



## THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Doctor of Philosophy (Tropical Agriculture)

### DEGREE

Tropical Agriculture

### FIELD

Agriculture

### FACULTY

TITLE: Characteristics and Properties of Paper Mulberry Yarn and Fabric

NAME: Miss Sakorn Chonsakorn

THIS THESIS HAS BEEN ACCEPTED BY

THESIS ADVISOR

( Assistant Professor Kajijarus Piromthamsiri, Ph.D. )

THESIS CO-ADVISOR

( Mr. Chanchai Sirikasemlert, Ph.D. )

GRADUATE COMMITTEE  
CHAIRMAN

( Assistant Professor Sudsaisin Kaewrueng, Ph.D. )

APPROVED BY THE GRADUATE SCHOOL ON \_\_\_\_\_

DEAN

( Associate Professor Gunjana Theeragool, D.Agr. )

THESIS

CHARACTERISTICS AND PROPERTIES OF  
PAPER MULBERRY YARN AND FABRIC



SAKORN CHONSAKORN

A Thesis Submitted in Partial Fulfillment of  
the Requirements for the Degree of  
Doctor of Philosophy (Tropical Agriculture)  
Graduate School, Kasetsart University

2014

Sakorn Chonsakorn 2014: Characteristics and Properties of Paper Mulberry Yarn and Fabric. Doctor of Philosophy (Tropical Agriculture), Major Field: Tropical Agriculture, Faculty of Agriculture. Thesis Advisor: Assistant Professor Kajjarus Pirothamsiri, Ph.D. 161 pages.

The objectives of this research were: 1) to determine the characteristics and physical properties of paper mulberry fiber, 2) to develop the spinning methods for paper mulberry yarn, 3) to determine the characteristics and physical properties of the paper mulberry yarns spun by the developed methods and 4) to experimentally produce paper mulberry fabric by weaving and knitting and determine the characteristics and physical properties of the paper mulberry fabrics produced.

The materials used for this study were the inner barks of paper mulberry trees (*Broussonetia papyrifera* (L.) Vent.), between 6 to 12 months old. Two hand spinning methods were developed modifying hemp spinning and cotton spinning methods. The paper mulberry yarns were spun by the modified hemp spinning method using 2, 4 and 6 mm bark strips and the modified cotton spinning method using 3.5, 5 and 6.5 cm fibers. The fiber, the yarns, the woven fabrics and the knitted fabrics produced were tested for physical properties according to American Society of Testing Materials standards (ASTM).

The results were as follows: 1) The fiber was found in clusters with an average diameter of 10 micrometers and had rounded corners with lumen and uneven texture and node. 2) The single fiber was a short fiber while the bundle fiber was an extra long fiber. The single fiber was 0.95 tex whereas the bundle fiber was 13.04 tex. The moisture content of the single fiber was 8.14% and that of the bundle fiber was 10.66%. The tenacity of the single fiber was 4.85 cN/tex and that of the bundle fiber was 15.90 cN/tex. The elongation of the single fiber was 4.50% and that of the bundle fiber was 11.21%. 3) The modified hemp spinning method using 2 mm bark strips produced the longest yarn (978 meters), whereas, the modified hemp spinning method with 6 mm strips produced the highest weight of yarn (975 grams) and the least waste. The modified hemp spinning methods produced much smoother yarns. In contrast, the modified cotton spinning methods produced more fuzzy and rough texture yarns. The yarns spun by different methods statistically had different yarn count, yarn twist, yarn breaking strength and yarn elongation at .01 level. 4) The paper mulberry woven fabrics made from the yarns spun by the modified hemp spinning methods were dense and smooth. In contrast, the paper mulberry woven fabrics made from the yarns spun by the modified cotton spinning methods were fuzzy and thick. The woven fabrics made from the yarns spun by different methods statistically had different thickness, weight, weft count, strength in warp direction, strength in weft direction, elongation in warp direction and elongation in weft direction at .01 level. 5) The paper mulberry knitted fabrics made from the yarns spun by the modified hemp spinning methods were dense and smooth, while, the paper mulberry knitted fabrics made from the yarns spun by the modified cotton spinning methods were rough and fuzzy. The knitted fabrics made from the yarns spun by different methods statistically had different thickness, weight, course count and wale count at .01 level.

---

Student's signature

---

Thesis Advisor's signature

## ACKNOWLEDGEMENTS

I would like to gratefully thank Asst. Prof. Dr. Kajjarus Piromthamsiri, my advisor for advice, encouragement and valuable suggestion for writing of thesis. I would sincerely like to thank Dr. Chanchai Sirikasemlert, my co-advisor for advice, suggestion and encouragement. I would like to sincerely thank Assoc. Prof. Dr. Banyat Saitthiti, for his suggestion and encouragement.

I would like to thank Assoc. Prof. Dr. Ying Yong Paisooksantivatana, Graduate program committee chairperson for his interest and support. I also would like to thank Assoc. Prof. Dr. Gunjina Theeragool, Dean of the Graduate School for interest and support.

I would like to sincerely thank Mae Fah Luang Foundation for providing materials and also Ms. Chum Yapradit for support during study and research work. I am greatly indebted to Assoc. Prof. Sutasnee Boonyopas, Asst. Prof. Chavalit Sangswasd, Dr. Rattanaphol Mongkholrattanasit and Asst. Prof. Marin Salee for their advice. I also thank to Department of Textiles Engineering, Department of Materials and Metallurgical Engineering, RMUTT and Textile Testing Center, Thailand Textile Institute, for their textiles testing.

This research was supported by Rajamangala University of Technology Thanyaburi and I give heartfelt thanks to my friends in the Department of Textile and Clothing, Faculty of Home Economic Technology, RMUTT for their friendship.

I especially appreciate my parents for their continuing help and encouragements, for their interest and support during my graduate study.

