dye, as presented in Table 4.12.6, the data provided reflectance and corresponding K/S values across different wavelengths:

At a wavelength of 590nm, the reflectance was recorded as 2.58, resulting in a K/S value of 18.40. As the wavelength increased to 600nm, there was a notable increase in reflectance to 6.07, leading

Table 4.46: Procion Red (RR)		
Wavelength (nm)	Reflectance	K/S
590	2.58	18.40
600	6.07	7.27
610	11.14	3.56

to a decrease in the K/S value to 7.27. At 610nm, the reflectance further increased to 11.14, resulting in a lower K/S value of 3.56.

In the analysis of Procion Green (RG) dye, at 500nm wavelength, the reflectance was measured at 1.38, resulting in a K/S value of 35.21. As the wavelength increased to 510nm, there was an increase in reflectance to 2.73, leading to a decrease

Table 4.47: Procion Green (RG)		
Wavelength (nm)	Reflectance	K/S
500	1.38	35.21
510	2.73	17.30
520	4.78	9.49
530	5.71	7.78

in the K/S value to 17.30. This observation pattern continued as the analysis progressed to 520nm, where the reflectance further increased to 4.78, resulting in a lower K/S value of 9.49. Afterwards, at 530nm, the reflectance experienced another increase, reaching 5.71, causing a

further decrease in the K/S value to 7.78.

Table 4.48 outlined the reflectance and corresponding K/S values of Procion Bright Pink (RBP) dye across various wavelengths. At 410nm wavelength, the reflectance was measured at 1.04, resulting in a K/S value of 47.036. As the wavelength increased to 420nm, there was an increase in reflectance to 1.73, leading to a decrease in the K/S value to 27.96. The analysis progressed to 430nm, where the reflectance further increased to 2.35, resulting in a lower K/S value of 20.31. Subsequently, at 440nm, the reflectance experienced another increase, reaching 3.47, causing a further decrease in the K/S value to 13.43. The pattern continued as the analysis proceeded

Table 4.48: Procion Bright Pink (RBP)		
Wavelength (nm)	Reflectance	K/S
410	1.04	47.036
420	1.73	27.96
430	2.35	20.31
440	3.47	13.43
450	4.57	9.97
460	4.56	9.99
470	3.23	14.51
480	1.48	32.72
600	2.34	19.55
610	8.07	5.24

through 450nm, 460nm, and 470nm, with fluctuations in reflectance and corresponding K/S values.

However, at 480nm, the reflectance decreased to 1.48, resulting in an increase in the K/S value to 32.72. At 600nm wavelength, the reflectance was measured at 2.34, resulting in a K/S value of 19.55. Finally, at 610nm, there was a notable increase in reflectance to 8.07, leading to a decrease in the K/S value to 5.24.

In the analysis of Procion Brown (RBR) dye, at 580nm wavelength, the reflectance was recorded as 1.37, resulting in a K/S value of 35.64. As the wavelength increased to 590nm, there was a slight increase in reflectance to 1.87, leading to a decrease in the K/S value to 28.81. It was continued as the analysis progressed to 600nm, where the reflectance further increased

to 2.45, resulting in a lower K/S value of 19.40.

Subsequently, at 610nm, the reflectance experienced another increase, reaching 3.20, causing a further decrease in the K/S value to 14.61. The pattern continued as the analysis proceeded through 620nm, 630nm, 640nm, and 650nm, with fluctuations in reflectance and corresponding K/S values.

At 640nm, the reflectance increased notably to 7.29, leading to a decrease in the K/S value to 5.89. Finally, at 650nm, there was a significant increase in reflectance to 9.98, resulting in a decrease in the K/S value to 4.06.

Table 4.49: Procion Brown (RBR)

Wavelength (nm)	Reflectance	K/S
580	1.37	35.64
590	1.87	28.81
600	2.45	19.40
610	3.20	14.61
620	4.18	10.98
630	5.47	8.16
640	7.29	5.89
650	9.98	4.06

Overall, the analysis indicates variations in the dye's absorbance and scattering properties across different wavelengths, providing insights into its color intensity and depth at specific points in the spectrum.

Wavelength vs Reflectance vs K/S value of dyed yarns (natural dyes)

Starting at 540nm wavelength, the reflectance of URR was observed to be 1.48, yielding a K/S value of 32.91. As the wavelength progressed to 550nm, there was an increase in reflectance to 2.23, resulting in a decrease in the K/S value to 20.95. The increment occurred as the analysis proceeded to 560nm, with reflectance further increasing to 3.29, leading to a decrease in the K/S value to 14.21.

Table 4.50:Ureirom (URR)

Wavelength (nm)	Reflectance	K/S
540	1.48	32.91
550	2.23	20.95
560	3.29	14.21
570	4.43	10.29
580	5.68	7.84
590	6.94	6.24
600	8.25	5.10
610	9.59	4.26

As the wavelength continued to increase, similar patterns were observed. At 570nm, reflectance reached 4.43, resulting in a K/S value of 10.29. The values persisted at 580nm and 590nm, with

reflectance values of 5.68 and 6.94, respectively, corresponding to decreasing K/S values of 7.84 and 6.24. Continuing this progress, at 600nm and 610nm, reflectance values further increased to 8.25 and 9.59, respectively, leading to decreasing K/S values of 5.10 and 4.26.

The provided table 4.51 depicted the reflectance and corresponding K/S values of YCB across various wavelengths:

At 410nm wavelength, the reflectance was recorded as 1.28, resulting in a K/S value of 38.22. As the wavelength increased to 420nm, there was a slight increase in reflectance to 2.10, leading to a decrease in the K/S value to 22.80. This increment persisted as the analysis progressed to 430nm, with reflectance further increasing to 3.00, resulting in a lower K/S value of 15.68.

Table 4.51: Yachubi (YCB)		
Wavelength (nm)	**Reflectance**	**K/S**
410	1.28	38.22
420	2.10	22.80
430	3.00	15.68
440	3.92	11.79
450	4.80	9.43
470	6.67	6.52
480	7.67	5.55
490	8.73	4.77
500	9.42	4.35

At 440nm, the reflectance increased to 3.92, leading to a further decrease in the K/S value to 11.79. Similar trends were observed as the analysis proceeded through 450nm, 470nm, and 480nm, with fluctuations in reflectance and corresponding K/S values. At 490nm, the reflectance reached 8.73, resulting in a decrease in the K/S value to 4.77. Finally, at 500nm, there was a slight increase in reflectance to 9.42, leading to a decrease in the K/S value to 4.35.

The table 4.52 showed the reflectance and associated K/S values for the Lamuk (LMK) dye analysis at various wavelengths:

The reflectance was measured to be 1.30 at 430 nm wavelength, yielding a K/S value of 37.49. The reflectance increased to 2.22 as the wavelength approached 440 nm, which resulted in a drop in the K/S value to 21.53. This pattern persisted until 450 nm in the analysis, at which point reflectance increased even more to 3.33, lowering the K/S value to 14.01.

The patterns remained identical as the wavelength increased. Reflectance reached 4.62 at 460 nm, thus the K/S value was 9.84. With reflectance values of 5.90 and 7.11 at 470 nm and 480 nm, respectively, this was continued, resulting in declining. At 490nm, reflectance increased to 8.22, leading to a decrease in the K/S value to 5.12. At 500nm and 510nm, reflectance values further increased to 8.87 and 9.33, respectively and resulting in decreasing K/S values of 4.68 and 4.40.

The table 4.53 illustrates the reflectance and matching K/S values for Kuthap (KTP) dye analysis across a certain wavelength range:

Table 4.52: Lamuk (LMK)		
Wavelength (nm)	Reflectance	K/S
430	1.30	37.49
440	2.22	21.53
450	3.33	14.01
460	4.62	9.84
470	5.90	7.50
480	7.11	6.06
490	8.22	5.12
500	8.87	4.68
510	9.33	4.40

With a wavelength of 400 nm, the reflectance was measured at 2.01, yielding a K/S value of 23.85. When the wavelength reached 410 nm, the reflectance clearly increased to 3.42, which resulted in a drop in the K/S value to 13.62.

The observations persisted until 420 nm in the analysis, at which point reflectance increased even more to 4.91, lowering the K/S value to 9.21. This particular range, which was between 400 and 450 nm, contained reflectance values that fell between 1 and 10 in the visible spectrum. Reflectance reached 6.64 at 430 nm, meaning that the K/S value was 6.56. At 440 and 450 nm, this pattern continued.

Table 4.53: Kuthap (KTP)		
Wavelength (nm)	Reflectance	K/S
400	2.01	23.85
410	3.42	13.62
420	4.91	9.21
430	6.64	6.56
440	8.53	4.90
450	10.41	3.85

The examination of Silok Sougri (SGR) dye at different wavelengths, the reflectance was measured starting at 400 nm wavelength and was 2.25, yielding a K/S ratio of 21.23. (Table 4.54)

The reflectance significantly increased to 4.14 when the wavelength approached 410 nm, which resulted in a drop in the K/S value to 11.09.

As the analysis was carried out to 420 nm, this trend continued, with reflectance rising to 6.11 and a lower K/S ratio of 7.21.The reflectance increased to 7.72 at 430 nm, which is equivalent to a K/S ratio of 5.51. With reflectance values of 8.71, 9.20, and 9.48 at 440, 450, and 460 nm, respectively and resulting in declining K/S values. At 470nm, the reflectance occurred at 9.60, with a corresponding K/S value of 4.25.

