Chapter II

REVIEW OF LITERATURE

A literature review is a critical evaluation and synthesis of existing research, publications, and scholarly works related to a particular topic or field of study. It involves systematically analyzing and summarizing the findings, methodologies, theories, and arguments presented in relevant academic articles, books, conference papers, theses, and other sources. In addition, the literature review justified the chosen research objectives, methodologies, and theoretical frameworks by demonstrating how they contributed to and built upon previous scholarship. In addition, it helped to avoid redundancies by ensuring awareness of what has already been studied and published. In addition, the literature review provided evidence to support the arguments or hypotheses presented in the research paper or thesis. Lastly, it informs future research directions by synthesizing existing literature and highlighting areas that require further investigation.

To establish the context for the research by providing an overview of the current state of knowledge on the topic at hand and help the researcher to identify gaps in existing literature, emerging trends, and unanswered questions. Extensive literature related to the study was reviewed. The researcher has gone through various books, articles, research papers, thesis, and dissertations available in the Hansa Mehta Library, the Department of Clothing and Textiles library, and the library of Faculty of Technology and Engineering of The Maharaja Sayajirao University of Baroda. The review was also collected from the websites of Indian Council of Agricultural Research, Krishi Vigyan Kendra, Govt. of India, INFLIBNET-Shodhganga, Council of Scientific and Industrial Research- Northeast Institute of Science and Technology, branch laboratory- Lamphelpat, Manipur.

The reviewed literature has been presented under following headings

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2.2 Research related Review

2.2.1 Natural minor fiber

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2.2.4 Threads

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2.2.4.2 Sewing threads

2.1 Theoretical review

2.1.1 Production of pineapple

Kingdom	Plantae
Family	Bromeliaceae
Genus	Ananas
Species	A. comosus
Binomial	Ananas comosus

Pineapple (scientifically known as Ananas comosus) is a tropical plant renowned for its delectable fruit and holds immense economic importance within the Bromeliaceae family. Originating from South America, where it has been cultivated for centuries, its introduction to Europe during the 17th century elevated its status to a symbol of luxury. Since the 1820s, pineapple cultivation has flourished in greenhouses and tropical plantations. These plants grow as small shrubs with individual flowers merging to form a single fruit. Propagation usually takes place in the form of offsets on top of the fruit or side shoots, and maturity usually occurs within a year.

Pineapple is a perennial herbaceous species that usually reaches a height of 1.0 to 1.5 m (3 ft 3 into 4 ft 11 in), although it can occasionally grow taller. It has a stout, compact stem and strong, glossy leaves. In the course of fruit development, it usually produces around 200 flowers, although some large-fruited varieties may exceed this number. After flowering, the individual fruits of these flowers merge to form a collective fruit structure. Once the initial fruit is produced, lateral shoots emerge from the leaf axils of the main stem, often referred to as suckers. These suckers may either be removed for propagation purposes, or they may be allowed to develop into other fruits on the original plant. Usually, suckers originating from the plant's base are cultivated in commercial settings. The plant consists of 30 or more elongated, succulent leaves measuring between 30 to 100 cm in length, arranged around a thick central stem, adorned with sharp spines along their edges. During the first year of growth, the central stem elongates and thickens, bearing numerous closely spiraled leaves. After 12 to 20 months, the stem transforms into a spike-like inflorescence, reaching up to 15 cm (6 in) in length, adorned with over 100 flowers arranged in spirals, each flower subtended by a bract.

Pineapple thrives in humid tropical climates and is suitable for cultivation both near the coast and further inland, provided that the temperature remains moderate. The ideal temperature range for successful growth is from 22 to 32 °C. However, excessively high night temperatures may prevent plant development, so it is preferable to maintain a temperature difference of at least 4 degrees Celsius between day and night. Pineapples can be grown up to 1,000 meters above sea level if the area is free of frost. To achieve optimal growth, it is necessary to receive adequate rainfall (100 to 150 cm). Sandy loam soils with a pH between 5.0 and 6.0 are considered to be ideal for pineapple cultivation. (Pineapple, National Horticulture Board, 2023)

2.1.1.1 Production of pineapple across the globe

According to the National Horticulture Board's Pineapple report (2002), the estimated annual production of pineapple (Ananas comosus) is 14.6 million tons of fruits. India became the 5th largest pineapple producer with a yearly production of about 1.2 million tones. Thailand, Philippines, Brazil, China, Nigeria, Mexico, Indonesia, Colombia, and the USA were the main producers of pineapple. The area of pineapple cultivation increased by 35% during the year 1991-92 to 2001-02 whereas the rate of production increased by 54%. The main exporters of this fruit are Philippines, Mexico, Brazil, Taiwan, Malaysia, and South Africa. While leading in imports are France, Japan, USA, Italy, Germany, Spain, UK and Canada. The export of India has been increased from 138 tons to 837 tons during the span of 1991-92 to 2001-02 year. The majority of the world's production is used in the canning industry since the trade for fresh consumption is limited.

The pineapple plant Annanas comosus comes under the Bromiliaceae family. It is widely produced for the fruit. Pineapple mainly grows abundantly in places which have high rainfall like West Bengal, Assam, and other northeast states, Western Ghats and coastal areas like Goa, Kerala and Karnataka. There are many varieties of pineapple grown in the world of which the major ones are:

I. Smooth Cayenne: Thailand, the Philippines and Indonesia have this variety.

II. Queen and Queen Victoria: found in Malaysia, China, Vietnam and India.

III. White Perola: Its origin is Brazil and contains white pulp.

IV. Giant Kew: Similar to the Kew variety and found in India where main growers are West Bengal, Meghalaya and Manipur.

The Kew variety is important for its palatable and nutritive value and is mainly produced for canning. It's highly juicy and contains aroma and flavor. The weight of each fruit varies from 1.5Kgs- 3Kgs. (Agrawal, N. 2018)

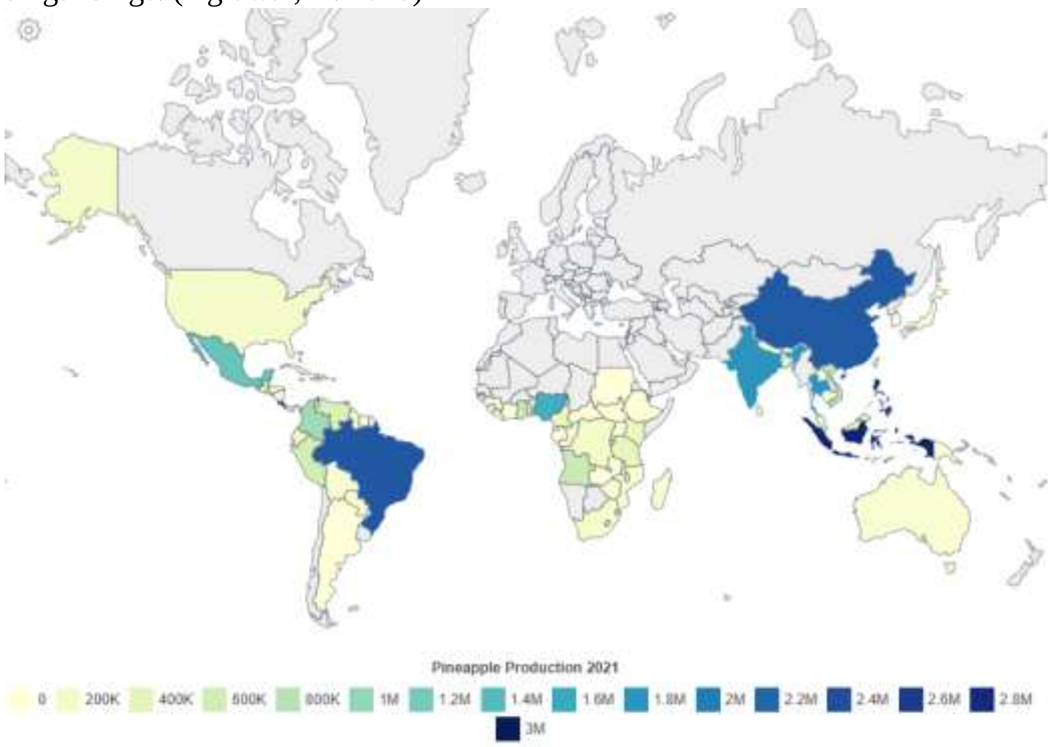


Fig 2.1: Countries producing pineapple in the world

In the report of pineapple production by country 2023- The Philippines is the largest pineapple-producing country in the world followed by Costa Rica and Brazil in the year 2023. The origin of the fruit is South America and the first cultivator is Central America, Brazil, the Caribbean and Mexico. The top ten pineapple-producing countries in the year 2021 were Costa Rica, Indonesia, Philippines, Brazil, China, Thailand, India, Nigeria, Mexico, and Colombia. Cayenne, Red Spanish, and Formosa (Queen) are the main varieties grown in the Philippines. Almost 70% of fruit production is used for fresh consumption in producing countries. Tropical regions are the best for growing this plant. (Pineapple production by country 2023)

After Banana and citrus fruit, pineapple is the tropical most cultivated fruit. Cayenne or smooth cayenne is the most consumed variety of pineapple. The short-lived perennial monocots can grow upto 2 to 4 inches and have spiky leaves. The optimum temperature for this plant is 68-86^{o} F. Moist acidic pH soil, and bright but indirect sun with high humidity are the right climatic conditions for cultivating pineapple. The plant resists drought but is prone to root rot due to too much wetness. The bromelain content of the fruit is used for digestive purposes. (Ananas comosus (Pineapple) 2023)

The earliest documented mention of pineapple comes from Christopher Columbus, González Fernández de Oviedo y Valdés, and Sir Walter Raleigh, who discovered its cultivation in the West Indies, where it was used both for food and wine production. It is believed that the Portuguese played a significant role in the spread of the pineapple and introduced it to Saint Helena shortly after the discovery of the island in 1502. From there he went to Africa and, around 1550, to India. By the end of the 16th century, pineapple cultivation had expanded across much of the tropical regions worldwide, including various islands in the South Pacific. Today, major pineapple-producing countries include Costa Rica, Brazil, China, India, and Thailand. (Pineapple- Plant and fruit, Britannica, 2024)

According to Tropical Permaculture, pineapples can now be grown in different parts of the world, despite their preference for tropical climates. It is particularly suitable for indoor cultivation in pots and offers a more manageable option compared to many other tropical fruits. However, outdoor growth requires a consistently warm and sunny environment, which is typically found in USDA zones 11 and 12, including areas such as Hawaii, Florida, and Puerto Rico.

Although pineapples originate from South America and the Caribbean, they are also extensively cultivated in tropical Asia, with Costa Rica, Indonesia, and the Philippines becoming the top three pineapple-producing countries in 2021, according to Statista. Contrary to popular belief, pineapples belong to the bromeliad family, as emphasized by the University of Wisconsin-Madison’s horticulture department. Among bromeliads, pineapples are the only variety that can produce edible fruit, as highlighted by Better-Gro.

As explained by the University of Florida’s Institute of Food and Agricultural Science Extension, propagation of pineapples commonly involves using vegetative growths from existing plants. The MasterClass recommends that the crown of a de-fruited pineapple should be planted in a suitable-sized pot after the stem has been allowed to root in water. According to the University of Florida’s IFAS Extension, under favorable conditions, a pineapple typically takes 18-24 months from planting to produce ripe fruit. (Where do pineapple grow, Usatoday, 2023)

Pineapple is one of the most popular fruits in the world, and people all over the world enjoy it widely. There are a lot of pineapple varieties around the world, but not all of them are readily available in grocery stores. From tiny pineapples to gigantic pineapples in this article, each type has its own distinctive flavor and attributes. (Different types of pineapple, Fruitonix, 2023)

Pineapple varieties span the globe, with unique attributes from sweetness like the Ripley to the exotic Antigua Black. The varieties found are:

1. Ripley: sweetest, reddish-green leaves, oval shape, pale copper color when ripe, yellow flesh.
2. Mordilona: Northeastern Colombia, Venezuela, green to yellowish-orange rind, cylindrical shape, sweet aroma.
3. Cabezona: Mexico, large stem, yellowish-orange spiky skin, white flesh turning yellow.
4. Giant Kew: India, large fruit, coppery-yellow rind, broad flat eyes, pale-yellow flesh.
5. Panare: Venezuela, medium-sized, bottle-shaped, green to orange rind, spiny leaves.
6. Brecheche: Southern Venezuela, olive-color leaves, cylindrical shape, juicy flesh with little fiber.
7. Mauritius: Small, conical shape, wide eyes, yellowish-orange layers, also grown in India and Malaya.
8. Maipure: Venezuela, sweet and sour taste, yellow rind and flesh.
9. James Queen: Round, reddish-orange exterior, large fruit, yellow juicy flesh.
10. Montufar: Central America, Guatemala, colorful green rind, juicy yellow flesh.
11. Cayena Lisa: Medium-sized, cylindrical shape, orange-reddish exterior, yellow flesh.
12. Monte Lirio: Globe-like shape, rough yellow rind, dark green leaves, sour-sweet flesh.
13. Pernambuco: South America, elongated oval shape, orange rind with spines, juicy yellow-whitish flesh.
14. Singapore Red: Ideal for canning, resistant to pests, red-striped leaves, reddish-golden middle section.
15. St. Michael: From Azores, Portugal, balanced acid-sugar profile.

16. Champaka: Not ideal for raw consumption, long with spiny dark-green leaves, and reddish spots.
17. Pinkglow: Pink flesh, candy-like taste, popular in grocery stores.
18. Rondon: Small with dark green outer part turning orange-red, white flesh.
19. Hilo: Small size, numerous pups for replanting.
20. Valera: Puerto Rico, yellowish-orange rind, green leaves with purplish tint, white flesh.
21. Antigua Black: Rare, yellow flesh with low acidity and high sugar levels.
22. White Kauai: Hawaii, white with minimal acidity, sweet.
23. Sugarloaf: Green rind, aromatic sweet flesh, common in Central and South America.
24. Monte Oscuro: Many spines, saw-toothed leaves, yellow juicy flesh with fiber.
25. Natal Queen: Sweetest when raw, green to yellowish-orange rind, sweet aroma.
26. Red Spanish: Caribbean, green leaves with reddish lining, oval shape, and yellow flesh.
27. White Jade: White flesh, sweet, low acidity, high sugar levels.

Among all the varieties of pineapple, the Natal Queen pineapple, known for its exceptional sweetness, thrives in the warm climate of Australia and is cultivated as a commercial crop in South Africa and Malaysia. When fully ripe, it emits a delightfully sweet aroma, signaling its readiness for consumption. (Ortiz, P. 2024)

2.1.1.2 Pineapple production in India

As per the report of Krishi Vigyan Kendra on Pineapple, pineapple cultivation is suitable for high rainfall and humid coastal areas and North Eastern states of India. Commercial producers of pineapple are Assam, Meghalaya, Tripura, Mizoram, West Bengal, Kerala, Karnataka and Goa. The fruit juice is being exported to countries like Nepal, the UK, Spain and UAE. Pineapples provide many health benefits to the immune and digestive systems, bromelain enzyme from the fruit is good for aid digestion, and help in the treatment of Dyspepsia, bronchitis, high blood pressure and arthritis. The ideal temperature for this plant cultivation is 20^{o}C to 36^{o}C with humid climate and soil pH should be acidic in nature (5.5 to 6). Sandy loam soil is best and heavy clay soil should be avoided. The most common varieties cultivated in India are Kew, Giant Kew, Queen, Jaldhup, Mauritius and Lakhat. Giant Kew and Queen are mostly found in Northeastern India. Pineapple usually flowers after 10-12months and another duration of 3-6months is required for harvesting. Full ripe fruit is usually harvested for fresh consumption but for canning, only when the bottom half of the fruit turns yellow. "Mealybug "and "hear rot" are the main pests and diseases respectively however, no serious pest or disease is found in the country.

Fig 2.2: Variety of pineapple grown in India

According to the ICAR Research Complex for Goa's 'Pineapple a profitable fruit crop for Goa'- India produces pineapple more than 8% of the total pineapple production. The major producing states of pineapple in the country are 1. Assam 2. West Bengal 3. Karnataka 4. Meghalaya 5. Manipur 6. Arunachal Pradesh 7. Kerala and 8. Bihar. Productivity of

pineapple in India is 1.53 million tonnes with 15.3t/ha. The plant requires very little water which makes it suitable for coastal and inland of southern India. Harvesting can be done after 16-17 months of plantation. Fruits of Mauritius mature faster than the Giant Kew which is one month later. The plantation of pineapple requires high nitrogen and potassium. Application of fertilizer during monsoon season is advisable.

Table 2.1: Top ten largest pineapple producing States in India
1. Assam
2. Meghalaya
3. Tripura
4. Manipur
5. West Bengal
6. Kerala
7. Karnataka
8. Goa
9. Gujarat
10. Maharashtra

Source- www.dailyrecords.com (2019)

The lead states which produce pineapple in India are mentioned in the data of (zeebiz webdesk's top ten pineapple-producing states in India. 2023). The annual production of pineapple in West Bengal is 3, 56,320 tonnes which accounts for 19.71% of the total production of India.

Assam produced 3, 38,980 tonnes per year with a coverage of 18.75% of the total country's output, Karnataka has a total production of 1, 69,540 tonnes per year with 9.38% output of the country's pineapple, Tripura has 1,44,600 tonnes annual production by covering 8% of the total production in the country, Meghalaya holds 7.69% of the total annual production by producing 1,38,930 tonnes, Manipur got 7.46% coverage of the total production with the production of 1,34,820 tonnes, Nagaland contributes 6.35% of the total production with 1,14,770 tonnes annual production, annual production & output of the total production of India- 1,13,760tonnes & 6.29%, 89,050 tonnes & 4.93%, and 66,770 tonnes & 3.69% for Bihar, Kerala and Andhra Pradesh respectively.

According to Agrifarming (2019) - Pineapple is of one the important commercial fruit crops in India. Because of its taste and flavor, it is popular across the globe. Pineapple contains vitamin A, vitamin B, rich vitamin C and minerals like magnesium, calcium, iron and potassium. It also contains a digestive enzyme bromelain. The total annual estimated production of this fruit is 14.6 million tonnes. India stood the fifth largest pineapple producer with a yearly production-1.2 million tonnes. The optimum rainfall for cultivation of the plant is 1500mm/year. The plant can grow well in sea areas as well as inland regions with temperature ranges from 15.5-32.5^{o}C. Pineapple is normally propagated by means of sucker, slip and crown. The plant has a planting density of 63,400 plants per hector in subtropical regions and for hot and humid conditions 53,300 plants per hectare. Northeast India has a lower density recommendation i.e. 31000 plants per hectare.

According to ABC fruits (2024), Pineapple is a vital commercial fruit crop in India with significant cultivation across states like North-East, Kerala, Karnataka, West Bengal, Bihar, Goa and Maharashtra. India is the fifth-largest pineapple producer in the world and contributes around 8.2% of global pineapple production. It is estimated that the annual output will be approximately 14.6 million tonnes.

Pineapple Season and Growing Conditions: Pineapple growing season in India typically spans from July to September. Pineapple cultivation flourishes in areas with high rainfall and humid coastal conditions, as well as in hilly areas of the northeastern regions. This plant requires a tropical climate and is intolerant to extremely high temperatures and frost.

Economic Importance and Utilization: Pineapple cultivation has various economic benefits for India. Pineapple can be consumed fresh and is also processed into juice, jam, syrup and squash, among other products. Pineapple juice is particularly popular and contributes significantly to fruit consumption. While India's pineapple processing industry continues to grow steadily, it still produces only a small part of the total fruit production, unlike other pineapple-growing countries, where the processing rate is much higher.

Nutritional Benefits: In addition to its commercial significance, pineapple is recognized for its nutritional value and health benefits. It is rich in vitamin C, aids digestion due to bromelain content, promotes bone health due to manganese content and has anti-inflammatory and antioxidant properties. These nutritional benefits make pineapple a valuable addition to diets and contribute to overall health and immunity.

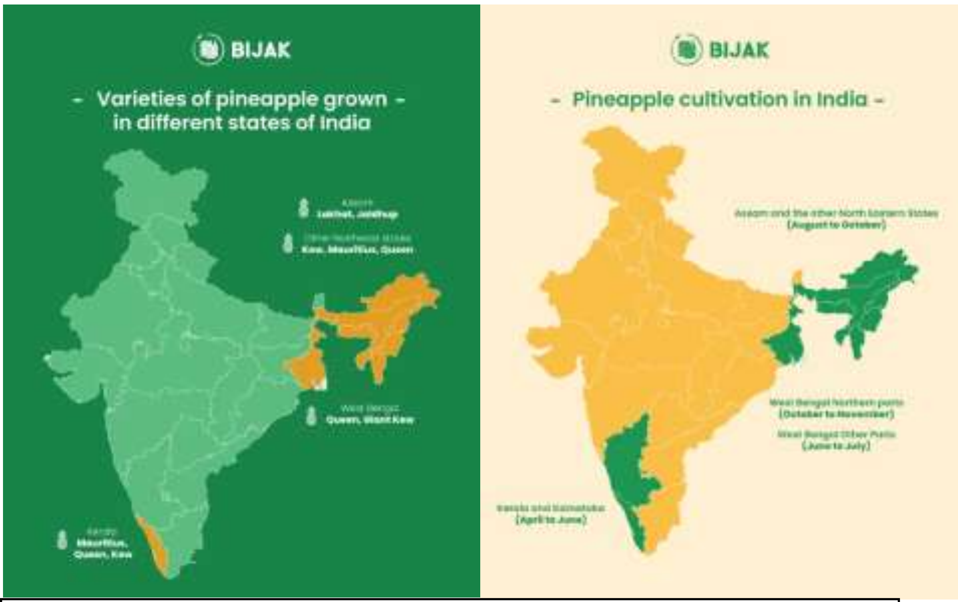
Pineapple cultivation in India is a key component of the agricultural sector, providing economic benefits, nutritional value, and health benefits to consumers both domestically and globally. In spite of its diversified use, there is still the potential for further growth and development of the pineapple industry in India, in particular as regards processing and value addition.

Pineapple, renowned for its sweet and tangy tropical flavor, is a valuable source of vitamins A, B, and C and minerals such as calcium, magnesium, potassium, and iron. Its cultivation plays a significant role in Indian agriculture, covering more than 89,000 hectares. Pineapple production in India has seen substantial growth over the years, evident from the expansion of cultivation areas from 71.3 thousand to 109.83 thousand hectares between 1995 and 2016. Presently, Assam is leading in pineapple cultivation due to favorable climate and soil conditions. Various varieties of pineapple are cultivated across India, each with distinct characteristics and a dedicated consumer base:

- Kew: Recognized as a prominent commercial variety, Kew is distinguished by its late maturation period, which contributes to enhancing the flavor of fruit. Each fruit weighs between 2 and 3 kg and ripens into a yellow colour when fully mature and boasts minimal fibres and a high juiciness.
- Queen: Among the oldest pineapple varieties, Queen is grown in India, Australia and South Africa. It weighs about 1 to 1.5 kilograms per fruit and ripens into a golden yellow. Its flesh is less juicy, but it has a more crisp texture than other varieties.