Sakorn Chonsakorn

July, 2014

**TABLE OF CONTENTS**

	<b>Page</b>
TABLE OF CONTENTS	i
LIST OF TABLES	ii
LIST OF FIGURES	vii
INTRODUCTION	1
OBJECTIVES	4
LITERATURE REVIEW	5
MATERIALS AND METHODS	78
Materials	78
Methods	80
RESULTS AND DISCUSSION	90
CONCLUSIONS AND RECOMMENDATIONS	146
Conclusions	146
Recommendations	152
LITERATURE CITED	155
CURRICULUM VITAE	161

## LIST OF TABLES

<b>Table</b>		<b>Page</b>
1	Physical properties of paper mulberry fiber	93
2	The yield of paper mulberry yarns from different spinning methods	97
3	Means of yarn count of the paper mulberry yarns produced by different spinning methods	100
4	Variations analysis of the means yarn count of the paper mulberry yarns spun by different methods	101
5	The analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn count of the paper mulberry yarns spun by different methods	102
6	Means of yarn twist of the paper mulberry yarns produced by different spinning methods	103
7	Variation analysis of the means yarn twist of the paper mulberry yarns spun by different methods	104
8	The analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn twist of the paper mulberry yarns spun by different methods	104
9	Means of yarn breaking strength of the paper mulberry yarns produced by different spinning methods	105
10	Variations analysis of the means yarn breaking strength of the paper mulberry yarns spun by different methods	106
11	The analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn breaking strength of the paper mulberry yarns spun by different methods	107
12	Means of yarn elongation of the paper mulberry yarns produced by different spinning methods	108

**LIST OF TABLES (Continued)**

<b>Table</b>		<b>Page</b>
13	Variations analysis of the means yarn elongation of the paper mulberry yarns spun by different methods	109
14	The analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn elongation of the paper mulberry yarns spun by different methods	110
15	Means of Characteristics and properties of paper mulberry yarns produced by different spinning methods	112
16	Means of fabric thickness of the paper mulberry woven fabrics made from different yarns	114
17	Variations analysis of the means fabric thickness of the paper mulberry woven fabrics made from different yarns	115
18	The analysis of Least Significant Ranges (LSR) to measure the mean difference of thickness of the paper mulberry woven fabrics made from different yarns	116
19	Means of fabric weight of the paper mulberry woven fabrics made from different yarns	117
20	Variations analysis of the means fabric weight of the paper mulberry woven fabrics made from different yarns	118
21	The analysis of Least Significant Ranges (LSR) to measure the mean difference of weight of the paper mulberry woven fabrics made from different yarns	118
22	Means of fabric warp count of the paper mulberry woven fabric made from different yarns	119
23	Variations analysis of the means fabric warp count of the paper mulberry woven fabrics made from different yarns	120
24	The analysis of Least Significant Ranges (LSR) to measure the mean difference of count of the paper mulberry woven fabrics made from different yarns	121

**LIST OF TABLES (Continued)**

<b>Table</b>		<b>Page</b>
25	Means of fabric strength in warp direction of the paper mulberry woven fabrics made from different yarns	122
26	Variations analysis of the means fabric strength in warp direction of the paper mulberry woven fabrics made from different yarns	123
27	The analysis of Least Significant Ranges (LSR) to measure the mean difference of strength in warp direction of the paper mulberry woven fabrics made from different yarns	123
28	Means of fabric strength in weft direction of the paper mulberry woven fabrics made from different yarns	125
29	Variations analysis of the means fabric strength in weft direction of the paper mulberry woven fabrics made from different yarns	126
30	The analysis of Least Significant Ranges (LSR) to measure the mean difference of strength in weft direction of the paper mulberry woven fabrics made from different yarns	126
31	Means of fabric elongation in warp direction of the paper mulberry woven fabrics made from different yarns	128
32	Variations analysis of the means fabric elongation in warp direction of the paper mulberry woven fabrics made from different yarns	129
33	The analysis of Least Significant Ranges (LSR) to measure the mean difference of elongation in warp of the paper mulberry woven fabrics produced by different yarns	129
34	Means of fabric elongation in weft direction of the paper mulberry woven fabrics made from different yarns	131

## LIST OF TABLES (Continued)

<b>Table</b>		<b>Page</b>
35	Variations analysis of the means fabric elongation in weft direction of the paper mulberry woven fabrics made from different yarns	132
36	The analysis of Least Significant Ranges (LSR) to measure the mean difference of elongation in weft direction of the paper mulberry woven fabrics made from different yarns	132
37	Means of fabric thickness of the paper mulberry knitted fabrics made from different yarns	135
38	Variations analysis of the means fabric thickness of the paper mulberry knitted fabrics made from different yarns	136
39	The analysis of Least Significant Ranges (LSR) to measure the mean difference of thickness of the paper mulberry knitted fabrics made from different yarns	137
40	Means of fabric weight of the paper mulberry knitted fabrics made from different yarns	138
41	Variations analysis of the means fabric weight of the paper mulberry knitted fabrics made from different yarns	139
42	The analysis of Least Significant Ranges (LSR) to measure the mean difference of weight of the paper mulberry knitted fabrics produced by different yarns	139
43	Means of fabric count (course/inch) of the paper mulberry knitted fabrics made from different yarns	140
44	Variations analysis of the means fabric count (course/inch) of the paper mulberry knitted fabrics made from different yarns	141
45	The analysis of Least Significant Ranges (LSR) to measure the mean difference of fabric count (course/inch) of the paper mulberry knitted fabrics produced by different yarns	142

**LIST OF TABLES (Continued)**

<b>Table</b>		<b>Page</b>
46	Means of fabric count (wale/inch) of the paper mulberry knitted fabrics made from different yarns	143
47	Variations analysis of the means fabric count (wale/inch) of the paper mulberry knitted fabrics made from different yarns	144
48	The analysis of Least Significant Ranges (LSR) to measure the mean difference of count (wale/inch) of the paper mulberry knitted fabrics made from different yarns	144

## LIST OF FIGURES

Figure		Page
1	Saa: Paper mulberry tree	6
2	Diagrams of single, ply and cord yarns	41
3	Diagrams of S and Z twist yarns	44
4	Hand pin knitting	54
5	Paper mulberry barks	78
6	Paper mulberry strips in three sizes width	81
7	Paper mulberry barks in three sizes length	82
8	Cross-section of paper mulberry fiber -150x (a) and Longitudinal section of paper mulberry fiber-150x (b)	91
9	A node on a paper mulberry single fiber in (a) 300x and (b) 2000x	92
10	The steps of the modified hemp spinning method (a) pounding strips, (b) joining strips, (c) hand spinning, and (d) boiling the yarns	95
11	The steps of the modified cotton spinning method (a) cleaning or scotching, (b) rolling bundle fibers, and (c) spinning to yarns	96
12	Longitudinal section of the yarn spun by different methods (a) modified hemp (MH) with 2 mm strip, (b) modified hemp (MH) with 4 mm strip, (c) modified hemp (MH) with 6 mm strip, (d) modified cotton (MC) with 3.5 cm fiber, (e) modified cotton (MC) with 5 cm fiber, and (f) modified cotton (MC) with 6.5 cm fiber	98
13	The evenness of the paper mulberry yarns spun by different methods (a) modified hemp (MH) with 2 mm strip, (b) modified hemp (MH) with 4 mm strip, (c) modified hemp (MH) with 6 mm strip, (d) modified cotton (MC) with 3.5 cm fiber, (e) modified cotton (MC) with 5 cm fiber, and (f) modified cotton (MC) with 6.5 cm fiber	99