Table 4.54: Silok Sougri (SGR)

Wavelength (nm)	Reflectance	K/S
400	2.25	21.23
410	4.14	11.09
420	6.11	7.21
430	7.72	5.51
440	8.71	4.79
450	9.20	4.48
460	9.48	4.32
470	9.60	4.25

The findings presented in the examination of Kabrang (MLB) dye, the reflectance was measured at 380 nm wavelength and was found to be 1.31, yielding a K/S ratio of 37.23. At 390 nm, the reflectance increased to 2.36, which resulted in a drop in the K/S value to 20.12. As the analysis was carried out to 400 nm, with reflectance rising to 4.00 and a decreased K/S value of 11.52. Similar patterns were seen with increasing wavelength. Reflectance reached 5.68 at 410 nm, meaning that the K/S value was 7.83. With reflectance values of 6.87, 7.77, and 8.48 at 420, 430, and 440 nm, respectively, this trend continued, resulting in declining K/S ratios of 6.30, 5.47, and 4.94.

Table 4.55 :Kabrang(MLB)

Wavelength (nm)	Reflectance	K/S
380	1.31	37.23
390	2.36	20.12
400	4.00	11.52
410	5.68	7.83
420	6.87	6.30
430	7.77	5.47
440	8.48	4.94
450	9.05	4.57
460	9.58	4.26
470	10.02	4.03

The reflectance increased to 9.05 at 450nm, leading to a reduction in the K/S value to 4.57. The reflectance values further increased to 9.58 and 10.02 at 460nm and 470nm respectively, which decreased the K/S values to 4.26 and 4.03.   (Table 4.55)

Starting at 470nm wavelength, the reflectance was found to be 1.14, resulting in a K/S value of 42.92. As the wavelength progressed to 480nm, there was an increase in reflectance to 1.79 and led decreased in the K/S value to 26.91. The reflectance further increased to 2.58 at 490nm, resulting in a lower K/S value of 18.32. As the wavelength continued to increase, increase in reflectance values was observed. At 500nm, reflectance reached 3.12, corresponding to a K/S value of 15.02. At 510nm, 520nm, and 530nm,

Table 4.56: Shamba (SMB)

Wavelength (nm)	Reflectance	K/S
470	1.14	42.92
480	1.79	26.91
490	2.58	18.32
500	3.12	15.02
510	3.79	12.21
520	5.43	8.24
530	7.30	5.89
540	9.03	4.58

with reflectance values of 3.79, 5.43, and 7.30 were observed respectively, with decreased K/S values of 12.21, 8.24, and 5.89. At 540nm, reflectance found to be 9.03 with the K/S value 4.58.

The reflectance and corresponding K/S values across different wavelengths were examined in the analysis of the provided data. Starting at 380 nm wavelength, the reflectance was 1.23, resulting in a K/S value of 39.76. As the wavelength increased to 390 nm, the reflectance increased to 1.95 and the K/S value decreased to 24.68. This trend continued as the analysis proceeded to 400 nm, with the reflectance further increasing to 2.67, resulting in a lower K/S value of 17.77. (Table 4.57)

Table 4.57: Tairen (TRN)

Wavelength (nm)	Reflectance	K/S
380	1.23	39.76
390	1.95	24.68
400	2.67	17.77
410	3.05	15.36
420	3.08	15.24
430	3.02	15.58
440	2.89	16.33
450	2.72	17.39
460	2.67	17.74

Similar patterns were observed as the wavelength continued increasing. At 410 nm, the reflectance reached 3.05, corresponding to a K/S value of 15.36. At 420 nm, 430 nm, and 440 nm, with reflectance values of 3.08, 3.02, and 2.89, respectively led to decreasing K/S values of 15.24, 15.58, and 16.33, respectively.

The reflectance increased to 2.72 at 450 nm, leading to a decrease in the K/S value to 17.39. The reflectance values further increased to 2.67 and 2.73 at 460 nm and 470 nm respectively, resulting in K/S values of 17.74 and

Wavelength (nm)	Reflectance	K/S
470	2.73	17.36
480	2.88	16.33
490	3.15	14.91
500	3.23	14.49
510	3.45	13.50
520	4.41	10.36
530	5.57	8.01
540	6.60	6.61
550	7.83	5.43
560	9.15	4.51

17.36. The highest reflectance value of 9.15 was recorded at 560nm, corresponding to a K/S value of 4.51.

The reflectance and corresponding K/S values across various wavelengths of MRG dye have been provided in the table. The reflectance was 1.75 at 410 nm, resulting in a K/S value of 27.60. (Table 4.58)

As the wavelength progressed to 420 nm, the reflectance increased to 2.74 and the K/S value decreased to 17.82. As the analysis proceeded to 430 nm, with the reflectance further increasing to 3.68, which resulted in a lower K/S value of

Table 4.58 Marigold (MRG)		
Wavelength (nm)	Reflectance	K/S
410	1.75	27.60
420	2.74	17.82
430	3.68	12.60
440	4.75	9.55
450	6.04	7.31
460	7.67	5.56
470	9.58	4.27

12.60. Similar patterns were observed as the wavelength increased. At 440 nm, the reflectance reached 4.75, which corresponds to a K/S value of 9.55.

The reflectance values of 6.04, 7.67, and 9.58 observed at wavelength 450 nm, 460 nm, and 470 nm respectively, resulting in decreased K/S values of 7.31, 5.56, and 4.27, respectively.

In the analysis of Kaphoi (PMG) dye, the provided data showcases the reflectance and corresponding K/S values across various wavelengths. The reflectance was 1.26 at 390 nm, resulting in a K/S value of 38.66. (Table 4.59)

As the wavelength progressed to 400 nm, the reflectance increased to 2.66, leading to a decrease in the K/S value to 17.80. As the wavelength increased, the reflectance values also increased.

Table 4.59 Kaphoi (PMG)

Wavelength (nm)	Reflectance	K/S
390	1.26	38.66
400	2.66	17.80
410	4.06	11.33
420	5.30	8.45
430	6.44	6.80
440	7.44	5.75
450	8.38	5.01
460	9.46	4.33

At 410 nm, the reflectance reached 4.06, corresponding to a K/S value of 11.33. The reflectance values of 5.30, 6.44, and 7.44, were at 420 nm, 430 nm, and 440 nm obtained respectively, resulting in decreasing K/S values of 8.45, 6.80, and 5.75, respectively. At 450 nm and 460 nm, reflectance further increased to 8.38 and 9.46, respectively with decreasing K/S values of 5.01 and 4.33, respectively.

The interaction between the dye and light at various wavelengths was examined in the Lac dye dataset.

At the shorter wavelength of 380 nm, the reflectance was 1.51, which resulted in a K/S value of 32.20, indicative of a moderate amount of light reflection and a relatively high color intensity.

As the wavelength increased, the reflectance steadily increased. For example, at 390 nm, the

Table 4.60: Lac (LAC)

Wavelength (nm)	Reflectance	K/S
380	1.51	32.20
390	2.91	16.19
400	4.76	9.53
410	6.63	6.57
420	8.14	5.18
430	9.43	4.35

reflectance increased to 2.91 and the K/S value decreased to 16.19, indicating a higher degree of light reflection. At 400 nm, the reflectance surged to 4.76, further reducing the K/S value to 9.53, indicating an enhanced reflectivity and a decrease in color intensity and depth.

This increasing reflectance pattern continued through 410 nm, 420 nm, and 430 nm, reaching 6.63, 8.14, and 9.43, respectively.

In the analysis of Manjistha (MJT) dye, the reflectance was 1.85 at 390 nm, resulting in a K/S value of 25.98. As the wavelength progressed to 400 nm, the reflectance increased to 3.01, resulting in a decrease in the K/S value to 15.64. At 410 nm, the reflectance increased to 3.66, corresponding to a decrease in the K/S ratio to 12.69. (Table 4.61)

At 420 nm, 430 nm, and 440 nm, the reflectance values of 3.90, 3.92, and 3.73, were observed respectively, resulting in decreased K/S values of 11.85, 11.77, and 12.41, respectively. At 450 nm and 460 nm, the reflectance values slightly decreased to 3.52 and 3.38, respectively, resulting in increased K/S values of 13.23 and 13.79, respectively. At 470 nm, 480 nm, and 490 nm, the reflectance values increased again, leading to decreasing K/S values of 14.06, 13.45, and 12.31, respectively. The highest reflectance value of 8.69 within 10 was recorded at 560nm, corresponding to a K/S value of 4.80.

Table 4.61: Manjistha (MJT)		
Wavelength (nm)	Reflectance	K/S
390	1.85	25.98
400	3.01	15.64
410	3.66	12.69
420	3.90	11.85
430	3.92	11.77
440	3.73	12.41
450	3.52	13.23
460	3.38	13.79
470	3.32	14.06
480	3.47	13.45
490	3.76	12.31
500	3.88	11,90
510	4.13	11.13
520	5.05	8.92
530	5.98	7.38
540	6.41	6.82
550	7.04	6.13
560	8.69	4.80

When comparing the overall characteristics of the natural dyes provided, the reflectance and K/S values varied across different wavelengths. Manjistha (MJT) dye exhibited relatively higher reflectance values, indicating greater light reflection and consequently lower K/S values, suggesting a vibrant and intense color. The lac (LAC) dye displayed moderate reflectance values across the spectrum, resulting in moderate K/S values, implying a balanced color intensity.