- Mauritius: Primarily cultivated in select regions of Meghalaya and Kerala, Mauritius pineapples are medium in size and have yellow or red skin variants. Notably, the yellow Mauritius variety is very sweet and rich in fiber compared to its red counterpart.
- Jaldhup and Lakhat: Domestic pineapple varieties named after their respective cultivation areas are commonly utilized for processing purposes in India. Even though they belong to the Queen variety, their smaller size, increased sweetness, and acidity distinguish them from the first Queen variety.

The future prospects for pineapple cultivation in India appear promising, with significant export growth in recent years. From April to December 2021, Indian pineapple exports surged by 100%, reaching 27.02 crores compared to 13.51 crores in the same period in 2013. The main export destinations include the UAE, Nepal, Qatar, Maldives and the US, with Middle Eastern countries becoming important buyers. In August 2022, Tripura alone exported 9,909 tons of pineapples worth 14 crores to Dubai and Qatar, highlighting the expanding market opportunities for Indian pineapple growers.



Source: https://blog.bijak.in/2022/09/20/pineapple-cultivation-trade-in-india/
Fig 2.3: Pineapple cultivation in India

2.1.1.3 Pineapple cultivation in Manipur

Manipur one of the northeastern states stands exceptionally in the 4th position in the data of the top 10 largest producing states in India. The Northeastern states of India also highly contributed to the cultivation of pineapple fruit. For the high yield of pineapple, temperature and soil quality are highly recommendable factors for a significant level. (Top 10 largest pineapple-producing States in India, www.Dailyrecords.com, 2019)

Department of Horticulture & Soil Conservation, Government of Manipur mention pineapple as ‘our product’. The fruit becomes the backbone of a large number of farmers who have been cultivating for their livelihood. The fruit was first cultivated in the year 1947. Locally known as ‘Lengthei’ is being cultivated in the 9 districts of the state. A survey was conducted by Manipur pineapple festival committee in the year 2008 when the country’s first pineapple festival was organized. According to the report, about 2400 acres of land have been used for the cultivation of this plant in the state. The pineapple fruit can be honored as the state fruit. However, the marketing of this fruit is the most challenging of all the farmers since it has no reliable industry. The market is over-saturated with the fruits in the state. Transportation becomes a problem since the farmers are located in remote areas without the presence of good transportation and communication. Cold storage is highly needed in order to store this perishable fruit. Government can work in this area by collaborating with the farmers to overcome the problems faced by the farmers.

Imphal Free Press said in their report on pineapple production that Manipur holds 6^{th} rank in India by producing 134.82 MT in the year 2021-22. The collaboration of central and state government through the Agricultural & Processed Food Products Export Development Authority (APEDA) holds in store show of Kew variety export promotion in Dubai for the certification of organic pineapples and to promote the local fruit in the international markets. In a few years, there has been a major increase in the production of pineapple in Assam, Manipur, Nagaland, Mizoram, Tripura, Arunachal Pradesh, Sikkim and Meghalaya. Tripura became the first exporter of queen variety to Dubai and Doha in the year 2018 and the state also exported to Bangladesh in 2019. The Northeast region had obtained 85.34% growth in the export of agri-products in the last 6 years.

Manipur Organic Mission Agency (MOMA) reported that the variety Queen and Kew are the most growing variety in Manipur. Queen endures a small size while Kew has a larger size. The Queen variety is harvested from June-August while the harvesting period of Kew is from September to November. The plant has been under the process of standards certification provided by APEDA- National Programme for Organic Production (NPOP) since 2016. Fourth-year certification has been done already for an area of 600 ha. Pineapple has many benefits in consumption which decreases the obesity risk, diabetes and heart disease. Also good for hair and skin complexion.

On 21st July 2008 at Andro in Imphal East district of Manipur, India celebrated its first-ever Pineapple Festival. More than one lakh of the spiky however juicy fruit had been reportedly produced. With the effort of a committee- Andro Kendra Development

Fig 2.4: Pineapple Festival of Manipur

Committee, the ‘First Manipur Pineapple Fair cum Youth Festival’ was held at Thambalnu Market of Andro. Imphal East district has become the largest producer of this fruit among all the districts of Manipur. For the last six decades, the Ngarian community, Andro and its surrounding Manipur have been cultivating pineapple as their major source of income. A local resident Khamzathang, a Second World War soldier and the chief of Bunglon village says, “The pineapple cultivation was first started in Manipur by Pu Songpu Gangte at Khousabung area in the district- Churachandpur, in the year India won her independence. (Pineapple India, 2008).

2.1.2 Pineapple leaf fiber

Pineapple cultivation produces non-fruit waste, such as leaves, stems and crowns, which are usually discarded or burnt during pruning and replanting activities. Pineapple leaves are hard and are arranged spirally around the stem of the fruit, containing a water storage area with varying volume. The crown, which emerges from the top of the fruit, can be used for propagation, but it may pose disposal problems if it is overproduced in relation to propagation needs.

These waste parts of the pineapple plant are rich in bromelain, a mixture of proteolytic enzymes used in food, cosmetics, and supplements. In addition, pineapple leaf extracts have the potential to gastrointestinal nematodes in ruminants.

In essence, pineapple production generates valuable non-fruit wastes that can be repurposed for bromelain content and other beneficial elements, thus offering sustainability benefits and resource optimization for the pineapple industry. (Okoli, C, I., 2023)

A forward-thinking company has developed an innovative method for transforming agricultural waste from pineapple production into natural textiles, addressing both environmental and social challenges. In view of the exponential increase in pineapple consumption worldwide, there has been an increase in pineapple waste, in particular discarded leaves, which accounts for 25 million tonnes a year. Traditionally, these leaves are incinerated or left to decompose, which contributes to methane emissions, a powerful greenhouse gas.

Simultaneously, the fashion industry, in particular fast fashion, has experienced significant growth and exerted enormous pressure on the environment. It is estimated that it accounts for 10% of greenhouse gas emissions and consumes a large amount of water, exacerbating freshwater depletion worldwide. Ananas Anam offers a dual solution to these pressing issues. By repurposing pineapple leaf fibers, Pinatex and Pinayarn have developed two natural fabrics. The process involves collecting discarded leaves, extracting long fibres using semi-automatic machines, washing, drying (natural or in ovens), and mixing them with corn polylactic acid to create a non-woven mesh that forms the foundation of the textiles. Piayarn is a compostable and biodegradable yarn, while Pinatex is a sustainable alternative to leather and does not require tanning, which typically involves harmful substances. In addition, avoiding leaf incineration significantly reduces CO2 emissions (approximately six kilograms for every kilogram of yarn produced).

This approach not only promotes circular textile production but also benefits pineapple growers, especially in rural areas such as Eco-Fresh Agro in Bangladesh, through transparent supply chains and partnerships. It underlines the potential of resource reuse beyond fashion trends and stresses the importance of sustainability and cooperation in promoting positive change. (Innovation Snapshot, 2023).

2.1.2.1 Pineapple leaf fiber extraction

Pineapple leaf fibre is extracted from the leaves of the plant after harvesting. It has a very short length stem which produces a leaves rosette at first and elongates its spirally arranged fibrous leaves said (Doraiswami, I., Chellamani P., & Gunasekaran, R. (1993)). The length of the leaves varies from 3 feet to longer, width is 2-3 inches, sword in shape, fleshy and dark green. From these leaves, strong, white, lustrous and shiny fibres are produced. Yield percentage is generally from 2% to 3% of the leaf's weight. The chief producers of the fibre are the Philippines and Taiwan. Brazil, Hawaii, Indonesia, India and the West Indies are also the producer of the fibre. It is estimated that India covers 87200 hectares of land for the cultivation of pineapple. Fibre yield could be approximately 6 lakh tonnes per year if the proper extraction method is adopted. Pineapple leaf fibre could be extracted from the leaves by means of mechanical or retting process. After one year old, leaves can be used for the extraction. By using a decorticator, machine extraction can be done. The machine extraction involves scrapping of the hard outer layer. The machine used for this work is known as the Raspador machine. SITRA has developed a semi-automatic Raspador. The yield capacity of this machine is 5kg of fibre per 8 hr. The machine has been already licensed for commercial production. Degumming of the fibre is done to soften and make it finer by using acids, alkalis or enzymes. The linear density of the degummed fibre was ranged from 16 to 20 denier.

Pineapple leaf fibre can be extracted from the leaves through means of manual or machines. In the manual extraction process, the scrapping of leaves after the retting process is done. In this method, a huge amount of fibre is damaged and the process takes a lot of time and labour. In the mechanical extraction method, the green leaves are crushed by using a raspador machine again soft parts of the leaves are also crushed and combed to get the fibre. At ICAR-NINFET, an improved extractor of pineapple leaf fibre is fabricated with the mechanism of a feed roller, scrapping roller and combing roller. Uniform and quality fibre can be achieved from this machine. This machine has multi-feeding in the feeding roller where 3 leaves can be put at a single time. It has a capacity of 30kg/hr having an average yield of 2 percent per leaf. (Nayak, N, K. 2021)

According to Textileblog (2020), in present days, pineapple leaf waste is being used in making textile materials like biocomposite. The usable green leaves for fibre are 40 tons/ha and the yield is 3%. Fresh leaves after harvesting are used for extracting the fibre. The fibre can be obtained with the aid of manual or machine extraction. Broken plates or coconut shells are used in the manual extraction process. The scrapped fibre is washed in water and dried in the open air. From one ton of leaves, 20-27 kg of fibre (dried) can be extracted. After drying the extracted fibre, waxing of the fibre is done to avoid entangling and the ends of the long fibre strand are knotted for the warping and weaving.

Pandit, P., Panday, R., Singh K.., & et al. (2020) said that the methods for extraction of pineapple leaf fibre can be done by hand scrapping/stripping, decorticator machines, and chemical extraction. Like sisal fibre, pineapple leaf fibre is obtained from the fresh leaves. In the process of hand stripping, a broken porcelain plate is utilized. In this method, two types of fibre are produced- namely bastos and liniwan. The scrapped fibres are washed with tap water thoroughly and dried in the air. In the decorticator, the leaves are fed manually for scrapping by the roller blades. Washing with water and sun-drying were done on the decorticated fibre. After this, dew retting or chemical retting/degumming or enzyme are performed to remove the coarse substance. In dew retting biological natural retting is achieved in which bacteria and fungi are the key ingredients.

2.1.2.2 Pineapple leaf fiber properties

Pineapple leaf fibre is white in colour, smooth, and glossy appearance like silk, the length is medium and the tensile strength is high. The fibre has a soft surface, good absorbency, and maintains a good colour when compared to the other natural fibre. It is hydrophilic in nature because of the high content of cellulose. PALF contains many chemical compositions. The multicellular fibre has polysaccharides, fat, wax, pectin, lignin, uronic acid, anhydride, pentosan, colour, pigment, and inorganic constituents. The cells of fibre are joined by pectin. The arrangement of fibre is the same as cotton fibre and the cellulose content is 70-82%. The tensile strength of the fibre is greater than jute fibre when the yarn is prepared. Considering the properties of the fibre, it can be utilized in making the reinforced composite material. PALF works well with synthetic fibres because of is economical and biodegradable. The superiority of the fibre's mechanical properties is associated with the high value of alpha-cellulose content with a low microfibrillar angle (14∘). (Asim, M., Adam, K., & Jawaid, M., & et. al. 2015)

‘Sourcing raw material is tough’ said the Anakaputhur weavers association in the article ‘Pineapple fibre comes handy for weaver’ published in The Hindu. The raw material is procured in majority from cultivators in Kerala and making an effort to get it from northeast States too. The fibres are cleaned through a strenuous bleaching process. After a very delicate process of removing single strands of the fibre, they are woven like any other material. As the fibre has a good affinity for dyes, attractive designs can be produced from the fibre. The fibre is in great demand, SHG (Self Help Group) and the members of the Association are trying to get the fibre in large amounts. (www.thehindu.com, 2017)

Singh Rao A., (2017) mentioned her article ‘A different approach towards textile by pineapple fibre’ which discussed the extraction of fibre by hand scraping of leaves, the process of making the fabric from fibre, the application of the fibre in textile utility products and benefits of the fibre. It also considered the care instructions of this fibre when laundry. In the study, the research provided the pineapple fabric benefits as beautifully elegant in appearance, lightweight, well blended with other fibres, similar in appearance when compared with linen, softer than hemp fabric, more textured than silk, easy to wash and care for, dry cleaning was not recommended. And the instruction of care for the pineapple fabric was shared in the form of a recipe.

The properties of the pineapple fibre are mentioned by Pandit, P., Panday, R., Singh K.., & et al. (2020) in their book chapter. Following are the properties of pineapple leaf fibre-

I. Pineapple leaf fibre is considered to have more delicacy than other plant fibres.

II. The length of the fibre is approximately 60 cm in length, different types of dyes can be easily absorbed and retained by its white and lustrous similar to silk.

III. The leaves contain high multicellular lignocellulosic fibre.

IV. Alpha-cellulose, hemicellulose and lignin are the major constituents of this fibre.

V. Very lightweight, easy to care for, linen-like fibre and elegant can be achieved from the fibre.

Vatsala, R. (2003) stated that the leaf fibre obtained from Ananas comosus provides strong, fine, white and silky fibre. It has high moisture absorbency and good abrasion resistance. Based on its cellulose content, the fibre has great potential in industries. Many Government and private organizations have shown interest in the use of fibre. In the Philippines, thin and sheer are produced from this fibre. The fibre is also good to be used as an insulators and soundproofing. The major uses of pineapple leaf fibre can be in making twines, threads and fabrics.

2.1.2.3 Pineapple leaf fibre in textile application

The determination for cultivating the pineapple is the fruit consumption. After harvesting the fruits, the use of leaves for manufacturing fibre is also a good commercial sense. Now eco-lover designers are making an effort to move away from synthetic fibre. By tradition, pineapple silk from the leaves of the plant is considered as the 'queen' of Philippine fabrics and the pina fabric is the choice of the Philippine elite. Generally, the fibre from the Red Spanish fiber is used to hand weave the fabrics which are worn as the traditional embroidered Philippine formal shirt *Barong Tagalog.* The other varieties Formosa and Cayenne are also used for obtaining the fiber. Pineapple textiles were popular in the world, but later it came along with cheap cotton competitors and consequently stopped pina textile manufacture. Pina has only been rejuvenated in the last two decades or so due to consumer demand for alternative natural fibres. (Fashion-collective, 2019)

Pina (pineapple leaf fibre) for textile purposes is obtained from the leaves of the pineapple plant. The soft, lustrous, white or ivory fibre is highly susceptible to acids and enzymes. It should be rinsed out the acids immediately and presoak in detergent should be avoided. Hand washing is recommended for the laundering of pina. The fabrics produced from the fibre are lightweight, sheer and stiff. Embroidery is often applied to the fabrics for formal and wedding garments in the Philippines. The fibre is also utilized in making mats, bags, tablecloths, and apparel. At present, research are conducted to produce a commercially viable pina that can be blended well with other fibre. (Kadolph, J, S. 2014)

The textile made from pineapple leaf fibre has light and airy properties. The cooling and slightly stiff properties make the fabric similar to linen and hemp, even though pina is a bit softer. The pineapple leaf fabric has a natural glossy effect similar to silk and is better in quality. This glossy surface protects the fibres of the fabric and as a result, pina does not need any treatment or modification with toxic chemicals. (Pina Fabric, Textiles of India, Aug 2018)

Mostly, leathers are made from animal skin, the leather from pineapple leaf fibre is an imitation of leather and it is called pinatex, made by the company Ananas Anam in England. The materials used in making this leather are pineapple leaf fibre, thermoplastic polyester, and resin of petroleum-based. Pinatex is available in many shades of dyes and finishes according to the end uses. The application of the leather is shoemaking, bags, furnishing, and accessories. Using the pineapple leaf fibre can decrease the consumption of fuax and animal leathers which ultimately will improve the impact of environmental issues. The leather made from pineapple leaf fibre is one of the non-woven textiles which has a leather appearance and feels like leather. No-animal byproducts are involved in making the leather. The leaves of pineapple are procured from Philippines for extracting the fibre. Waxing is done on the leather surface and requires occasional re-waxing. Pinatex can be used in making many textile goods. (Libertyleathergoods.com, 2021)

Pineapple leaf fibre is a raw material for manufacturing cloth and the fibre is also come as blended with silk and polyester for textile applications. Table linens, bags, mats and other apparel items can be from pineapple leaf fibre. Various regions of the world are using this fibre for different textile uses. The eco-friendly and diverse application of this fibre has a huge potential. The scope of this fibre can be seen in Assam and other northeastern states the leading producers in India. PALF (pineapple leaf fibre) can be a great choice for copolymer and composite materials used in the textiles of automobiles and railway coaches. Fibres like ramie, jute, flax and hemp are already established in the market when compared to the PALF. Many interior furnishings products, coasters, and handbags can be produced from pineapple leaf fibre. Because of the very high initial modulus, fibre has opportunities in the industry of textiles. Conveyor belt cords, v-belt cords duck cloth (lightweight) can be manufactured using fibre. Clothing which requires lightweight, sheer, and stiff can be made. The paper industry also uses pineapple leaf fibres in making paper as pulp material. (Pandit, P., Panday, R., Singh K.., & et al. 2020)

2.1.3 Woven Traditional Textiles of India

"Textiles serve as a non-verbal form of communication and when decorated as defensive talismans, motifs, colours, and composition impart one's identity and occupation, and very frequently social status." (Askari, N., & Crill, R., 1997)

The expression of Indians in textiles has always been influenced by the countryside's topography, climate and natural resources like water, salt and minerals. The origin of the Indian textiles can be found from 2500-1500 BC along the holy Indus valley. People of the Indus Valley had advanced knowledge of colour fixing, dyeing and manufacturing procedures of textiles. Furthermore, there is evidence that Mohenjo Daro People knew about the art of cotton cultivation and transforming cotton balls into woven fabrics for protecting their bodies. (Karolia, A. 2019)

A profound connection between the weaving of textiles and aspects of our inner knowledge has originated from the old time and it continues to exist till today. It is implicit, not explicit, for textiles they are a form of non-verbal communication and project the socio-religious and cultural history of people. Textile terminology has been used from the foremost times to express Indian concepts of philosophy. The Buddhists used the word 'sutra' originating from thread or sut. Sutra means 'to string together'. Yantra or Jantra is the word used for a loom. Tantra also means a loom. Traditionally, weaving textiles takes as an act of worshipping and wearing a sacred fabric is a significant aspect of creative tasks, and religious and divine security as well (Dhamija, J. 2014)

In view of Bhatnagar (2005), India represents a rich subcontinent which has different physical features where huge variations in climate, agronomy and living perspectives from different cultural and historical aspects can be found. The diversity taught me to work as a think tank to get ideas rather than hindrances. The subsistence of many empires and states, accessibility of local resources, trade routes and relations, had cherished in outspreading visual diversity to any materials, procedure and medium, therefore, influenced the Indian tradition.

Hand weaving is the oldest and the most universally practised craft. Hand-woven textiles are found across all different regions of India. Every kind of handloom textile from the oldest backstrap or loin loom (still used in the northeastern states of India) to the complex naksha looms for the intricate weaving of brocade. The weavers of India produce different woven textiles in a range of plain weaves, twill weaves and satin weaves to the more intricate plain and twill tapestry. These techniques are still practised in different centres of India. For surface ornamentation different techniques like weaving, dyeing, printing, resisting and embroidering are used. Handloom weaving is the second-largest economic activity in India even today. Handloom fabrics can be categorized as Khadi fabric using handspun then hand-woven and handloom fabrics using machine spun and then handwoven. (Karolia, A. 2019)

Throughout history, India has been renowned for its exquisite hand-woven textiles, with foreigners, travellers, and writers marvelling at the textures and designs for centuries. Different regions employ various looms, including pit, frame, 'jala,' and back-strap looms, each contributing to the rich tapestry of Indian weaving. From the intricate Kani shawls of Kashmir to the luxurious silks of Varanasi and the delicate Jamdani fabrics of Bengal, India boasts a diverse array of weaving traditions. Gujarat, Maharashtra, and South India are also celebrated for their contributions to the textile industry. While men typically handle the weaving process in most parts of India, women take the lead in the northeastern states, creating stunning designs on backstrap looms. These textiles serve myriad purposes, from clothing to furnishings, showcasing India's enduring tradition of craftsmanship. Despite the rise of mill and power looms, handloom weaving remains cherished by both younger generations and visitors to the country. We can categorize these weaving styles based on their end products, including saris like Banaras brocades and Kanjeevarams, shawls such as Kashmir and those from the northeast, and floor coverings like carpets and durries. (NCERT, 2014). Following are the different hand-woven traditional textiles:

Saris

Banaras Brocade saris hail from the ancient city of Varanasi, situated on the banks of the Ganges River in Uttar Pradesh, India. These saris are renowned for their intricate gold and silver brocade work, crafted from finely woven silk. The designs are created using a combination of warp and weft threads, often incorporating extra warp or weft elements to enhance the pattern. Special techniques like 'Minakari' add a raised, enamelled effect to motifs. Common motifs include chrysanthemums, paisleys, and traditional Mughal-inspired patterns such as floral jaals and hunting scenes. Historically, these textiles were prized exports to Europe and were favoured by royalty for garments and furnishings. Today, Banarasi brocades find use in a variety of applications, from traditional saris and dupattas to contemporary dresses, accessories, and home decor items. They remain a staple in every Indian bride's trousseau, symbolizing luxury and tradition.

Fig 2.5: Banaras Saree

Source- NCERT

Fig 2.6: Baluchari Saree

Source- NCERT

Baluchari saris, known for their exquisite craftsmanship, are primarily crafted in the Murshidabad district of West Bengal, India. What sets Baluchari saris apart from other Indian saris is their unique feature of depicting Nawabs and their spouses on the pallu, or the loose end of the sari draped over the shoulder.

The intricate process of creating motifs for the pallu and other parts of the Baluchari sari involves traditional techniques that have evolved over time. Initially, these saris were woven on jala looms, but modern jacquard techniques have gradually replaced them. Traditionally, motifs were woven using softly twisted extra weft yarns, which created a plush, embroidered effect without the use of zari. Nowadays, jacquard attachments are used for weaving patterns onto the sari. Designs are first drawn on graph paper, colored, and then punched onto jacquard cards, which are subsequently arranged and fixed onto the jacquard machine atop the loom.

