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Production of Natural Dyed Palm Yarns and Fabrics

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Abstract

Palm fibre is a waste product from the fruit crushing-extracting process in local communities. This study examined the characteristics of natural dyed palm yarns and fabrics produced from treated palm fibres. The results showed that fibre characteristics were improved by anaerobic fermentation, and following crushing and carding, were 3-5 times smaller, softer and more pliable. In the production of palm/cotton yarns of No. 7 (50/50), No.10 (40/60), No.16 (30/70) and No.10 (0/100), the 3-5 denier palm yarns and cotton yarns were spun in open-end spinning units. Regarding the physical properties, the blended yarns showed more unevenness and higher tensile strength and elongation at break than 100% cotton yarn. However, it was found that the coarser yarns were lower in strength than the finer yarns. Fibre sorting by denier leads to a decrease in unevenness caused by thin and thick patches and neps. When dyed with natural dyes, the palm yarns were found highly fast to light, but only moderately fast to washing. Dark dye spots distributed on the palm fibre yarns formed a natural pattern structure in the woven textiles. The tested woven textiles from the weft palm yarns are lighter in weight and higher in tensile force and tear strength than their cotton counterparts. The results suggest that palm fibre yarns should be promoted and introduced in Thai textile craft markets to provide diversity and added value to Thai textiles. Moreover, this study offers an opportunity to use palm waste to provide an alternative income source while preserving the environment in local communities. Such community-level industries may provide a sound basis for sufficiency community economies and green textile product development.

Keywords: Palm fibre; yarn from palm fibres; local textile

Introduction

Thailand's biodiversity underpins the country's potential to develop the production of environmentally-friendly textile products. Several studies have been conducted of the production of yarns from banana fibre [1] and pineapple fibre [2] blended with other fibres such as cotton and polyester, carried out variously in Japan, China and Thailand. Overall it was found that blended yarns demonstrated lower strength than pure cotton due to the low fibre cohesion and coarseness of pineapple and banana fibres. Therefore, applications for such blended yarns are limited to production of thick fabrics, handicrafts and decorative items. However, a study entitled "the Development of Palm Fibre Products for the Textile Industry" [3] demonstrated the potential of palm fibre yarn as an innovative source for textile manufacture in Thailand. The yarn is unique in its characteristic pattern and is stronger than cotton. When woven, the fabric is high in drapability like linen, lighter than cotton, rich in lustre, and characterized by the unique palm fibre pattern. Most importantly, the process makes use of locally available waste products to create value added products through an eco-friendly production process. However, the previous study revealed that palm fibre can be used to produce only relatively coarse yarns because of its size and stiffness, presenting a major challenge for industrial production of yarns using the open-end spinning method. Thus, further research and development into developing smaller, softer, and more pliable palm yarn would address this production challenge by reducing percentage loss and the resulting high production costs.

The current study aimed to open the door to the creation of yarns of different sizes and suitability for alternative textile applications. The research also studied the development of quality fibre, the creation of alternative yarn colours using natural dyes and new weave and product designs. The research was carried out in accordance with the social geography and the need to improve the quality of local textiles. Palm fibre fabric echoes Thai identity and culture that has long been related to the Palmyra palm. Moreover, the fact that the palm fibre is produced from palm waste left over from crushing of ripe Palmyra palm fruit helps add value to the product. The researchers are optimistic that this further study may offer a practical means of improving the quality of local textiles and will provide new alternatives for the selection of yarns from natural fibres to produce local textile products. It may also offer opportunities for larger-scale commercial production for domestic consumption and the export trade.

The study findings may provide the basis for production of innovative handmade and industrial textiles which are environmentally friendly and proudly represents Thai identity. The objectives of this research are: (1) to improve and develop preparation processes of the palm fibre as a suitable raw material in the production of yarns; (2) to produce a palm/ cotton blended yarn using the open-end spinning process in the textile industry; (3) to create alter-native yarn colours using natural dyes through public participation of local hand-woven textile groups; and (4) to design textile weaves and related products from the palm fibre through public participation of local hand-woven textile groups.

Materials and methods

The research study comprised of four stages: (1) improvement and development of preparation processes of the palm fibre; (2) production of the yarn using the open-end spinning process in the textile industry; (3) dyeing process using local plants; and (4) production of hand-woven fabrics from palm/ cotton yarns. The detailed processes are described below.