Similarly, Kaphoi (PMG) and Marigold (MRG) dyes exhibit increasing reflectance with wavelength, indicating a tendency toward lighter shades. Shamba (SMB) dye exhibited a progressive increase in reflectance, resulting in a decrease in K/S values, suggesting a shift toward lighter hues. Kabrang (MLB) dye exhibits a consistent increase in reflectance with wavelength, indicating a gradual transition towards lighter tones. In general, each natural dye exhibits unique optical properties, contributing to a diverse range of color intensities and depths.

Colour Difference

The color difference described the discernible variance in color between two samples. In the case of the dyes under consideration, the color difference was assessed by contrasting the color of the dyed sample with that of the control sample.

The controlled sample served as a standard representing the original color and was compared with the dyed samples. This analysis provided valuable insights into the efficacy of the dyeing process and the extent to which the dye affected the color of the material. Color difference is often quantified using color difference metrics, with the most commonly used being the CIE Value. Colour difference of all the dyes was obtained with difference in colour between the controlled sample (undyed pineapple yarn) and the dyed pineapple yarn.

The value of 'Da*' functions as a marker for the difference of presence of red or green tones in a dye from the controlled color spectrum. A positive 'Da*' value indicates a red hue, while a negative value signifies the presence of green. The 'Db*' value is used to determine difference of a dyed sample from the controlled sample. A positive 'Db*' value suggests a yellow tint, while a negative 'Db*' value indicates the presence of blue tones. Additionally, the 'Dc*' value is a measure difference of dyed sample chroma from the standard sample, which represents the saturation or intensity of a color. It gauges the distance from the L axis, which represents the lightness in the color space. A higher 'c' value indicates a more intense color saturation. DL* represents difference of dyed sample and the controlled sample lightness.

Color difference of pineapple yarn dyed with reactive dyes

The below figure represents the difference of a*b*c*L* of RP, RBY, RY dyed pineapple yarn samples from the controlled sample (undyed pineapple yarn).

Reactofix Dark Pink (RP)		Procion Brilliant Yellow (RBY)		Procion Yellow (RY)	
DIFFERENCE		**DIFFERENCE**		**DIFFERENCE**	
DL* = -47.857	Darker	DL* = -9.277	Darker	DL* = -10.506	Darker
Da* = 49.055	Redder	Da* = 7.049	Redder	Da* = 12.156	Redder
Db* = -23.354	Less Yellow	Db* = 70.972	Yellower	Db* = 70.646	Yellower
DC* = 31.040	Brighter	DC* = 71.311	Brighter	DC* = 71.675	Brighter

Fig.4.56: Colour difference values of Pineapple yarn dyed with RP, RBY &RY

The RP dyed sample was darker by 47.857 units, redder by 49.055 units, less yellow by 23.354 units, and 31.040 units brighter compared to the controlled sample. Compared to the controlled sample, the RBP dyed sample was darker by 9.277 units in L*, Redder by 7.049 units in a*, Yellower by 70.972 units in b* and brighter by 71.311 units in C*. The RY dyed sample differed noticeably from the controlled sample. In terms of lightness (L*), the RY dyed sample appeared darker by 10.506 units. Additionally, it demonstrated a notable increase in redness (a*), with a difference of 12.156 units, indicating a shift towards warmer hues. Moreover, the RY dyed sample displayed a substantial increase in yellowness (b*), with a difference of 70.646 units. Additionally, it was 71.675 units brighter (C*), indicating a more intense coloration.

Procion Brilliant Orange (RO)		Procion Black (RB)		Procion Red (RR)	
DIFFERENCE		**DIFFERENCE**		**DIFFERENCE**	
DL* = -34.145	Darker	DL* = -66.810	Darker	DL* = -47.889	Darker
Da* = 45.370	Redder	Da* = -2.701	Less Red	Da* = 44.250	Redder
Db* = 36.572	Yellower	Db* = -19.733	Less Yellow	Db* = 11.777	Yellower
DC* = 54.117	Brighter	DC* = -19.917	Duller	DC* = 36.389	Brighter

Fig.4.57: Colour difference values of Pineapple yarn dyed with RO, RB &RR

The RO (reactive orange), RB (reactive black), RR (reactive red) dyed samples differed significantly from the controlled one (Fig…..). In RO dyed sample, it appeared 34.145 units darker (L*), 45.370 units redder (a*), and 36.572 units yellower (b*). Additionally, it was 54.117 units brighter (C*), indicating a more vibrant coloration. The RB (reactive black) dyed sample exhibited notable variations when compared to the controlled sample, displaying the following dissimilarities: it was 66.810 units darker in L*, 2.701 units less red in a*, 19.733 units less yellow in b*, and 19.917 units duller in C*.The RR dyed sample exhibited the following distinctions, It was 47.889 units darker in L*, 44.250 units redder in a*, 11.777 units yellower in b*, and 36.389 units brighter in C*.

Fig.4.58: Colour difference values of Pineapple yarn dyed with RBP, RBR &RG

The RBP dyed sample demonstrated differences in comparison to the controlled sample: Firstly, it appeared darker by 47.947 units (L*), it exhibited a redder hue by 26.787 units (a*) and a less in yellowness i.e. - 4.336 units (b*). Lastly, it appeared brighter by 13.024 units (C*). The Reactive Brown (RBR) dyed sample showed significant differences compared to the controlled sample: it appeared darker by 57.344 units (L* obtained as negative) since the brown shade was dark and earthy, 26.787 units redder (a*), and 4.336 units less yellow (b* observed as negative), while also appearing 13.024 units brighter (C*). The Reactive Green (RG) dyed sample differed notably from the controlled sample: it appeared darker by 51.239 units (L*), 40.721 units less red (a* is negative) which meant greener, and 4.513 units yellower (b*), while also appearing 24.237 units brighter (C*). Each dyed sample demonstrated distinct effects on the samples' color properties.

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Color difference of pineapple yarn dyed with natural dyes

The URR dyed sample exhibited significant differences. It appeared darker by 45.560 units in L*, it was 26.284 units redder in a*, 18.028 units yellower in b*, and it was 27.523 units brighter in C*.

Ureirom (URR)		Yachubi (YCB)		Lamuk(LMK)	
DIFFERENCE		**DIFFERENCE**		**DIFFERENCE**	
DL* = -45.560	Darker	DL* = -21.801	Darker	DL* = -26.770	Darker
Da* = 26.284	Redder	Da* = 6.061	Redder	Da* = 1.054	Redder
Db* = 18.028	Yellower	Db* = 12.283	Yellower	Db* = 13.285	Yellower
DC* = 27.523	Brighter	DC* = 13.259	Brighter	DC* = 13.315	Brighter

Fig.4.59: Colour difference values of Pineapple yarn dyed with URR, YCB & LMK

The YCB dyed sample demonstrated, a decrease in lightness by 21.801 units. It showed a Da* value that had redder by 6.061 units however, the value was less compare to the URR. It also had a yellowness by 12.283 units, and a brighter by 13.259 units in terms of color intensity. The LMK dyed sample exhibited a lightness by -26.770 units (darker) compared to the controlled sample. The Da* value indicated a slight increase in redness by 1.054 units, although less pronounced compared to other dyed samples. Additionally, it showed a yellower value 13.285 units. Moreover, it appeared brighter by 13.315 units in terms of color intensity.

Silok Sougri (SGR)		Kuthap(KTP)		Kabrang(LMB)	
DIFFERENCE		**DIFFERENCE**		**DIFFERENCE**	
DL* = -31.443	Darker	DL* = -11.223	Darker	DL* = -29.585	Darker
Da* = 22.673	Redder	Da* = 1.136	Redder	Da* = 0.351	Redder
Db* = -15.949	Less Yellow	Db* = 8.655	Yellower	Db* = -16.238	Less Yellow
DC* = 4.965	Brighter	DC* = 8.729	Brighter	DC* = -15.446	Duller

Fig.4.60: Colour difference values of Pineapple yarn dyed with SGR, KTP, & LMB

The SGR dyed sample exhibited, 31.443 units darker in DL* value. It was 22.673 units redness difference in Da*. It displayed a decrease in yellowness by 15.949 units in b* and appeared 4.965 units brighter in terms of color intensity (C*). Compared to the controlled sample, the KTP dyed sample appeared darker by 11.223 units in L*. It showed a slight increase in redness by 1.136 units in a*. Additionally, it exhibited an increase in yellowness by 8.655 units in b*. Moreover, it appeared brighter by 8.729 units in terms of color intensity (C*). Compared to the controlled sample, the MLB dyed sample appeared 29.585 units darker in L*. It exhibited a slight increase in redness by 0.351 units in a*. Additionally, it showed a decrease in yellowness by 16.238 units in b*. Furthermore, it appeared 15.446 units duller in terms of color intensity (C*).

