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Tora (Alpinia allughas) for Sustainable Textiles and Food Applications: Fibre Processing, Blending and Value Addition

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Abstract: *Tora (Alpinia allughas) is an underutilized bast-fibre plant with potential for sustainable textile applications. This study investigated fibre extraction and wet processing, evaluated Tora–cotton blended fabrics, and considered opportunities for value addition. Tora stems were mechanically decorticated and subjected to water, chemical and enzymatic retting. Water retting for 30 days produced an 85% fibre yield, although the fibres remained stiff and sticky. Chemical retting with 9% NaOH for 3 h yielded 55% fibre with the highest reported bundle strength of 25.5 g/tex, while 3% pectinase produced a maximum yield of 56.2%. Subsequent scouring, bleaching and softening reduced fibre diameter from 100 to 76.4 µm and increased moisture regain from 7.57 to 11.4%. Tora–cotton yarns with blend ratios of 70:30, 50:50 and 30:70 were woven with cotton warp in a plain weave. Among these fabrics, the 50:50 blends showed the highest reported thickness (1.32 mm), mass (466 g/m²), wicking height (1.52 cm warp; 1.98 cm weft) and thermal insulation (3.10 tog). Tora–cEri silk fabrics had a pilling rating of 4. The findings indicate that retting and wet processing can modify Tora fibre characteristics and support its incorporation into woven textiles. Food-related applications are also considered as a potential avenue for integrated utilization. These results suggest opportunities for further development of Tora-based materials within a circular bioeconomy.*

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Introduction

Tora (Alpinia allughas), a member of the Malvaceae family, is an underutilized plant resource with potential applications in sustainable textile development and natural fibre-based product innovation. Its stem yields bast fibres that can be extracted and processed for textile applications. Research on A. allughas has demonstrated its potential as a source of natural cellulosic fibres, with untreated fibres containing 56.12% cellulose, increasing to 65.43% following alkali treatment. These findings indicate the potential of Tora fibre for developing sustainable materials and blended textile products (Ramnath et. al., 2023; Ramnath et. al., 2024).

In Assam, the utilization of Tora fibre could provide opportunities for diversifying natural fibre resources and promoting locally available plant-based materials. However, a reliable state-level estimate of annual Tora fibre production in Assam was not identified in the available research literature. Therefore, the production of Tora fibre should not be quantified using statistics reported for other fibre crops, such as jute or toria. The absence of documented production data highlights the need for systematic assessment of Tora cultivation, fibre extraction yield and its potential availability as a textile raw material.

Beyond textile applications, Tora offers opportunities for integrated utilization through food products, natural fibre blending and value-added material development. Blending Tora fibres with cotton, silk or jute may facilitate the development of sustainable yarns and fabrics with diversified properties. The integration of textile and food applications can support resource efficiency and reduce biomass wastage, thereby contributing to a circular bioeconomy. The present study therefore explores the potential of Tora for sustainable textile development, natural fibre blending and food applications, with emphasis on its utilization as a renewable resource for value-added products.

Materials and Methods

The following methodology is rewritten from the uploaded Tora fibre research document in a scientific journal format. The original study covers fibre extraction, characterization, blending with cotton and jute, fabric development and product diversification. It does not include experimental procedures for silk blending or food product development; these are identified separately at the end.

1. Collection of Tora

Leaves of Tora will be collected, cleaned and processed using appropriate food preparation method to develop nutrition rich curry (Bolleddu, et.al. 2023). The study was undertaken through a structured literature review approach to document the ethnobotanical, phytochemical, pharmacological and ecological significance. Relevant information was collected from published research articles, scientific journals, books, reports and online databases following the methodological framework described by Kumar (2025).

2. Collection and extraction of Tora fibre

Tora (Alpinia allughas) stems were harvested and cut into 60 cm lengths. The stems were subjected to mechanical decortication on the day of harvesting to obtain the bast fibres. The extracted fibres were subjected to different retting treatments to optimize the extraction process.

Water retting was conducted at room temperature using a material-to-liquor ratio of 1:30 for 20, 25, 30 and 35 days. Chemical retting was carried out using different concentrations of sodium hydroxide (NaOH) at 100°C and a material-to-liquor ratio of 1:30. The treated fibres were washed, neutralized with 2% acetic acid, rinsed and shade-dried. Enzymatic retting was performed using different concentrations of pectinase at 50°C for 1 hour, maintaining the same material-to-liquor ratio. The fibre yield and quality were evaluated to determine the optimum extraction conditions (Adamesen et al. 2002., Konczewicz et al., 2018.