1) Improvement and development of preparation processes of the palm fibre

1.1) Construction of equipment for improving the palm fibre via a physical process

a. Palm fibre crushing machine, comprising a 1-hp motor and two rollers with diameter of 4 inches, rotating in opposite directions with rotation speed of 120 rpm. The machine is used to crush the fibres and make the fibres soft and bendable (Figure 1).

b. A fibre carding machine comprising a 1-hp motor and two different sizes of spiked rollers. As a result of the rotation of the rollers, the different sizes of the fibres are separated, which sorts out the large size of the fibres (Figure 1).

c. A palm fibre boiler is made from a 250 liter oil drum with an LPG heating system. The boiling capacity is 10-15 kg/ batch. The fibres were cleaned using heat and a sodium (NaOH) solution (Figure 1).

1.2) The palm fibre was prepared through anaerobic fermentation and physical processes (boiling, crushing and carding) as shown in Figure 2.

The palm fruit fibre was cut into 2-5 cm. length and subjected to fermentation under anaerobic conditions for 14 days to remove pectin and lignin. Molasses and nitrogen were added as a food source for microorganisms at a 1:1:10 ratio. The fermented fibres were then boiled in a 2% sodium hydroxide (NaOH) solution for 2 hours; 2% hydrochloric acid (HCl) was then added to regulate acidity for 1 hour. The fibres were then rinsed with water, soaked in softener, and left to dry in the sun.

The dried fibres were then crushed and carded. The double roller crusher rendered the fibres softer and more pliable, and reduced fibre size, while the carding machine made use of spiked rollers to separate and distribute the fibres, and remove the largest fibres.

The chemical properties of the fibres were tested for its principal components, including hemicelluloses, cellulose, lignin and pectin [4]. Testing of physical parameters included microscopic cross-section, fibre length (ASTM D1440), fibre size (ASTM D1577), fibre strength (ASTM D3822) and moisture regains (ASTM D 629:1999). The test was performed at the Textile Testing Center, Thailand Textile Institute.

2) Production of palm fibre yarn

The prepared fibres, fermented under the anaerobic conditions and improved through the boiling, crushing and carding processes, were used to produce fibre yarns in 3 sizes: No.7, No.10 and No.16 using the open-end spinning process with the support of Kong Kiet Textile Company Limited (Figure 3) as described below.

2.1) The raw fibres were processed in a carding machine to clean and sort the fibres by size. The fibres were sorted into 3 sizes: 6-5 denier for large yarns, 4-3 denier for medium yarns, and <3 denier for small yarns.

2.2) The next processes were fibre mixing, cleaning and preparing the fibre lap. The weight percent mixing ratios of the palm fibres to cotton were processed by computer. The mixing ratios were 50:50 of the 4-3 denier palm fibres (first carded) to cotton for No.7 yarns; 40:60 of the 4-3 denier fibres (first carded) to cotton for No. 10 yarns, and 30:70 of the <3 denier fibres (second carded) to cotton for No.16 yarns.