Tairen(TRN)			Shamba(SMB)			Lac (LAC)		
DIFFERENCE			**DIFFERENCE**			**DIFFERENCE**		
DL* =	-31.498	Darker	DL* =	-24.798	Darker	DL* =	-21.384	Darker
Da* =	21.840	Redder	Da* =	22.091	Redder	Da* =	15.097	Redder
Db* =	10.165	Yellower	Db* =	45.270	Yellower	Db* =	-9.226	Less Yellow
DC* =	18.583	Brighter	DC* =	49.613	Brighter	DC* =	0.331	Brighter

Fig.4.61: Colour difference values of Pineapple yarn dyed with TRN, SMB, & LAC

Compared to the controlled sample, the TRN dyed sample exhibited the following differences from the controlled sample, it had 31.498 units darker in DL*, redder value 21.840 units in Da*. It displayed a difference of 10.165 units in Db*.Moreover, it appeared 18.583 units brighter in terms of color intensity (C*). In case of the SMB dyed sample, it was found to be -24.798 in DL* which meant darker. It showed a difference in redness by 22.091 (redder) in Da*. It exhibited a considerable increase in yellowness by 45.270 units in b*. Moreover, it had 49.613 units brighter in terms of color intensity (C*). For the LAC dyed sample compared to the controlled one, there was a decrease in lightness (DL*) by 21.384, indicating it was darker. Additionally, the a* value increased by 15.097, signifying it was redder, while the b* value decreased by 9.226, indicating it was less yellow. Furthermore, the color intensity (DC*) was only slightly higher by 0.331.

Fig.4.62: Colour difference values of Pineapple yarn dyed with MJT, MRG, & PMG

Compared to the controlled sample, the MJT dyed sample appeared significantly darker by 27.717 L*. Additionally, it exhibited a notable increase in redness, being 37.209 a* redder. Furthermore, it showed an increase in yellowness by 15.641 b*. Moreover, the color intensity of the MJT dyed sample was notably brighter by 33.131 C*. Compared to the controlled sample, the MRG dyed sample demonstrated noticeable alterations in its color properties. Firstly, it appeared 12.570 units darker, indicating a shift towards a darker shade. Additionally, there was an increase in redness by 3.993 a*, suggesting a bit of red hue. Furthermore, the sample exhibited an increase in yellowness by 20.087 units, indicating a stronger yellow undertone. Moreover, the color intensity of the dyed sample was brighter by 20.459 C*. The PMG dyed sample was observed to have been 18.593 L* darker, 5.514 a* redder, 7.849 b* yellower, and 8.841 C*brighter compared to the controlled sample.

The provided color differences indicate how each dyed sample deviates from the controlled sample in terms of color characteristics. For instance, negative values for L* indicate a darker appearance, positive values for a* and b* indicate increases in redness and yellowness respectively, and positive values for C* indicate a brighter color. Analyzing these differences helps to understand how different dyes affect the overall color properties of the samples.

Colour fastness Properties of dyed pineapple yarns

Color fastness refers to the ability of a dyed or printed material to retain its color when subjected to various environmental factors or treatments. These factors may include washing, rubbing, exposure to light, perspiration, and other chemical agents. Essentially, color fastness measures how well the color of a textile material resists fading, bleeding, or transferring onto other materials during use or care processes. The dyed pineapple yarn colourfastness towards washing and light were observed.

Wash fastness properties of pineapple yarn dyed with reactive dyes

A rating scale of 1-5 (1-Very poor, 2- Poor, 3- Good, 4-Very Good, 5- Excellent) was used for grading the performance of the dyed samples towards wash fastness test. All the reactive dyes were observed as very good to excellent results.

Table 4.62: Wash fastness of dyed pineapple yarn (reactive dyes)

Sr. No.	Reactive dyed sample*	Rating out of 5
1.	RP	3-4
2.	RO	4
3.	RBY	4
4.	RY	4
5.	RB	4
6.	RG	3-4
7.	RP	3-4
8.	RR	3-4
9.	RBR	4

(*)reactive colours with the code- RP- Reactofix dark pink, RO-Procion brilliant orange M-2R, RBY-Procion brilliant yellow M-4G, RY- Procion yellow M-3R, RR-Procion brilliant Red M-5B, RB-Procion black, RG-Procion green, RBP-Procion pink and RBR- Procion brown .

The color fastness ratings for various reactive dyed samples were examined. The ratings ranged from 3 to 4 for most samples, indicating good to very good color fastness. Specifically, samples RP, RBY, RY, RB, and RBR received a rating of 4, reflecting very good color fastness.

Sample RO obtained a rating of 4, indicating excellent color fastness. Samples RG, RP, and RR received ratings ranging from 3 to 4, suggesting generally good color fastness with slight variations. Overall, the data indicates satisfactory color fastness properties for the reactive dyed samples, with most samples demonstrating good resistance to color fading or bleeding when subjected to washing or other environmental factors.

Wash fastness properties of pineapple yarn dyed with natural dyes

The wash fastness of pineapple yarn dyed with natural dyes was evaluated. The samples were assessed using a rating scale ranging from 1 to 5, with 1 representing very poor wash fastness and 5 indicating excellent wash fastness.

Table 4.63: Wash fastness of dyed pineapple yarn (natural dyes)

Sr. No.	Samples*	Local name	Rating out of 5
1.	URR	Ureirom Laba	4
2.	YCB	Yachubi	4
3.	LMK	Lamuk	4
4.	KTP	Kuthap	4
5.	SGR	Silok Sougri	**2-3**
6.	MLB	Kabrang	**2-3**
7.	TRN	Tairen	4
8.	SMB	Shamba	4
9.	MRG	Sanarei	4
10.	PMG	Kaphoi	4

*URR- Kamala or Kumkum tree- *Mallotus philippensis, YCB-* Malabar melastome-*Melastoma malabathricum,* LMK-Koda tree- *Ehratia acuminate,* KTP- Hill glory bower-*Clerodendrum infortunatum,* SGR- Roselle- *Hibiscus sabdariffa,* MLB- Mulberry-*Morus nigra,* TRN-Red cedar- *Toona Ciliata,* SMB-*Indian Trumpet tree- Oroxylum indicum,* MRG-*Marigold-Tagetes erecta,* PMG-Pomegranate- *Punica granatum.*

Among the samples, URR (Ureirom Laba), YCB (Yachubi), LMK (Lamuk), KTP (Kuthap), TRN (Tairen), SMB (Shamba), MRG (Sanarei), and PMG (Kaphoi) received a rating of 4, indicating very good wash fastness. These samples demonstrated strong resistance to color fading or bleeding when subjected to washing. However, SGR (Silok Sougri) and MLB (Kabrang) received lower ratings of 2-3, indicating moderate to good wash fastness. These samples showed some susceptibility to color fading or bleeding after washing, suggesting the need for further optimization or treatment to enhance their wash fastness properties. Overall, the majority of samples exhibited satisfactory wash fastness, highlighting the potential of natural dyes for dyeing pineapple yarn.

Light fastness properties of pineapple yarn dyed with reactive dyes

The ratings ranged from 1 to 8, with 1 indicating poor light fastness and 8 indicating excellent light fastness. The scale 1-8 rating (1-2- Very poor, 2-3 poor, 3-4 Fair,4-5 Good, 5-6 Very Good ,6-7 Excellent, 7-8 outstanding) was used for light fastness test. The grading scale allowed for consistent evaluation of the dyed samples, with grades ranging from very poor to outstanding based on their ability to retain color and resist fading when exposed to sunlight.

Table 4.64: Light fastness of dyed pineapple yarn (reactive dyes)

Sr. No.	Reactive dyed sample*	Rating out of 8
1.	RP	6-7
2.	RO	6
3.	RBY	6-7
4.	RY	6-7
5.	RB	6
6.	RG	6
7.	RP	6
8.	RR	5-6
9.	RBR	5-6

(*)reactive colours with the code- RP- Reactofix dark pink, RO-Procion brilliant orange M-2R, RBY-Procion brilliant yellow M-4G, RY- Procion yellow M-3R, RR-Procion brilliant Red M-5B, RB-Procion black, RG-Procion green, RBP-Procion pink and RBR- Procion brown .

The light fastness of dyed pineapple yarn using reactive dyes was assessed. The samples were evaluated using a rating scale ranging from 1 to 8, where 1 represented poor light fastness and 8 indicated excellent light fastness. Most of the reactive dyed samples, including RP, RBY, RY, RB, RG, and RP, received ratings of 6-7, indicating very good to excellent light fastness. Sample RO obtained a rating of 6, suggesting very good light fastness. However, samples RR and RBR received ratings of 5-6, indicating good to very good light fastness.

Overall, the results revealed that the majority of reactive dyed samples exhibited satisfactory to excellent light fastness properties, with only a few samples demonstrating slightly lower ratings.