The pallu of the Baluchari sari is particularly noteworthy, featuring niches bordering a central square or rectangle. Within each niche, human figures are depicted, often portraying kings smoking hookahs or queens with fans or flowers. Additionally, ornate paisley motifs adorn the centre of the pallu, surrounded by woven niches with human figures. Baluchari saris also showcase patterns of suns, moons, stars, mythical scenes, and natural objects, with small butis embellishing the field of the saris. Traditional color choices include maroon, blue, red, and dull dark terracotta, with extra weft motifs in off-white, white, yellow, and dull orange hues for ornamentation.

Historically, Baluchari saris were favored by women from upper-class and zamindar households in Bengal for festive occasions and weddings. In recent times, motifs depicting scenes from the Ramayana and Mahabharata have become popular, accompanied by brighter, polychromatic colors and the use of zari yarns for added ornamentation. Despite modern adaptations, Baluchari saris continue to preserve their rich cultural heritage and artisanal excellence.

Jamdani saris, originating from West Bengal, are renowned for their sheer and delicate nature, crafted in villages such as Phulia, Nadia, and Shantipur. These saris are meticulously woven using a combination of cotton with cotton, cotton with silk, and silk with silk. The hallmark technique employed in crafting Jamdani saris involves interlocking extra weft yarns to create intricate motifs within the fabric.

Fig.2.7: Jamdhani Saree

Source- NCERT

Fig.2.8: Paithani Saree

Source- NCERT

These saris are woven on traditional handlooms, showcasing the artisanal expertise passed down through generations. Commonly featured motifs in Jamdani saris include floral designs, geometric patterns, creepers, paisleys, and delicate leaves. These motifs add a sense of elegance and sophistication to the fabric, reflecting the rich cultural heritage of West Bengal's weaving traditions.

Paithani saris, originating from Paithan and Yevla villages in Aurangabad, Maharashtra, are renowned for their heavy silk craftsmanship, making them a preferred choice for wedding trousseaus and festive attire.

These saris are intricately woven using the interlock twill tapestry technique on traditional handlooms. Bright jewel tones such as emerald green, ruby red, and yellow silk yarns are commonly used, with midnight blue being a particularly favored color. The interlocking technique creates geometric angular forms within patterns, featuring motifs such as florals, paisleys, parrots, peacocks, and lotus flowers. Historically, the pallu of Paithani saris used to feature a broad band of zari, but contemporary designs often incorporate lotus and peacock motifs in vibrant colors. Another prominent motif seen on Paithani saris is the bird (munia) motif.

Paithani saris hold significant cultural value in India and are cherished as precious heirlooms, passed down through generations. The exquisite silk from Paithani was once highly sought after and exported to various countries, often traded for gold and precious stones, further enhancing its prestige and allure.

Kanjeevaram saris originate from Kanchipuram in Tamil Nadu and are renowned worldwide for their luxurious quality, making them a staple for special occasions. Crafted from pure mulberry silk and gold zari on hand-operated pit-looms, these saris feature rich colors like mustard, deep green, maroon, and aubergine. Their motifs draw inspiration from nature and temple architecture, incorporating elements such as peacocks, parrots, rosary beads, mythical creatures, and scenes from epics like the Ramayana and Mahabharata.

Fig. 2.9: Kanjeevaram Saree

Source- NCERT

Fig. 2.10: Chanderi Saree

Source- NCERT

Chanderi saris, hailing from Chanderi near Gwalior in Madhya Pradesh, are prized for their lightweight, diaphanous quality, ideal for summer wear. Woven by Muslim Ansari weavers, these saris blend cotton with degummed silk, displaying pastel hues adorned with small motifs like gold coins, mangoes, bricks, and rosary beads. The pallu typically features fine lines in zari yarn.

Maheshwari saris, originating from Maheshwar near Indore, Madhya Pradesh, are known for their delicate summer wear. These saris feature a unique weaving technique with cotton weft and silk warp dyed on the loom. They often showcase plain or tone-on-tone designs with striped or checked borders and three decorative bands of zari on the pallu. Inspired by architectural carvings from Maheshwar's Ahilya Fort, motifs include chevrons, mats, and other intricate patterns.

Fig.2.11: Maheshwari Saree

Source- NCERT

Each of these saris represents a distinct regional tradition, weaving technique, and motif inspiration, contributing to the rich tapestry of India's textile heritage.

Shawls

Kashmir Shawls, also known as Pashmina Shawls, originate from Kashmir, a region celebrated for its natural beauty and artisanal crafts. These shawls have been cherished worldwide for centuries, with the English word "shawl" derived from the Persian term "Shal," signifying a woven woolen fabric used for warmth.

The Kashmir shawl industry has a rich history spanning over 300 years, evolving through different periods of political rule in India, including the Mughals, Afghans, Sikhs, and Dogras. King Zain-ul-Abidin is credited as the pioneer of Kashmir shawl making, introducing the craft with the help of experts from Turkistan. The Mughal emperor Akbar was a notable patron of Kashmir shawls, inspiring weavers to innovate with new motifs and techniques, such as the twin shawl method.

Kashmir shawls are primarily produced in three districts: Srinagar, Ganderbal, and Budgaon, with specific villages like Kanihama, Batpora, and Manzhama renowned for Kani Shawl weaving. These shawls are crafted from materials like woolen fleece, Pashmina, Shatoosh, and Angora wool. Pashmina, known for its softness and warmth, is sourced from the fleece of the Capra hircus mountain goat, primarily shed during summers in high-altitude regions.

Two main types of Kashmir shawls are distinguished by their production techniques: loom woven Kani shawls and needle embroidered Sozni shawls. Kani shawls are meticulously woven on hand-operated pit-looms using wooden spools called Tujis, which interlock colored threads to create intricate patterns. These shawls require tremendous skill and patience, often taking years to complete due to their complexity.

Various layouts and motifs adorn Kashmir shawls, drawing inspiration from nature and architectural elements. The motifs include mangoes, almonds, chinar leaves, birds, and hunting scenes. Pashmina fleece is naturally available in neutral colors, but dyeing techniques allow for a vibrant array of hues, enhancing the beauty of Kani shawls.

Traditionally, Kashmir shawls were worn as warm protective garments against the cold, but modern usage has evolved to wearing them as stoles or draped over the shoulder for style. However, the decline of the Mughal kingdom and subsequent taxation during Afghan rule led to a downturn in the Kashmir shawl trade, forcing artisans to seek alternative livelihoods.

In contemporary times, efforts have been made to revive and protect the Kashmir shawl industry. **The Kani shawl** has been granted a Geographical Indicator (GI) status, ensuring legal protection and authenticity. The government has allocated funds to support weavers in purchasing new looms and modernizing existing ones, aiming to safeguard this cherished craft for future generations.

Kullu and Kinnaur, located in Himachal Pradesh, are renowned for producing high-quality woolen shawls. These shawls traditionally feature base colors such as red, maroon, black, brown, and off-white, with vibrant hues inserted into the borders using extra weft techniques. Geometric motifs, inspired by nature, adorn the colorful borders, adding to their aesthetic appeal.

Fig.2.12: Kinnuari Shawl
Source- NCERT

Kinnauri shawls, in particular, are celebrated for their intricate and labor-intensive weaving process. These shawls are heavily adorned with motifs and are highly valued by the women of Himachal Pradesh. They are draped in two distinct styles, often paired with heavy silver jewelry to enhance their festive appearance.

The craftsmanship and attention to detail in Kullu and Kinnaur shawls reflect the rich cultural heritage and skilled artisanal traditions of the region, making them cherished items among locals and collectors alike.

Northeast hand woven textiles

The northeastern region of India, often referred to as the "seven sisters," comprises Assam, Arunachal Pradesh, Nagaland, Mizoram, Manipur, Tripura, and Meghalaya, home to both tribal and non-tribal communities. Textile weaving in this region is primarily carried out by women, reflecting a rich diversity of more than 38 tribes, each with its distinct designs, color combinations, and ceremonial patterns. These designs not only vary between tribes but also within clans of the same tribe and different villages, serving as markers of social status.

Fig.2.13: Back strap loom of northeast
Source-NCERT

Originally, shawls and wraps were crafted from cotton, with wool introduced later. Traditional colors such as black, dark blue, red, and yellow were prominently used. Textile weaving remains an exclusively female occupation in the northeast, with women utilizing back strap portable looms for domestic consumption.

In Assam, hand-woven fabrics include cotton, muga, pat (mulberry silk), and eri (wild silk). Muga silk, known for its natural golden hue, offers mild warmth and is well-suited for winter wear. Assamese textiles encompass a wide range of products, including bedspreads, furnishing materials, mekhala-chaddars, rihas (traditional women's garments), gamosas, shawls, and saris. Designs often feature motifs such as animals, human figures, flowers, birds, and diamonds, each symbolizing the diverse tribal and ethnic groups of the region.

From the reviews, the researcher carried out a SWOC (Strengths, Weaknesses, Opportunities, and Challenges) analysis on the ancient declined textiles of India:

Strengths:

Cultural Significance: These textiles hold immense cultural and historical value, reflecting the craftsmanship and artistic traditions of ancient India.

Artisan Expertise: The intricate weaving, dyeing, and embellishment techniques involved in producing these textiles highlight the exceptional skills of traditional artisans.

Unique Designs: Ancient textiles like Patola, Kalamkari, and Tanchoi boast distinct designs, motifs, and color combinations, setting them apart from modern textiles.

Weaknesses:

Laborious Production: The traditional methods of crafting these textiles are time-consuming and labor-intensive, resulting in higher production costs and limited scalability.

Skills Decline: With decreasing demand and production, there's a risk of losing the knowledge and skills required to create these textiles, jeopardizing their preservation.

Limited Market Appeal: These textiles may struggle to attract a wider market due to their traditional designs and higher price points compared to mass-produced alternatives.

Opportunities:

Revival Initiatives: Efforts to revive interest in ancient textiles through educational programs, cultural initiatives, and targeted marketing campaigns can emphasize their historical significance and exceptional craftsmanship.

Design Innovation: Introducing contemporary elements and design innovations while preserving traditional techniques can appeal to new markets and attract younger consumers.

Sustainability Trends: The rising demand for sustainable and eco-friendly fashion presents an opportunity to promote ancient textiles as environmentally friendly alternatives to synthetic fabrics.

Challenges:

Competition from Synthetics: Ancient textiles face tough competition from cheaper, mass-produced synthetic fabrics, which dominate the market due to their lower costs and versatility.

Infrastructure Limitations: Limited access to modern infrastructure, machinery, and technology hampers the scalability and efficiency of traditional textile production.

Market Dynamics: Shifting consumer preferences, globalization, and the fast-paced fashion industry pose challenges in maintaining sustained demand for ancient textiles in today's marketplace.

In summary, while ancient Indian textiles boast rich cultural heritage and artisanal craftsmanship, addressing weaknesses and capitalizing on opportunities will be crucial for their revival and sustainable growth in the modern textile industry.

2.1.4 Handlooms of Manipur

Manipur is one of the Northeastern states of India, with the capital city of Imphal. It is bounded by Nagaland to the northern side, in the south by Mizoram, and Assam to the west, Myanmar found in its east. Manipur is the land of numerous groups of people speaking various dialects and languages having various cultures and traditions.

In the article of (Oinam, N.,2018), in the valley regions of Manipur, the weaving skills of Meitei women are widely recognized, extending beyond borders to neighboring areas such as Bangladesh, Myanmar, Assam, and Tripura, where Meiteis settled during times of strife in Manipur. It's a longstanding tradition for Meitei girls to learn weaving, with proficiency in this craft once considered crucial for potential brides.

2.1.4.1 Raw materials of Manipuri handloom

In the report of (Bahadur, M., 2012) - Tribal people in Manipur grew cotton for weaving their essential textiles. The use of cotton by the tribals has been reported long back. As an annual tribute to the king Khagemba (1597-1652 AD), his people paid cotton. However, during 1950s the staple fibre yarn was imported from outside Manipur. The tribal people shifted their raw material to acrylic wool in the period of 1960s to 1970s. They used one or two ply in their weaving. Around 1980s, acrylic wool of one and two plied yarn turned out to be the most suitable yarn for weaving of tribal. This is because acrylic wool gives warmth, cheap price, and easily available with different colour and hence no need to dye with vegetables which was hard and had little scientific methods. Nettle fibre are used for making thread by Mao, Poumai and Maram tribes. Tarao tribe also used fibre from Sougri mesta in earlier timesfor their cloth Bulapun.

"In Manipur, women possess exceptional weaving skills, with most households equipped with either a loin loom or fly shuttle looms. The tradition of weaving is passed down from generation to generation, with girls naturally acquiring these skills from their mothers or sisters. Approximately fifty years ago, Manipur produced some cotton, and the older generations were well-versed in the manual process of ginning cotton, spinning yarns, and weaving cloth. Additionally, they had expertise in rearing silk worms, extracting raw silk, and spinning both eri silk and mulberry silk yarns. Silk production from Tasar was also practiced in the hills. Some ancient clothes, dating back to around 500 years, worn by figures like Khamba and Thoibi of Moirang, are still preserved and accessible in Ningthoukhong and Ngangkhalawai. Manipur's mulberry silk is renowned for its soft texture, while Tasar silk exhibits a remarkable luster. The Department of Sericulture, Government of Manipur, promotes silk production and weaving by offering various incentives, including inputs, seed supply, training for silk farmers, and cocoon procurement. The Ministry of Textiles, Government of India, through the Central Silk Board, provides financial assistance for sericulture schemes.

Each tribe in Manipur showcases unique designs, patterns, and color combinations in their woven fabrics. Fly shuttle loom usage is somewhat limited among the tribes, with most patterns and designs for garments like phaneks (sarongs) and shawls created using traditional extra weaves, specific to each tribe. The choice of loin looms remains prevalent among the tribals for various reasons. Weaving expertise is inherited through generations, facilitating easy learning. Certain designs and patterns are more conveniently woven on loin looms, possibly due to their smaller width and easier accessibility. Cloth woven on loin looms tends to be thicker and heavier in appearance. Many weavers in the hills of Manipur primarily weave cloth for personal use, although some also cater to market demands." said by Oinam, N. 2018.

Karolia, A. 2019 stated that the yarns for weaving Manipuri textiles are prepared from cotton and mulberry silk (Kabrang) and its union blends. Earlier cotton was grown in both plain and hills of Manipur. Later, the weavers purchased different yarns directly from the wholesaler in the local market. The woven textiles of the weavers are marketed by the wholesaler in other places like Guwahati, Mysore, Bangalore, and even China. Some weavers have started weaving using acrylic yarns, polyester yarns, and synthetic yarns to lower down the price of raw materials.

2.1.4.2 Weaving of traditional Textiles (Meitei)

The textiles of Manipur carry their own unique features and characteristics. Traditional Manipuri textiles for women includes a chadder called innaphi, and phanek a warp around skirt. A Manipuri man's traditional textiles includes- dhoti, jacket and white pagri or turban.

The Meiteis, the indigenous habitants of Manipur, have traditional motifs and designs in their embroidery whose origin is traced back to intriguing nobility. The most popularly known is the work done on the border of phanek mayek naibi- a sarong. A very basic pattern, tindongbi motif is done in satin stitch. An intricate design akoibi mayek is circular one- a series of joining circles, with each circle broken into patterns. (Kamaladevi Chattopadhyay, 1973).

Manipur has a superior distinctions in handloom and handicrafts products. The main textiles of the Manipur women are phanek which has white, deep & plum red and dark brown stripes with popular motifs- akoibi (circles), lotus, fish and parrot and *moirangphee* bordered Chadder and flower designs. *Zengnoupal shawls* in white and green colour, Haora with red and white stripes with crossed border designs are also attractive traditional textiles of Manipur**.** (Mandira Borthakur, 2013)

Textile weaving seems to play a key role in socioeconomic life of Manipur. Women considered their weaving as a part of their home activity. It is believed that the Khwang iyong (loin loom) has been used since immemorial, traced back to Christian period. The traditional Manipuri textiles for women includes a blouse, phanek- a lower warp around, and a shawl called innaphi. Brides wear a decorative cylindrical costume known as potloi, which similar to the costume worn by Manipuri raas-leela dancers. Some Meiteis wear a phanek-iinaphi with a special headgear known as kajenglei. Types of Phanek are achamba phanek, mayek naibi, and pungou phanek, types of innaphi- Wangkhei phi, Moirangphee, lai phi, Rani Phi. Motifs and designs are Khongunmelei, gulap, thambal, kundo, akoibi mayek, namthang khuthat, leirong, lindo mayek, mitlaobi mayek, upambi mayek, sami lanmi, til mayek and Hija mayek. Colour used in textiles are red- angangba, green-ashangba, yellow- hangam mapan, white- angounba, saffron- ureirom, violet- loiyumba and black-amuba. For weaving, three types of loom are used – Loin loom-khwaing inyong, throw shuttle-pang iyong and fly shuttle- kon yonkhan. (Karolia, A., 2019)

Tangkhul Naga shawls are woven by using the loin loom by Naga women for men, using mercerized cotton for the warp and the weft. The compactly woven fabric consists a bold and harmonious combination of colours. At the ends of the shawl, finely woven jewels like motifs can be seen (Dhamija, J., 1989)

On occasions, Meitei women wear phanek and innaphi with intricate borders. The phanek are woven on loin loom having warp stripes all from end to end. The backgrounds of off-white or cream colour are horizontal stripes woven with brown, maroon, mauve and others colours. Beautiful Naga shawl embroidered with Shamilanmi motifs are worn by women for wearing in winter. The traditional textiles of Meitei are found in woven, embroidered, and printed pattern. The colour combinations of Meitei are somewhat bright and distinct. Manipur's hill tribes present a collection of fantastic attires and costumes. (Das, A, K., 2017). The textiles used by Meitei male dancers are white turban and dhoti. In Thang-ta dance, men wear short dhoti of black colour and a red colour waist sash.

2.1.4.3 Hand-woven traditional Textiles (Meitei)

Meitei women engage in weaving for both personal and economic reasons. Many weave clothing for their families while also using weaving as a means of income generation. There are touching accounts of sisters and mothers tirelessly weaving day and night to fund their children's education.

In certain villages of Manipur especially for crafting the traditional striped sarong known as **Phanek Mayeknaibi**, the use of loin looms persists despite their slower and more labor-intensive nature.

Despite shifts in fashion and the adoption of Western attire by unmarried women, the practice of donning Meitei traditional garments like **Phanek Mayeknaibi and Moirang Phee/Rani Phee/Wangkhei Phee** for local ceremonies like weddings and Chakouba endures. To cater to evolving tastes while adhering to traditional dress codes, intricate designs are woven into silk Phee, resulting in the creation of high-value cloth, particularly Ranee Phee.

Silk sarees, typically reserved for women in other states, woven with silk extra weave, can command prices of up to thirty thousand rupees. Silk weaving, requiring dexterity, patience, and hard work, offers better financial returns for weavers. The contribution of the **Rani of Wangkhei, a skilled weaver,** in promoting silk weaving is widely acknowledged. Notably, a well-established supply chain of handloom products, including Rani Phee, Wangkhei Phee, and other handloom items, exists in Manipur. Furthermore, numerous women entrepreneurs have established contemporary showrooms for handloom products across various locations. (Oinam, N., 2018)

(Munal, N., 2020) "**The Leirum Phee** is a significant traditional shawl, known for its large size and coarse texture, often used as a wrapper, and distinguished by its unique woven design. It holds immense cultural importance, particularly in the context of marriage ceremonies, where it serves as an indispensable gift from parents to their daughters.

Fig.2.14: Leirum Phee
Source-
https://indianculture.gov.in/node/2790509

The origins of the Leirum Phee can be traced back to the reign of KhuiTompok, the Meitei king of Manipur, around 154-264 AD. According to historical records, during the marriage of Nongmoinu Ahongbi, an Angom princess, to Khui Tompok, her parents presented her with a Leirum cloth as a wedding gift. Since then, it has become a customary practice to gift Leirum cloth during Meitei marriages. Additionally, there are references to the Leirum cloth being given as a gift by a Tangkhul King during the marriage of his daughter, goddess Ireima, to King Irengba. Various stories and versions exist regarding the significance of the Leirum cloth, reflecting the diversity of communities and their traditions. Over time, the design of the cloth has evolved, with different communities incorporating their own variations while preserving the essence of the original Leirum design. As a result, the Leirum Phee symbolizes not only cultural heritage but also unity in diversity among communities. It represents purity, strength, trust, and the interconnectedness of life, embodying the shared values and traditions of the people who cherish it. Extensive research and study are necessary to fully understand the rich history and significance of the Leirum Phee across different communities."

The **Wangkhei Phee** is a renowned textile fabric crafted from fine white cotton, famed for its transparency and intricate designs adorning its body. It holds a special place among the women of Manipur, particularly worn during marriage ceremonies and festive events. Initially, it was exclusively woven using muslin and reserved for the Royal family of Manipur. Weaver stations were established at the Wangkhei Colony near the palace, although production has now expanded to various locations across Manipur.

Fig.2.15: Wangkhei Phee

Source- https://www.ibef.org/experience-india/products/wangkhei-phee

Crafted from exceptionally fine white cotton yarn, the Wangkhei Phee boasts a closely woven texture, resulting in its distinctive transparency. The weaving technique involves the meticulous interlacing of cotton weft and warp threads by women, spaced widely apart to maintain the fabric's translucent quality. Intricate patches featuring standard designs such as Kheiroithek, Thangjing Tangkai, KabokChaiba, among others, are seamlessly incorporated into the fabric. Notably, the longitudinal borders of the Wangkhei Phee showcase Moirang Phee designs, adding to its aesthetic appeal. The weaving process of the Wangkhei Phee employs two distinct methods, each utilizing different shuttle techniques. The fly shuttle loom method involves crafting the fabric in a single continuous piece, whereas the throw shuttle loom method entails creating the fabric in two separate pieces, subsequently joined together through stitching to form a complete textile. These techniques, passed down through generations, ensure the production of exquisite Wangkhei Phee fabrics cherished for their elegance and cultural significance in Manipur. (Experience India, 2024)

The **Inaphi**, which takes its name from "phi" representing cloth and "ina" referring to the upper body, is essentially a garment wrapped around the upper torso. This fabric is characterized by its delicate, semi-transparent texture, serving as a form of embellishment in its own right.

Fig.2.16: Mulberry Silk Innaphi
Source-
https://cdn.shopify.com/s/files/1/0066/3381/6117/products/Muga_Set_Chaddar_1200x1200.jpg?v=1572787671

In contrast to traditional textiles known for their vibrant colors and bold patterns, the designs, motifs, and color schemes found on the Inaphi woven by Manipuri artisans exude a subtle and calming allure.