Figure 1 Fibre crushing machine, carding machine and boiler

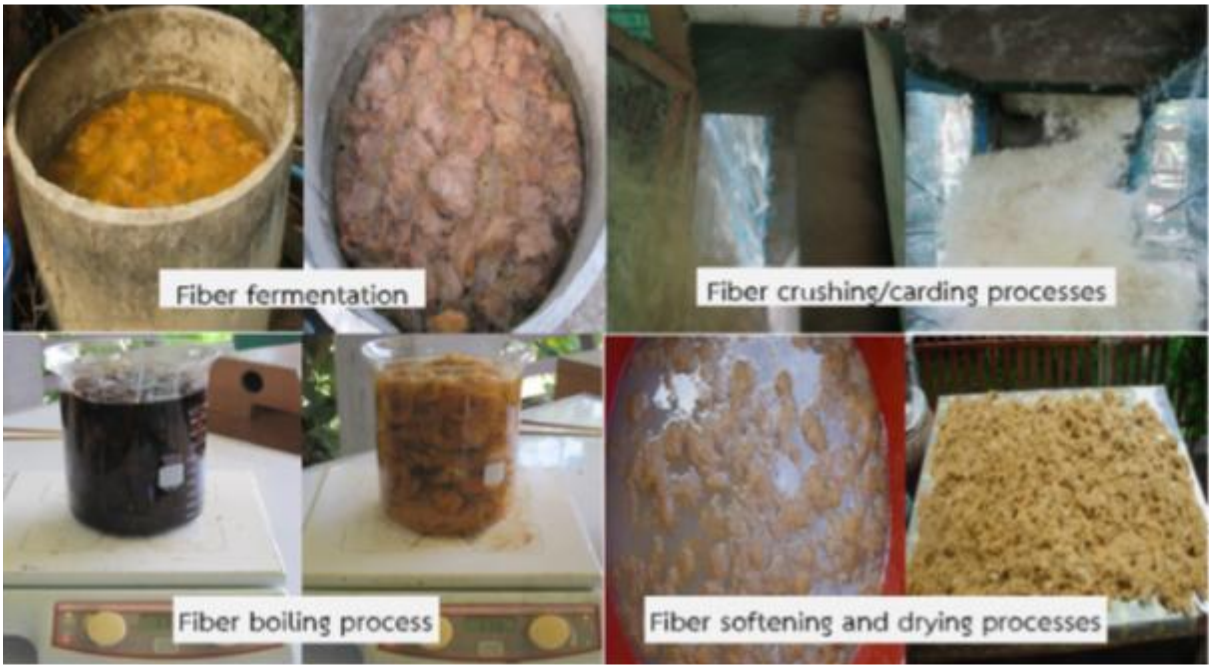

Figure 2 Improvement of palm fibre through fermentation under anaerobic conditions followed by physical processing (boiling, crushing and carding)

The palm fibres and cotton of each ratio were then carried to the blow room, and mixed with the blending feeders. The mixed fibres were sent into the air blowing room and cleaned. The cleaned fibres were then sent into the picking room where the fibres were loosened, separated, and then rolled into skeins or balls. The picking machine then wrapped the fibres into laps.

2.3) The fibres were then spun into yarns of the No.7, No.10 and No.16 counts using the open end spinning process at Kong Kiet Textile Company Limited.

2.4) The physical properties of the yarns were tested in terms of yarn size (ISO 2060: 1994 (E) OPTION 1), strength and percent-tage elongation (ISO 2060: 1993)(E) Method B) and unevenness (ASTM D 1425:1996) at Textile Testing Center, Thailand Textile Institute.

3) Palm fibre yarn dyeing using native plants

The prepared yarns of the 3 sizes were dyed with native plants including mangosteen leaves for brown, indigo plants for blue, and *Harrisonia perforata* fruits for purple and grey. Dyeing auxiliaries included alum ($AB(SO_4)_2.12H_2O$), potassium hydroxide (KOH) and drilling fluid. The experiment on the natural dyeing process was per-formed (Figure 4) in Lablae, Lablae District, Uttaradit Province. rRandom samples of the dyed yarns were tested at the Textile Testing Center, Thailand Textile Institute, for colour fastness to light (AATCC TM 16:2004 OP-TION 3), fastness to washing (AATCC 61:2007 METHOD 1A) and fastness to perspiration (AATCC TM 15: 2009) in accordance with the American Association of Textile Chemists and Colourists (AATCC) standard test method.

4) Production of hand-woven fabric from palm/cotton yarns

Weft palm yarns, both naturally-dyed and undyed, and warp cotton yarns of No. 42/2 and 20/2 were woven into fabric (Figure 5) by Ban Nern Chai Community Weaving Group in Thong Saen Khan District, Uttaradit Province and Ban Ton Ha Community Weaving Group in Muang District, Phrae Province. The fabrics were weaved in three designs: plain weave, figured weave with supplementary warps, and 4-harness denim weave. The quality of the woven fabric was evaluated using woven textile parameters including yarns per inch (ASTM D 3775:2008), fabric weight (ASTM D 3776:2009 OPTION C), tensile force (ASTM D 2261:2007) and tensile strength (ASTM D 5035:2006) following the American Society For Testing and Materials method.