3. Wet processing of extracted fibres

The extracted fibres were subjected to scouring, bleaching and softening treatments. Scouring was carried out using NaOH concentrations of 9, 10 and 11 g/L, along with 3% sodium silicate and 1% Teepol, at 100°C for 30, 60 and 90 minutes. The fibres were subsequently rinsed, neutralized with acetic acid (2 ml/ltr) for 10 minutes and shade-dried.

Bleaching was performed using different concentrations of hydrogen peroxide at 100°C for 1.5, 2 and 2.5 hours, maintaining a material-to-liquor ratio of 1:30. The fibres were washed, neutralized with 2% acetic acid, rinsed and shade-dried. For softening, the bleached fibres were treated with amino silicone softener at concentrations of 0.5%, 1% and 2% for 30, 60 and 90 minutes at room temperature. The treated fibres were thoroughly washed and shade-dried.

4. Characterization of Tora fibres

The physical, chemical and morphological properties of Tora fibres were evaluated at different processing stages.

The burning behaviour, ash formation and odour of the fibres were observed using a spirit lamp. Fibre pH was determined by shaking 2 g of fibre in 100 ml of distilled water for one hour and measuring the pH of the decanted solution.

Chemical properties, including cellulose, hemicellulose, lignin, pectin, ash, fat and wax content, and moisture regain, were determined using standard TAPPI and BIS methods. Cellulose and hemicellulose were determined using TAPPI T-17 m-555, while ash content was determined according to TAPPI T-211 cm-86. Lignin content was determined using the TAPPI standard method, and fat and wax content were assessed using Soxhlet extraction. Moisture regain was determined according to TAPPI T-264 cm-97.

Physical properties, including fibre length, diameter, wall thickness, fineness, bundle strength, elongation, shrinkage, density and water absorbency, were determined using standard textile testing procedures (Lakshmi, 2014.,).. Fibre length was measured manually, while diameter and wall thickness were measured using a digital projection microscope. Fineness was determined using an airflow method, and bundle strength and elongation were measured using a Stelometer tester. Water absorbency was evaluated using the immersion method. Fibre colour was measured using a Hunter Lab Color Flex spectrocolorimeter in terms of CIE L*, a* and b* values.

The surface morphology of the fibres was examined using scanning electron microscopy (SEM). The samples were mounted on specimen holders using

conductive tape, gold-coated using an ion sputter coater and examined using a JEOL scanning electron microscope at an accelerating voltage of 15 kV.

5. Blending, yarn preparation and fabric development

Tora fibres were blended with cotton in three proportions: 30:70, 50:50 and 70:30 (Tora: cotton). Pure cotton yarn was also prepared as a control. The blended fibres were spun into yarns, and the resulting yarns were used for fabric development.

Due to the hairiness and strength characteristics of the blended yarns, they were considered unsuitable for use as warp yarns. Therefore, cotton yarn was used in the warp direction and Tora–cotton blended yarns in the weft direction. The fabrics were constructed using a plain weave structure on a handloom. Pure cotton and jute fabrics were also prepared as control samples. The fabric was also union with Eri silk in weft and Tora in warp). The constructional parameters of the fabrics, including yarn count, reed count and cloth width, were recorded.

6. Evaluation of woven fabric properties

Before testing, all fabric samples were conditioned at 25 ± 2°C and 65 ± 2% relative humidity.

The mechanical properties of the fabrics were evaluated in terms of fabric count, cover factor, thickness, mass per unit area, stiffness, crease recovery and dimensional stability. Fabric count was determined using a pick glass by taking ten random readings of ends and picks per inch. Cover factor was calculated separately for warp and weft directions.

Fabric thickness was measured using a Heal's thickness gauge. Fabric weight was determined by weighing a 5 × 5 cm specimen and expressing the result in grams per square metre. Stiffness was evaluated using Shirley's Stiffness Tester, while crease recovery was determined using Shirley's Crease Recovery Tester. Dimensional stability was assessed by soaking 20 × 20 cm fabric specimens in a soap solution (2 gm/ltr) for one hour, followed by rinsing and shade-drying.

7. Development of value-added products

The developed Tora-blended fabrics were utilized for the preparation of diversified textile products, including cushion covers, pencil skirts, waistcoats and winter shawls.