**LIST OF FIGURES (Continued)**

<b>Figure</b>		<b>Page</b>
14	The paper mulberry woven fabrics made from different yarns (a) modified hemp (MH) with 2 mm strips spun yarn, (b) modified hemp (MH) with 4 mm strips spun yarn, (c) modified hemp (MH) with 6 mm strips spun yarn, (d) modified cotton (MC) with 3.5 cm fibers spun yarn, (e) modified cotton (MC) with 5 cm fibers spun yarn, and (f) modified cotton (MC) with 6.5 cm fibers spun yarn	113
15	The paper mulberry knitted fabrics made from different yarns (a) modified hemp (MH) with 2 mm strip spun yarn, (b) modified hemp (MH) with 4 mm strip spun yarn, (c) modified hemp (MH) with 6 mm strip spun yarn, (d) modified cotton (MC) with 3.5 cm fiber spun yarn, (e) modified cotton (MC) with 5 cm fiber spun yarn, and (f) modified cotton (MC) with 6.5 cm fiber spun yarn	134

## CHARACTERISTICS AND PROPERTIES OF PAPER MULBERRY YARN AND FABRIC

### INTRODUCTION

Over the last 100 years the ancient art of hand weaving has been a tradition in Thailand, within its long history of beautiful fine weaving textiles. Many Thais are familiar with traditional Thai cloth in ceremonial dress and everyday use in peoples' clothing. Weaving is the main skill for employment in many provinces in Thailand, such as Chiang Mai, Nong Khai, Khon Kaen and Sukothai. Cotton, silk and hemp have traditionally been the main fibers used throughout Thailand's textile industry to weave cloth throughout its ancient history. Today, the use of hemp is largely confined to the hill tribes in rural and remote farming locations throughout the country. However we can prove that this weaving technique still remains in a few items today, with a growing demand in export to Europe for ecological, sustainable and environmentally friendly clothing. In addition, there is a growing demand for furniture production and paper materials. Most natural materials are woven. The main use for Thai native textiles are, cotton, silk and jute yarns. Most of these are not handmade, nevertheless the trend of handmade yarns is still a favorite for general customers and weavers alike. Moreover, The Thai Textile Statistics have revealed that the value of yarns imported during the years 2008-2011 was \$731.3 million US dollars (Thailand Textile Institute, 2011).

Saa, or the popular name given as the paper mulberry tree, is a coarse, strong, rigid material and has a natural based fiber. (Latin botanical name: *Broussonetia papyrifera*). It is the main raw material for handmade paper in Thailand (Ujjin *et al.*, 2000a). From the saa tree, paper mulberry has been produced as a very popular raw material used for making paper in Japan, Taiwan and Korea for over the past twenty years. There are many named varieties, such as the preferred scientific name "*Broussonetia papyrifera* (L.) Vent" and the family name, Moraceae. Related to the fig tree family, the common, widely used name is "paper mulberry." Other useful translated international descriptive references include: English, "*ai masi*"Fiji,

“*aute*” Australs, New Zealand, “*hiapo*” Tonga, Niue, “*hiapo, tutu*” Uvea, “*lafi*” Futuna, “*mûrier à papier*” French, “*u’a*” Samoa, “*ute*” Marquesas, “*wauke*” The most popular name for the material in Thai to date, is generally called “Por Sa or Saa”. The mulberry tree is widely cultivated in East Asia for the fiber of its bark. A fast growing, deciduous tree measuring 15 metres in height. Left undisturbed at the foot of the mountains, the tree’s growth invades rapidly where the soil is fertile. It has fruits that can be harvested for future growth, leaves, wood, stem, bark, and fibers. At present the demand of paper mulberry inner bark is rapidly increasing for the use in paper and material production, being a natural sustainable environmentally friendly farmed resource. At present, the price of paper mulberry inner bark is approximately 15 Thai Baht per 35 kg, depending upon the quality. In Thailand, it was referred to for many years as the best choice for its weaving properties and paper manufacturing and for its sustainable, robust and durable properties. The stem of the paper mulberry has a hairy reddish brown feel to it, the bark is tan in color and the inner bark is smooth to moderately furrowed. Paper mulberry is a unique, long and very strong fiber. It is the best choice by many to be used for making high quality paper.

The American Society for Testing Materials (ASTM) defines a yarn as a continuous strand of textile fibers, filaments, or materials in a form that can be used to make fabric. Fiber properties can be enhanced or modified by the way the fibers are made into yarns. Some fibers need expensive processing to become yarns while others, such as monofilament, need very little processing. The resulting yarns are used to make knitted or woven fabrics (Elsasser, 2005). Until recently, most textiles were produced from fibers of primarily natural origin. The important natural fibers presently in use for apparel applications are cotton, flax, wool, and silk. These fibers have certain inherent characteristics that make them suitable for conversion into yarns and ultimately into the fabrics that are most commonly used in day-to-day wear. In addition, there are many other natural fibers, such as jute, hemp, ramie, sisal, and kapok, that have utilized for certain specific end-uses (Goswami *et al.*, 1997). It has been used for various products such as household textiles, technical textiles and handicrafts. Also of importance is the susceptibility and durability to various treatments and their reaction to finishing processes. Much of the variety, beauty and

texture of fabrics is due to yarn differences, creating individual and unique finishes (Collier and Tortora, 2001).

This research work focuses upon studying paper mulberry fiber and the creation of its resourceful yarn and fabric, in order to make aware, educate and encourage the utilization of paper mulberry fiber for an environmentally friendly and sustainable use for natural textiles. The properties of paper mulberry fiber and yarn, will lead to the development of a new source of green textiles that will be processed and widely used, in woven fabric and knit wear, as an individual trademark sustainable product from Thailand. This project in turn, will have the potential to create large amounts of employment opportunities throughout Asia, especially for the young women that have helped to raise the standard of living of the indigenous ethnic farming minorities. The aim of this study is to encourage the growth of creative eco-based naturally sustainable, environmentally friendly farming tree plantations, aiding skills, knowledge and education, within the importance of the natural environment and rural economy in Thailand. In addition, this study aims to encourage sustainability in tree plantation farms, in turn promoting and encouraging natural habitation of certain wildlife species native to Asia.