Rani-Phi, also referred to as the "Rani cloth," is an essential element in the traditional attire of Meitei women, a name attributed to its originator, Chungkham Rani. These saris are adorned with motifs that are indigenous to the state of Manipur and are highly cherished within the community. Legend has it that the inspiration behind weaving in Manipur stems from the intricate beauty of a spider's web. According to Meitei tradition, Leimaren, the goddess associated with wealth and prosperity, entrusted the art of weaving to women to ensure the welfare of society. Across Manipur, women are renowned for their mastery of weaving, a skill passed down through generations. Chungkham Rani, a skilled weaver, designer, and entrepreneur from Wangkhei, is credited with introducing the Rani Phi sari. Despite facing hardships, including the loss of her husband at a young age, Rani chose to channel her energies into her craft, infusing her creations with vibrant colors and intricate designs.

Fig. 2.17: Rani phi
Source-
https://isha.sadhguru.org/en/outreach/save-the-weave/indian-weaves/rani-phi

Inspired by the splendor of nature, Rani wanted to incorporate motifs depicting flowers, birds, and designs from distant lands into her fabrics. Departing from conventional designs such as the Taj Mahal, she embarked on experiments with motifs like swans, lotuses, and leaves, meticulously perfecting their execution. Additionally, she introduced the use of silk threads, further enhancing the grace of her creations, which garnered widespread acclaim. Within the Meitei community residing in the Imphal Valley, the production process of silk garments is a laborious endeavor carried out within artisans' homes. Crafting a single Rani Phi requires approximately 40-50 grams of silk, obtained from around 50 silkworm cocoons. Depending on the intricacy of the design, artisans devote around a week to complete a single sari, showcasing their expertise and commitment to their craft.

Lasing phee is a widely used cotton quilt in Manipur, renowned for its exceptional warmth and comfort. Unlike traditional quilting methods that involve stitching multiple layers of fabric together, lasing phee distinguishes itself by being woven on a backstrap loom. This unique weaving process contributes to its distinctive quality and popularity among users in Manipur. (Indianculture, 2024)

Fig. 2.18: Lashing phi
Source- https://akm-img-a-in.tosshub.com/lingo/styles/medium_crop_simple/public/images/story/202210/lasing_phee_textile_from_manipur.jpg

(Borah, N., 2022) “The Lasing Phee fabric originating from Manipur is a highly insulating quilt, meticulously handwoven on looms by skilled artisans and filled with cotton batting. Despite its remarkable qualities, this textile has largely remained obscure due to insufficient communication channels connecting it with both domestic (markets within the country, excluding Manipur) and international markets.”

The Dhoti, referred to as Pheijom in Manipur, is a traditional attire for men with significant cultural importance in Manipuri society. It consists of a lengthy piece of fabric, typically white or cream in color, wrapped around the waist and legs in a specific manner. While the style of wearing may vary, it generally extends to the ankles, facilitating unrestricted movement. In Manipuri culture, the Dhoti or Pheijom signifies more than just clothing; it embodies tradition and reverence. It

Fig. 2.19: Pheijom with Lengyan Phee (Muffler)
Source- Leiteng creation

is commonly donned during important events such as religious rituals, weddings, and cultural festivities, symbolizing purity, dignity, and a deep connection to Manipuri heritage.

Traditional attire for women in Manipur typically consists of a blouse, a lower garment called **phanek**, and a shawl known as innaphi. Brides often adorn a decorative cylindrical costume called potloi, reminiscent of the attire worn by Manipuri raas-leela dancers. Additionally, some Meitei women pair their phanek and innaphi with a distinctive headgear called kajenglei. Varieties of phanek include achamba phanek, mayek naibi, and pungou phanek. (Karolia, A., 2019)

Fig.2.20: Phanek mayek naibi
Source-
https://www.thisday.app/en/details/phanek-a-cultural-identity-of-meitei-women

Fig.2.21: Phanek achamba (plain)
Source-
https://www.gitagged.com/product/phanek-online/

(Mohammed, R., 2024) The **Phanek,** a wraparound skirt made of handwoven silk or cotton, showcases vibrant colors and intricate motifs, often reflecting legends and cultural heritage. It is more than attire; it symbolizes power and strength for Manipuri women, who weave it tirelessly on traditional looms, even amidst modern conveniences. The weaving process, typically done on a loin-loom, is a skill passed down through generations and holds deep cultural significance. The Phanek serves as both a source of income and a testament to the hardworking nature and resilience of Manipuri women, worn proudly on everyday occasions and during significant events, embodying their cultural identity and heritage.

2.1.5 Use of agro waste in textile

The largest sector -agriculture in India plays a significant role in Indian economy. It provides a livelihoods to farmers and consumer. Majority of the Indian population are still into agricultural sector. Cultivation of crops is the major source of income for rural sectors. Being the top sector of the country economy, waste from the agricultural land is a predominant factor in environment. In order to overcome the issues of agricultural waste, many research institutes, Government organizations, industries are working on the utilization of waste from the agricultural output. Extraction of textile fibre from the waste plants after harvesting is one of the ongoing effort of many individuals and organizations. Plants like banana, coconut, palm, flax, pineapple, corn, kenaf etc. after harvesting the crops can be utilized in making sustainable textiles products.

2.1.5.1 Extraction of plant fibre from agro waste

(Das, A., 2021) reported fibre from plant can be considered as a composite material since its major composite is cellulose, hemicellulose, lignin, pectin etc. Greater characteristics like eco-friendly, renewability, cost effective and performance per mass can be obtained from the plant fibre than the available conventional fibre. According to the location of the fibre extracted from the plant, classification of the fibre can be acquired. Bast fibre, seed fibre, leaf fibres, fruits fibre, root fibre, grass fibre are the classification of the plant fibre. To get the high quality fibre, retting is the first process extraction method. Since earlier times, several retting process have been developed. However, enzyme retting is found to be an environmental friendly due to its mild retting factors yet getting high quality. Enzymatic retting, dew retting, water retting, chemical retting, and mechanical retting are the types of retting. Since all plant fibres are cellulosic in nature therefore, they can be considered as natural cellulosic fibre.

Cellulose fibre extracted from the leaf, stalk or pseudo stem have large economic significance and play a vital role in lives and food security of many farmers and processors. Newly developed extractor can ensure the supply of extracted plant fibre throughout the year moving towards the value addition of textiles and its product diversification. Extraction of Plant fibres will also help in improvement of poor rural people and employment generation rural and semi-urban sectors as well. Extraction of banana, pineapple and flax fibre and other plant fibre are done in the ICAR-NINIFET, Kolkata by using the newly developed extractor machines. For the extraction of banana fibre- peeling of truck is the first step. The extraction of fibre from the white and green part of the waste stalk of banana plant is done by means of two methods- hands scrapping and machine stripping. The stripping process is known as tuxing and the stripped stem are called tuxies. Mechanized machine is developed to reduce the labour and time consuming. Extraction of flax fibre is done after retting process, the retted dried stalk is forwarded for scutching process where the the fibres are separated from the outer composites of the stalk. An improved extractor has been developed with the use of an additional two scutching roller. This will help in breaking down of stalk at smaller intervals. Pineapple fibre are extracted from the waste leaves by crushing the hard outer layer of the leaves. Scrapping and combing in the extractor of pineapple leaf fibre has been facilitated. (Nayak, L, K., 2021)

Fig. 2.22: Manual extraction of pineapple leaf fibre
Source- N.M.N. Azlin (Author)

Fig.2.23: Dicorticator of pineapple leaf fibre
Source-https://link.springer.com/chapter/10.1007/978-981-287-742-0_3

Coconut fibre- coir is a coarse fibre which is obtained from the portion between the husk and the outer shell of coconut. The extracted fibre is brown in colour. Mature brown coir fibre has more lignin content and less cellulose than the fibres like cotton and flax hence it is stronger but less flexible. The fibrous shells are soak in a slow moving water stream using net or pits to soften and swell out the fibres from the shells. Separation of fibres from the compact shells is known as wet-milling process. Sifting is done to remove dirt and impurities followed by sun drying and packed them into bales. To straighten and remove shorter fibre from long bristle the fibre steel comb is used. White coir can also be extracted from the immature shells by doing water retting up-to ten months. Hand beating is done after retting to separate out long fibres prior to cleaning and drying. (Rastogi, M., 2018)

Chaudhary, H., Kaur, N., and Parmer M, S., (2017) in Fibre2fashion stated that corn or maize is the largest agricultural crop in worldwide. Corn a lingo cellulosic fibre plant generally discarded after eating corn. Variety of uses from stalk, leaves, and husks can be considered. Extraction of fibre are carried out from the husks by using alkali and enzyme treatment. The raw husk is required to undergone alkali treatments at high temperature range from 80^{o}C-90^{o}C for certain time to get the fibre. The cellulose content of the fibre is usually 80-87 percent and less lignin content i.e. 6-8 percent. To remove short fibre and impurities, washing is done. If finer fibre is required, enzyme treatment can be done which removes the lignin and hemicellulose. Depending on the plants, the yield percentage of the fibre is ranged from 10-30 percent. Corn husk provides higher cellulose content with significant benefits than other agricultural byproducts.

2.1.5.2 Spinning of agro waste fiber

The basic principles applied for spinning of fibres are not same for all different fibres. Even the spinning principles and steps of same fibre may vary according to their properties. To mention that process of spinning cotton is different from spinning of wool again it is also quite different from Jute. Carding basic principles involve in case of cotton and jute spinning may be similar but the separation of individual fibres of jute is done during the carding process itself while cotton fibre individual entity is already existing before the carding process. (Bhowmick, M., & Basak, S., 2021). Appropriate application of Plant minor fibres are still needed due to its availability and hence belong to unorganized sector. These fibres are usually used in making local handicrafts. If we launch these fibers in larger area, **then extraction and spinning systems like jute and cotton can be established for these allied fibres, it can play a dynamic role in textile segment**. Blended pineapple leaf fibre yarns spun on cotton and jute spinning system is found to be suitable for the Construction of curtains, bed sheets, carpets, furnishing cloths, towels etc. (Nayak, L, K., 2021).

“Very long, fine, silky and slippery fibres are obtained from Banana plant. The spinning of banana fibre should be almost same as the spinning method of silk fibre. Worsted spinning method can be used by maintaining short forward draw. The fibre is quite slippery in texture so, it does not have crimp effect. Banana fibre requires a high twist to get the fibre strand together. And this plant fibre yarn should be dyed with plant to get more sustainable”. (All fibre arts, 2023)

As per the Spinnova Company, if cotton which is a stress to both water and land get replaced with wheat as an alternative, then based on the production wheat plants, 30 percent of straw can be utilized into bio-based ecosystem. Equal amount of fibres can be extracted as from the cotton field with less water consumption. A large amount of straw after harvesting is burned in Asiatic countries which causes emissions of harmful substances to the environment leading climate change. The available agricultural biomass can be used as energy and fibre for textile. This will solve the biggest issue of the world where the growing population that needs more and more natural resources for the food and clothing production. The company has developed technology for spinning the fibres out of wool and waste stream based cellulose. Not like the process of making viscous, this technology involves sustainable process which dissolving and other complex chemical use is not required.

Debnath, S. (2017) has stated that plant fibres are classified based on their sources- leaf fibres from leaves, seeds fibres, bast fibres from stem, and fruit fibres from fruits. Many natural fibre based textiles are becoming important in our fashion industry. As far as the fashion is concerned about the plant fibre, flax blended with other fibres both natural and synthetic for making yarns is popular. Banana fibre is also another unexplored plant fibre for the textile and fashion for sustainable product development. Suitable spinning process for banana fibre is jute spinning system. Blended banana fabric can be developed form the spun banana yarns. Blended with jute and mesta at different proportions is already done for making different products. 100 percent banana fibres in yarns preparing shows inferiors results when compared to banana blended yarns. There is a great potential for green banana fibre products to design and develop.

From the reviews, different fibre from agrowaste can be spun based on the following system:

I. Cotton spinning system

A typical sequence in cotton spinning, which transforms raw cotton fibers into usable yarn. Here's a breakdown of each step:

1. **Unprocessed raw cotton**: This is the starting point of the process, where raw cotton fibers are sourced from farms or suppliers. These fibers are often in a compressed form, such as bales.
2. **Opening**: In this step, the compressed bales of cotton are opened up to loosen the fibers and remove any impurities like dirt, seeds, or other debris. This is often done using machinery like a cotton bale breaker.
3. **Carding**: The opened cotton fibers are then carded, which aligns the fibers parallel to each other to form a thin web. This process also further removes impurities and short fibers.
4. **Drawing**: After carding, the fibers are drawn out into long, thin strands to improve their alignment and consistency. Drawing helps ensure that the resulting yarn will have uniform strength and thickness.
5. **Roving (flyer)**: Roving is a slightly twisted strand of cotton fibers. It is produced by further attenuating and twisting the drawn fibers. The roving stage prepares the fibers for spinning by giving them a slight twist and reducing their thickness.
6. **Ring spinning**: In ring spinning, the roving is fed into a spinning machine where it is twisted and wound onto a spindle to form yarn. This twisting imparts strength to the yarn and holds the fibers together.
7. **Winding**: After spinning, the yarn is wound onto a bobbin or cone for storage or further processing. This step ensures that the yarn is neatly wound and ready for use in subsequent processes or for sale to customers.
8. **Yarn steaming**: Yarn steaming is a process used to set the twist in the yarn and improve its strength and stability. Steam is applied to the yarn under controlled conditions to relax the fibers and set the twist, resulting in a more uniform and consistent yarn.

II. Jute spinning system

The jute spinning process begins with the selection and batching of raw jute fibers, which are then pieced up and softened with suitable additives like jute batching oil (JBO) in water emulsion. The softened fibers undergo piling and conditioning before being subjected to carding using a Breaker card followed by Finisher carding. Intercarding may be used for coarser types of raw jute to produce coarser jute yarn.

After carding, the fibers go through three to four passages of drawing to further refine their alignment and consistency. The finisher drawing sliver is then processed in a jute spinning machine, employing either slip draft or apron draft techniques, to produce jute yarn of the desired count. (Textile learner, 2012).

The typical flow chart of the jute spinning process includes batching/selection of raw jute, piecing up, **softening, pilling, jute carding, and three stages of drawing before the jute spinning stage.** The key elements of the spinning process are drafting, twisting, and winding on. All jute spinning frames feature two sets of rollers—retaining and drawing—each comprising a positively driven member and a pressing member between which fibers are gripped. Drafting attenuates the material and reduces its weight, with the frames reach slightly longer than the longest fibers. Between the rollers lies a smooth metal plate called the breast plate or slip draft, which helps control the movement of short fibers. The twist in the roving adds cohesion to the strand without impeding movement. Kiron, I, M. (2021).

III. Flax spinning system

(Corbman, P, B., 1983) The flax spinning system involves several stages to convert flax fibers into usable yarn. Here's the process:

1. **Retting**: Flax fibers are derived from the stem of the flax plant. Retting is the process of separating these fibers from the woody stalks of the plant. It can be done through dew retting (exposure to moisture) or water retting (submerging in water).

2. **Scutching**: After retting, the flax stalks undergo scutching, where the outer bark is removed from the fibers. This process can be done mechanically or manually.

3. **Hackling**: The scutched fibers are then hackled to further remove impurities and align the fibers parallel to each other. This process also helps in separating the long, quality fibers from the shorter ones.

4. **Spinning**: Once the fibers are cleaned and aligned, they are ready for spinning. Flax spinning can be done using techniques similar to cotton spinning, including carding, drawing, and spinning on spinning frames or spinning wheels.

5. **Twisting and Winding**: During spinning, the fibers are twisted together to form yarn. This yarn can then be wound onto bobbins or spools for storage or further processing.

6. **Finishing**: After spinning, the flax yarn may undergo additional processes such as bleaching, dyeing, or sizing to prepare it for use in textile production.

IV. Coir spinning system

The coir spinning system involves the transformation of coir fibers derived from the husk of coconuts into usable yarn. The coir spinning process begins with the extraction of fibers from coconut husks, which are then cleaned and sorted to ensure uniformity. After carding to align the fibers, they undergo drawing and roving to further strengthen and stretch them into thin strands. These prepared fibers are then spun into yarn using various spinning techniques, resulting in a versatile material suitable for different applications. During spinning, the fibers are twisted together to form yarn, which is wound onto bobbins or spools for storage. Additional finishing processes, such as washing, bleaching, or dyeing, may be applied to enhance the yarn's appearance and performance. The resulting coir yarn finds application across diverse industries, including agriculture, construction, and textiles, where it is used to produce mats, ropes, geotextiles, and upholstery, among other products. The coir spinning system thus plays a pivotal role in converting raw coir fibers into sustainable materials with widespread utility.

The resulting coir yarn can be used in various industries, including agriculture, construction, and textiles. It is commonly used to make products such as mats, rugs, ropes, geotextiles, and upholstery. The coir spinning system plays a crucial role in converting raw coir fibers into versatile and sustainable materials with a wide range of applications.

Hand spinning methods

Hand spinning methods refer to the techniques used to transform fibers into yarn using manual tools and equipment, typically without the use of mechanized spinning machinery. These methods have been practiced for thousands of years and are still used by artisans, hobbyists, and communities around the world. Some common hand spinning methods include:

Drop spindle spinning provides an accessible method for creating yarn and serves as an excellent introduction to the art of spinning, often serving as a precursor to using spinning wheels. With a history spanning thousands of years, drop spindles have been pivotal in transforming wool into thread. While the technique is relatively straightforward and can be mastered with practice, it does require some initial effort to become proficient. Two common variants of the drop spindle are the bottom whorl and top whorl designs, both of which are utilized with leader strings in a similar manner. The top whorl variant is favored for its ease of use during the "park and draft" technique, where the spindle shaft is held between the spinner's knees.

Fig. 2.24: Drop spindle
Source- http://www.sticksandscribbles.com/adventures-in-spinning-with-drop-spindles/

A drop spindle is versatile, capable of spinning various fibers such as sheep wool, flax, hemp, horsehair, and cotton into yarn. The spinning process begins with fiber preparation, with wool often being recommended for beginners due to its suitability. It's ideal to select fibers that strike a balance between not being overly grippy or too silky in texture.

The charkha, or spinning wheel, epitomized Gandhi's constructive program, symbolizing principles like Swadeshi, self-sufficiency, and interdependence. It served as a nexus connecting cotton growers, carders, weavers, distributors, and users. Additionally, the charkha embodied the dignity of labor, equality, and unity, as all volunteers were encouraged to spin daily. Furthermore, it represented independence, as British control over India was tied to domination of indigenous industries like textiles. Nehru referred to khadi, the homespun cloth, as "the livery of our freedom."

Spinning played a central role in Gandhi's Constructive Programme, akin to the "sun" in a "solar system." Virtually everyone, regardless of age, social status, or gender, participated in spinning or other aspects of cloth production, from planting cotton seeds to wearing khadi. Spinning had both symbolic and practical significance, providing employment for millions and fulfilling a fundamental need in Gandhian economics. (Metta Center, 2015)

The term "charkha," which translates to "wheel," is commonly used in India to refer to any spinning wheel or hand-cranked spinning machine. In the United States, the specific type of charkha typically encountered is known as **the box charkha**. These various models of **box charkhas/ Peti charkhas** have been developed and produced by Gandhi's associates and

Fig. 2.25: Peti charkha
Source- https://www.etsy.com/in-en/listing/221289425/?ref=shop_home_active_1

supporters as part of his khadi movement, aimed at promoting self-sufficiency in cloth production. Gandhi himself introduced the innovation of the double-wheel drive, which enhances speed, control, and portability.

Initially, the box charkha was offered in just two sizes: "briefcase" and "book." The smaller "book" charkha was more portable but slightly more challenging to adjust and use, making the "briefcase" charkha the preferred choice. More recently, a medium-sized box charkha has also been introduced, providing a compromise between portability and ease of use. (Shephard, M., 2012)

Unfortunately, hand spinning on the traditional Indian Charkha has been overlooked and forgotten, overshadowed by the popularity of the **faster semi-mechanized Amber charkha** in recent times. Traditional Indian charkhas are capable of hand spinning yarns up to 115's count, while the **Ambar charkha can handle yarn counts from 115 to 150's, allowing them to compete with mill yarns that typically average at 120's count**. The main distinction between the Traditional Indian Charkhas and Ambar charkhas lies in the level of twist imparted to the yarn. Hand-spun yarns from the traditional spinning wheel have a lower twist compared to those produced by the mechanized Ambar spinning wheel, which emulates the spinning mechanism of mills manually. Consequently, fabrics woven from hand-spun yarns are softer and more absorbent. (https://etradinglines.com/InfoBase/spinning/khadi)

Fig. 2.26: Amber charkha
Source- https://www.mkgandhi.org/about-us.html

In 1949, Shri Ekambaranathan (a disciple of Mahatma Gandhi) of Papankulam in Tirunelveli District, Tamil Nadu, invented the two-spindle wooden Charkha-**Amber Charkha**. This small Charkha utilized the ring spinning technique and featured a special apparatus for drawing tubular slivers. Equipped with two-ring spindles and two-horn rollers weighted by springs, the Charkha's rotation was driven by a large hand-wheel linked to smaller wheels by cotton bands. While the early model had a productive capacity of slightly more than one hank per hour, the yarn spun on it lacked uniformity despite satisfactory strength. Recognizing its potential, the A.I.S.S. considered it a promising first attempt deserving further research. Shri Ekambatanathan was rewarded for his initiative and provided with research facilities to enhance his model, initially in Kovilpatti and later in Tiruppur.

The Ambar Charkha, intended for widespread adoption across the country, is a hand-operated wooden spinning wheel with four spindles. It measures 21 inches in length, 16 inches in width, and 21 inches in height, weighing 26 lbs. Constructed from seasoned wood, the frame includes three wooden multi-grooved pulleys, each equipped with varying numbers of grooves (four, three, and two). These pulleys are connected to the main hand-operated wheel via cotton bands. The iron components of the Charkha comprise four spindle rings, four fluted rollers, a pair of gear wheels, harwar bows, travelers, and springs. Additionally, there are four pairs of rubber rollers positioned over the metal-fluted rollers, each about one and a half inches wide.