Table 4.65: Light fastness of dyed pineapple yarn (natural dyes)

Sr. No.	Samples*	Local name	Rating out of 8
1.	URR	Ureirom Laba	6/7
2.	YCB	Yachubi	7
3.	LMK	Lamuk	6/7
4.	KTP	Kuthap	6/7
5.	SGR	Silok Sougri	6/7
6.	MLB	Kabrang	6/7
7.	TRN	Tairen	7
8.	SMB	Shamba	7
9.	MRG	Sanarei	7
10.	PMG	Kaphoi	6-7

*URR- Kamala or Kumkum tree- *Mallotus philippensis, YCB-* Malabar melastome-*Melastoma malabathricum,* LMK-Koda tree- *Ehratia acuminate,* KTP- Hill glory bower-*Clerodendrum infortunatum,* SGR- Roselle- *Hibiscus sabdariffa,* MLB- Mulberry-*Morus nigra,* TRN-Red cedar- *Toona Ciliata,* SMB-*Indian Trumpet tree- Oroxylum indicum,* MRG-*Marigold-Tagetes erecta,* PMG-Pomegranate- *Punica granatum.*

The light fastness of dyed pineapple yarn using natural dyes was evaluated. The samples were graded on a scale from 1 to 8, where 1 indicated poor light fastness and 8 represented excellent light fastness. The majority of samples demonstrated good to very good light fastness, with ratings of 6/7 or 7. Specifically, samples URR (Ureirom Laba), LMK (Lamuk), KTP (Kuthap), SGR (Silok Sougri), MLB (Kabrang), TRN (Tairen), SMB (Shamba), MRG (Sanarei), and PMG (Kaphoi) all received ratings of 6/7 or 7, indicating their ability to withstand sunlight exposure well.

Overall, the analysis indicated that the dyed pineapple yarn using natural dyes exhibited satisfactory to very good lightfastness properties, ensuring that the colors remain stable and vibrant even when exposed to prolonged sunlight.

In conclusion, the data suggests that both reactive dyes and natural dyes can be viable options for dyeing pineapple yarns, with each offering unique advantages in terms of colorfastness properties. Further research and optimization may be needed to enhance the wash and lightfastness of certain samples, but the results overall highlight the potential of both dye types for various applications in the textile industry.

4.9. Extraction of bromelain enzyme

The text describes a process of extraction followed by centrifugation and filtration for separating solids from liquids.

Extraction: Two different extraction methods were used:

- Extraction with alkali water (groundwater) at a Material Liquor Ratio (MLR) of 1:30 at 100°C.
- Extraction using distilled water at an MLR of 1:20 at 100°C.

Centrifugation Optimization: Centrifugation is a process used to separate components of a mixture based on density differences by spinning it at high speeds.

- Various time intervals were tested for centrifugation: 2 minutes, 5 minutes, 10 minutes, and 15 minutes.
- It was observed that 2 minutes and 5 minutes were not sufficient for complete separation.

- Optimal centrifugation time was found to be 10 minutes, as after this duration, no further separation was observed.

- The centrifuge machine used had a regulator with 5 stages of speed, but the optimum speed was found to be at stage 2.

Capacity and Equipment: The centrifuge machine has the capacity to hold 8 tubes of 15 ml each.

Filtration:

- Filtration is a process used to separate solids from liquids by passing the mixture through a porous material, typically a filter paper or mesh.

- Filtration was performed after centrifugation to further separate any remaining solids from the liquid.

Storage: After filtration, the separated liquid was stored in a refrigerator, likely to maintain its stability and prevent microbial growth or chemical reactions.

Fig.4.63: Before centrifugation   Fig.4.64: After centrifugation

In summary, the process involves extracting substances using different methods and ratios, followed by centrifugation to separate solid components from liquid components. Optimal conditions for centrifugation were determined based on time and speed, and filtration was employed to ensure complete separation. Finally, the resulting liquid was stored in a refrigerator for preservation. Further study can be done on the extraction for extent application of bromelian enzyme in textile applications.

4.10. Cost Calculations of the constructed fabric

Cost of the yarn required for making a meter of each fabric (Rani phee, Lengyan phee, Muga innaphee and Muga phanek) was calculated. The details are given in the table 4.21.:

Table 4.66: Raw Material Cost

The yield of the fibre from waste is 4%.	Total cost
1. To produce 1kg of fibre, 40kg of waste leaves are procured @ Rs 10/Kg	Rs 400
2. Transportation charge	Rs 600
3. Cost of Extraction + Scouring	Rs 2000
4. Spinning	Rs 5000
5. Total cost of yarn per Kg	Rs 8000

The process involved obtaining waste leaves as raw material, processing them through extraction, scouring, and spinning to produce yarn. The total cost per kg of yarn, considering all associated expenses, was Rs 8000. This cost structure was used to calculate the cost of yarn required for making a meter of each fabric, namely Rani phee, Lengyan phee, Muga innaphee, and Muga phanek.

The analysis of cost calculation of 1 meter of each developed fabric, highlighted the unique features and related costs of four different fabrics—Rani Phee, Lengyan Phee, Muga Innaphee, and Muga Phanek—while providing a thorough review of each. With a breadth of 55cm, Rani Phee, made of a combination of silk and pineapple yarns, provided a delicate yet alternative. It cost Rs 3,010 per metre in total because of its complex weaving and designs. Lengyan Phee has a wider width of 82 cm and is made by combining cotton and pineapple yarn. Priced at just Rs 2,193 per metre, it is reasonably priced without sacrificing elegance because to its intricate weaving that includes designs. Muga Innaphee, a Rayon and Pineapple blend, has a 97cm width and is a sumptuous alternative with detailed designs. Its quality is reflected in its cost of Rs 2,318 per meter.

Lastly, with a width of 63 cm, Muga Phanek, woven from polyester and pineapple yarn, offers a more affordable option. At a reasonable price of Rs 759 per metre, this durable material featuring temple stoop motifs is offered. In summary, every fabric takes into account the distinct qualities of pineapple fiber into their designs while accommodating a range of tastes and price points.

Table 4.67: Cost calculation of 1 meter of Fabric

Fabric -Silk/pineapple (Rani Phee) width -55cm	Total cost
1.Yarn used in warp: 13.33gm @ Rs 9000 per Kg	Rs 120
2.Yarn used in weft : 17.5gm @ Rs 8000 per Kg	Rs 140
3. Weaving charge with motifs @ Rs 5500 per Rani phee	Rs 2750
Fabric- Cotton/pineapple (Lengyan Phee) width- 82cm	Rs 13
1. Yarn used in warp: 25.5gm @ Rs 500 per Kg	
2. Yarn used in weft: 35gm @ Rs8000 per Kg	Rs 280
3. Weaving charge (with motifs) @ Rs3800 per Lengyan	Rs 1900
Fabric- Rayon/pineapple (Muga Innaphee) width- 97cm	Rs 14
1. Yarn used in warp: 37gm@ Rs 350 per Kg	
2. Yarn used in weft: 38gm @ Rs 8000 per Kg	Rs 304
3. Weaving charge (with motifs)- @ Rs 4000 per Innaphee	Rs 2000
Fabric- Polyester/pineapple (Muga Phanek) width- 63 cm	
1. Yarn used in warp: 30gm@ Rs 300 per Kg	Rs 9
2. Yarn used in weft: 50gm @ Rs 8000 per Kg	Rs 400
3. Weaving charge (with temple stoop motif)- @ Rs 700 per Muga phanek	Rs 350

Therefore, the total cost of the silk/pineapple (Rani phee) per meter= Rs 3,010

The total cost of the cotton/pineapple (Lengyan phee) per meter = Rs 2,193

The Total cost of the rayon/pineapple (Innaphee) per meter = Rs 2,318

The Total cost of the polyester/pineapple (Innaphee) per meter = Rs 759

4.11. Feedback from the consumer

The compatibility of the fibre as an alternative to conventional material in weaving the textiles was found to feasible. Based on their physical appearance of pineapple leaf fibre, yarns, and constructed textiles, interview was conducted to gather feedback from the 74 consumer including weavers of age group 18-60 years from Meitei community. The questionnaire was created in both open ended and closed ended questions in English and local language (Manipuri). **The questionnaire was categorized into Background information of the respondent, Preliminary information about the topic, Looking and felling the samples, feasibility in the market.** A total of 24 questions were included in the questionnaire

Background information of the respondent

The background details collected from consumers provided valuable insights into their demographics and affiliations. Information such as name, age, gender, educational qualification, profession, Institute/Industry/Organization affiliation, and contact details were gathered.