## OBJECTIVES

The main purposes of this study are to develop a new textile fiber from paper mulberry bark, with the specific objectives as follows:

1. To determine the characteristics and physical properties of paper mulberry fiber.
2. To develop the spinning processes of paper mulberry yarn.
3. To determine the characteristics and physical properties of paper mulberry yarn.
4. To experimentally produce the paper mulberry fabrics by weaving and knitting and determine the characteristics and physical properties of the paper mulberry fabric produced.

## LITERATURE REVIEW

### Paper mulberry

#### 1. General characteristics of paper mulberry

Paper mulberry is native to Japan and Taiwan and was introduced centuries ago across the Pacific as far east as Hawaii. Although the tree is fertile in its native range, the plants carried into the Pacific were all male clones, transported and planted as rootstock or stems. Thus, the female plants with flowers and consequently fruit, are absent. The tree reaches a height of 12 meters or more if allowed to grow, but in practice it is usually harvested at a much shorter height when the stems are about 2.5 cm in diameter and 3-4 meters tall. The tree is very important in traditional Polynesian culture, as its bark supplied one of the most important materials in ancient Polynesia, tapa cloth. Today, the tree has disappeared from most of its traditional range and is cultivated to any extent only in Tonga, Fiji and Samoa. It is important in these places because it is a major source of handicraft income in the form of finished tapa cloth. The tree is grown in plantations and home gardens on islands where tapa cloth is still made. It can tolerate a wide range of environmental extremes and even does well in temperate climates. Since only the male clones are present in Polynesia, the tree has no potential for becoming invasive (Whistler and Elevitch, 2006).

##### 1.1 Species

Paper mulberry, preferred scientific name is *Broussonetia papyrifera* (L.) Vent, family name is Moraceae, common names are paper mulberry (English) *ai masi* (Fiji) *aute* (Societies, Cooks, Australs, New Zealand) *biapo* (Tonga, Niue) *biapo, tutu* (Uvea) *lafī* (Futuna) *mûrier á papier* (French) *u'a* (Samoa) *ute* (Marquesas) *wauke* (Hawai'i) (Whistler and Elevitch, 2006). Thammincha (2001) studied the po-saa and found that the Thai language uses the common name in English as paper mulberry. It is a tree of medium size of the *Maracee* family. Generally it is called Thai po-saa. There are other trees of *Broussonetia* founded in Thailand, *B. Kurzii* or *tonsalae* which uses the fiber for papermaking and young flowers for food, *B. Kazinoki* and *B.*

*Kaempferi*. These two flowers are generally called Japanese po-saa and are fast growing trees of big bushy trunks. It can be propagated by seed, stem, root, stolon and tissue culture techniques.

## 1.2 Physical characteristics

Paper mulberry is a medium size tree up to 12 m in height (Figure 1), but it is often not allowed to get that tall in cultivation. Flowers, occur in clongate, male spikes up to 8 cm long and female auxillary globose heads up to 2.5 cm. long, on separate male and female trees. Female flowers have a two-to four-lobed perianth and a superior ovary with a filiform style. Male flowers have four valvate tepals and four free stamens with filaments inflexed in the bud. Flowering is unknown or infrequent over most of the tree's distribution in the Pacific. Leaves are simple, alternate, blade ovate to three- to five-lobed, 8-20 cm long, lower surface densely tomentose, upper surface scabrous; margins serrate; petiole nearly as long as the blade. The fruit is a globose to club-shaped syncarp 1-2.5 cm in diameter comprised of numerous red to yellow drupes (Whistler and Elevitch, 2006).



**Figure 1** Saa: Paper mulberry tree.

**Source:** Mongkolsuk *et al.* (2004)

## 2. Uses and products

Whistler and Elevitch (2006) noted that the most significant part of paper mulberry is its strong, fibrous bark used in making native bark cloth commonly known as tapa cloth. The plant has other less important uses including medicinal ones.

### 2.1 Fiber and clothing

Whistler and Elevitch (2006) pointed out that the inner bark has been used for centuries in Southeast Asia for paper and textiles. The bark is traditionally used in Polynesia to make bark cloth known as tapa. The bark is stripped from the cut stems by making a lengthwise incision across the stem and pulling it off intact to obtain a single long strip. The inner bark, or bast, is then separated from the outer bark and any green matter remaining on the bast is removed using scrapers; the bast is then washed to remove the slimy sap. The strips are pounded on a wooden anvil by using a square, billyclub-like beater made of hard wood. Mongkolsuk *et al.* (2004) pointed out that a fiber from the bark is used in making paper, cloth, rope etc. The fiber can be produced by beating strips of bark on a flat surface with a wooden mallet. A very fine cloth can be made in this way and the more the bark is beaten the finer the cloth becomes. Larger sizes can be made by overlapping 2 pieces of bark and beating them together.

Ujjin *et al.* (2000b) studied the fiber characteristic of paper mulberry from various clones. The sampling of 6 month old paper mulberry (*Broussonetia papyrifera* Vent) inner bark from Sri Satchanalai, Num Som, Mae Charim, Suan Pung and Kozo clones were used. It was found that paper mulberry fiber was thick-walled. Shape of fiber ends were pointed, blunt and scalloped form. Fiber dimension was also measured. It was found that the average fiber length of Sri Satchanalai, Num Som, Mae Charim, Suan Pung and Kozo clones were 6.9, 7.4, 8.1, 10.2 and 9 mm respectively, while the average fiber widths were 18, 18.1, 18.3, 15.9 and 22.8 microns respectively. Average fiber lumen was 5.2, 5.9, 5.6, 6 and 6.4 microns respectively. Fiber wall averaged 6.4, 6.1, 6.3, 4.9 and 8.2 microns respectively.

Runkel ratios were 2.5, 2.1, 2.2, 1.6 and 2.6 respectively. Slenderness ratios were 384.4, 410.1, 440.7, 639.9 and 395.5 respectively. Finally, wall fractions were 28.7, 32.6, 30.6, 37.7 and 28.7 percent respectively. In addition, Punsuvon (2000) studied the comparison of chemical components in different grades of paper mulberry bark. The results were paper mulberry bark grades SA and A had holocellulose percent higher than grades B and grade C and grades SA and A had ash and lignin content lower than grades B and C. The glucose percent was related with holocellulose percent and alpha cellulose percent.