The CIRCOT-**Phoenix Charkha** represents a significant innovation in the realm of cottage-level fiber spinning, particularly tailored for handling coarse long-staple fibers such as those derived from banana pseudo stem fibers. Unlike traditional hand-operated charkhas, this machine is pedal-driven, offering an efficient means of spinning natural fibers that are typically challenging to process manually. One of the key advantages of the CIRCOT-Phoenix Charkha lies in its ability to produce relatively fine yarn with a high degree of uniformity from these otherwise difficult-to-spin fibers. This capability opens up new possibilities for utilizing natural fibers in various applications, enhancing their commercial viability. Moreover, the versatility of this

Fig.2.27: Phoenix charkha
Source-CIRCOT

charkha is evident in its adjustable yarn count range, spanning from 150 to 600 tex. This flexibility allows for the production of yarns tailored to specific requirements and applications, further increasing the utility of the machine. In terms of productivity, the CIRCOT-Phoenix Charkha demonstrates impressive output potential. With a moderately skilled operator at the helm, the machine is capable of producing approximately 4.0 kilograms of yarn in a single day, significantly enhancing the efficiency of fiber spinning operations at the cottage level.

This innovative spinning solution is licensed to M/s. Phoenix Products, headquartered in Belgaum, Karnataka, indicating its potential for widespread adoption and utilization in the textile industry. The collaboration with Phoenix Products further underscores the commitment to advancing the accessibility and efficiency of fiber spinning technologies, particularly for cottage-level producers. (CIRCOT, 2020)

2.1.5.3 Agro waste fiber in making textile products

Fibre from agro waste like straw are used in making hats. Straw a dried form of grass is also utilized in stuff like mattress. Flax and pineapple are used in manufacturing clothes usually blended with cotton. Coir fibre is being used in production of twine, mats like floor mats, door mats, mattresses, floor tiles even sacking. Roselle fibre can be utilized as a substitute for jute fibre in making burlap. Kenaf fibre obtained from Hibiscus cannabinus plant is specially used in making rope, twine, coarser cloth which similar to cloth made from jute. Increasing uses of kenaf fibre are making wood insulator and clothing grade fabrics, boards, oil absorbent, bedding for animal, packaging material, organic filler to blend with plastics, mats and containers. Banana fibre are cultivated in Japan way back in 13th century for clothing and households textiles. Coarser fibre from the outermost layer of the stem is used in making table cloth and the finer quality is used for making kimono and Kamishimo. Banana fibre is used in making high end rugs with texture similar to silk in Nepal. (Rastogi, M., 2018)

Coir fibre sometimes known as coco fibre. The cinnamon-brown color fibre has good resistance to water, weather and abrasion. The fibre procured from Sri Lanka is mainly used in making indoor and outdoor mats, brushes, tiles and rugs. Fabrics produced from this fibre has very visible texture, pattern and structure of weave because of its coarse, stiff and wiry features. The floor textiles made from this fibre is very durable and it goes well together with other interior items. Linen is famous for making bed sheets, table cloths and bath items, interior accessories for home and industrials use, apparels and technical textiles. Linen wallpaper and wall covers are popular in home furnishings. Apparels made from linen are used in making apparels for warm-weather, high fashion, formal and informal wear. Even luggage, bags, purses, and sewing thread of technical textiles are made with linen. Hibiscus and kenaf fibre has potential use like jute fibre. Kenaf can be utilized in making twine and cordage. Hibiscus fibre is stronger than jute fibre and has potentiality in making textiles like bags and rugs and some apparels can be made by blending with other fibre. (Kaldolph J, S. 2014)

Basak, S., & Bhowmick, M. (2021) stated that there are different types of technical textiles application from plant fibre. The uses of plant fibre in protective textiles are flame protective, UV resistance and mosquito repellent clothes. Agro textiles are manufactured from plant fibre they are made for protection of crops-mulching, bird net etc. and fertilization. Physiochemical properties like Strength, elongation, stiffness, bio-degradation, resistance to sunlight and resistance to toxic environment are the essential properties. Reports on use of medical textiles from agro-plants is very less. In Geotextiles ICAR-NINFET has worked on development of plant based woven and non-woven bio-composites matrix. Engineered of natural fibre based footwear becomes one of the rising areas in ream of footwear industry. Plant fibres like coir, pineapple, jute, hemp, cotton, wool etc. and their various textile features- weaves, knitted and non-woven have been well utilized by the footwear industry because of their biodegradability, great availability, high modulus, tensile strength, resistance to abrasion, toughness and breaking load. In addition, production of vegan leather from pineapple, banana and cactus are also there.

2.1.6 Natural dyes

From the early excavations of Harappa and Mohenjodaro civilization and cave paintings, it is clearly seen that people of prehistoric era knew how to colour their bodies, clothing, and items including the surroundings. Colours were extracted from different sources such as plants, animals and minerals.

2.1.6.1 Sources & extraction of natural dyes

Different sources of natural dyes obtained from plant such as flowers, fruits, barks, leaves, roots, weeds, vines, grasses, and lichens were used in the ancient period. Woad, indigo, madder, log wood, fustic, safflower, and fustic dyes are still used in many places of the country. Woad was the first used natural dye. Woad dye was replaced by indigo because of its deeper and fastness value of blue colour. Red colour of Madder was used to get other colours by using various mordants. However, fast black dye was not known.

Indigo was originally extracted from *Indigofera tentoria* by using fermentation. At present, synthetic supplements are used with this dye. Madder found in Turkey, Belgium and france gave alizarin. The dye is made from its long dried slender roots by grinding and extracting. Annato is extracted from the fermented fruit- Bixa Orellana, pomegranate rind is from Punica granatum, Myrobalan dye got from Terminalia chebula, and species of Acacia, Areca, Mimosa, and Terra japonica provide cutch dye from their wood and pods. Balsam is grown in India and has 500 species. Harshingar, Juglone, Kamala, onions, Persianc berries, Quercitron, tissue are other dyes yielding plants. (Vatsala, R., 2003)

In the view of Ratnapandian, S. (2020) Natural dyes were the only used in ancient times until W.H. Perkin discovered the first basic dye-mauviene in 1856. A wide range of dyes from plant- bark, leaves, flower, pods and roots has been identified. India alone has more than 300 species of dye yielding plants. The most simple dye technique of extraction is I. Steeping II. Boiling or fermentation III. Simple filtration IV. Settling and V. Evaporation to extract the final dye paste, cake, granule or powder. This process reduces the cost of carrying of raw materials as well as gets standardized dye. Newly developed techniques are spraydrying and super critical carbon dioxide extraction. At present, commercially produced some natural dyes are available.

Common natural dyes obtained from different parts of the plant are 1. Root- madder, turmeric, onions and beetroot. 2. Bark of trees- Sappan, Khair, and sandalwood. 3. Leaf- indigo, henna, coral jasmine, lemon grass, 4. Flowers- marigold, dahnia, tesu and kusum and 5.Fruits- myrobalan, pomegranate rind and latkan. At present, approximately 500 vegetable dyes are existing. Natural dyes can be extracted in a solution in acidic or alkaline in nature depending on the dye stability in different pH level. Natural dye can be classified as substantive or mordant dyes. Substantive dye can be directly applied on the fabric without any treatment and mordant dyes are applied with use of mordants. (Samanta, K, K. & Chattopadhay, S, N., 2021).

Vegetable dyes are obtained from different parts of the plants- bark, pods, leaves, flower and fruits. A large variety of plant dyes has been used for direct application or combination with different dyes. Mordanting can be done before or after the dyeing process. Common vegetables dyes are- Indigo, Indian madder is used to produce red shades on fabrics, cutch-this brown dye is suitable to use on wool, silk and cotton, tesu-this yellowish brown is produced abundantly in Uttar Pradesh and Bihar, pomegranate rind- range of brown colours can be developed from this dye, turmeric-with different treatment various shades of yellow can be obtained, walnut rind-olive brown, deep brown, bright brown can be obtained, French marigold-bright lemon or orange dyes are obtained and henna- variety of brown are extracted from henna leaves. (Rastogi, D., & Chopra, S., 2017)

Although there is growing interest in natural dyes among independent fashion brands, they have not gained widespread commercial traction due to various factors. These include the high costs associated with raw materials, inventory management, limited color options, and concerns about color bleeding. The pricing of naturally dyed products is influenced by factors such as the availability and concentration of dyes in raw materials, which can vary depending on climatic conditions and soil quality. Experts emphasize the importance of shifting consumer perceptions to encourage the adoption of naturally dyed products. Additionally, sellers must ensure that naturally dyed products meet the same standards of color fastness and other characteristics as those dyed with synthetic dyes to scale up their commercial application.

Despite their benefits, such as being gentle on the environment and easier effluent treatment, natural dyes are often perceived as inconsistent. Dyeing processes can struggle to achieve consistent shades, and color bleeding is a common concern. Moreover, the overall cost of naturally dyed products remains high due to factors like infrastructure, inventory management, labor, and energy consumption. (Raina, S., 2023)

Cheynekoh. (2020) Using natural dyes may pose certain risks and drawbacks:

1. Hematin and hematoxylin found in logwood, a natural dye, are highly toxic and should not be inhaled or absorbed through the skin.

2. Indigo can cause irritation to the eyes and respiratory system.

3. Natural dyeing requires more water compared to synthetic dyes.

4. Natural dyes tend to fade when exposed to light and can wash off easily, even when treated with mordants. While natural mordants like salt and pomegranate have been

historically used, they do not offer complete fastness. Additionally, natural mordants such as alum, although considered safe, are still toxic.

5. The range of hues and shades attainable with natural dyes is limited compared to synthetic dyes, which can produce endless colors, including imitations of natural hues. Given the importance of replicating a wide array of colors in manufacturing, synthetic dyes are more preferred.

6. Textiles dyed with natural dyes are generally more expensive due to several factors:

    - Large quantities of dye stuff are required to achieve satisfactory coloring.
    - Growing the plants from which natural dyes are extracted is time-consuming.
    - The dyeing process with natural dyes takes longer compared to synthetic dyes.
    - More natural dye is needed to color fabric compared to synthetic dye.

The ecological sustainability of natural dyes is also a concern, as their increased commercial use could lead to depletion of natural resources faster than they can be replenished.To encourage the use of natural dyes, research should focus on making their production more efficient and sustainable for large-scale fabric dyeing. Some producers of dyestuffs have already begun efforts in this direction and have made significant progress. For instance, the Global Organic Textile Standard (GOTS) approved natural dye extracted from madder in 2008, as it offers better handling, color-fastness, and efficiency without the need for additional chemicals.

2.1.6.2 Phytochemicals of natural dyes

Asim, K. & Choudhary, R. (2017) opined natural dyes may be categorized based on the method of application- substantive dye and non-substantive dye. Substantive dye requires no mordant for dyeing the fabric while non-substantive dye require mordanted fabrics. Natural dyes can be either monogenetic or polygentic based on the mordant applied-. Monogentic means only one dye is produced irrespective of used mordant, polygenetic means multi colours can be obtained by using different mordants. Based on the chemical nature vegetable dyes can be of-

I. Dairylol methane II. Carotenoid III. Alkaloids IV. Quinonoid V. Flavonoid VI. Benzoquinone VII. Anthraquinone.

"Plant origin natural dyes are related with chemicals substance like carotenoids, anthocyanidins, falvones, anthrauinones, digydropyrans, and alpha napthginomes etc. direct utilization cannot be done. With the use of aqueous, acids, alkali, alcohol methods. In aqueous method extraction, parts of the plant to be used are boiled with plain water and filtration is done. In acid method, one percent of rendered acidic lac is used and 1% alkali by ratanjot is used in alkali method. 1:1 water/alcohol proportion is used in alcohol extraction method for instance- quercitron and Persian berries." (Vatsala, R., 2003)

The chemical groups of plant dyes provided by Ratnapandian, S. (2020) is given below:

Table 2.2: Chemical groups of plant dyes

Dye plant	Shade	Chemical group
Indigofera tinctoria	Blue	Indigo
Bougainvillea glabra	Yellow	Flavonoid
Caesalpinia sappan	Red	Anthocyanin
Urtica dioica	Green	Chlorophyll
Haematoxylum campechianum	Black	Tannins
Bixa Orellana	orange	Tannins
Acacia catechu	Brown	carotenoids

Indigofera, polygonum species and isatis are primarily produced indigo dyes. The chemical involves in flavonoid is luteolin with shades of yellow. The largest chemical group of dye is flavonoid. Anthocyanins contain red and blue dyes of fruits and flowers. Carotenoids are initially extracted from carrots. These are direct dyes which produce yellow to orangey red colour. Anthracenes have two main groups- anthraquinones and napthoquinones. Anthraquinones produce red, yellow and pink shades and napthoquinones produce pink, purple or brown shades. Chlorophyll, the green pigment of plants are available as dyes in two class chlorophyll a and chlorophyll b. chlorophyll dye is unpopular because of its poor light fastness. Seguin introduced the term tannin in 1790 which is used mainly for converting animal skin to leather. Tannins are identified as polyphenols.

According to Chakraborty, J.N., (2014) - Natural organic dyes contain a wide range of chemical groups, viz. Anthraquinone, nathoquinone, carotenoid, indigo, flavone, di-hydropyrans anthocyanidin and flavonol. Majority of the red dyes contain anthraquinone structure. Indigo is found to be the oldest used by human. The dye is probably originated in pre-historical India. Indigo and tyrian purple possess indigoid structure. Lawsone or henna is the main dye which contain alpha napthoquinone. Carotenoid found is found in orange pigment of carrots. Flavones, isoflavones, chalcones and aurones are the flavonoid dyes.

As per the chemistry of natural dyes by the fox and the knight, (2021)

The Flavonoids: Flavonoids are a common group of compounds found in natural dyes, known for yielding yellow dyes through flavones and isoflavones. Their resurgence in recent years, encouraged by organizations like the World Health Organization, is due to their non-toxic and sustainable properties, making them suitable for textile dyeing, as well as cosmetics and pharmaceutical products.

The Carotenoids: Carotenoids, notably sourced from carrots, are responsible for producing orange hues in natural dyes. This coloration is attributed to double bond conjugation. While carrots are a familiar source of orange dye, saffron, derived from Crocus sativus flowers, is a notable but expensive source of carotenoid dye compounds.

The Indigoid: Indigoid compounds, particularly indigo, are renowned for their deep blue hues. The percentage of indigotin in indigo determines the intensity of the blue color. Indigo is obtained from the seed of the Indigofera Tinctoria plant through a fermentation process involving microbial communities. This process leads to the reduction of indigo, resulting in the formation of indigotin.

The Anthraquinone: Anthraquinones are chemical compounds utilized to produce red dyes from plants and insects, valued for their excellent lightfastness. Madder, cochineal, and lac are popular sources of red dyes containing anthraquinone compounds.

The Alpha naphthoquinones: Alpha naphthoquinones, found in dyes like walnut tree bark and henna, offer ease of accessibility. Henna, when used on cotton fabric, exhibits strong UV protection, underscoring the importance of natural dyes for sustainability.

The Dihydropyrans: Dihydropyrans, structurally related to flavones, are present in dyes like logwood and brazilwood. Logwood chips produce shades of purple, while brazilwood offers a range of pink to deep red hues. It's crucial to ensure sustainable sourcing, especially concerning endangered species like Caesalpinia echinata.

The Anthocyanidins: Anthocyanidins, found in red, blue, and purple flowers and fruits, yield dyes like carajurin from Bignonia chica leaves, imparting orange hues. These water-soluble pigments belong to the phenolic family.

The Tannins: Tannins, also from the phenolic family, are readily available in barks, leaves, roots, and galls. They aid in mordanting fibers and can produce colors with modifiers like iron, resulting in shades like gray. Tannins have demonstrated antimicrobial and UV-protective properties, as well as enhanced antioxidant properties on dyed wool.

Onions skins and luteolin dyes represent historical examples of yellow dyes derived from flavonoids, showcasing the longevity and versatility of natural dye compounds.

Phytochemicals are secondary metabolites naturally produced by plants, contributing to their color, aroma, flavor, and cellular functions regulation. Recognized for their medicinal potential with minimal side effects, the characterization and evaluation of phytochemicals are crucial for pharmaceutical discoveries from plant-derived sources. (Lifeasible, 2024)

Lifeasible, a leading plant biotechnology company, offers comprehensive methods for both plant extraction and phytochemical detection, catering to diverse plant materials and target compounds' characteristics.

Extraction Methods:

1. **Plant tissue homogenization:** Homogenizing plant tissues in specific solvents, followed by filtration to obtain the extract.
2. **Serial exhaustive extraction:** Successive extractions with solvents of varying polarities.
3. **Soxhlet extraction:** Suitable for compounds with low solubility.
4. **Fluid extraction:** Placing plant materials in solvent-filled containers with agitation until dissolution.
5. **Decoction:** Boiling plant extracts for 15 minutes, ideal for water-soluble components.
6. **Digestion:** Macerating plant materials through gentle heat treatment.
7. **Percolation:** Macerating plant materials in a percolator for 24 hours.

8. **Sonication:** Applying sonication to facilitate the permeability of plant cell walls for efficient extraction.

Qualitative Analysis Methods: Qualitative tests for different types of phytochemicals include:

- **Alkaloids:** Mayer's, Wagner's, Dragendorff's, and Hager's tests.
- **Carbohydrates:** Molisch's, Fehling's, Barfoed's, Benedict's, Borntrager's, and Legal's tests.
- **Saponins:** Froth and foam tests.
- **Proteins and amino acids:** Millon's, Biuret, Ninhydrin, and Xanthoproteic tests.
- **Flavonoids:** Alkaline reagent, lead acetate, and magnesium and hydrochloric acid reduction tests.
- **Phytosterols:** Libermann-Burchard's and Salkowski's tests.
- **Phenols:** Ferric chloride test.
- **Tannins:** Gelatin test.
- **Diterpenes:** Copper acetate test.

Quantitative Analysis Methods:

- **Chromatography:** Gas Chromatography (GC), Liquid Chromatography (LC), High Performance Liquid Chromatography (HPLC), High Performance Thin Layer Chromatography (HPTLC), and Optimum Performance Laminar Chromatography (OPLC).
- **Spectroscopy:** Ultraviolet (UV), Infrared (IR), Mass (MS), and Nuclear Magnetic Resonance (NMR) spectroscopy.
- **X-Ray Crystallography:** Provides accurate molecular structures.

In the article of Dye by Britannica, (2024) until the 1850s, the majority of dyes were sourced from natural origins, primarily derived from plants, trees, lichens, and occasionally insects. Evidence from Egyptian tombs, dating back over 4,000 years, demonstrates the ancient use of dyed fabrics, as described in hieroglyphs outlining dye extraction and application methods. Despite numerous attempts to extract dyes from brightly colored plants and flowers, only a limited number found widespread application, likely due to the instability of many natural dyes and their occurrence within complex mixtures. However, studies in the 1800s laid the groundwork for the development of synthetic dyes, which eventually dominated the market by 1900.

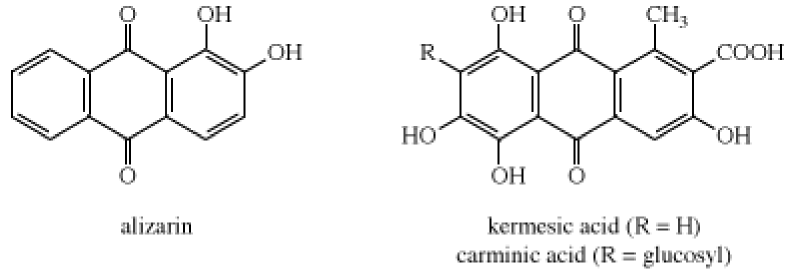
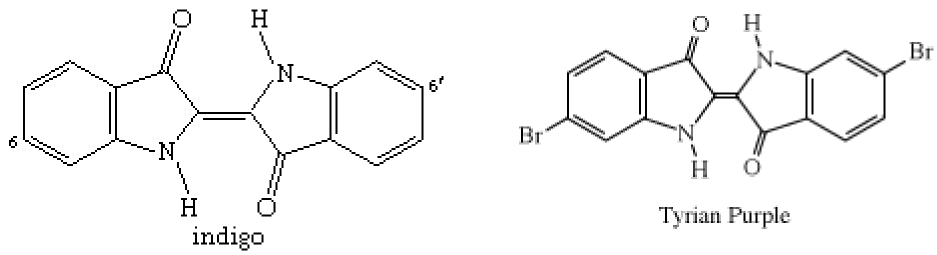
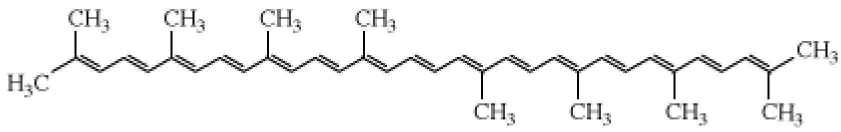


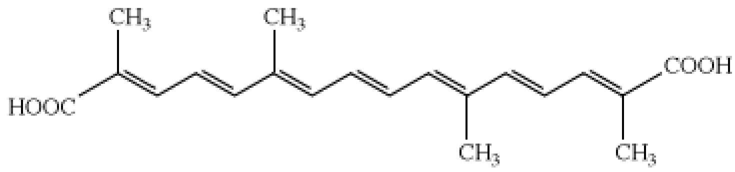
Fig.2.28: Chemical structure of dyes

Among natural dyes, alizarin and indigo hold significant importance. Alizarin, a red dye obtained from the roots of the madder plant (Rubia tinctorium), along with red dyes from scale insects like kermes and cochineal, were extensively used. Indigo, a blue dye extracted from plants such as Isatis tinctoria and Indigofera tinctoria, remains highly valued for its excellent dyeing properties, particularly in denim production, despite the replacement of natural indigo with synthetic alternatives. Tyrian purple, a derivative of indigo extracted from snail glands, was historically reserved for royalty and high-ranking individuals, but its production declined with the fall of the Eastern Roman Empire.

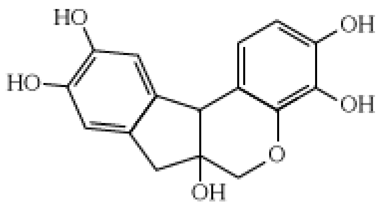




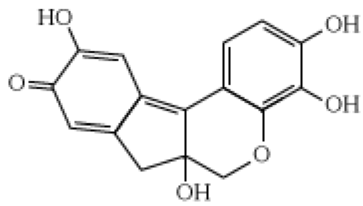
lycopene



crocetin



hematoxylin



hematein

Fig2.29: Chemical structure of different dyes

Today, logwood is the only natural dye still in use, extracted from the heartwood of the logwood tree (Haematoxylon campechianum). Hematoxylin, obtained from logwood extracts, oxidizes to hematein, which, when combined with chromium, produces shades ranging from charcoal to black, primarily used for dyeing silk and leather.