Regarding age distribution, the data revealed that the majority of respondents fell within the age range of 20-30 years, comprising 39.18% (highest) of the total. This was followed by the 30-40 years age group at 22.97%, and the 50-60 years age group at 18.91%. The age groups of 18-19 years and 40-50 years constituted 8.1% and 10.81% of the respondents, respectively (Graph 4.9).
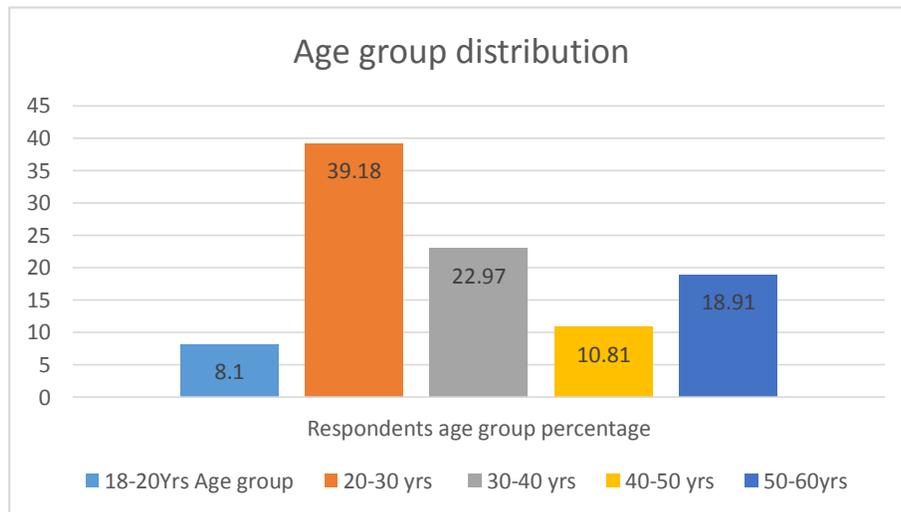
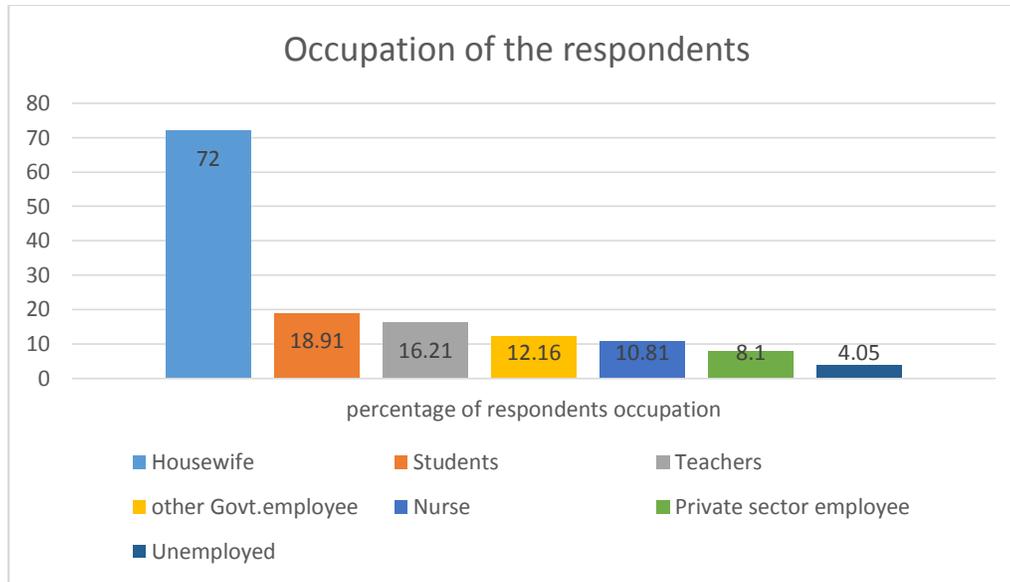**Graph 4.9: Age group distribution of the respondents**

Notably, only a small percentage (5.4%) of male respondents participated in the study, indicating a predominantly female respondent base, since the developed textiles were mainly for females except the Lengyan phee which was for both gender.
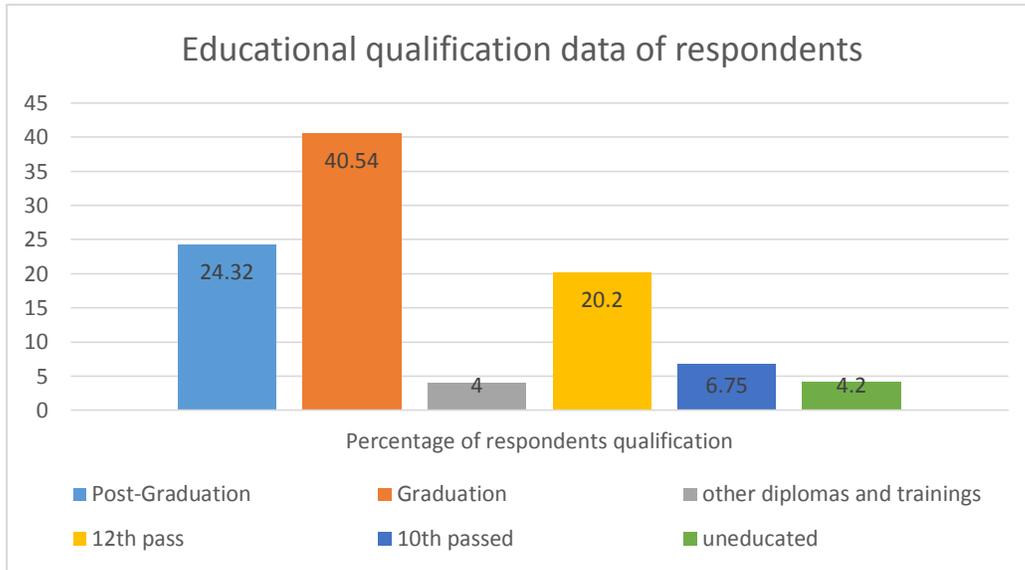
Graph 4.10: Educational Qualification of the respondents

In terms of educational qualifications (Graph 4.10), graduates accounted for the largest proportion of respondents at 40.54%, followed by post-graduates at 24.32%. Those with a 12th-grade education represented 20.20% of respondents, while 10th-grade graduates constituted 6.75%. A smaller percentage (4%) included respondents with other qualifications such as diplomas and training, while 4.2% of respondents in the 50-60 years age group were categorized as uneducated.

The occupation distribution (the below graph 4.11) among respondents revealed that the majority (72%) were housewives. Students represented 18.91% of respondents, followed by teachers (16.21%), including both private and government educators. Other government employees made up 12.16% of respondents, while those employed in the private sector accounted for 8.10%. A small percentage (4.05%) identified as unemployed.

Graph 4.11: Occupation of the respondents

This detailed breakdown of background information provides a comprehensive understanding of the consumer demographics involved in the study, shedding light on their age distribution, educational qualifications, and occupational profiles. Such insights are crucial for interpreting the feedback obtained from the questionnaires and understanding the potential market reception of textiles woven from pineapple leaf fiber.

Preliminary data about the topic

In the collected preliminary data, 100% of the interviewed consumer wore their traditional textiles. Also, all of them had never heard about the pineapple leaf fibre and had never seen the fibre or yarn before. They committed that they only heard about the pineapple leaf fibre from the researcher. However, they did hear about the banana fibre before. All the respondents said yes to the utilization of wasted pineapple leaves for making fibre for their traditional textiles would be helpful to the local people. All of them agreed that the use of synthetic fibre in making textiles harms our environment, and the incorporation of pineapple leaf fibre in traditional textiles is an innovative and eco-friendly alternative. Every respondent felt appealed by the fabrics in terms of appearance and liked to wear their traditional textiles made from pineapple leaf fibre. They also loved to wear something organic and natural.

Looking and feeling the samples

All the respondents expressed that the fabrics made from pineapple leaf fibre were suitable for wearing as their traditional textiles. 97.3 % of the respondents felt that the pineapple fabrics are similar to their silk textiles. Apart from the local silk, 4% of the total respondents had seen other fabrics (such as khadi, and tussar silk) similar to the pineapple fabrics. Out of the total respondents, 8% disagreed that the use of only traditional motifs on the fabrics would preserve the originality of the traditional textiles. Every respondent liked the natural colour of the pineapple fabrics. In the awareness about the traditional colours used in making their traditional textiles, 7% of respondents weren't able to answer the traditional colours. The traditional colours listed by the remaining 93% of respondents were white, off-white, cream, black, green, yellow, orange, violet, red and pink. Many of the respondents from the age group 50-60 years even answered in the local traditional terms of the colour such as Kumjingbi (black & white), loirang (brown shade), and chalembu (green). All the respondents expressed that obtaining dyes from plants would add value to making their textiles and appreciated that the designs of the developed fabrics were similar to the ones used in their traditional textiles.
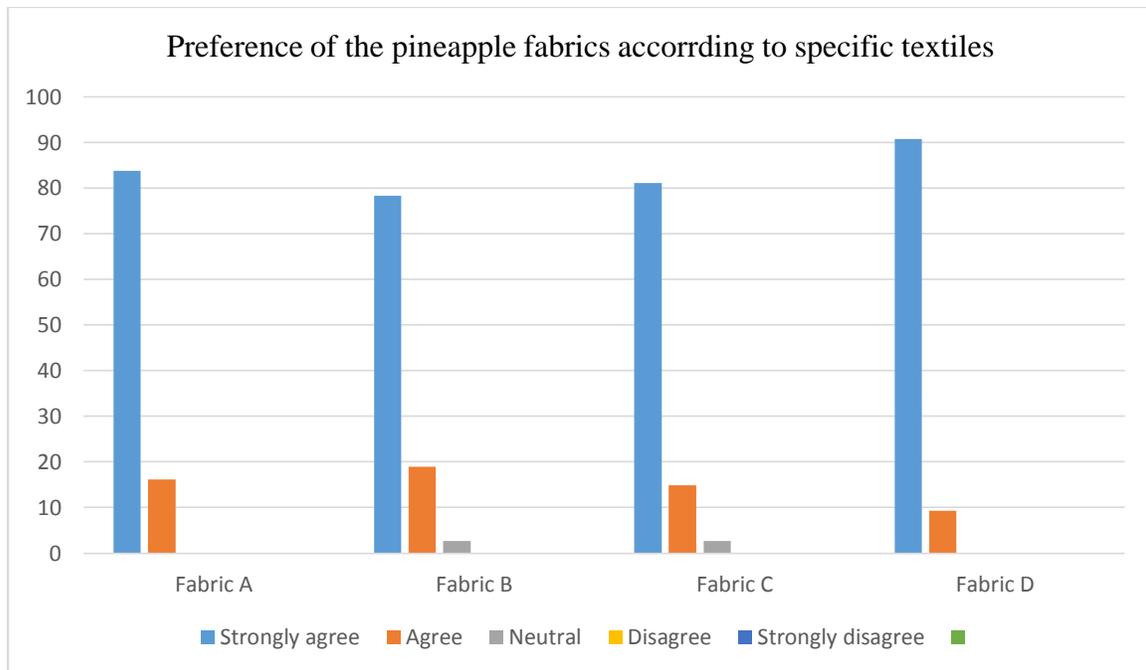
Graph 4.12: Preference of the respondents (in percentage) for specific textiles