## 2.2 Hand made paper

When used for making paper branches are harvested after the leaves have fallen in the autumn, they are steamed and the fibers stripped off. The inner and outer bark is then separated by scraping the fibers are then cooked for 2 hours with lye before being hand pounded with mallets. Thammincha (2001) found that the paper varies in color if the outer and inner barks are used together or separately. In Thailand Po-saa bast fiber is 70 percent domestically produced. The other 30 percent was imported from Laos and Myanmar. Fifty percent of domestic supply came from natural grown saa in the forest along streams and rivers. Thirty percent of saa bark was from cultivation and another 20 percent of the raw material was cut from the natural grown trees in farmer's fields.

## 2.3 Other uses

Thammincha (2001) considered the botanical characteristics of Thai po-saa. According to his study, Po-saa utilization can be classified according to its parts as follows: leaves: for diuretic, skin balm, animal feed and natural dye. Fruits: ripe fruit for kidney tonic, physical strength and bird feed. Bark (bast fiber): stops bleeding, prevents coughing, anti-vomit and papermaking raw material. Woody core: short fiber source for pulping and fuel.

### 3. Mulberry paper production

The paper from paper mulberry trees are mostly produced by handmade processes in northern Thailand (Tajima *et al.*, 2001). In addition, Thammincha (2001) stated that presently saa-bark and paper mulberry growing can be a good side-career for farmers, especially in the north and northeast. Harvesting of saa-bark was started in the rainy season from the end of April to October. Preparation of saa-bark for papermaking should be dried clean bast fiber without outer-skin. Production capacity from young strong men aged 23-40 years old was 15-20 kg per person per day or 225-300 Baht per day. Older people or woman can produce 10-15 kg per person per day or 150-225 Bath per day. It was found in the 1998 survey that total consumption of dried saa-bark was 6,900 tons; this could be classified as a domestic production of 4,000 tons at the value of 60 million Baht. Average saa-handmade papermaking in each village of the production zone was 1-2 mills. Most of the workers were women and age people at an average labor cost of 75-90 Baths per day per person. This was calculated from the output as paper sheets of 0.5-3.0 Bath. It was realized that in rural communities, saa-handmade papermaking was a significant side job to make additional income for families. Some Thais believe that the production of saa bark and paper will be terminated soon because the young generation does not pay attention to this kind of work. Furthermore, there is no development in the processing of papermaking and converting for the modern international market. Then concerned organizations should promote strategies to motivate the new generation for the development of papermaking to compete in the world market.

#### 3.1 Process of saa paper

Process of saa paper are as follow.

3.1.1 To make the mulberry paper, a lot of mulberry bark has to be used. The first steps to making mulberry paper are retting and boiling the mulberry bark in alkali water to detach their tissues. After that, the detached, tissues are washed with fresh water several times to clean out alkali.

3.1.2 The mulberry tissues are then placed into a tank that is full of water. It is stirred and hit until the tissues break into small pieces. After that, the mulberry tissue is weighed for quantity that is suitable for making one sheet mulberry paper.

3.1.3 Put the mulberry tissue into the frame that is in the water and spread it throughout the frame and decorate with fresh leaves and petals. Then lift the frame from the water and dry each sheet in the sun.

3.1.4 Remove the mulberry paper from the frame and dry again in the sun. Collect the mulberry papers, keeping them in stock and waiting for the packing process.

### 3.2 Products from paper mulberry

The bark of the saa or paper mulberry tree is used in the production of saa paper which, in turn, is used as decorative packaging or elements of gift items, such as pictures or photo frames, notebooks and other utensils.

### **Bast Fibers**

Bast fibers are those that grow in the stems of plants. As the name implies, these fibers are obtained from the inner bark of the stems of plants called dicotyledenous. These fibers are also composed of cellulose. They are made up of long, thick-walled cells glued together by noncellulosic materials (lignins and pectins) resulting in long fiber bundles running the entire length of the stem. The bast fibers are removed from the woody stems by the process known as “retting” The function of this process is to ferment the noncellulosic material binding the fibers and removing it by washing in water (Franck, 2005).

Frings (1999) noticed that the most widely used natural fibers are cotton, wool, flax and silk. Others include ramie, jute, sisal and hemp. There is a trend toward blending natural fibers to create new texture. Gillow and Sentence (1999) concerned the bark fiber on the American Northwest coat in which the Tlingit and Kwakiutl wove blankets from the shredded bark of the red cedar. The Ainu of Hokkaido, Japan, traditionally wear garments woven from the thin bark of the atsui tree or of elm-bark fiber.

Bast fibers that are widely used in textiles include flax, ramie, jute, kenaf and hemp.

## **1. Flax**

### **1.1 Introduction of flax fiber**

Gillow and Sentence (1999) stated that bast fibers are obtained from the stalks of certain dicotyledonous plants. The supreme example of a bast fiber is linen, which is made from the stems of the flax plant, *Linum usitatissimum*. Diamond and Diamond (2007) noticed that flax is a gold-colored, strawlike plant whose stems are used for fiber.

Muir and Westcott (2003) found that flax is made from the fibrous material in the stem of the flax plant "*Linum Usitaissimum*", the specific name for flax within the family Linaceae, aptly describes its usefulness and versatility. In fact, the name Linum originated from the Celtic word *lin* or "thread," and the name *usitatissimum* is Latin for "most useful". These plants grow in many temperate and subtropical regions of the world.

Flax had the widest distribution of any of the fiber-bearing plants during prehistoric times. Archeological evidence shows that flax plant stems were used in basket making long before flax fiber came into use for cloth. Techniques for removing the long fibers from flax stems were developed later. At first, wild flax was gathered,

but subsequent cultivation of the plant spread it rapidly throughout the Middle East, Northern Africa and Europe. Interest in linen was stimulated in the early 1990s by ecological concerns of consumers, since flax is grown virtually free of herbicides and pesticides. The United States imports linen fibers, yarns, fabrics and completed garments, although flax for fibers is not cultivated here (Frings, 1999).

In addition, Elsasser (2005) noticed that the historical importance of linen is reflected in the current use of bed linen, table linen and household linen for products. Today, most flax is produced in Belgium, China, Egypt, France, Italy, Ireland, Poland, Spain and Russia.