8. Statistical analysis

The experimental data were analysed using a one-factor Completely Randomized Design (CRD). Analysis of variance was performed using the F-test to determine significant differences among treatments. Standard errors and critical differences were calculated wherever significant treatment effects were observed. The critical difference was determined at the 5% level of significance.

Results and Discussion

1. Optimization of Tora fibre extraction

The extraction of Tora fibre was influenced by the retting method and treatment conditions. Water retting for 20 and 25 days was insufficient to remove the gummy

substances from the stems. Although retting for 30 and 35 days produced relatively high fibre yields of 85% and 84.8%, respectively, the fibres remained stiff, sticky and unsuitable for further textile processing.

Chemical retting using NaOH resulted in improved fibre quality. The highest bundle strength of 25.5 gm/tex was obtained at 9% NaOH concentration for 3 hours, with a fibre yield of 55%. However, the maximum fibre yield of 56% was obtained at 10% NaOH for 3 hours, with a slightly lower bundle strength of 24.7 gm/tex. The fibres treated with 6% and 7% NaOH retained gummy substances and were unsuitable for textile applications shown in Table 1.

Enzymatic retting using pectinase produced a maximum fibre yield of 56.2% at 3% enzyme concentration. The yield decreased at higher enzyme concentrations. These findings indicate that chemical retting at 9% NaOH for 3 hours provided the best combination of fibre strength and quality, while 3% pectinase offered a potential alternative for fibre extraction.

2. Wet processing of Tora fibres

The wet processing treatments significantly influenced the chemical and physical properties of Tora fibres. Scouring using 10 gm/ltr NaOH at 100°C for 1 hour was selected as the optimum condition based on fibre strength, diameter and visual appearance. Bleaching with 6% hydrogen peroxide at 100°C for 2 hours improved fibre whiteness, while treatment with 1% amino silicone softener for 1 hour at room temperature produced fibres with improved softness and handling characteristics.

3. Chemical and physical properties of Tora fibres

The chemical composition of the fibres changed considerably during processing. Cellulose content decreased from 54% in retted fibres to 30% in softened fibres, while lignin content decreased from 24% to 14%. Pectin content also declined from 4% to 2.36%, indicating the progressive removal of non-cellulosic substances. Moisture regain increased from 7.57% to 11.4% after processing, suggesting an improvement in moisture absorption characteristics.

Table 1 Chemical analysis of Tora fibres

Chemical constituents							
Fibres	**Cellulose (%)**	**Hemicelluloses (%)**	**Lignin (%)**	**Pectin (%)**	**Ash (%)**	**Fat & wax (%)**	**Moisture regain (%)**
Retted	54.0	36.0	24.0	4.00	2.18	1.00	7.57
Scoured	47.9	34.0	20.0	3.46	1.46	0.54	8.80
Bleached	32.0	33.0	15.1	2.74	1.00	0.44	10.1
Softened	30.0	30.0	14.0	2.36	0.86	0.40	11.4
S.E(d)	0.02	0.01	0.01	0.02	0.01	0.00	0.03
CD (0.05)	0.04	0.02	0.03	0.08	0.03	0.01	0.07

The physical properties also varied with treatment. Scoured fibres exhibited the highest fibre length (13.7 cm) and bundle strength (27.3 g/tex). Softened fibres showed the lowest diameter (76.4 µm), fineness (33.1 µm) and wall thickness (3.12 µm), together with the highest elongation (4.51%) showed in Table 2. These findings demonstrate that wet processing improved the fineness, flexibility and handling properties of Tora fibres, making them more suitable for textile applications

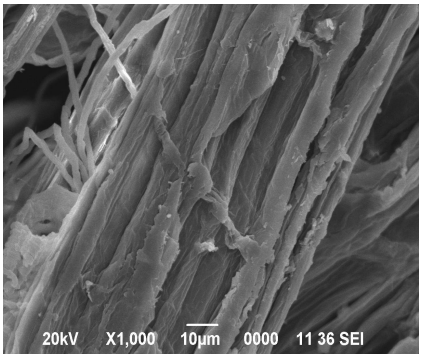
Table 2 Physical properties of Tora fibres obtained from different treatments