In ranking (5-strongly agree, 4- agree, 3-neutral, 2-disagree and 1- strongly agree) the pineapple fabrics according to the specific traditional textile of their community (Meitei), 83.78% of the total respondents felt 'strongly agree' on Fabric A (Silk/Pineapple) for Rani Phee, and the remaining 16.21% felt 'agree' on the same. For the Fabric B (Rayon/Pineapple) as Khurkhul muga Innaphee, 78.37% of the respondents ranked 5 (strongly agree), 18.91% ranked 4 (agree), 2.7% ranked 3 i.e. neutral. In the ranking of Fabric C (Cotton/Pineapple) as Lengyan phee, 'strongly agree' was given by 81.08% of the respondents, 'agree' was constituted by 14.86%, and only 2.7 % felt neutral upon this. In the case of Fabric D (Polyester/Pineapple) as Muga Phanek, 'Strongly agree' was provided by the majority of the respondents which contributed 90.7 % of the total and the remaining 9.3% had 'agree'. Fabric D got the highest 'strongly agree' among the other fabrics (Graph 4.12).

Feasibility in the market

In examining the market feasibility, 100% of the respondents thought the developed pineapple fabrics would be commercially viable. 97.3 % of the respondents would like to try fashion garments from the developed pineapple fabrics. 'The fabrics would be suitable for garments in the niche market' was agreed by 96% of the total respondents. In terms of price preferences for the developed fabrics, Fabric A (Silk/Pineapple) received 87.83% of respondents willing to pay Rs 8000 (out of this 8.1% felt that the fabric should be priced more than Rs 10,000) and above. 6.76% preferred a price range of Rs 7000-8000, and 5.4% opted for Rs 6000-7000.

For Fabric B (Rayon/Pineapple), 8.10% of respondents were willing to pay Rs 8000 and above, 14.86% preferred Rs 7000-8000, and 66.21% chose Rs 6000-7000. Additionally, 7.75% selected Rs 5000-6000, and 3% preferred Rs 4000-5000.

For Fabric C (Cotton/Pineapple) price range of Rs 8000 & above was preferred by 4% of the total respondents, Rs 7000-8000 was chosen by a percentage of 6.5 out of the total respondents, the majority of the respondents (43.24%) had selected the range of Rs 6000-7000 followed by 35.13% respondents for the range of Rs 4000-5000 and lastly, 10.81% of the respondents selected Rs 5000-6000. Separate price ranges were kept for Fabric D (Polyester/Pineapple) since it was different from the three fabrics. In the case of Fabric D,

respondents contributed 79.3% for the price range of Rs 2000-3000 and 12.7% for the range of Rs 1000-2000.

Table 4.68: Preference on price of the pineapple fabrics

Fabric	Price Range (Rs)	Percentage of Respondents
Fabric A (Silk/Pineapple)	8000 and above	87.83%
	7000-8000	6.76%
	6000-7000	5.4%
	8000 and above	8.10%
	7000-8000	14.86%
Fabric B (Rayon/Pineapple)	6000-7000	66.21%
	5000-6000	7.75%
	4000-5000	3%
	8000 and above	4%
	7000-8000	6.5%
	6000-7000	43.24%
Fabric C (Cotton/Pineapple)	5000-6000	10.81%
	4000-5000	35.13%
Fabric D (Polyester/Pineapple)	2000-3000	79.3%
	1000-2000	12.7%

The data feature 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 have the opportunity to carve out a significant presence in the textile industry, catering to both traditional and modern fashion markets.

From the feedback of feasibility in the market, emphasizing the "**97.3 % of the respondents would like to try fashion garments from the developed pineapple fabrics**" and the total hand value of Kawabata analysis outcome i.e. suitable for women thin dress fabric, The Researcher explored an experiment to check the visual effect of making high fashion garments using the developed pineapple fabrics.

Fig.4.65: Fashion garments made from the pineapple fabrics

Mini mannequins of 7.5x5x25 cm were used for making the drape fashion garments. This approach allowed for a precise examination of how the pineapple fabrics drape and interact with the form of the mini mannequins, providing valuable insights into their suitability for high-fashion applications.

Testing of Hypothesis

The two framed hypothesis of the study are given below-

Null hypothesis (H_0) - 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

For testing the hypothesis, the observed data from the consumer feedback related to the alternate hypothesis i.e. "Traditional textiles using pineapple leaf fiber will be accepted by the consumer" were taken.

Using Chi-square test

To reject the null hypothesis, chi-square test was adopted. Since numerical data was needed to conduct the adopted test, the hypothesis had been reframed with expected results which is as follows:

Null hypothesis (H$_0$) - Traditional textiles using pineapple leaf fiber will not be accepted by more than 50% the consumer

Alternate hypothesis (H$_1$) - Traditional textiles using pineapple leaf fiber will be accepted by more than 50% of the consumer

Categorical Data collected (Yes or No) from the feedback related to the alternate hypothesis-

1. 100% of the respondents sensed appealed by the developed fabrics regarding the appearance and loved to wear their traditional textiles made from pineapple leaf fibre.

2. All the respondents stated that the fabrics made from pineapple leaf fibre were appropriate for wearing as their traditional textiles.

3. 97.3 % of the respondents said yes to the pineapple fabrics are similar to their silk textiles.

4. Every respondent said they like the natural colour of the pineapple fabrics.

5. 100% appreciation was given that the designs of the developed fabrics were similar to their traditional textiles.

A chi-square value of 230.34 was observed using the given categorical results data (percentage of yes) and expected data (51% yes for each data). This value indicates a large discrepancy between the observed and expected frequencies. The larger the chi-square value,

the greater the difference between the observed and expected values, suggesting a stronger association between the variables being analyze (more than 50% respondents acceptance is true) and **p- value was found to be 1.111** (exceeded critical value). According to the hypothesis test, if the calculated test statistic falls beyond this critical value, we would reject the null hypothesis.

To interpret the chi-square value, the chi-square value exceeds the critical value or if the p-value is below a chosen significance level (e.g., 0.05), it indicates that the association between the variables is statistically significant, and the null hypothesis of independence is rejected. Hence, use of pineapple leaf fiber in making the traditional textiles of Meitei Community is accepted by the consumer.

Using ANOVA (Analysis Of Variance)

In support of the chi-square test on the hypothesis, comparison data from drape-coefficient of the developed pineapple fabrics and existing traditional textiles of Manipur (Meitei Community) was used.

Table 4.69: One way ANOVA (Between group's variants) of the developed Fabrics-Drape- coefficient comparison

Developed Fabric	Drape coefficient	Fabric (existing textile)	Drape coefficient (Starched)
Silk/Pineapple (S/P)	67.57%	Silk/Silk(S/S)	60.61%
Rayon/Pineapple(R/P)	57.13%	Rayon/Silk(R/S)	53.65%
Cotton/Pineapple(C/P)	64%	Cotton/Silk(C/S)	64.09%

Sum of Squares SS	Mean Square MS	F-Stat	P-Value (0.05)
17.85	17.85	0.63	0.47

The analysis revealed a Sum of Squares (SS) value of 17.85 and a Mean Square (MS) value of 17.85. The F-statistic, used to evaluate differences in drape coefficients among fabric groups, was calculated as 0.63. Additionally, the corresponding P-value (0.05) was determined to be 0.47. These statistical findings suggest that there were no significant differences observed in drape coefficients among the various fabric compositions. The inclusion of pineapple yarns made the drape coefficients remained relatively consistent across the developed fabrics and their traditional textiles. This indicates that the addition of pineapple yarn did not significantly alter the drape characteristics compared to traditional textiles, which are typically starched. Therefore, the null hypothesis is rejected.

4.12. Awareness of pineapple leaf fiber for making textiles

Talk in the Khangminashi Program episode 18 by Impact TV, 2022 on the topic 'Pineapple leaf fiber'

The discussion began with an introduction to pineapple leaf fiber, highlighting its origins and properties. PALF is a natural, renewable fiber extracted from the leaves of the pineapple plant, which is abundantly grown in Manipur. Emphasis was placed on the eco-friendly nature of PALF, as it is a byproduct of the pineapple industry and does not require additional cultivation or resources for its production. The talk elaborated on the extraction process of PALF, detailing the steps involved in obtaining the fiber from pineapple leaves. This process typically included collecting leaves after harvesting the fruits, decorticating or stripping the fibers from the leaves, and water retting them get usable fiber strands.

The researcher also emphasized the various potential uses of PALF, particularly in the context of traditional textiles of Manipur. PALF has versatile applications in textile, handicraft, and eco-friendly product industries. The talk highlighted potentiality of local initiatives in Manipur that promote the use of PALF and support pineapple farmers and artisans in the region. Potentials like community-based projects, cooperatives, or entrepreneurial ventures utilizing PALF had been showcased, demonstrating its economic and social impact on local communities.