2.2 Research Related Review

2.2.1 Natural minor fiber

A comparative study on the performance of 100% jute and 50:50 coir-jute blended yarn was carried out by Karim, Md. R., Sultana, R., Barua, P., et, al. (2019). The procured coir fibre underwent a chemical softening treatment with NaOH and a wetting agent in 1:25 MLR at 100^{o}c for 1hr. After the softening, neutralized with 5% (w/w) acetic acid was done followed by washing and drying. Batching of jute fibre was done with 24% emulsion for 72hrs. Yarns of 16lbs/spy each were produced from both the blended fibre and the 100%. From the results, the coir jute blended yarn had better properties than the 100% jute yarn. Properties of the prepared yarns are given below-

Table 2.3: Properties of coir-jute blended

Property	Value
Yarn Count	16lbs/spy
Tensile strength	19.45lbs
Quality ratio	121.56%
Coefficient of variation (strength)	12.13%
TPI	3.2

Table 2.4: Properties of 100% jute yarn

Property	Value
Yarn Count	16lbs/spy
Tensile strength	15.9lbs
Quality ratio	107.27%
Coefficient of variation (strength)	14.18%
TPI	3.2

The study concluded that the blend of coir-jute fibre showed the feasibility of producing 16lbs/spy in a 50:50 ratio on a jute spinning system. The tensile strength, coefficient of variation of the strength and quality ratio fell within the acceptable range. CV of the strength of the blended yarn provided uniformity. Hence, the method of preparing blended yarn appeared to be effective.

Thilagavathi, G., Pradeep, E., Kannaian, T., et al. (2010) studied on development of bamboo, banana, and jute non-woven for application as car interiors for noise control. The three types of non-woven were developed with the needle punch technique by blending bamboo/polypropylene, banana/polypropylene, & jute/polypropylene at a 50:50 ratio each. By using the impedance tube method, the sound absorption coefficient was tested. A comparison of physical properties for all the developed samples was done. From the results, the bamboo/polypropylene (PP) non-woven had a compact structure which gave lesser CV% of mass per unit area and higher tensile strength than banana/PP & Jute/PP by 510% and 97.3% respectively. The flexural rigidity was too 16.2 % higher than banana/PP and 48.1% higher than jute/PP, the elongation of bamboo/PP was the lowest which was 4.4% lower than banana/PP and 43% lower than the jute/PP. The bamboo fibre was finer than polypropylene hence had a good cohesiveness and gave a compact structure. However, the banana/polypropylene blend had the lowest thermal conductivity which could be used as a thermal insulator. Because of the less cohesiveness between the fibres banana/PP had the lowest air permeability with a difference of 702.4% from bamboo/PP and 12.9% from jute/PP. In absorption coefficient, bamboo/PP and jute/PP reached the target level at 800Hz, but 22% lower in the case of banana/PP. For a higher frequency of 1600Hz, an increase in the thickness of the non-woven could be done to overcome the reduction from the target level. The study concluded that bamboo/PP non-woven could be used in automotive interior noise control because of its better properties. Banana/PP non-woven with low thermal conduction of 0.0178W/m/k was recommended for thermal insulating applications. Apart from the car interior, other applications such as theatres, generator rooms, auditoriums, and floor mats were suggested for the developed non-woven.

To extract the fibre from the bract of banana flower and analyse its properties for the exploration of its potential uses in textile production was the study conducted by Sakthivel, J, C., Sivaraman S, S., Sathish, J., & Venkatesh, J. (2020). The mechanical and chemical treatments were used for the extraction of the fibre. In mechanical treatment, scrapping and stripping resulted in fibre rupture and damage. Hence, The effective chemical treatment was preferred (retting) i.e. 1% NaOH conc. at 60^oC for 30mins.The extracted fibre was tested and analyzed its characteristics, such as length, fibre strength, fibre elongation, and moisture regain. The majority of the fibre length was between 17- 19 cm which was sufficient for preparing staple spun yarn and the fibre extracted from the inner bracts had a shorter length. The maximum tensile strength was found to be 1.73N but the majority value was 0.5-1N and the tenacity was in a range of 37.05-45.90. The elongation percentage was 15.3. In the case of moisture regain, it was found to be 8.51-11.63% which was comparable to cotton, jute and banana pseudo stem fibre. A staple spun yarn count of 6Ne was prepared by using a rotor spinning machine. The linear density of the card sliver was 0.213Ne. It was found that the 100% bract yarn was feasible to prepare. The study concluded that the fibre could be utilized as an eco-friendly and biodegradable textile material. The bract fibre showed a higher value of tensile strength and elongation than the minimum required for textile fibre. Observation of sufficient length, strength and good moisture meant good enough to produce textile products. This rotor staple yarn created the way for manufacturing novel textile products and applications.

Agrawal, E., & Rastogi, S. (2018) carried out a research entitled “A study on properties of union fabrics developed with sisal fibre for textile application”. The union fabrics developed were sisal/cotton (F1), sisal/cotton-viscous (F2), sisal/polyester (F3) with plain weave in the proportion of 50:50 each. Evaluation of these developed fabrics was done. The maximum thread count used in the fabrics was 30.4 (warp) x 23.2 (weft) of F2. The drape coefficient among the fabrics was found minimum in F2 i.e. 69.64 and Maximum in F1 i.e. 90.17. In thickness measurement too, F2 was found to be minimum and F3 had the maximum value. The highest crease recovery in the warp direction of the developed fabrics was observed in F2 and in the weft direction, it was F3. In the case of tearing strength, the values were F3-4140.8, F1-3788.8 and F2-3648. F1 (sisal/cotton) had the maximum tensile strength both in warp and weft direction. The abrasion test was done at different intervals 20 cycles, 30 cycles, and 60 cycles. Similar bending length was found in all three fabrics. The study concluded that F3 had shown good results in tearing strength and abrasion resistance. On the other hand, F2 sisal/cotton-viscous showed good drapability, crease recovery, and bending length. However, to overcome the hardness of sisal for making a garment, the lining could be used. The developed union fabrics could be used in upholsteries, curtains, room dividers, table runners, wall hangings, folders, bags etc. The study would impart market value to sisal fibre by enhancing the profit of sisal farming.

‘Studies on tensile behaviour of Ramie blended yarns’ was the study investigated by Sett, S.K., Mukhopadhyay, A., Biswas, M., et al. (2016). For blending, ramie and pineapple fibre were cut into 39mm staple and viscous fibre of the same length was used. Ramie/viscous and ramie/pineapple blends were prepared in the proportions of 75:25, 50:50, 25:75, and 100 % ramie. A cotton spinning system was used for making yarn. The properties of the fibres were tested. The Tenacity (cN/tex) values of the viscose, pineapple and ramie were 25.24, 30.18 and 37.14 respectively. Maximum extension was found in viscose i.e. 14.22%, followed by pineapple- 4.81% and ramie-3.58%. The fineness (tex) of viscose was 0.17, pineapple-2.1 and 1.2 for ramie. The tensile properties of the blended yarns are shown in the table below-

Table 2.5: The tensile properties of the ramie blended yarns

Yarn	Tenacity(cN/tex)	Initial modulus(N/tex)	Breaking Extension%
100% R	9.02	2.93	3.31
75:25 RV	8.99	2.26	3.84
50:50 RV	8.79	2.3	4.63
25:75 RV	10	1.58	7.19
100% V	11.75	1.66	9.27
75:25 RP	7.36	1.7	2.76
50:50 RP	7.4	2.12	2.59
25:75 RP	6.5	1.96	2.51
100% P	4.62	1.61	2.08

From the results, the study concluded that the properties of the blended yarns with compatibilities between the fibres were most dependent on the tensile and fineness properties. The three major properties that governed the characteristics of the blended yarns at different proportions were fibre tenacity, breaking extension and fineness.

Yassin, H., Hassan, N., and Sean, H. (2018) conducted a study "Experiment on Abaca fibre and its implementation in product making". To identify the potential area for new products to be created handmade paper from the abaca fibre was developed and analyzed. The handmade paper was analyzed to determine the fibre thickness, texture, and translucency features. According to this parameter, a design prototype was developed according to the end use which was lampshade. Different thicknesses of 1mm, 3mm, and 5mm of abaca fibre handmade paper were developed based on 'with pressing' and 'without pressing'. Under pressing, couching-pressing-drying was followed to make sheets A, B and C. Only drying was followed far without pressing and sheets D, E and F were developed. The developed sheets A, B, C, D, E and F were tested with 4-watt, 5-watt & 8-watt LEDs of warm white bulbs and 5-watt and 8-watt of cool daylight bulbs. Based on the thickness, toughness, ability to shape and translucency, sheet E (3mm without pressing) was selected as the best material for the lampshade design and 4 watt warm white bulb was chosen for the lightening. The design of the lampshade was inspired by the Japanese Senben tori. The developed sheet used in making the lampshade was in its natural colour. Under various factors- aesthetic, ergonomic, construction method, safeness, sustainability, functionality, and cost, the lampshade prototype was successfully made. Further studies on abaca fibre with natural dyes to make this type of material were recommended. A combination of this fibre with other natural fibres to develop new products for economic development was suggested.

Suvitha, L. (2021) investigated a study on the fabrication and evaluation of agave Americana leaf fibre. Water retting and manual extraction of the fibre followed by w scouring and bleaching were carried out. For scouring, sodium hydroxide (0.2 to 0.3 g/l) and 0.5g/l non-ionic detergent solution were used at 40 to 50ºC for 30 mins with the MLR of 1:20. Hydrogen peroxide at 0.5g/l was used for bleaching and same temp, time and MLR 1:20 was maintained same as the scouring process. The treated fibre was softened with 2.5 per cent Turkey red oil and spun on a jute spinning system. 100 per cent agave yarn was prepared at the rate of 3500m/Kg and 4500m/kg. The prepared yarn was woven on the handloom with plain weave and dyed with the dye solution containing 2.5 per cent cold brand reactive dyes, 3gm salt, and 1 gm soda ash at 30ºC for 1hr maintaining MLR 1:20. To overcome the stiffness, the dyed fabric was treated with 1-2 per cent silicon for 30 min at room temperature with the MLR of 1:10 followed by washing with cold water and drying. The results showed the following properties: micron of the fibre 17.73 µm, the linear density of 458 deniers, at the constant temperature 25ºC, the density valued ranged from 0.475-0.497 g/cc, degree of crystalline 65.625 per cent and 10.02 per cent moisture content and the breaking strength and elongation was 802.20g and 6.58 per cent respectively. The CV (coefficient of variation) of breaking strength and elongation was 36.75 per cent and 16 per cent respectively. The fabric Thickness was 2.88mm for the unfinished and 3.13 mm for the silicon finished. More absorbency occurred in the case of silicon-treated fabric. In the wash fastness test, a good wash fastness property was observed. Good rub fastness in dry rubbing and average rub fastness in wet rubbing were found. The Agave Americana fibre extraction was concluded as an eco-friendly, effective and affordable process. The fibre was too stiff hence found difficulties in the spinning process. Due to the stiffness weaving on power-loom was not possible. The stiffness of the handloom woven fabric could be reduced with the use of silicon. The dyeing behaviour and fastness properties of the treated fabric were good. Further research on softening of the fibre to overcome the stiffness was recommended. Since the fabric had good results in reactive dyeing, another study on dyeing the fibre with natural dyes was expected as a future scope.

2.2.1.1 Agro waste fiber

Production of cost-effective, biodegradable, disposable feminine sanitary pads of 200mm (small size) & 260 mm (large size) using banana fibre was studied by Petchimuthu, P., Petchimuthu R., Basha, A. S., et al. (2019). The adopted methodology was 1. Preparation of banana fibre sheet – extraction of banana fibre was done manually and the fibre was cut into small pieces. Boiling with distilled water and sodium hydroxide was done for an hour. Filtration was carried out and the filtered fibre was moulded to a required shape and dried. The banana sheet was made by using this dried fibre. 2. Softening of canvas cloth- the canvas fabric was used as a top layer in making the sanitary napkins. To soften the starched cloth, scrubbing with a brush was done. This process also increased the pore size of the cloth. 3. Layering of the sanitary napkin was carried out in this way- a. Canvas fabric b. muslin fabric c. cotton d. banana fibre e. cotton f. Muslin fabric g. Canvas fabric. As per the survey conducted women preferred sanitary pads that can be used for 3-4 hours and wanted to try different brands with chemical free. UV sterilization test showed good results that had an absorbance capacity of 5 hours without rashes or foul smell, pH 7.5-8.5, no fluorescence, and dispersibility was observed in water within 6 minutes. The produced sanitary napkins were distributed in the villages. Eco-friendly and cost-effective sanitary pads as a replacement for non-biodegradable napkins could be achieved using natural resources.

Sugarcane bagasse (SCB) and its potential use for textile effluent treatment were studied by Orjnela, C, C, J., Anaguano, H, A., & Restrepo, M, A., (2017). The feasibility of using SCB (sugarcane bagasse) as an alternative, potential, and low-cost absorbent for the removal of dye (BR46) was the aim of the study. The parameters- point of zero charge, pH, size of the particle, absorbent dosage, dye concentration, contact time and ionic strength were determined for the optimization and correlation using a full 24 factorial (composite design based on the factors) and a central composite design of the experiment. Absorbent pre-treatment was done with washing using deionized water and 2% (v/v) hydrogen peroxide to remove organic materials followed by oven drying at 100oC for 4hr. The compositional analysis of the fibre was performed and the point zero charge (the pH at which the net charge of the absorbent surface equals zero) was determined using the Farahani and co-workers' method. For the preparation of dye solution BR46 dye–cationic, an azo compound group was used. To establish the influence of the variables pH and particle size in the dye removal onto SCB, some preliminary experiments were conducted. The optimum pH of the fibre was 6.0 and particle size was 30 gL-1. The effect of the ionic strength was carried out with the solution of calcium chloride and sodium in the range of 0.0 to 0.2 mlL-1 at room temperature. The 24 full factorial design analysis provided that the most important factor in the dye removal was the dosage of SCB with a positive effect. The central composite design allowed reaching a maximum dye removal of 95 % under 40mg L-1 initial concentration (dye), 6.7gL-1 dosage (fibre), 6pH and contact time was 2hr. The results suggested that SCB could be a non-conventional absorbent for BR46 dye removal from the solution. The use of SCB in the removal of dye effluent would be an instrument for the improvement of environmental aspects.

Adam, A., Yusof, Y., and Yahya, A. (2016) conducted research on "Extraction of pineapple leaf fibre: Josapine and Moris. Both varieties Josapine and Moris were extracted by using pineapple leaf fibre machine 1 (PALF M1). The extracted fibre was categorized as wet (freshly extracted fibre), dried (dried after extraction), and usable (ratio of dried fibre and original fibre). 5-8 months old leaves were used. Treatment of the leaves with NaCo3 and hot water at 100oC was done for 5 minutes before the machine extraction to speed up the extraction process or to reduce damage to fibre. The fibre yield percentage was calculated after extraction. The Josapine leaf had an average weight of 42.75g and 43.87g for 5 months and 8 months respectively and Moris had a weight of 35.58g and 35.81 for 5 months and 8 months respectively. Josapine were heavier and had bigger leaves. Leaves that were treated with sodium bicarbonate fibre gave more dried fibre percentage in the case of Mors i.e. 71% as compared to Josapine, 65%. However, 8-month leaves of Josapine had a higher dried fibre percentage than Moris in all the conducted tests. The dried fibre percentage for No treatment- was 74% and 73%, Hot water treatment- was 71% and 67% and Sodium bicarbonate- was 80% and 78% for Josapine and Moris varieties respectively. The wet fibre percentage of 5 months of Josapine and Moris leaves- No treatment- 16.74% & 13.92%, hot water treatment- 18.01% & 12.33%, and sodium bicarbonate treatment -13.90% and 14.69% respectively. The 8-month leaves Josapine had higher values in all treatments except the sodium bicarbonate treatment. From the result analysis, Josapine could be more suitable for fibre production for industrial uses. In addition, Josapine fruits had a higher price than Moris fruits therefore, it would be a better selection for the production.

2.2.1.2 Pineapple leaf fiber

Zhuang, Z., Zhang, J., Li, M., & et al. (2016) conducted a study on optimizing the extraction of the antibacterial compound from pineapple leaf fibre with the aim of separation and purification of the active substances from the fibre by providing a theoretical basis and basic data. Self-developed semi-automatic extractor was used for the extraction of fibre. For the test of antibacterial from extracted fibre, Escherichia coli ATCC25922 was used. Dry fibres were powdered and added to a single solvent of 400ml each containing chloroform, ethyl acetate, acetone, petroleum ether, or distilled water and water bathed for 2hr and cooled to 25^{o}C. Filtration and evaporation were followed and stored in a refrigerator at 4^{o}C. This process was adopted for the preparation of polar crude extracts. Agar diffusion was done to study the bacteriostatic activity. Qualitative analysis was done on the 5 extract samples using special colour-developing agents. Determination of optimal parameters was done by adopting an orthogonal experiment. The antibacterial activity was observed only in the extracts of ethyl acetate (10.20mm), acetone, and distilled water (12.32mm) with acetone having the greatest inhibition zone i.e. 14.76mm. The qualitative analysis of 5 extracts using the special colour-developing agent provided flavonoids and phenols from all the extracts except the petroleum ether extract. The obtained flavonoid and phenols could be from Cannabis saliva and Apocynum venetum. Therefore, pineapple leaf fibre likely contained the two said compounds. Acetone extract was used to check the optimal parameters since it had the greatest antibacterial activity. With the consideration of extraction rates and antibacterial activity, optimum temperature, time and solid-liquid ratio were 45oc, 8hr, and 1:40 (g/ml) respectively. The optimal process condition obtained from the orthogonal experiment was found suitable for the extraction of an antibacterial substance from the fibre.

Agarwal N, (2018) conducted an exploratory study on Pineapple fibres for its use in woven textiles. The objectives were to study the fiber with respect to its cultivation regions extraction of the fibre, the feasibility of making yarn, and construction fabric from it. Testing the properties of prepared yarn and developed fabrics was involved.

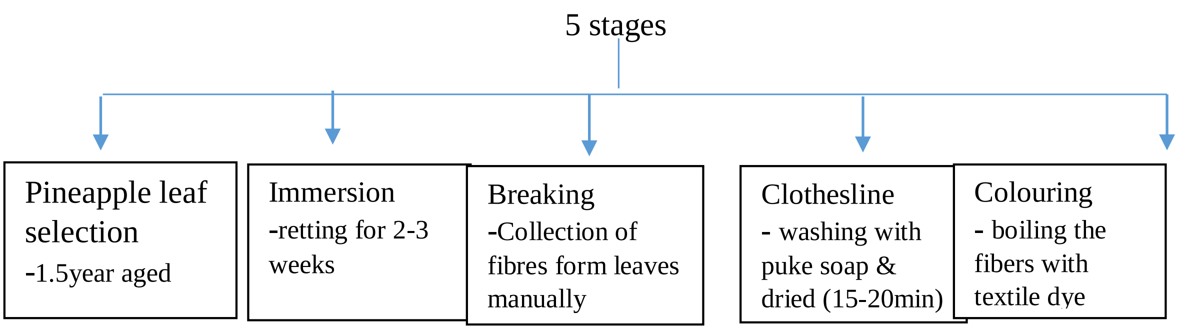
The procurement of fiber and treatment with chemicals & enzymes were done. For the chemical treatment, fibres were scoured with 4% conc. Of Na_2CO_3 at 70^o- 80^o C at pH 10-12 for 1hr maintaining a liquor ratio of 1:40. The scoured fibers were bleached with H_2O_2 for 1hr at 80^o C maintaining pH 3-4 in the liquor ratio of 1:40. In enzymatic treatment, 1% conc. of pectinase and 1% conc. of cellulose were used and the fibres were treated with this enzyme for 2, 4, 8hr separately. After the treatment of fiber, the application of an optimized treatment, yarn preparation and physical testing was involved. Preparation of fabric, physical properties testing and analysis were done. From the results and discussions, it was concluded that scoured + bleached fiber is considered the best treatment with the highest whiteness index by maintaining its tensile strength. Among the two enzymes, pectinase treatment for 4hr showed good results with the increase in tensile strength. Union fabrics were developed using 100% pineapple in weft and 100% cotton in warp. Blended fabrics with ratios of 90: 10, 70: 30, and 50:50 viscose/pineapple were also developed. Twill weave had maximum strength and thickness as compared to the other two weaves i.e. plain and satin weave due to the number of intersections per repeat. On the other hand, more open structure and strength decrease were observed when the ratio of pineapple fibre was increased. Therefore, the study observed that pineapple leaf fiber could be a source for manufacturing apparel and home textiles.

Ismoilove, K., Chauhan, S., Yang, M., & Heng, Q.,(2019) experimented research on the spinning system for pineapple leaf fiber via Cotton spinning system by Solo and Binary blending and identifying yarn properties. For the testing and analysis of properties i.e. fiber length, fibre morphology, and tensile properties, the fiber obtained was chopped off to make staple length. Two separate types of research were conducted with the consideration to produce resultant yarn by spinning of PALF. 1) Yarn derived by solo spinning technique of 100% PALF and 2) PALF blended with polyester and cotton fibres through binary blending technique in equal proportion(50% PALF + 50% cotton) & (50% PALF + 50% polyester) had been spun, after evaluation and analyze. All the three types of yarn showed good tensile strength than the solo staple fiber yarn but with poor yarn evenness. All the prepared yarn had good tensile strength despite having unevenness. However, Pretreatment and spinning modification could be performed to increase the yarn evenness. PALF can be used in making breathable apparel since it is a natural cellulosic fiber which has hydrophilic properties. This fiber can be used in producing garments by giving efficient modification.

J. Juraidi, N. Shuhairul, S. Azuan, et al. (2013) led an investigation of the tensile properties of pineapple leaf fiber and pineapple peduncle fiber-supported polyester composites. Composites were created utilizing leaf fiber and peduncle fiber with fluctuating fiber length and fiber stacking. The two strands were blended in with polyester composites the different fiber volume parts of 4, 8 and 12% and with three distinct fiber lengths of 10, 20 and 30 mm. The composite boards were manufactured utilizing a hand-spread-out strategy. The tractable test was done to understand ASTM D638. The outcome showed that pineapple peduncle fiber with 4% fiber volume division and fiber length of 30 mm gives the most noteworthy elastic properties. From the general outcomes, pineapple peduncle fiber showed higher tractable properties contrasted with pineapple leaf fiber. It was discovered that by expanding the fiber volume division the malleable properties have altogether diminished yet by expanding the fiber length, the tractable properties will be expanded relatively. Minitab software was utilized to play out the two-way ANOVA investigation to gauge the huge. From the investigation done, there is a huge impact of fiber volume portion and fiber length on the elastic properties.