Properties	Length (cm)	Diameter (µm)	Fineness (µm)	Wall thickness (µm)	Bundle strength (g/tex)	Elongation (%)	Density (g/cc)
Retted	10.0	100	40.0	5.18	25.5	3.76	1.11
Scoured	13.7	95.1	38.4	4.18	27.3	4.18	1.25
Bleached	12.1	81.1	34.9	3.54	26.9	4.31	1.35
Softened	11.6	76.4	33.1	3.12	26.9	4.51	1.41
S.E (d)	0.73	0.17	0.15	0.06	0.10	0.05	.006
CD (0.05)	1.57	0.37	0.32	0.13	0.22	0.11	0.01

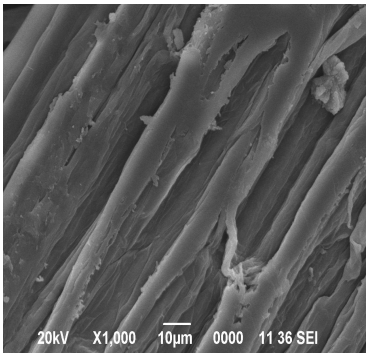
4. Colour and morphological characteristics

The colour measurements revealed an improvement in the whiteness and brightness of Tora fibres following wet processing. The lightness index increased from 56.6 in retted fibres to 62.4 in softened fibres, while the yellowness index decreased from 30.0 to 24.9. The colour strength (K/S) also decreased from 13.7 to 5.39, indicating the removal of colouring and cementing materials during processing showed in Table 3.

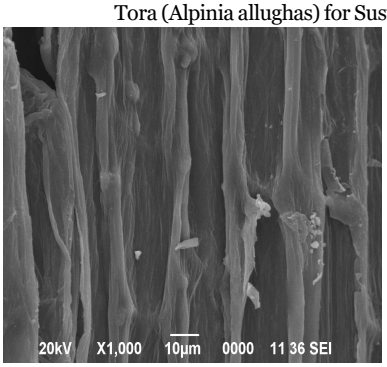
Scanning electron microscopy revealed that retted fibres had a rough surface with irregular fibrils, indicating the presence of residual gummy substances. Scoured fibres exhibited a comparatively smoother surface, while bleaching and softening further improved the surface appearance. These morphological changes support the findings of chemical analysis and demonstrate the effectiveness of wet processing in removing non-cellulosic materials showed Figure 1.



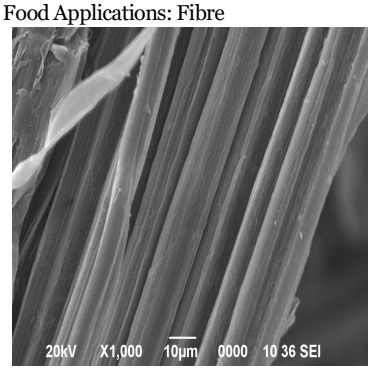
(a)



(b)



(c)



(d)

Figure.1 Scanning Electron Microscopy image of (a) extracted fibre, (b) scoured fibre, (c) bleached fibre and (d) softened fibre

5. Physical and Functional Properties of Tora–Cotton Blended Fabrics

Tora fibres were blended with cotton at different proportions and woven into plain-weave fabrics. Cotton yarn was retained in the warp, while the blended yarns were used in the weft because they had comparatively lower strength and greater hairiness. The physical and functional properties of the fabrics were evaluated alongside a 100% cotton control showed in table 4.

Fabric count represents the number of warp ends and weft picks per inch. Among the Tora–cotton fabrics, the 50:50 blend had the highest weft count (17 PPI), while the 70:30 and 30:70 blends had the lowest (16 PPI). Differences in count may be associated with yarn characteristics and weft insertion during weaving.

Cover factor indicates the extent to which yarns cover the fabric area. The highest total cover factor among the Tora–cotton blends was recorded for the 50:50 fabrics (21.39), while the 70:30 and 30:70 fabrics had the lowest values (20.50). Cover factor reflects fabric compactness and may influence thickness, air permeability and handle.

Thickness ranged from 1.26 to 1.32 mm among the Tora–cotton fabrics. The 50:50 blends was the thickest (1.32 mm), while the 70:30 blend was the thinnest (1.26 mm). Fabric mass ranged from 397 to 466 g/m², with the 50:50 blend showing the highest mass and the 70:30 blend the lowest. These differences may be related to yarn characteristics and fabric construction.