A training program

A training program on awareness about the pineapple leaf fibre was conducted for handloom weavers cluster group of Khurkhul, a village in Imphal West district, Manipur. The background of Khurkhul being a hub for local mulberry silk production, known as Khurkhul muga, set the platform for introducing a new material like pineapple leaf fiber. The core objective of the program was to build awareness among the weavers about the properties, benefits, and potential applications of pineapple leaf fiber in textile production. This involved practical demonstrations, discussions, and hands-on sessions to familiarize the weavers with the material and its usage. Given the outbreak of violence since May 3, 2023, traditional methods of conducting group training had been disrupted. Recognizing the challenges posed by the violence, the researcher adapted the training program to fit the circumstances. Instead of conventional group sessions, the researcher opted for cluster groups, likely smaller gatherings that could be managed more safely and effectively.

Incorporating home visits into the awareness program was strategic. It allowed for a more personalized approach, ensuring that each weaver received attention and information about the fiber. Moreover, it demonstrated a commitment to reaching out to the weavers despite the challenging situation. By providing the weavers with knowledge about new materials and techniques, the program not only diversified their skill set but also opened up potential economic opportunities.

- 2 newspaper articles on exploration of pineapple leaf fibre in Manipur and pineapple yarn in making traditional textiles published in Sanaleibak Daily, Manipur, dated- 13-07-2022 & 05-12-2022.

- Products display during the 9th National handloom day 7th Aug 2023, awareness about the pineapple leaf fiber in making handloom textiles was disseminated through the local news channel.

Venue- Institute of Fashion Technology

Faculty of Family and Community Sciences

The Maharaja Sayajirao University Of Baroda, Vadodara, Gujarat.

4.13. SWOC Analysis

The SWOC analysis for utilizing pineapple leaf fibers (PALF) in making traditional textiles in Manipur provided a comprehensive understanding of the feasibility and challenges associated with this endeavor.

1. **Strengths:**

   - PALF offers inherent advantages such as sustainability, biodegradability, and eco-friendliness, aligning well with the growing demand for environmentally conscious products.

   - Its fine yarn production capabilities and tensile strength with the use of motorized pineapple leaf fiber charkha make it a suitable alternative to traditional textile materials like silk.

   - PALF provides additional income opportunities for farmers through the sale of waste leaves, complementing their fruit sales and contributing to economic sustainability.

   - There's cultural significance in integrating PALF into traditional weaving techniques, preserving local weaving skills while incorporating a new raw material.

2. **Weaknesses:**

   - Processing PALF involves time-consuming and expensive hand extraction, which hinders scalability and cost-effectiveness. This limitation necessitates the development of machine extraction methods.

   - Quality consistency issues may arise due to variations in leaf quality, affecting the overall reliability of PALF as a textile material.

   - Limited mass production and marketing efforts hinder widespread adoption and consumer awareness of PALF as a viable textile material.

3. **Opportunities:**

- Growing demand for sustainable products presents a significant opportunity for PALF, positioning it as an eco-friendly alternative in the textile market.

- PALF can serve as an alternative to silk in traditional textile production, particularly in regions like Manipur where traditional weaving techniques are valued.

- There's an opportunity to capitalize on the versatility of PALF by exploring its applications beyond traditional textiles, potentially expanding its market reach.

4. **Challenges:**

- The need for installation of extraction machines presents a technical and financial barrier to mass production of PALF, requiring investment and infrastructure development.

- Limited availability in the market and competition with synthetic fibers pose challenges in establishing PALF as a mainstream textile material.

- Addressing consumer education gaps is crucial to increasing awareness and acceptance of PALF among consumers, requiring targeted marketing and outreach efforts.

5. **Integration and Strategy Formulation:**

- Develop cost-effective and efficient machine extraction methods to overcome processing challenges and enhance scalability.

- Collaborate with local communities and weaving artisans to integrate PALF into traditional textile production, imposing its cultural significance.

- Invest in research and development to improve quality consistency and explore innovative applications of PALF in various industries.

- Implement targeted marketing and education campaigns to raise awareness and generate demand for PALF products, emphasizing its sustainability and unique qualities.

By implimenting strengths, addressing weaknesses, capitalizing on opportunities, and mitigating challenges, strategies can be formulated to promote the sustainable and widespread adoption of PALF in the textile industry, particularly in regions like Manipur where traditional weaving techniques are deeply rooted.

Alignment of pineapple leaf fiber in Sustainable Development of Goals

Utilizing pineapple leaf fiber in sustainable textiles within Manipur and other Northeast Indian states, which are known for pineapple cultivation, presents a significant opportunity to advance towards the Sustainable Development Goals (SDGs). By considering the economy, environment, and society of the region, this initiative can address several key SDGs:
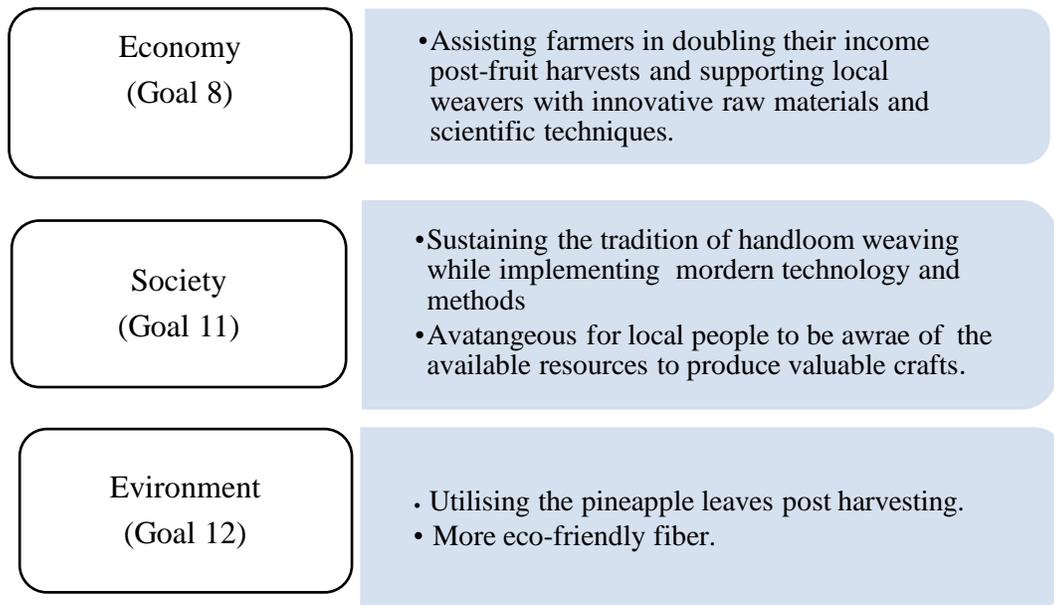
Economy (Goal 8)	• Assisting farmers in doubling their income post-fruit harvests and supporting local weavers with innovative raw materials and scientific techniques.
Society (Goal 11)	• Sustaining the tradition of handloom weaving while implementing mordern technology and methods • Avatangeous for local people to be awrae of the available resources to produce valuable crafts.
Evironment (Goal 12)	• Utilising the pineapple leaves post harvesting. • More eco-friendly fiber.

Fig. 4.66: Three SDGs for sustainable textile

1. **Goal 8: Decent Work and Economic Growth**: Incorporating pineapple leaf fiber into textile production can create employment opportunities and promote economic growth in the region. This initiative can provide meaningful and sustainable livelihoods for local communities, particularly farmers and artisans involved in pineapple cultivation and textile manufacturing.

2. **Goal 11: Sustainable Cities and Communities**: By promoting the use of pineapple leaf fiber in textiles, we can contribute to building sustainable cities and communities in Northeast India. This approach encourages the development of local industries and value chains, reducing dependency on external markets and adopting **self-reliance & Vocal for local.** Additionally, sustainable textile production practices can help mitigate environmental impact and promote social interconnection within communities.

3. **Goal 12: Responsible Consumption and Production**: Utilizing agro-waste like pineapple leaves in textile products aligns with the principles of responsible consumption and production. By upcycling this waste material, we minimize environmental pollution and resource depletion. This contributes to more sustainable patterns of consumption and production, fostering a circular economy approach that conserves resources and minimizes waste.

Meeting Goal 8 aligns with Goal 9, focusing on industry, innovation, and infrastructure, while simultaneously supporting Goal 1, eradicating poverty, and Goal 2, ensuring zero hunger. Achieving Goal 11 fosters sustainability in Northeast India and contributes to addressing Goals 1 and 2. Fulfilling Goal 12 is pivotal for advancing other objectives, including Goal 13, climate action, and Goal 14, life below water, particularly due to the textile sector's significant role in water pollution.

In conclusion, the comprehensive exploration of utilizing pineapple leaf fiber in textile production, as outlined in the various sections, underscores its potential as a sustainable and versatile material. From extraction and modification to yarn preparation, weaving, dyeing, and consumer feedback, each aspect has been studied and analyzed. The findings suggest that pineapple leaf fiber holds promise for creating a range of traditional textiles with desirable properties. Furthermore, the awareness generated and the SWOC analysis conducted shed light

on both the opportunities and challenges associated with integrating this natural resource into the textile industry. Overall, this research lays a solid foundation for further innovation and development in sustainable textile manufacturing, contributing to the advancement of both local economies and global sustainability goals.