Results and discussion

1) Chemical properties of palm fibre before and after bio-physical improvement

In terms of chemical properties, prior to treatment the palm fibre contained 7.0% moisture, 1.0% ash, 4.0% fat and wax, 11.0% lignin, 52.0% cellulose, 12.0% hemicelluloses and 13% pectin. As the fibre was high in cellulose, the fibres had a high capacity for water absorption, high strength and were resistant to acids and bases. When high in other non-fibre components such as hemicelluloses, lignin and pectin, cellulose tends to bind with pectin or lignin. Thus, non-fibre components should be regulated and eliminated before spinning into yarn.

Following fermentation under anaerobic conditions, the fibres were found to be 4 times lower in percent of hemicelluloses, pectin, and fat and wax, causing an increase in the dry weight of cellulose from 52.00% to 77.00%. This was in accordance with the study of Ujjin et al. [2] on the improvement of pineapple fibres, as well as the work of Soyraya et at. [1] on banana fibres. These studies found that biofermentation and boiling of the fibres in sodium hydroxide reduced the amount of non-cellulosic components such as lignin, hemicelluloses and pectin.

The current study showed that the crushing and carding processes exposed non-fibre residues and separated them from the cellulose component. As a result of compression force from the rollers, the fibres, especially the large ones, were loosened and separated; and the fibres became soft and pliable. Moreover, the process resulted in an increase in cellulose content from 69.0% to 73.0%. The spiked rollers caused the fibres to scatter, scratched the cutin, and sorted other non-fibre residues such as palm husk and dust. The largest sized fibres, which were considered poor as a raw material for yarn production, were also removed.

Figure 3 Mixing and producing fibre laps in the open- end spinning process

Figure 4 Colour dyeing of palm fibre yarns: green from Indian almond (*Terminalia catappa*) leaves and blue from the indigo plant

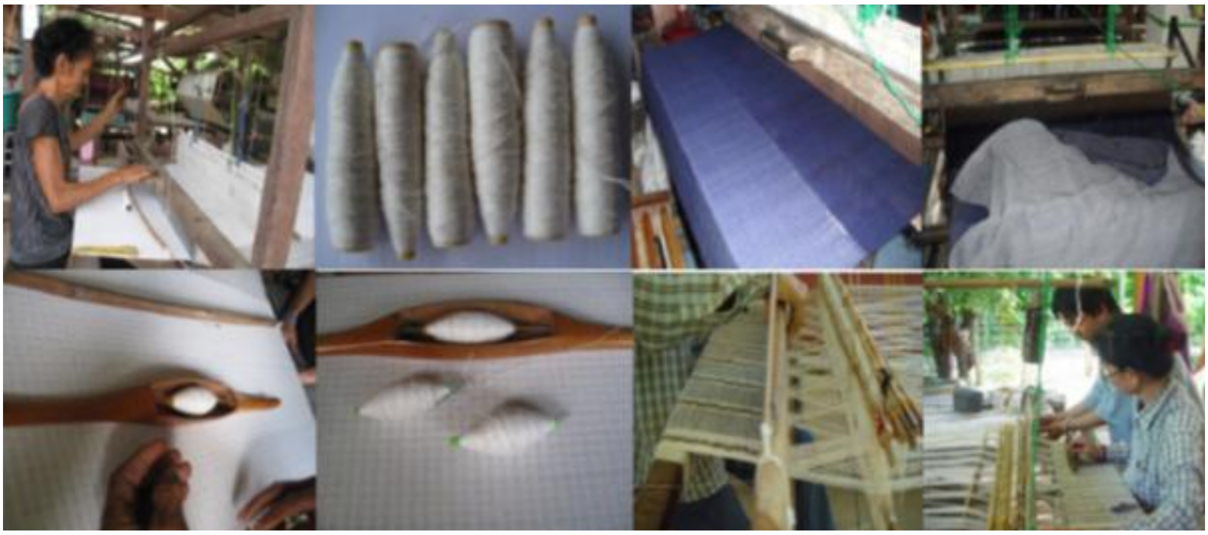

Figure 5 Palm fibre textiles through public participation of local hand-woven textile group

2) Physical properties of the palm fibre before and after bio-physical improvement

The Palmyra palm fibre is a long fibre, exhibiting collateral branches and curly lines on its surface. The fibre is oval-round in cross-section with thin cell walls and a fine lumen. It is 11.15 ± 2.43 cm in length, 15.58 ± 9.39 denier in size, 12.32 ± 2.82 g/denier in tenacity, and 43.50 ± 10.32% in elongation at break. Inconsistent fibre sizes severely limit the yarn spinning process. In terms of physical properties including fibre size, tenacity, and elongation at break, the properties of palm fibres are similar to those of pineapple [2,5,6] and banana [1]. Palm fibres have higher strength and elongation at break than cotton fibres; however, they are 6 times thicker (0.90-2.70 denier).