Yusof Y., Yahya A S., and Adam A. (2014) studied a new approach for PALF (pineapple leaf fiber) production and spinning system with surface treatments on the fiber and compared it with the hand extracted. The fresh leaves collected after harvesting were extracted within three days to get good-quality of fibers by using PALF M1 (pineapple leaf fiber extraction machine). After the extraction, the fibres were scoured and dried by utilizing PALF M2 (pineapple leaf fiber scouring machine). Three treatments – an alkaline treatment, a heat treatment, and a combination of alkaline and heat treatment were applied to the scoured fibres. For the first treatment, in a solution of 3% Na2CO3, untreated PALF was immersed for 1hr and washed several times by using distilled water to get it neutralized and kept as an alkaline treated PALF. In heat treatment, the fibres were boiled for 1hr at 100o C. For the combination of heat and alkaline treatment, PALF was first boiled at 100oC and sun-dried before putting into the 3% Na2CO3 solution for 1 hr. All the treated fibres were sun-dried. Results revealed that the average diameter of both untreated and treated PALF extracted by the machine PALF M1 and the conventional method was 75.7µm and 90.7µm respectively. Finer and thinner fibres were observed in PALF M1. A higher tensile strength and modulus value of 613.75 MPa & 1379500.0GPa respectively was shown in PALF M1 PALF. The lowest tensile properties (393.70MPa & 7254.2GPa) were seen in the PALF extracted using the conventional hand-scrapping method. On the other hand, the tensile properties of the treated and untreated PALF had an increase in tensile strength with surface treatment. However, heat treatment did not provide significantly enhanced tensile strength. Apparently, a combination of heat and alkali-treated PALF showed lower tensile properties- 312.10MPa & 2155.3GPa than the untreated PALF. For the hand scrapping PALF, the highest tensile strength of 551.49MPa compared to other samples was found in alkali treatment. 100% PALF was spun on a cotton spinning system with some modifications and produced a favourable tenacity of 14.0g/tex. The study recommended that coarser PALF can be done by softening treatments by using acid, alkali, or axes. Further studies were required for the hairiness of PALF. Developmental work for the extraction, and treatments especially for wet strength improvement were required. Assured enough supply of natural fiber including PALF was needed. The increase in the plantation of pineapple and its industrial importance made economic and environmental sense to enhance the research and development on PALF production and utilization.

Widowati T., & Amalia N S A. (2021) experimented with the utilization of pineapple leaf fiber for making false eyelashes. Checking the feasibility of pineapple leaf fiber utilization as a material for manufacturing false eyelashes was studied. A descriptive percentage analysis of documentation with a quantitative approach to demonstrate the feasibility of using the fiber for parties was used and an organoleptic test was done. The eyelash was produced under certain steps- first, pineapple leaf fiber processing which was done manually included 5 stages-



pineapple leaf selection, immersion/washing, breaking, translation and colouring. 1.5-year-old pineapple plants were selected for the extraction. Immersion i.e. retting was done for 2-3 weeks. Breaking- collection of fibers from the leaves was done manually and washing with puke soap until clean and sun-dried for 15-20 min were followed. For dyeing, boiling the fibers with textile dye was performed. For the eyelash production, the fiber was knotted on the strings of the strands mounted on 2 spikes with a length of 2.5 to 3cm with a desired thickness according to the model for parties. Straightening the eyelashes with ironing and then rolling on the pipe coated with toni paper with a little moist on it was followed. Unrolling and tidying up the shape of the eyelashes were done after preheating in the oven for ±5 min. The validity assessment was examined based on the eyelash's shape, colour, texture, neatness and harmony. The assessment was carried out by vocational school teachers, eyelash craftsmen, beauticians, and saloon owners. It was found that all the experts had given a result very feasible ranging from 85%-95%. Similarly, the sensory test assessment was taken by 3 expert groups- vocational school teacher, saloon owner, and home industry owner of false eyelashes and the result was also 'very feasible' (rated by 86.67% experts on average)based on the criteria shape, colour, texture, and neatness. The preference-based shape, colour, ease of use, and neatness test was found to be very feasible (93%) by the 15 semi-trained panellists i.e. students of the beauty education program. Hence, the use of pineapple leaf fiber in making false eyelashes was feasible.

Research on the effect of pretreatment in the processing of pineapple leaf fibers was conducted by Malou R.J., Tita W., Perret J., et al. (2017). The effect of hot water pretreatment on crushed pineapple leaves for a short time and comparison with alkali-treated pineapple leaves by analyzing the physical properties of the extracted fibre were the objectives. For the pretreatment, a length of 0.15m leaves were cut and crushed. For hot water treatment (treatment A), the leaves were boiled for 15, 30, and 45 minutes at varying temperatures (50, 70, and 90°C) during the pre-treatments and oven-dried at 60° C for 24 h then strands were decorticated. In alkali pretreatment (treatment B), pineapple leaves were submerged in alkali (NaOH) at 3 different concentrations. (2, 4, and 6% w/w) for 3 treatment time (2, 4, and 6 h). After the leaves were oven-dried for 24 hours at 60^{o} C. Afterwards, the Physical properties of these fibre strands were assessed. Colour difference values ΔL*, Δa* and Δb* of PALF after hot water and alkali treatments were estimated by concerning non-treated PALF (control). The highest average tensile strength of 1206.3±753.02 MPa was found in the PALF treated at 70°C for 15 min. The minimum tensile strength of 353.1± 41.51 MPa was recorded with the PALF treated at 50°C for 45 min. The PALF showed an increment in its tensile strength with an increase in the conc. of Alkali and treatment time. The maximum tensile strength was 1137.2 MPa (PALF treated with 2% alkali solution for 6 hrs) and the minimum was 553.5 MPa (PALF treated with 2% alkali solution for 2 hrs).

The tensile strength of two pre-treated PALF fell within the satisfactory range for industrial applications. Control PALF samples had the highest percentage of elongation, followed by PALF treated at 50°C for 15 minutes and 70°C for 15 min. In treatment B, it was found that control PALF samples had the highest elongation, followed by PALF treated with 2% NaOH for 4 hrs 4% NaOH for 2 hrs, and 6% NaOH for 6 hrs as the lowest elongation. The study concluded that treatment A PALF showed higher values of change in colour (ΔE), with higher L* values which give brightness/whiteness. While analysis of the treatments revealed that 6% of alkali-treated PALF had the best surface properties. In terms of tensile strength and percentage elongation, there was no significant difference between the outcomes of the two treatments.

2.2.2 Natural minor fiber application in traditional textiles

To examine the potential use of pineapple leaf fiber in the batik textile restoration was carried out by Kamarudin Z., Yusof Mohd F N. (2016). The study was carried out in two stages with the following steps, first- preparation of material to make fiber thread from pineapple leaves, 1. Selection of leaves, 2. Cleaning of selected leaves, and 3. Extraction of fiber from the leaf's second stage was- fundamental experimentation on the fiber chemical and physical properties to determine its 1. Acidity 2. Moisture content 3. Density ratio, shape identification, tensile strength and extensibility. The colour red, blue and yellow were used for dyeing and examination of the dye absorbency of the fiber.

The result showed a pH level between 5.63 i.e. 5 to 6 (weak acid). Hence, it was safe to be used for the restoration. The moisture content value was found to be good i.e. 6-15 and the density of the fiber was about 1.301(g/cm3) which the value was within the range of natural fiber density. The average tensile strength values of both pure and PALF with CMC were 0.237 KGF and 0.422 KGF respectively. Results on the dyed fiber showed the fiber had the ability to absorb the batik colour and based on the restoration experiment, it could be used for the conservation of batik textile since it had fine thread and was not easily seen. Therefore, the pineapple leaf fiber had the potential to make an eco-friendly thread for the restoration of the textile. The use of pineapple leaf fibre in replacement of man-made fiber was highly recommended. Extensive research was recommended for the chemical properties, biotechnological and engineering aspects to improve the quality and application.

Kordhanyamath J., & Bai K S. (2019) studied on the specialty of banana yarn on Ilkal handloom sarees woven with murgi motif. Selection and implementation of banana yarn and regenerated cellulose yarns in Ilkal sarees using murgi motif to encourage traditional handloom weaving, digitization of kasuti murgi motif for jacquard weaving technique, acceptance from the targeted customers were the objectives of the study. In materials and methods, 1kg of cotton yarn for the warp, 600 of modal yarn for the weft, and 200 gm of banana yarn for weaving the motif were used for one saree and the same quantity of these materials with the replacement of modal with bamboo was used for weaving another saree. Vat dyes (maroon-P.n-1617, black-P.n-13911), chikkiparas border, and a traditional murgi motif-elephant motif were used. Digitizing the selected motif, punch card preparation, jacquard set up with 256 hooks, and prin winding was done for modal, bamboo and banana. The loom was ready for weaving with the kondi warp technique. For cotton/modal saree, maroon pallu except for the two solid portions in cream color and cream colour body were used. Different colour combination was used in the case of cotton/bamboo saree. Acceptance of the developed sarees was taken by interviewing 50 women of 25-30 age group. From the results and discussion, 95% of women felt that incorporating of kasuti murgi motif in Ilkal sarees was an excellent idea while remaining rated as a good idea. For the idea of introducing banana yarns and regenerated cellulose yarns in the saree, 86% rated excellent and 13% rated good. The use of the elephant motif was rated excellent by 92% of women and the remaining felt good. 92% of women appreciated the colour combination. The interviewed women gave a positive response by appreciating the changes in yarn and colour combination without affecting the traditional Ilkal kondi weaving technique. The study had lent a new way to the traditional Ilkal sarees while retaining the traditional kondi technique and handloom weaving.

Bhardwaj S., & Pant S. (2017) conducted a study on nettle, acrylic blend with ratios of 70/30, 50/50 & 30/30. From the blends, yarn count of 16Ne and 24Ne with Z twist were prepared on ring spinning. Yarn with count 24Ne yarn could not be prepared from the blend of 70/30. On the hand carding machine, only 7Ne yarn was produced since it was not possible to produce 16Ne and 24Ne yarns. The fabrics were developed on the handloom with plain weave. Union dyeing of reactive dyes and acid dye was conducted with different percentages of dye exhaustion. Colour fastness tests based on washing, ironing, crocking and sunlight were carried out. From the developed fabrics, three garments- kurti, jacket and gents shirt were made. The findings of this study revealed that the rough and yellowish nettle fiber was stronger than acrylic fibre and had more breaking elongation. The blends of 16Ne yarns were stronger than the 24Ne blended yarns but had more yarn hairiness. 16Ne yarn had more evenness than 24Ne yarn.

In the case of fabric, with an increase in the component of the nettle fibre & cloth cover factor weight of the fabric increased. More abrasion resistance in blended fabrics, 16Ne fabrics provided more stiffness and high flexural rigidity, and more percentage of acrylic in blended fabrics had less stiffness and better drape ability. Not much difference in drape coefficient was observed between 16Ne and 24Ne fabrics but the latter had more crease recovery value. An increase in acrylic improved the crease recovery value. Fabrics made from 16Ne yarns had more tearing strength both in warp and weft compared to the 24Ne fabrics. Highest air permeability in 100% nettle fabric and lowest in 100% acrylic fabric.

In dyeing, maximum dye exhaustion was found in the pure nettle fabric, excellent to very good in light fastness, noticeable changes in colour in the wash fastness test, excellent with negligible stain in ironing, and good in both dry and wet crock fastness test. From the above findings, it was concluded that a blend of these two fibres could be used for making apparel. Blending with other fibres, spinning on different spinning systems, chemical finishing, and different types of weaves were the recommendations for further study.

"The possibilities for value addition by printing methods of natural fiber Himalayan nettle Girardinia diversifolia" was studied by Bado R., & Himadri G. (2019). To make 100% nettle fibre yarn and application of different printings on the fabric made from the prepared yarn was the main purpose of this study. However, for the fabric production, yarn preparation was done as a trial on both cotton and jute spinning systems. Due to fibre brittleness and coarser, it was not possible to make 100% nettle yarn with these spinning systems. Then the blending of fibre with viscous was carried out with a cotton spinning system and the nettle fibre with jute was done on a jute spinning system. 100% nettle yarn, 50:50 (nettle/jute) yarn, 70:30 & 50:50 (nettle/viscose) yarn were prepared. 100% nettle yarn and nettle/jute yarn were made with a rotor spinning system and a ring spinning system was operated for making the nettle/viscose yarn of 7Ne and 10Ne but 7Ne from 70:30 nettle/viscose blended could not be produced. Plain weave Fabric made from 50:50 nettle/viscose yarn was used because of its fine count (10Ne). After the printing process, physical and chemical testing were conducted. Traditional motifs (buti, lehriya, one geometrical) of Dabu print using naphthol were applied on the constructed fabric and other prints i.e. screen, bagru, block, spray, tie and dye, stencil printing by using pigment, direct, vat and natural dye were done at the pilot stage. Two pieces of footwear and one wallet had been made from the constructed traditional print textile of nettle/viscose fabric. Dyeing was done at the yarn stage and 100% nettle yarn had shown good results in basic dyes and natural dye in the case of direct dyes, it had an uneven distribution of dye making patching and dull shade with poor wash fastness but it had good light fastness. Except for natural dyes, nettle/jute yarn had very dull shades on its surface without the dyes reaching the core, poor wash fastness, and light fastness. However, all the dyes performed very well in nettle/viscose yarn by showing easily dyed, bright colours, and good fastness properties. Hence, it was concluded that Oct to mid-December was the optimum harvesting time, the fibre was resistant to acetic acid but not to sulphuric acid and the blended fibre strands were semi-smooth and had a flat surface under SEM. The nettle fibre blended fibre could be possible to make different counts of yarn and mass production would be feasible since the yarn could be made with a ring spinning system. Dyeing and printing could be performed on the developed fabric. Further studies on the blending ratio of yarn and cost calculation based on the market scenario could be conducted. Fancy and decorative items could be made to benefit the rural people and to give market exposure.

Hwang M S. (2006) conducted a study titled "contemporary hemp weaving in Korea". This study covered hemp fabric production, focusing on the traditional way of fibre production in Andong as well as how people used hemp fabric in the past and present in Korea. The hemp stalks were sorted according to their diameter. 80-100 bundles were steamed for 6-7 hours and the bundles were spread out for sun drying (1 day) in tobacco dryers, stalks were soaked in water for 2 hours and extraction of fibre was done with a metal scraper. Each strip of fibres was split using fingers and followed by combing and sun drying. It took a day to split the fibres to prepare yarn for making a fabric of 15 meters in length and width of 0.35 meters. A continuous length of hemp yarn was prepared by joining the ends of split strands. A traditional body tension loom called baetl was used for weaving the fabrics which was then bleached. Two types of bleaching were followed-for first, the fabric was bleached in a solution of caustic soda and kept in a plastic container, wrapped with a cotton cloth sealed with plastic on the top and maintained at a temp of 25°C. After 2-3 days, the fabric was rinsed several times and for the second bleaching method, bleaching was done with a bleach called sarasi. To get the yellow colour, dyeing with gardenia seedpods was done. Andong people developed a traditional hemp fabric, Andongpoh. Musam was a traditional textile known as a representative of Korean hemp fabric. Musam had a coarser and thicker feature than the Andongpoh. Musam was woven for funeral shrouds. Four kinds of hemp products were marketed- raw fibre, yarn, sambe (daily wear worn by farmers and their servants during summer) and the last one suûi, a set of burial clothing. The most expensive suûi was made with andong hemp fabric. The introduction of Christianity reduced the involvement of hemp garments in funerals. However, there has been a trend of using hemp fabrics in making bedding sets and ordinary summer clothes. People began to realize the drawbacks of synthetic fabrics, therefore, they showed interest towards natural fibres. Hemp fibre was recognized as one of the people's most desirable fibre in Korea.

2.2.3 Dyes on natural fiber

Vashishtha P. (2013) conducted a research work titled 'An experimental study on using waste flowers for extraction of dye and development of colour palette on silk and wool' by keeping in mind the board aim to reduce the waste and reutilize in the form of dye on textile for the maintenance of environment eco-friendly. In this study, colour pigments were extracted from the waste flowers and leaves available in temples and marriage avenues and studied to get an understanding of the process taking place during its application in the colouration of textiles. The colour palette was prepared by using the selected three dyes marigold, rose, and bael leaves and their combination 1:1:1. The mordants used were lemon rind and pomegranate rind (natural mordants) and two metallic mordants- copper sulphate and stanneous chloride. Silk and wool were selected for the application of the dyes. Samples were dyed at different shades using 1%, 3%, 5%, and 7% of dye liquor. Dyed samples were tested and analyzed for K/S value, C.I.E L* a* b*, wash fastness and light fastness, and rub fastness. From the results, lemon rind gave good results and pomegranate rind gave lightness in shades. Copper sulphate as mordant gave the best results in marigold dyed followed by rose, composite and bael leaves dyed samples. Among all the mordants, stannous chloride gave the best results and this mordant showed higher colour depth with rose dye compared to other dyes. Darker shades were obtained from the wool fabric than from silk fabric. No consistent pattern was found between the increase and decrease of dye concentration with colour depth. Excellent to good wash and rub fastness were found in the dyed samples.

Some samples after exposure of 10-15 hours showed darker shade. The study recommended that the supply of waste flowers and leaves as a dye material can be done without any problem, ecologically safe in extraction and dyeing process and a variety of shades with various mordants and concentrations can be produced for the market.

Sricharussin W., Ree-iam P., Phanomchoeng W., & Poolperm S. (2009) conducted a study on the effect of enzymatic treatment on the dyeing of pineapple leaf fibers with natural dyes. Fiber was extracted from the plant leaves and conventional scouring was followed for 30 min at 80^{o} C with the liquor ratio -1:25 containing 1ml/1 of wetting agent- laventin type and 2% owf Sodium hydroxide. The scoured fiber was washed and dried. For the unconventional scouring, enzymatic scouring was conducted. The fiber was scoured for 2hr using pectinase (Pectinex Ultra SPNNM) at 45^{o} C to maintain pH 4.5 and cellulose enzyme at 55^{o} C at pH 7. A solution containing the enzyme, 2% owf, 1ml/1 wetting agent with liquor ration 1:40 was maintained. For the removal of the excess enzyme, boiling of the fiber was done for 10min followed by washing and drying. These two enzymes were used for the treatment separately and dyed the prepared yarns with 5 natural dyes. Yarns were prepared with the treated fiber by using the semi-automatic spinning machine. Both in-house natural dyes and commercial natural dyes were used. In the in-house natural dyes, the dyes were extracted from Indian almond leaves and basts of indica using a liquor ratio 1:40 (4kg in 1 litre). The commercial natural dyes supplied by East Asiatic Ltd. (Thailand) and a distribution company for Silva Chimica (Italy) originated from- Schinopsis lorentzii (orange, CAS 1401-55-4) and chlorophora tinctoria (yellow, CAS 480-16-0) and a mixture of chlorophora tinctoria, Sumac extract, sumac leaves, and indigo (green). The yarns were dyed with 2% owf, liquor ratio 1:40 at 60^{o} for 30 min. In the 1% ferrous sulphate solution at 40^{o} C, the yarns were immersed for 10 min before proceeding with the same dyeing process while conducting the experiment with a conventional pre-mordant process. The properties of dyed fibre were studied and a comparison between the enzyme-treated fiber and NaOH-treated fiber (with or without inorganic mordant) was done. From the results, the NaOH-treated fiber had greater weight loss than the enzyme-treated, enzymes led to higher dye exhaustion, comparable or greater strength, and lighter shades close to those of the NaOH-treated fiber without mordants but similar light fastness ranging from 3-4. The fiber treated with ferrous sulphate showed lower L* (darker shades). The basts of indica dyed yarn showed a high value of L* and b*. Therefore, enzyme-treated pineapple leaf fibre could be effectively dyed with natural dyes. Enzymatic scouring of the fiber could be an alternative to conventional scouring with mordant pretreatment. The use of enzymes could help in reducing environmental impact and appealing to the consumer.

Sharma Manoranjan H., Devi Radhaoriya A., and Sharma Manihar B. (2005) conducted a study on vegetable dyes used by the Meitei Community of Manipur. The study Describes 34 species of plant belonging to 30 families used in the extraction of natural dyes by the Meitei community. Parts of the plant used, extraction methods and their uses were included in the study. It also identified the plants that are used as mordents from these 34 species. People who still engaged in old traditions were interviewed during 1997-2002. Written documents and the reports available in the local were involved in the investigation. The colour of these dyes used in handloom products i.e. phanek mayek naiba- thambal leikhok macho, higok machu & sana phige machu, Rani phi in sana phige macho was also observed. The plant species involved in this study were categorized as dye-yielding plants (34 species), Plants used as sources of alkaline dye mordant, and acidic dye mordant plants. From the study, it could be concluded that the local people were still practising the dyeing of handloom products with natural dyes extracted from the plants. So far no systematic investigation has been performed to explore all the dye-yielding plants in the state. The hues and chroma of the extracted natural dyes didn't match with synthetic dyes. Recommendation of locally available natural dyes could be made for dyeing the handloom products like pungou phanek, thangjing mapal phanek, muga phanek, etc. Further study on the total number of dyes yielding plants could be performed. Needs of effort to increase the use of natural dyes on a larger scale, conservation and revival of these dyes were mentioned in the study.

Akhter A., Hossain K Md., Khatun S., et al.(2014) investigated on dyeing effect on mordanted & un-mordanted silk-fabrics by using green coconut (cocos nucifera) shells from local markets as vegetable dye. In the prepared dye conc., the identification of the phenolic compound was examined by applying ferric chloride test. A solution of extracted dye, ethyl alcohol and 1N HCL 1ml each and 3% ferric chloride solution was prepared. The presence of phenolic compounds was found in the solution. The silk fabrics of size 25x30 cm were boiled in the 3% soap solution for 1hr followed by washing with distilled water for degumming it. In the mordanting process, treatment of fabric with an aqueous solution of 2% stannous chloride, 1% sodium potassium tartrate or cream of tartar and oxalic acid at

90^o C ± 5^o C for 20min was done. Application of trisodium phosphate at 90^o C ± 5^o C for 20 min on fabric was carried out for the fixation of mordant. Dyeing was done in a solution of 2-5% dye containing phosphoric acid (buffering agent) at pH 3-5 for 1 hr. The same procedure was followed for 2% aluminium sulphate. MLR 20:1 was maintained in both mordanting and dyeing. During the testing of fastness properties, the dyed samples were exposed to sunlight for 8hrs a day for 15 consecutive days and the samples were washed with a solution of 3% soap for 20 min and dried respectively. The results showed that silk fabric can be used for dyeing with green coconut shells by applying mordant. The pH of the dye bath, the concentration of the dye, and the dyeing period affected the shades on both mordanted and unmordanted fabric samples. The shades were changed from light to medium at the increase in pH range, above 4.5 showed almost the same result as pH 4-4.5. The optimum pH of mordanted fabric was 4-4.5 for 2% and 3% dye conc. and 3-3.5 for 5% conc. The optimum time in all cases was 1 hour. The influence of pH on the shades was revealed as a reason for the different in the extent of protonation of -NH3+ ion of the silk fabric and subsequent combination between negatively charged hydroxyl groups present in the polyphenolic compounds of the dye molecule. Appreciable color and good light fastness and wash fastness were achieved on the silk fabrics dyed with green coconut shell dye. More dull and poor to slight fast to light and distinct loss in depth of dyeing occurred on unmordanted fabrics washing with soap. Mordanted fabric showed an increase in light to medium to heavy shades with fair to good fastness properties. Therefore, the study concluded as utilization of the waste green coconut shell can be a cheap source of vegetable dye in silk fabric.