## 1.2 Preparation of flax fiber

Preparation of flax and other bast fibers require extensive processing to remove the fibers from the woody stem in which they are held, a factor that adds considerably to the cost. The procedure is similar for all bast fibers. The deseeded flax straw has to be partially rotted to dissolve the substances that hold the fiber in the stem. This first step in preparing the fiber is called retting. Retting is accomplished through the breakdown of the materials that bind the fibers into the plant stems. Highly specific enzymes attack only the binding materials and not the fibers that are secreted by fungi and bacteria. The fiber grow in bundles in the bast layer of the stem, just underneath the bark. Retting processes are of three types (Collier *et al.*, 2009):

1.2.1 Dew retting: Dew retting takes place in the field. The flax is laid out in swaths in the fields where the action of rain and dew, together with soil-borne micro-organisms causes the bark of the stems to become loosened. This may take from 3 to 6 weeks, depending on weather conditions (Collier *et al.*, 2009).

1.2.2 Water retting: Water retting takes place when flax is submerged in water for 6 to 20 days. When water temperature is cooler and the process takes a longer amount of time. Water retting may be done in ponds, vats, or in sluggish

streams. As in dew retting, the bacterial action causes the bark to become loose (Collier *et al.*, 2009).

1.2.3 Chemical retting: Processes of several types have been developed. In one, flax is sprayed with a systemic herbicide that kills the flax as it grows. If weather conditions are right, retting takes place in the standing plant and the dry, retted flax can be pulled (Elsasser, 2005).

When processing flax, first the seeds are removed by rippling or pulling the stems through a coarse comb. The stems are soaked in water so that the bast fiber can be separated easily from the woody parts. This is called retting. Then the stems are broken by beating or crushing them in a hinged wooden device called a brake. Finally, the stems are tapped and stroked to free the bast fibers from the unwanted woody portions and combed through a hackle with iron teeth. The end product is a fine fiber that can be spun into tough thread or yarn (Gillow and Sentence, 1999).

## 2. Ramie

### 2.1 Introduction of ramie fiber

Collier *et al.* (2009) noticed ramie, or China grass, come from a plant in the nettle family. Like flax, the fibers are found in the outer layer of the stalk. A perennial shrub, the ramie plant grows in semitropical regions.

Various members of the nettle family, genus *Urticaceae*, have been exploited in Asia and North America including ramie, *Boehmeria nivea*, a native of China and the East Indies (Gillow and Sentence, 1999). In addition, a strong abrasion-resistant fiber is used extensively today with cotton for sweaters (Diamond and Diamond, 2007).

Elsasser (2005) noted that ramie or China grass, is a bast or stem cellulosic fiber. It is also called rhea, grasscloth and Army/ Navy cloth. Ramie comes

from a plant in the nettle family. The fibers are taken from the stalk. A perennial shrub, the ramie plant grows in semitropical regions. Ramie growth and processing are concentrated in the Philippines, Brazil and the People's Republic of China. Hong Kong, Taiwan and Korea while Japan processes ramie but does not grow ramie. Ramie stalks are planted and the fiber is harvested the third year after planting. Three crops may be cut each year. After cutting the stems, the leaves of the plant are beaten off, the stems are split lengthwise and the bark is stripped from them. In Addition, ramie is a formerly rare fiber that is now being used for apparel because its importation into the United States is not restricted (Frings, 1999).

## 2.2 Preparation of ramie fiber

Before spinning, the fiber must be retted out of the ribbons. Both dew and wet retting, similar to that used with flax, can be done. A chemical retting process that uses sodium hydroxide and an acid rinse has been patented and is used in industrially developed countries. Ramie has properties similar to flax, but it has fairly low resiliency and flexibility and a high modulus (Frings, 1999).

## 3. Jute

### 3.1 Introduction of jute fiber

Jute fiber is taken from the stem of the jute plant. Successful cultivation of the plant requires fertile soil and a hot, moist climate. Jute is grown in India and Bangladesh and, to a lesser extent, in Thailand and other southeast Asian countries. It is the most commercially important of the bast fibers (Collier *et al.*, 2009).

Gillow and Sentence (1999) noticed the Indian province of West Bengal has an economy largely based on the processing of jute, *Corchorus capsularis* and *C. olitorius*.

Alam and Arifuzzaman (2007) noticed jute, a major source of natural fiber has some drawback such as low tensile strength, poor color fastness and high production cost. Jute fiber is taken from the stem of the jute plant. Successful cultivation of the plant requires fertile soil and a hot, moist climate. Jute is grown in India and Bangladesh, to a lesser extent, China, Thailand and other southeast Asian countries. Jute plants grow from 2 to 5 meters high. Jute has long been in demand as the cheap, useful packaging material burlap. It is one of the major jute bagging fabrics. Jute has also traditionally been used for carpet backings and cordage.

### 3.2 Preparation of jute fiber

The stalks are cut just after the flowers begin to fade. Like other bast fibers, separation of the fiber requires retting. Many jute producers use chemical retting processes with chlorine compounds. After retting, the stems are broken and the fiber is removed (Collier *et al.*, 2009).

## 4. Kenaf

### 4.1 Introduction of kenaf fiber

Kenaf is also a bast fiber, similar to jute in that it is composed of short ultimate fibers that are separated from the stalk as fiber bundles. When harvested, the plant stems are decorticated to remove the inner part of the stalk, then retted to obtain the fiber bundles (Collier *et al.*, 2009).

Mechanical fiber properties are similar to those of jute, but kenaf is stronger. It is also whiter, more luster and can be bleached and dyed more easily. While kenaf has high moisture regain, it is not wet as quickly as cotton. Botanically, it is related to both cotton and okra. Grown predominantly in Africa and India, kenaf has sparked renewed interest as an alternative crop in the South and West of the United States (Franck, 2005). Traditionally, kenaf was used in making rope and twine, for which its high strength was important. Recent development have focused on the

use of these fibers in paper making because paper of kenaf fibers is smoother and whiter than that made from wood pulp (Collier *et al.*, 2009).

#### 4.2 Preparation of kenaf fiber

When harvested, the plant stems are decorticated to remove the inner part of the stalk and then retted to obtain the fiber bundles. Traditionally, kenaf was used in making rope and twine for which its high strength was important. Recent developments have focused on the use of these fibers in paper making since paper of kenaf fibers is smoother and whiter than that made from wood pulp. New methods for processing the kenaf stalks to obtain longer fibers have led to the production of nonwoven and woven textiles (Franck, 2005).

### 5. Hemp

#### 5.1 Introduction of hemp fiber

The hemp plant, *Cannabis sativa*, is a member of the mulberry family and a type of marijuana plant. The fiber bundles come from the bast layer of the stem. Hemp has high tensile strength comparable to that of linen. It has good absorbency but poor elasticity. In its chemical properties, hemp is similar to cotton and flax (Collier *et al.*, 2009).