Stiffness was highest in the Tora–cotton 50:50 fabric, with warp and weft values of 3.92 and 3.80 cm, respectively. The 70:30 blends had the lowest values (3.20 and 3.10 cm), indicating comparatively greater flexibility. Crease recovery was highest in the 70:30 blend (103.5° warp and 102.0° weft) and lowest in the 50:50 blend (102.0° and 101.2°).

Tensile strength was greater in the warp than in the weft direction across the fabrics, consistent with the use of cotton warp yarns. The 30:70 blend had the highest warp tensile strength among the Tora–cotton fabrics (35.2 MPa), while the 70:30 blend had the lowest (29.4 MPa). The highest weft tensile strength was recorded for the 30:70 blend (1.26 MPa), and the lowest for the 70:30 blend (1.04 MPa). Elongation was also higher in the warp direction. The 50:50 blends had the highest weft elongation (10.9 mm), while the 30:70 blend had the highest warp elongation (31.3 mm).

Wicking height was highest in the 50:50 blend in both warp and weft directions (1.52 and 1.98 cm), while the 70:30 blend showed the lowest values (1.17 and 1.27 cm). Shrinkage was highest in the 70:30 blend (2.55% warp and 2.10% weft) and lowest in the 50:50 blend (2.30% and 1.72%). Air permeability was highest in the 70:30 blend (424.3 $cm^3/cm^2/s$) and lowest in the 50:50 blend (420.2 $cm^3/cm^2/s$). Thermal insulation was highest in the 50:50 blend (3.10 tog) and lowest in the 70:30 blend (2.64 tog). All three Tora–cotton fabrics received a pilling rating of 4, indicating slight pilling under the test conditions.

Table.4 Physical and functional properties of control and Tora-blended woven fabrics

Fabric	Count (EPI × PPI)	Cover factor (warp / weft / total)	Thickness (mm)	Mass (g/m^2)	Stiffness (warp / weft, cm)	Crease recovery (warp / weft, °)	Tensile strength (warp / weft, MPa)	Elongation (warp / weft, mm)	Wicking (warp / weft, cm)	Shrinkage (warp / weft, %)	Air permeability ($cm^3/cm^2/s$)	Thermal insulation (tog)	Pilling rating
Cotton control	35 × 16	17.5 / 8.0 / 20.50	1.27	397	3.25 / 3.18	103.1 / 101.9	38.2 / 11.6	32.2 / 8.02	1.07 / 1.12	2.89 / 2.69	424.1	2.77	4
Jute control	37 × 16	18.0 / 8.5 / 21.04	1.33	465	3.96 / 3.82	103.0 / 101.5	22.1 / 1.90	34.3 / 1.15	1.46 / 2.00	1.74 / 1.60	420.4	3.00	4
Tora:cotton 70:30	35 × 16	17.5 / 8.0 / 20.50	1.26	397	3.20 / 3.10	103.5 / 102.0	29.4 / 1.04	33.2 / 8.05	1.17 / 1.27	2.55 / 2.10	424.3	2.64	4
Tora:cotton 50:50	37 × 17	18.5 / 8.5 / 21.39	1.32	466	3.92 / 3.80	102.0 / 101.2	33.1 / 1.13	32.6 / 10.9	1.52 / 1.98	2.30 / 1.72	420.2	3.10	4
Tora:cotton 30:70	35 × 16	17.5 / 8.0 / 20.50	1.27	449	3.26 / 3.18	103.0 / 101.7	35.2 / 1.26	31.3 / 10.2	1.40 / 1.51	2.45 / 2.00	424.0	2.91	4

6. Physical Properties of Tora and Eri silk Union Fabric

The table 5 indicate that the union fabric had a count of 39 × 18 EPI × PPI, a thickness of 1.45 mm and a mass of 491 g/m^2. Its warp/weft stiffness was 4.14/4.96 cm, crease recovery was 101.2°/102.2°, tensile strength was 36.2/5.43 MPa and elongation was 33.7/5.38 mm. The fabric also showed warp/weft wicking of 2.60/3.96 cm, air permeability of 403.3 $cm^3/cm^2/s$, thermal insulation of 3.54 tog and a pilling rating of 5. Related union-fabric research shows that blend composition and weave structure can affect fabric count, mass, thickness, tensile

behaviour, elongation and comfort properties (Bharali et. al. 2025: Baruah et.al. 2022)

Fabric	Count (EPI × PPI)	Thickness (mm)	Mass (g/m²)	Stiffness (warp / weft, cm)	Crease recovery (warp / weft, °)	Tensile strength (warp / weft, MPa)	Elongation (warp / weft, mm)	Wicking (warp / weft, cm)	Air permeability (cm³/cm²/s)	Thermal insulation (tog)	Pilling rating
Tora:Eri 50:50	39 × 18	1.45	491	4.14 / 4.96	101.2 / 102.2	36.2 / 5.43	33.7 / 5.38	2.60 / 3.96	403.3	3.54	5

7. Preparation of value-added and diversified product: The union fabrics were utilized for preparation of different products i.e. cushions cover, pencil skirt, waist coat and winter shawl showed in Fig 2.