Investigation on morphological, mechanical, and color strength properties of IR (infrared) dyed pineapple leaf fibers in comparison with the conventional EX (exhaustion) dyeing technique was conducted by Amin Mohd N A., Ruznan S W., Suhaini A S., et al. (2023). Water retting of leaves for 75 hours was involved prior to the manual extraction method. After extraction, combing and hot air oven dry on the fibers at 70^o C for 30 min were carried out. The surface morphology of the dyed fiber was examined by using SEM and the tensile strength of the raw fiber and the dyed fiber was tested. In both dyeing methods, four samples of approximately 5g each were selected and dyed with the concentrations 0.25%, 1%, 2% and 4% each of three primary colours reactive red 11, reactive blue 5, and reactive yellow 86 using liquor ratio 1:20, soda ash at 20g/L and sodium chloride at 60g/L with 70°C for 60mins and soaping with 5g/L standard soap for 20min at 100oC and oven dry were performed. From the SEM analysis, no significant difference between samples was found. The highest breaking strength of raw pineapple leaf fibre occurred at 82.60N/mm2. The highest breaking strength- 69.60 N/mm2 of the dyed fiber was gained in red reactive dye samples at 1% dye conc. of IR dyeing. The lowest value was 51.90 N/mm2 at 0.25% dye conc. of reactive red EX dyeing technique. In comparison, more force was required to break the fiber dyed with IR dyeing. However, the fiber dyed with 2% conc. in EX dyeing had a higher breaking strength value than IR dyeing. Standard deviations for each dye were calculated. The result of the wash fastness of all the samples was found to be good (4) to very good (4/5). Similar perspiration results- moderate (3/4) to very good (4) in both dyeing techniques were observed. IR dyeing provided excellent light fastness similar to conventional EX dyeing. At each dye conc. higher K/S values in IR dyeing were obtained. Therefore, the investigation concluded that IR dyeing was found to be an optimum process for dyeing the fiber by providing brilliant colour shades and higher colour strength value. The use of the IR dyeing technique on pineapple leaf fiber was indicated as an eco-friendly dyeing process. Further studies on IR dyeing on other natural fibers with different dyes were recommended.

'Study of natural dyes and pineapple leaf fibre growing locations within plant stems on dyeing intensity' was conducted by Rej, A., Adhiguna, T. R., Rajagukguk, G, B. (2018) Suji leaves, turmeric, and sappan wood were used for dyeing the fibre. The location of the pineapple leaves within the plant stem were divided as the base (0-100mm), the middle (100.1-200mm), and the top (200.1-300mm). The physical properties of the dyed sample were measured using a procedure reported by Billmeyer and Saltzman and analysis was done using the analysis of variance processed with differences (significant $P < 0.05$). From the effect of natural dyes types on color intensity- the fibre dyed with suji leaf extract had highest L* value i.e. 59.73 while sappan wood lad lowest value 4.40. The highest a* value was found in turmeric i.e. 12.57 with the lowest value in Suji leave dyed i.e. 6.63. The highest value of b* was also observed in turmeric (22.67) while the lowest was sappan wood dyed (4.80). In the results of effect of fibre growing location on colour intensity, the pineapple leaf fibre grown in the base and middle within the stem impacted the brightness intensity (L*). The highest value was 53.17 of the base and the lowest was 49.00 of the top portion. The highest average a* intensity value was found in the middle i.e. 10.10 and the lowest was found in the base with value of 12.53. Therefore, a* b* was affected by the growing location within the plant stems. The study concluded that the utilization of pineapple leaf fibre from the base of the plant was found more suitable for textile raw material because of its higher lightness value.

Khan, A., Mahummad, S., Razzaque, A., et al. (2009) studied on grafting of acrylonitrile monomer onto bleached okra bast fibre and its textile properties. The modification was initiated under the potassium persulphate-ferrous sulphate redox system. For the treatment of okra bast fibre (OBF) – 1). Scouring was done by using 3.5 g sodium carbonate and 6.5 g detergent per litre of water at 60^o C for 30 min maintaining 1:50 MLR. 2). Bleaching was carried out in a solution of 0.7% sodium chlorite at pH 4 for 2h at 90-95^o C maintaining the MLR 1:50 and the bleached fibre was treated with 2% sodium metabisulphite solution for 15min at MLR 1:50 followed by washing with distilled water. Grafting with acrylonitrile (AN) - Solutions for the grafting bath were prepared by putting the measured amount of dissolved (in distilled water) AN monomer, initiator, and catalyst. Starting from the temp of 30^o C up to 90^o C, the process was carried out for 210 min at 1:50 MLR with occasional stirring and allowed to stand for 30 min to cool down. Hot distilled water was added to the bath to compensate for the loss of water. Testing of tenacity, FTIR and surface morphology of the bleached and AN grafted OBF were conducted. Dyeing on the bleached and grafted fibre was carried out by using two direct dyes. Colour yield, colour strength and C.I.E lab values were calculated. From the results and discussions, the optimum grafting condition of AN & OBF is shown as for monomer concentration was 3 x 10-2 mol L-1, and 4 x 10-3 mol L-1 and 5 x 10-3 mol L-1 were for catalyst conc. and initiator conc. respectively. The treatment time was 120 min, temp 70^o C, and a percentage of 11.48 for graft yield. The FTIR test result showed that the monomer was grafted as the fibre-forming polyacrylonitrile (PAN) on the OBF cellulose substrate. A considerable amount of PAN grafted onto the surface of the OBF was observed during SEM analysis. In dyeing, the K/S value of the bleached fibre was higher than the AN grafted fibre possibly due to the availability of external surface of the fibre and the dye ions. A very similar change of shade was found in both cases of the fibre. However, the AN grafted fibre had a lesser affinity towards moisture and it could protect the yellowness of fibre. The Tenacity and elongation at the break of the grafted fibre were higher than the bleached OBF. Hence, the study concluded that the grafting of AN monomer with Okra bast fibre significantly improved the textile-related physio-chemical properties of OBF. This agricultural waste fibre could be an industrial importance after modification.

‘Dyeing properties of banana fibre dyed with different dyes’ was the study conducted by Islam, T., Kasim, R. Md., Roy, M., et al. (2019). The study initiated the extraction of banana fibre by manual methods followed by a scouring and bleaching process. Dyeing of the scoured-bleached fibre was done using 1.5% dye conc. of different dyes: direct dyes- at temperature 90^{o}C for 40min, basic dyes- 80 ^{o}C for 40 min, reactive dyes- 60 ^{o}C for 40min, vat dyes -70 ^{o}C for 15 min maintaining the 1:20 MLR soda ash and acetic acid were used as an activator of required pH according to the different dyes. After the dyeing process- an assessment of the whiteness index value of scoured- -bleached samples, and an assessment of colour fastness to wash fasting were conducted. From the results, the average whiteness of the grey banana fibre and scoured bleached were 14.22 and 58.88 (three times higher) respectively. The wash fastness was assessed by obeying the ISO 105 C06 method. The results showed that the banana fibre dyed with VAT dyes had better results (4-5 rating) than the other samples which had comparatively low but acceptable. In the case of colour staining sample dyed with vat and reactive dyes provided an excellent rating. The ISO 105 x 12 methods were maintained in the assessment of colour fastness to rubbing almost all the dye samples obtained better results during dry and wet rubbing. Therefore, the properties of the banana fibre could be concluded as suitable for synthetic dyes. From the analysis, it was recommended that the vat, reactive and basic dyes for bulk production of dyed banana fibre.

2.2.4 Threads

2.2.4.1 Threads used in surface ornamentation

To develop a stretchable embroidery thread by using elastane filament, polyvinyl alcohol (PVA) and dyed polyester and viscose fibers on a DREF-3 spinning machine was the aim of the “Development of speciality embroidery thread for application in stretchable knitted fabrics for body fit garments” conducted by Agrawal, N., Parmar, M, S., & Agarwal, V. (2019). For making a thread, 40deneir elastane filament is used as a primary core, PVA fibre as an inner sheath, and polyester & viscose as an outer sheath. Hand and machine embroidery was done on the knitted fabric using the developed embroidery thread and the normal thread. The fabric embroidered in the developed thread was treated with hot water;

the inner sheath- PVA was soluble in water and dissolved. Hence, created the stretchability between the core sheath and the outer sheath. The stretchability was checked at the embroidery area of the fabric. A comparison between the developed embroidery thread count (11.91Ne) and the normal embroidery thread count (2/23.8Ne) was done. It was observed that the quality of the developed thread had slightly poorer quality than the normal embroidery thread in terms of strength, evenness and imperfection because of the friction spinning technology. Before and after washing stretch ability tests were conducted on both the threads and embroidered knitted fabrics. More stretchability was observed in the developed thread and the stretchability at the embroidery area of knitted fabrics was tested in wale-wise and course-wise directions where the stretchability was gained 15% in the hand embroidered fabric with developed thread when compared with the normal thread embroidered fabric. The stretchability gained in the machine embroidery of the developed thread on the knitted fabric was 13-16% when compared with the normal thread embroidered fabric. The developed embroidery thread was given silicon oil treatment to decrease the breakage rate while operating on the embroidery machine. Hand embroidery was found to be satisfactory and it was almost equal to the performance of the normal embroidery thread. Therefore, the multi-component thread for embroidery might be beneficial to use in knitted garments which have stress and strain.

The research conducted by Daukantiene, V., & Mikelionyte, K. (2020) aimed to assess how various embroidery technological parameters and thread types affect the geometric parameters and tension characteristics of original design elements embroidered on PU-coated polyester (PES)-knitted fabric. Materials included commercially available PES-knitted fabric coated with porous PU layer fabric, polyester nonwoven fabrics (NF) for stabilization, and different embroidery threads coded as SL1, SL2, SL3, SL4 with the composition in terms of fiber content 100% PES for polyester (SL1 & SL2), 50% PES, 50% PP for polyester and polypropylene blend (SL3) and 36% PES, 42% PA, 22% others (SL4) respectively. The experimental setup involved measuring thickness, and area density, and conducting uniaxial tension tests on the embroidered samples. Geometric parameters were analyzed using digital imaging, while tension characteristics were assessed through uniaxial tension testing using a computerized tension machine. Changes in thickness, widths, and lengths of embroidered samples compared to the designed digital images are influenced by filling type, stitch density, and thread type. In the analysis of the results, satin filling resulted in higher thickness increases compared to Tatami filling, with thickness increasing with higher stitch density for both filling types. Different thread types showed varying effects on embroidery thickness, with SL3 fluorescent thread causing the highest increase due to specific finishing and higher stiffness. The breaking force and elongation at the break of embroidered samples decreased compared to the CF (coated fabric) and the multilayer fabric system (CF+2NF) in most cases. The breaking force decreased when using SL4 metallic thread, while elongation at break remained almost unchanged. The S2- satin stitch (auto split every 9mm) density 80%, was identified as optimal for investigating the influence of thread type on embroidery quality. Correction of digital image design based on fabric structure, deformation properties, and thread type can help avoid poor embroidery quality. The conclusion highlighted the importance of considering various factors such as filling type, stitch density, and thread type in optimizing embroidery quality and ensuring compatibility with fabric properties. Adjustments in digital image design and the selection of appropriate technological parameters are essential for achieving high-quality embroidered products.

With the aim of developing a sustainable and effective method for enhancing the properties of hand embroidery threads by synthesizing zinc oxide nanoparticles (ZnONPs) using molokhia stem extract and coating them onto the threads, a study was conducted by Ashehri, A, L., & Attia, F, Nouri. (2023). Specifically, the study aimed to investigate the impact of the coated nanoparticles on the tensile strength and antibacterial properties of the threads.Synthesis of Zinc Oxide Nanoparticles (ZnONPs): Molokhia stem extract was prepared and utilized as a reducing and capping agent for the synthesis of ZnONPs. The synthesis process involved the dissolution of zinc acetate dihydrate in deionized water, followed by the addition of sodium hydroxide solution and molokhia stem extract. The obtained ZnONPs were then wrapped with starch chains. Preparation of Hand Embroidery Thread Coatings: Cotton hand embroidery threads (1-7) were individually immersed in the colloidal solution containing ZnONPs and starch chains. The coated threads were dried and labeled accordingly as 1-T and 2-T till 7-T where number denoted the number of threads and T meant Treated. Characterization: The surface morphology of untreated and treated cotton hand embroidery threads was examined using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The size, shape, and dispersion of ZnONPs in the coatings are analyzed. The mechanical properties (tensile strength) of the threads were evaluated using a tensile testing machine. The antibacterial properties of the coated threads against Staphylococcus aureus bacteria were assessed. Synthesis and Coating of ZnONPs:

The TEM images revealed spherical ZnONPs with an average size of 10 nm, coated with molokhia stem extract and starch chains. SEM images confirmed the dispersion of ZnONP-coated starch chains on the surface of the treated threads. Tensile Strength: The coated threads exhibited improved tensile strength compared to untreated threads. The reinforcement effect is observed across all coated samples, with a maximum enhancement of 6.7% in sample 6-T (number of threads treated). Antibacterial Properties: The coated threads demonstrated significant antibacterial activity against Staphylococcus aureus bacteria. The clear inhibition zone was measured, indicating the effectiveness of the coatings in inhibiting bacterial growth. This research developed zinc oxide nanoparticle-coated hand embroidery threads using eco-friendly molokhia stem extract. The coated threads showed improved strength and antibacterial properties, suggesting potential applications in textiles and healthcare. This green synthesis approach underscores a sustainable pathway for enhancing textile functionality.

2.2.4.2 Sewing threads

Rajput, B., Kakde, M., Guljhane, S., & et al. (2018) an analysis of seam quality on the three types of weft-knitted cotton fabrics to study the effect of sewing parameters on seam strength and efficiency. The three types of weft knitted fabric were plain single jersey, 1x1 double rib jersey, and interlock double jersey. The fabrics were sewn by using three different polyester/cotton sewing threads- 1. 40tex linear density with tenacity 43.89 (cN/tex) at 25.07% break elongation. 2. 60tex with tenacity 54.09 (cN/tex) at 27.00% elongation at break and 3. 80tex having tenacity 60.97 (cN/tex) at 28.67% elongation at break. The twist direction was maintained the same for all the types of threads as Z/S. The constant stitch density was taken at 14 stitches per inch. Juki lock stitch, flat stitch, and over-lock stitch sewing machines were used for the stitching at a speed of 4500 stitches per minute and produced superimposed seams. With the use of L9 orthogonal design, the effect of types of fabric, thread, and stitch class were investigated at three levels. To check the component's effect on the seam quality of lock stitch chain stitch and over-edge stitch, the ANOVA technique was carried out. The results of the study revealed that the highest strength was observed in interlock double jersey. The stitch length and the stitch density have a negative influence on the seam strength. It was observed that the length of the stitch was indirectly proportional to the seam strength. The 80tex thread had shown the highest strength in all types of fabrics. This might be due to the higher tenacity of the thread. The over-edge stitch had better strength than the other stitches because of the influence of low needle thread tension. A considerable effect of linear density on seam efficiency was seen. The increase of seam efficiency with an increase in linear density was due to the incorporation of fibres in the coarser thread. The statistical analysis showed the effect of the fabric type, thread type and stitch class on the strength and efficiency of the seam at a significant level. Therefore, the work concluded that it would be beneficial to study the sewing performance of thread on any type of fabric for different applications.

An application of lubricants (Ruco-Fil SCI & Ruco-Fil SNV) to three types of sewing threads- air-jet textured (PET), core-spun (PET/PET) and (PET) spun was done under controlled conditions by Koncer, P., Gurarada, A., Kaplangiray, B., & Kanik, M. (2014). Two different feeding rates i.e. 0.2- 1g/min were used. A lockstitch sewing machine Juki DDL-5550 was run at a speed of 2000rpm with produced 5 stitches per cm. The needle used for stitching was DB X 1BP SES NM 80R. A thread tension sensor, BTSR mode was used for measuring the tension. The tension of 1-250g with a linear output of 0-10 volts was provided by the sensor. The study investigated the impact of sewing thread type on needle thread tension. It was found that core-spun (PET/PET) sewing thread experienced higher tension compared to (PET)-spun threads. This effect was particularly noticeable at specific main shaft rotation angles during the stitch cycle. Additionally, it suggested that air-jet textured sewing threads provided better fabric locking compared to continuous filament threads due to their loop structure, resembling spun yarn. Results indicated that the type of lubricant significantly influenced tension, with paraffin-based lubricant (Ruco-Fil SCI) decreasing tension. However, excessive paraffin application could lead to an undesirable grease film, increasing friction. Furthermore, the type of lubricant affected the sewing thread friction coefficient, with SCI lubricant yielding better values than pure silicone fluids due to its paraffin content. Sewing threads coated with SCI lubricant exhibited lower tension compared to SNV lubricant-coated threads. Additionally, paraffin application could reduce friction by around 50%. Moreover, lubricant feeding rates generally affected thread tensions, which are crucial for lockstitch seam quality.

Yildiz, Z. E., & Pamuk, O. (2023) investigated the effects of sewing thread, sewing thread count, sewing process, and repeated washing cycles on the seam performance of woven fabrics. The breaking strength of different sewing threads unravelled from the seams with that of the parent sewing thread was compared and the seam strength of samples sewn with different threads. They examined 24 commercial sewing threads commonly used in the ready-made garment industry and classified them into 7 groups based on their thread construction. Plain-weave cotton fabric was used for the sewing tests. A JUKI 1-needle lockstitch machine (DDL-9000A) with two layers of fabric in the warp direction was used to sew the specimens at 3 stitches/cm. SES needle. No. 90 was used for threads between 24 and 40 tex and No. 110 needle for threads between 50 and 105 tex. Sewing speed, thread tension, and other settings were kept constant during the sewing process. After sewing, the samples were divided into two groups (before and after 10 washing cycles with EN ISO 6330:2012 standard). Washing was carried out using a standard detergent at 40 °C followed by fabric lying flat on a table for 24 hours under atmospheric conditions. After sample preparation, the needle threads were carefully removed from the seam to assess the change in tensile properties after sewing and washing. The main results obtained from these analyses are summarized as follows:

- The breaking force of each parent thread was significantly greater than that of its corresponding sewn and washed-sewn thread strength. This difference was attributed to the repeated forces exerted on the thread during sewing, which reduced the breaking strength.
- The highest breaking force value was calculated for PES-PES core-spun threads, whereas the lowest was observed for mercerized cotton threads, both for the parent and sewn threads. Furthermore, as the thread size increased, the breaking strength increased for each sewing thread type.
- Regarding the strength loss after sewing and washing, it was found that among the different types of sewing threads, the samples sewn with core-spun threads exhibited lower strength loss, whereas those sewn with cotton threads showed the highest loss.
- The seam strength values after washing were higher for the PES-Co core-spun and mercerized cotton threads than before washing. However, the opposite trend was observed for the samples sewn with polyester spun and PES-PES core-spun thread.
- High correlations were observed between the parent thread and the strength of the sewn thread (r=0.990), the strength of the washed-sewn thread (r=0.964), and the seam strength before washing (r=0.856). This indicates that if the thread has a high

breaking strength value, the seam strength will also be higher after it is incorporated into the seam. Therefore, a higher breaking strength of the sewing thread leads to a more durable structure in subsequent steps.

Investigation of the impact of thread properties on seam pucker, focusing on lightweight fabrics commonly used in garment sewing was conducted by Fathy, F., & Ebrahim, S. (2012). Polyester and cotton sewing threads with varying properties were selected for the study. The methodology involved evaluating seam pucker immediately after sewing, after a period of time, and after washing and drying. The mechanical properties of the threads were tested using a ZWICK/Z005 testing machine. The investigation also included determining fabric dimension changes using the FAST-4 testing technique. In results and discussions, polyester threads generally produced better seam pucker results initially. Cotton threads exhibited higher pucker after washing and drying due to yarn swelling. Seam pucker coefficients were mostly minor, not exceeding 2%, with the exception of specimens sewn with fabric S3, which reached 4%. After 24 and 48 hours of sewing, seam pucker values changed negligibly compared to initial measurements. Washing and drying significantly impacted seam pucker, with greater influence than the passage of time. Sewing three fabric layers resulted in weaker seam pucker compared to sewing two layers. Seam pucker tended to be influenced by the mechanical properties of the sewing threads, with threads featuring higher reversible strain leading to greater pucker. The study concluded that the mechanical properties of sewing threads play a crucial role in determining seam pucker. Polyester threads initially produced better results, while cotton threads exhibited higher pucker after washing and drying due to yarn swelling. The findings underscored the importance of considering sewing thread properties in garment manufacturing to predict seam quality accurately. By understanding the relationship between seam pucker and thread properties, apparel manufacturers can make informed decisions about optimal thread selection for high-quality seams.

From the extensive reviews it can be concluded the utilization of agro waste, such as pineapple leaf fiber, indeed holds great promise for sustainable textile production. This natural fiber possesses several characteristics that make it suitable for textile applications, including its strength, flexibility, and biodegradability.

In the realm of traditional textiles, research and exploration of minor fibers like pineapple leaf fiber have been relatively limited compared to more common fibers like cotton or wool. Traditional textiles often rely on established materials and techniques passed down through generations, which are not readily incorporate newer, alternative fibers.

It's worth observing that while pineapple leaf fiber has been extensively explored in technical textile applications, such as in the production of nonwoven fabrics, composites, and reinforcement materials, its integration into traditional textiles presents a different set of challenges and opportunities.

Furthermore, there may be a need for research and development to optimize the processing and finishing of pineapple leaf fiber for traditional textile applications, ensuring that the resulting fabrics meet the desired quality standards in terms of strength, durability, and comfort.

Despite these challenges, the integration of agro-waste fibers like pineapple leaf fiber into traditional textiles holds significant potential for enhancing the sustainability and diversity of fabric production. By incorporating the unique properties of these natural fibers, textile artisans and manufacturers can create products that appeal to environmentally conscious consumers while also preserving cultural heritage and promoting economic development in agricultural communities. As research continues to explore innovative methods and applications, the adoption of agro-waste fibers in traditional textiles can be grown, contributing to a more sustainable and resilient textile industry.