The major uses of hemp are in the production of industrial fabrics, twine and ropes because of its good tensile strength and high modulus that provide initial resistance to force. Interest in apparel and household fabrics made from hemp, as well as craft items, have increased recently. A number of well-known fashion designers have added designs containing hemp fibers and fabrics to their lines (Collier *et al.*, 2009).

#### 5.2 Preparation of hemp fiber

Mature plants are cut off and spread on the ground where they are left to dry for 5 or 6 days. Leaves and seeds are beaten off and bundles or sheaves of hemp

are formed after additional drying. Retting, breaking and scotching complete the fiber extraction process. Hemp has tensile strength comparable to that of linen; it is one of the strongest of the natural fibers (Franck, 2005).

### **Properties of textiles fibers**

Elsasser (2005) noticed that the fiber has properties that may be physical, mechanical, chemical and environment. The important properties of fibers, considering the individual fibers, as distinct from yarns and fabrics made from them, are discussed below.

#### **1. Physical properties of textiles fibers**

Physical properties are properties that can be evaluated with the naked eye or with a microscope. Because fibers are small, it is usually best to observe fibers under a microscope. Physical properties include: color, shape, covering power, hand and luster (Elsasser, 2005). The physical appearance of these fibers is best observed under a microscope. With a microscope, it is possible to observe such properties as length, diameter, shape and color. The physical characteristics of each individual fiber affect the appearance and behavior of the yarn and fabrics into which the fibers are manufactured (Collier and Tortora, 2001).

##### **1.1 Color**

The color of a natural fibers varies with just enough pigment to make them yellow or off-white; like wool, colors may range from white to black in shade, from white to brown, tan and black (Collier and Tortora, 2001).

##### **1.2 Shape**

Physically all fiber has length, cross section, surface contour and diameter (Elsasser, 2005). Collier and Tortora (2001) noticed that the shape and contour of a fiber can be examined both in cross section and in its longitudinal form.

Cotton fibers have a peanut-shaped cross section while silk fibers have a somewhat irregular triangular shape. Differences in shape and contour contribute to differences in fiber characteristics such as luster, covering power, appearance, hand or feel and surface texture.

1.2.1 Length: Fiber may be staple (short) or filament (long). Regarding the length of the fiber, one can readily observe the ratio of the length of the fiber in relation to its width. Although fibers are, by definition, always long and narrow, the length of the fiber is one basis for division or classification (Collier and Tortora, 2001). The staple fibers range from less than 3 cm to 40 cm long. Filament fibers are indefinitely long and, therefore, are measured in meters. Staple and filament fibers have different characteristic when they are made into yarns and fabrics (Elsasser, 2005).

1.2.2 Cross section: The cross section of a fiber is the appearance of the fiber across its diameter. The cross section of the fiber affects other properties. In addition, Collier and Tortora (2001) found that, the cross-sectional view is a practical way in which to view the three-dimensional form of a fiber, cross section are often used as a means of comparison. Cross sections vary from fiber to fiber, ranging from circular to oval, triangular, dog-bone shaped, U-shaped, trilobal to multilobal and hollow.

1.2.3 Surface contour: Elsasser (2005) noticed the surface contour is sometimes called longitudinal appearance. Therefore, Collier and Tortora (2001) noticed some fibers have smooth and are even contoured when examined longitudinally; others are rough and uneven. Wool is covered with many small scales that cause wool fibers to cling closely together. Cotton is twisted, making it reflect light unevenly and giving it a dull appearance.

1.2.4 Diameter: The diameter of a fiber is the width of the cross section. Fiber diameter is measured by the denier system or by the International system (Elsasser, 2005). The diameter of a fiber is the distance across its cross section.

In natural fibers the diameter usually varies from one part of the fiber to another because of irregularities in fiber size. Fiber diameter is measured in millimeters or in microns. One of the properties that distinguishes textile fibers from other fibrous material is their high aspect ratio, which is the ratio of length to diameter. Fiber diameter is an aspect of fineness, usually expressed as linear density, or weight per unit length (Collier and Tortora, 2001).

Ingamells (1993) concerned the fibers for clothing need to be soft and pliable, that is, their diameter must be small. But if the diameter is halved, the corresponding increase in softness is accompanied by a four-fold reduction in breaking strength. Consequently there are also lower limits needed for the fiber diameter if damage is to be avoided during processing. Fiber diameter also has a significant influence on the dyeing properties of the fiber, because the surface area of a given mass of fibers is higher for finer fibers. This relative difference between the surface areas of fine and coarse fibers allows the finer fibers to take up dye more rapidly.

### 1.3 Covering power

The covering power is the ability of a fabric to hide what is beneath it. Fiber with round cross sections tend to have poorer covering power, or cover less surface, than those with dog-bone or flat cross sections. Fibers with texture or crimp have better covering power than do smooth fibers (Elsasser, 2005). Therefore, Collier and Tortora (2001) noticed that the covering power is related to the ability of the fiber to hide what is placed beneath it. The more transparent the fiber, the less covering power it has.

### 1.4 Hand

The hand or texture of the fiber refers to the feel of the fiber. All the shape characteristics of a fiber have an effect on hand. In addition, Collier and Tortora (2001) stated that the hand or feel, of the fabric is affected by the use of either

filament or staple fiber. If a smooth filament form is selected, there are fewer fiber ends on the surface of the fabric, creating a smooth, even surface. If staple fibers are used, the short fiber ends on the surface of a fabric can create a fabric that feels soft and fluffy to the touch.

### 1.5 Luster

Luster is the amount of light that is reflected from a fiber. Silk is a natural fiber with high luster. Collier and Tortora (2001) noticed that luster is the amount of light reflected by the fiber. Luster may be desirable in some products and undesirable in others. The cross-sectional shapes can affect the luster of fibers as well. Completely flat cross sections have a high luster and some manufacturers have produced flat fibers with a glittering luster.

Ingamells (1993) focused on several factors contribute to fabric luster, including the fiber diameter and cross-sectional shape. Such factors influence the way in which light is reflected from the surface of the fabric. The alignment of the fibers in the yarn and the structure of the fabric also have an influence. A harsh shine is associated with large smooth filaments arranged parallel, whilst finer fibers with a less uniform surface in a yarn with a lower degree of fiber orientation produce multiple reflections and a correspondingly subdued luster.

## 2. Mechanical properties of textiles fibers

The mechanical properties of fibers are determined in a textile testing laboratory. Testing procedures have been developed by organizations such as the American Association of Textile Chemists and colorists (AATCC) and the American Society for testing and Materials (ASTM). These procedures make possible accurate evaluations of the qualities of textile products (Elsasser, 2005).