Biofermentation under anaerobic conditions resulted in a reduction in size to 6.25±1.88 denier, and an increase in tensile strength and elongation at break. After boiling in sodium hydroxide solution, followed by crushing and carding, fibre size was again reduced to 2.32± 1.10 denier (Table 1). However, the crushing and carding processes had no effect on tensile strength and elongation at break, causing only a decrease in fibre size and eliminating cutin and other residual components from cellulose via the action of the spiked rollers. It was evident that following the bio-physical processes, palm fibres were suitable for industrial yarn production. This conclusion was congruent with the findings of similar studies by Ujjin et al. [2] who found that pineapple fibres were well separated and became softer after processing in the crushing machine.

3) Physical properties of palm fibre/cotton yarns

The results revealed that there was no significant difference between the palm yarns and cotton yarns of No.7, No.10 and No.16 in terms of toughness and elongation at break. Table 2 shows the physical properties of palm fibre/cotton mixed yarns in different ratios. Regarding the properties following the fermentation, crushing and carding processes, it was found that the palm/cotton blended yarns tended to have lower tenacity and elongation at break with decreased mixing percent of the palm fibres. However, palm fibre yarns had higher tensile strength and elongation at break than 100% cotton yarns.

Increasing the mixing ratio of the palm fibres led to greater unevenness, thin and thick spot, naps and hairiness. As a consequence of collateral branches and the relatively large fibre size, the palm fibres appeared more dominant on the surface of the blended yarns than the cotton fibres. This is as expected, since finer fibres typically migrate towards the centre when twisted into blended yarns, while coarser fibres remain scattered at the outer regions. The palm fibre yarns were less even than 100% cotton yarns; however, the unevenness of the palm fibre created unique characteristic patterns on the palm fibre yarns. Other rations indicated the utility of palm fibre for various purposes. A 30:70 ratio of palm fibre to cotton fibre of No.16 Ne blended yarns showed increased strength; the blended yarn tended towards increased evenness at mixing ratios below 30:70. The findings were in accordance with the studies of Ujjin et al. [2] and Soyraya [5] which found that mixing ratios of pineapple fibres to cotton fibres below 25:75 of No. 20 Ne blended yarns showed high strength and better evenness. Furthermore, concerning visual and tactile surface characteristics, the palm fibre yarns of every size exhibited good lustre and a superb ability to reflect light.

Table 1 Physical properties of palm fibre before and after fermentation under anaerobic conditions, followed by boiling, crushing and carding

Chemical properties	Physical properties of the palm fibre				
	Before	After fermentation	After boiling	After crushing	After carding
Fibre length (cm)	11.15±2.43	3.21±2.33	3.21±2.33	3.21±3.13	2.03±1.18
Fibre size (denier)	15.58±9.39	6.25±1.88	5.05±2.88	3.92±0.30	2.32±1.10
Tenacity (g/denier)	12.32±2.82	18.37±2.34	16.17±3.24	15.46±1.90	16.46±2.90
Elongation at break (%)	43.50±10.3	45.6±10.26	46.32±1.26	43.10±6.60	42.80±10.4

Table 2 Physical properties of palm fibre/cotton mixed yarns in different ratios

Yarn count (open end spring)	No. 10	No. 7	No. 10	No. 16
- Palm fibre (%)	0	50	40	30
- Cotton fibre (%)	100	50	60	70
Yarn size: ISO 2060: 1994 (E) OPTION 1				
- Yarn size (Ne)	9.68	6.60	9.50	14.90
Physical property: strength: ISO 2062: 1993 (E) method B				
- Tensile strength (N)	2.33	6.78	5.07	3.07
- Elongation at break (%)	6.12	13.46	11.11	11.48
Evenness: ISO 16549: 2004 (E) by USTER EVENNESS TESTER 3 V 2.50				
- Unevenness (%)	4.67	11.64	11.46	13.26
- CV of unevenness (%)	10.73	15.08	14.94	17.24
Imperfections: ISO 16549: 2004 (E) by USTER EVENNESS TESTER 3 V 2.50				
- Thin places, -50%	0	4	4	28
- Thick places,+50%	3	286	344	636
- Neps +200%	5	3,062	1,365	3,342