8. Tora plant used for Food Application: Tora leaves has been identified as a source of phytochemicals such as flavonoids, phenolics, polyphenols, terpenoids, alkaloids and polysaccharides in different plant parts, with leaf essential oils containing bioactive compounds such as 1,8-cineole and β-pinene (Pathak & Singh 2022). These constituents are associated with antioxidant, antimicrobial, anti-inflammatory, analgesic, antibacterial, antifungal and other pharmacological activities. Its tender shoots, young rhizomes and fruits are consumed as vegetables, condiments and flavouring agents, while its local trade provides supplementary income, particularly for women vendors and small-scale Fruit extracts have also been utilized for the green synthesis of silver nanoparticles exhibiting antimicrobial and photocatalytic potential. It is considered as a valuable resource for sustainable food systems, nutraceutical development, traditional healthcare and biodiversity conservation. Due to the nutritive and excusive smell the Tora leaves were used as product wrapper for making traditional food items showed in Fig 2 Plate 6.. Different ethnic community of North Eastern India used the leaves for religious purposes also.

Conclusion

The study demonstrates the potential of Tora (Alpinia allughas) as an alternative natural fibre resource for sustainable textile development and value addition. Chemical retting with 9% NaOH for 3 hours produced fibres with the highest bundle strength (25.5 g/tex), while enzymatic retting with 3% pectinase achieved the maximum fibre yield (56.2%). Subsequent scouring, bleaching and softening improved fibre fineness, flexibility and moisture regain. Among the Tora–cotton blends, the 50:50 ratio exhibited favourable thickness, fabric mass, wicking and thermal insulation properties. The Tora–Eri silk union fabric also demonstrated promising physical and functional characteristics, supporting its application in diversified textile products. Furthermore, the traditional use of Tora leaves in food wrapping and their reported phytochemical properties indicate additional opportunities for food-related value addition. Overall, Tora has potential for integrated textile and food applications, contributing to sustainable resource utilization, product diversification and the promotion of a circular bioeconomy. Further research is required to establish its food safety, nutritional value and commercial-scale processing potential.

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Plate 1. Cushion cover (Tora:cotton 70:30)

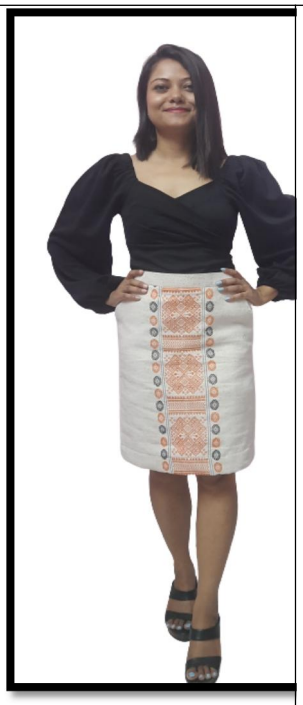


Plate 2. Pencil skirt (Tora:cotton 30:70)



Plate 3. Waist coat (Tora:cotton 50:50)



Plate 4. Winter shawl (Tora:cotton 30:70)

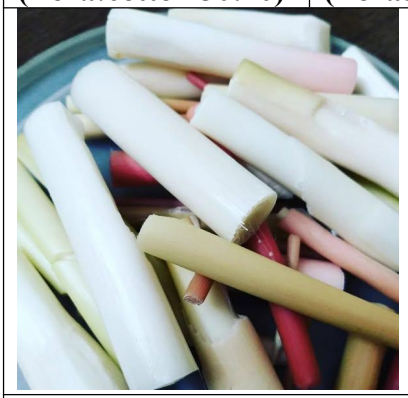


Plate 5. Edible part of Tora plant



Plate 6. Tora leaves used as food wrapper

Fig 2 Diversified product from Tora plant