Source: Colour fastness test results

In the study, yarns dyed naturally in the primary colours of blue, yellow and red as well as dominant colour shades such as green, pink, purple, brown and black were catalogued. Dyed yarns in three different colours representing each colour shade were selected-brown from mangosteen leaves, green from Indian almond (*Terminalia catappa*) leaves and bark, and blue from indigo plants. Colour fastness to washing, light, and perspiration was determined for each sample. The test result revealed that the dyed fibre yarns exhibited great colour fastness to light with values ranging between Levels 4 to 5, and moderate colour fastness to washing. Little dye transfer onto other garments occurred when washed in high alkaline detergent. Natural dyes typically have a limited colour fastness to washing and light. From visual and tactile observations, it was evident that the palm fibre yarns processed with acid or alkaline dyeing agents had high dye absorption ability, making the palm fibre yarns visibly darker in hue than the cotton yarns. The acid/alkaline conditions cause dissociation of hydroxyl groups, forming a bond with reactive atoms in the dye molecule [7]. Dark dye spots distributed on the palm fibre yarns produced a natural pattern structure in the woven textiles.

4) Physical properties of palm fibre textiles

Textiles were woven from the palm/cotton blended yarns. No.7, No.10 and No.16 dyed and undyed palm fibre yarns were used as weft yarns, and cotton yarns, rayon yarns or silk yarns as warp yarns. The three weave designs tested were 1) plain weave, 2) 4-harness weave, and 3) figured weave. The weaves were designed in accordance with the use of naturally dyed yarn colours. The plain weave textiles were woven from both dyed and undyed fibre yarns. To produce the plain weave textiles from dyed yarns, purple dyed weft and warp yarns were used. The figured weave textiles were woven from undyed weft and warp yarns. Indigo dyed yarns were used to make the 4-harness weave textiles. Table 3 summarizes the physical property test results. The data showed that the palm fibre textiles were lighter in shade than their cotton counterparts. Moreover, the studied textiles had higher tensile force and tensile strength, with a value of tensile force ranging between 934.19–988.35 Newton, and tensile strength between 87.83 –99.19 Newton. High tensile strength and elongation at break contributes to greater durability of the textile. Good textile elasticity allowed the garments to maintain their shape if stretched. According to visual and tactile observations, it can be seen that a 30% ratio of the palm fibres showed no significant difference in textile pattern characterization from a 50%.

5) Textile products from palm fibres

Prototypes of textile products from palm fibre yarns were produced from textiles of dyed and undyed plain weaves, figured weave and 4-harness weave. The textiles were woven from No.7, No.10 and No.16 dyed and undyed palm fibre yarns as weft yarns, and cotton yarns, rayon yarns or silk yarns as warp yarns. The product models were divided into two main categories: garments including dresses, jeans and jackets, and interior decoration and miscellaneous products including curtains, shoulder bags, stationery sets and small bags as shown in Figure 6.

Conclusion

Palmyra palm yields a natural, uneven-sized fibre. The study resulted in improvement of the fibre production process through biofermentation under anaerobic conditions and crushing/carding processes, resulting in fibres that were 3-5 times smaller, softer and more pliable. According to the production of palm/cotton blended yarns of No.7 (50% palm + 50% cotton), No.10 (40% palm + 60% cotton) and No.16 (30% palm + 70% cotton) and cotton yarns of No.10 (100% cotton) on an open-end spinning system, the blended yarns were superior in terms of their physical properties and evenness than the 100% cotton yarns. It was also found that coarser yarns had lower strength, tensile strength and elongation at break, although the blended yarns exhibited higher strength than the cotton ones. Regarding unevenness, large yarn size showed less thick and thin places and neps. This is attributed to the fact that fibres were sorted out by their denier before the spinning process, hence reducing the loss percentage in raw materials. Additionally, the naturally-dyed yarns were high in fastness to light, but moderate in fastness to washing. The distribution of dark dye spots on the palm fibre yarns created a characteristic natural pattern structure within the woven textiles. Influenced by the weft palm/cotton blended yarns, the textiles from the palm yarns were lighter than those from the cotton yarns. Furthermore, the palm fibre textiles showed higher tensile force and tensile strength than their cotton counterparts. In summary, palm fibres, usually discarded as waste products, offers potential as a raw material for producing natural yarns for the textile industry, and additional opportunities for livelihoods in local communitites.

Table 3 Physical properties of palm fibre/cotton textiles in different ratios

Weaves	Undyed plain weave1/	Undyed plain weave2/	Dyed plain weave3/	Figured weave4/	4-harness weave1/
Palm fibre (%)	0	50	30	30	40
Cotton fibre (%)	100	50	70	70	60
Fabric weight (g/m^2)	194.12	184.23	179.32	176.12	186.65
Yarns per inch					
- Wrap yarns	41.00	50.00	49.00	49.00	68.00
- Weft yarns	36.00	34.00	35.00	37.00	47.00
Total of wrap and weft yarns (per inch^2)	77.00	84.00	84.00	86.00	115.00
Tensile force (N)					
- Wrap yarns	361.21	967.20	1,373.20	1,039.35	1,131.00
- Weft yarns	412.33	934.19	983.35	962.21	988.35
Tensile strength (N)					
- Wrap yarns	32.45	187.20	367.25	172.35	233.20
- Weft yarns	34.56	99.19	92.35	87.83	98.41

1/No. 20/2 cotton yarns as weft and warp yarns
2/No.7 palm fibre yarns as weft yarns and No. 20/2 cotton yarns as warp yarns
3/No. 16 palm fibre yarns as weft yarns and No. 40/2 cotton yarns as warp yarns
4/No. 16 palm fibre yarns as weft yarns and No. 20/2 silk yarns as warp yarns
5/No. 10 palm fibre yarns as weft yarns and No. 20/2 rayon yarns as warp yarns

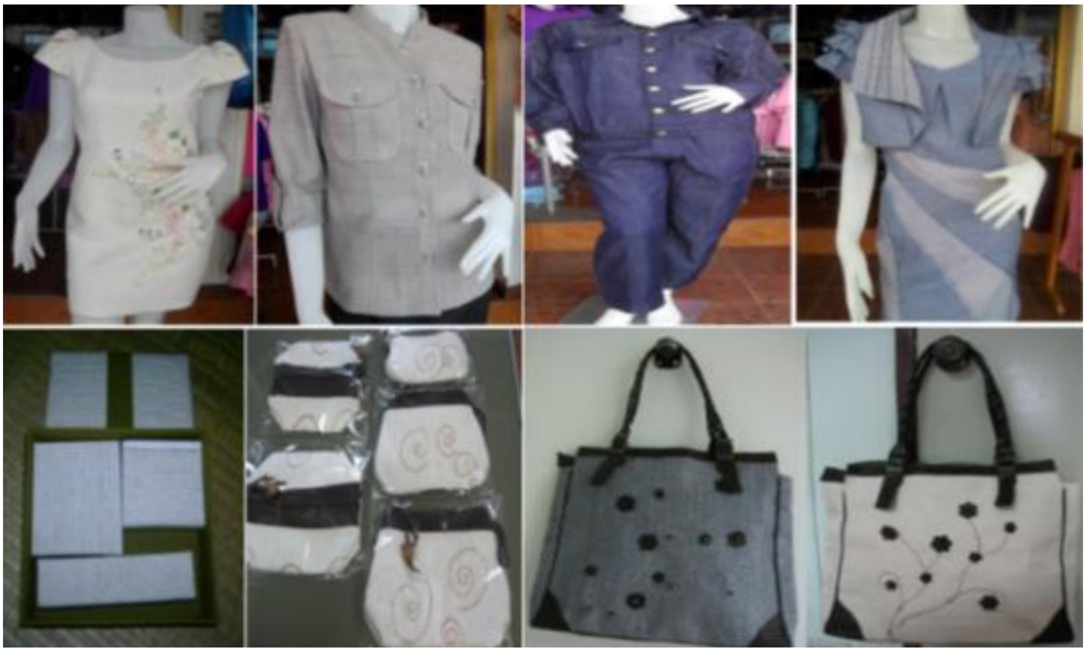

Figure 6 Products from palm fibre textiles

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