## 2.1 Abrasion resistance

Collier and Tortora (2001) noticed that one of the most important properties of a fiber in relation to durability of textile products is its ability to withstand abrasion. Abrasion is the rubbing or friction of fiber against fiber or fiber against other material. Fiber with poor abrasion resistance break and splinter, which produces worn or broken areas in fabrics.

## 2.2 Pilling

Elsasser (2005) considered that the formation of little balls of loose fibers on the surface of a fabric, results from abrasion. Pills form during wear and may be found near pockets, on sleeves and in the underarm areas of a garment. The tumbling action of washing and automatic drying may also cause pilling.

## 2.3 Dimensional stability

Fiber that neither stretch nor shrink when exposed to moisture or heat are dimensionally stable. Shrinkage is a decrease in the length of fibers and may be accompanied by an increase in the width of the fiber. Fibers that absorb moisture readily will exhibit this behavior (Collier and Tortora, 2001). In addition, Elsasser (2005) focused on the ability of a fiber to maintain its original shape, neither shrinking nor stretching.

## 2.4 Elastic recovery or elongation

Elastic recovery or elongation is the amount of stretching or lengthening of a fiber under a tensile force. Elongation does not imply that the fiber will return to its original form but merely that the fiber length can be elongated or extended. Measurement of elongation is commonly made as elongation to break, the amount of stretch the fiber can withstand before it will break. A fiber that will stretch or elongate more before breaking will show greater toughness, or durability, than a stiffer fiber that breaks at the same load but at lower elongation (Collier and Tortora, 2001).

## 2.5 Flexibility

Collier and Tortora (2001) noticed that the flexibility of the fibers is their ability to be easily bent or folded and is an essential quality of textile fibers. The consumer perceives fiber flexibility in terms of stiffness. It is difficult to spin inflexible, high-modulus fibers into yarn. Flexibility is of course related to fiber fineness. Heavy, coarse fiber will be relatively inflexible and fabrics made from them will be feel stiff (Elsasser, 2005).

## 2.6 Resiliency

Elsasser (2005) examined the resiliency or wrinkle recovery, or the ability of a fiber to return to its original shape after being bent or folded. In addition, resiliency refers to the ability of a fiber to spring back to its natural position after folding, creasing or compression. Fiber with high resiliencies are likely to recover from creasing or wrinkling more quickly. Although resiliency and elasticity are not the same, high elastic recovery is usually associated with good resilience (Collier and Tortora, 2001).

## 2.7 Compressional resiliency or softness

Elsasser (2005) stated that compressional resiliency or softness is the ability of a fiber to return to its original thickness after it is crushed.

## 2.8 Specific gravity or density

Specific gravity or density compares the mass of the fiber to an equal volume of water. The specific gravity of water is 1.0. A specific gravity of greater than 1.0 indicates that the fiber is the heavier than water (Elsasser, 2005).

## 2.9 Tenacity

Elsasser (2005) stated that tenacity or fiber strength, is important to the wear life of a textile product. In general, strong fibers last longer and provide more service than do weak fibers.

## 3. Chemical properties of textiles fibers

The chemical properties of a fiber determine how it will react when it is exposed to the many substances used in production and in cleaning. The chemicals used in cleaning include soaps, detergents and dry cleaning fluids (Elsasser, 2005).

### 3.1 Absorbency and wicking

The ability of a fiber to absorb or take water into itself affects many aspects of its use. The ability of a bone-dry fiber to absorb moisture is called moisture regain (Collier and Tortora, 2001).

### 3.2 Chemical reactivity

Many of the substances used in the manufacture of fibers, in their finishing and in the care of fabric in the home are common household chemicals. Therefore, the behavior of textiles when they are exposed to these chemical substances is important to the consumer as well as to the textile technologist (Collier and Tortora, 2001).

### 3.3 Effects of heat

Textile products may be subjected to heat not only during manufacturing and processing, but also in use. Cellulose and protein fibers scorch or turn brown. The specific behavior exhibited by each fiber will, of course, determine the way in which the fiber must be handled during manufacture and use (Collier and Tortora, 2001).

### 3.4 Flammability

Collier and Tortora (2001) considered that some fibers ignite and burn, some smolder and others are noncombustible. Fibers that ignite but then do not continue to burn, whether or not the ignition source is removed, are designated as flame resistant.

## 4. Environmental properties of textiles fibers

Environmental conditions may be harmful to textile products. The climate, microorganisms and insects can damage textiles (Elsasser, 2005).

### 4.1 Sensitivity to climate

Climatic conditions such as sunlight and air pollution will cause some fibers to deteriorate. Some fibers are very sensitive to sunlight. They may lose strength and/or become discolored (Elsasser, 2005).

### 4.2 Sensitivity to microorganisms

Elsasser (2005) determined that microorganisms, such as mold and mildew, can damage some textiles.

## Processing of Yarns

Collier and Tortora (2001) concluded that if fibers are to be woven or knitted into cloth, they must be formed into long continuous strands called yarns. Fiber for yarn is supplied either in long filaments or short staple lengths. The type of yarn chosen for a fabric affects its appearance, durability, hand and draping characteristics. Yarn construction can serve either to enhance or detract from the inherent qualities of the fiber from which the yarn is made. The term spinning is generally used to describe the conversion of fibers into yarn.

Lawrence (2003) considered the spinning system and found that the important aspects of any spinning system are the fiber types that can be spun, the count range, the economics of the process and very importantly, the suitability of the resulting yarn structure to a wide range of end uses.

## **1. Types of process**

Gong and Wright (2002) wrote about the processing of making fibers into yarns. There are two types of processes: general, which are common to many yarns and texturizing, to obtain special textured effects, extra bulk, stretch, or a combination of these properties in the fabrics made from them. There are many large, intricate machines for yarn making; often there are several different machines for a single process, Somewhat different types of machines are required for wool, linen, cotton, and silk.

### **1.1 General Processes**

The general processes include opening, picking, cleaning, blending, tinting, degumming, scouring, bur picking, carbonizing, carding, combing or hackling, drawing, spinning, winding, throwing, quilling, slashing and rewinding. No fiber goes through all these processes (Gong and Wright, 2002).

1.1.1 Degumming: This process is the removal of the sericin from raw silk. The silk is soaked in warm soapy water until the gum is dissolved or softened and then is passed between parallel plates set closely enough together to remove any adhering gum or other matter (Gong and Wright, 2002).

1.1.2 Scouring: This method has been used since ancient days to remove grease, suint, dirt and other foreign material from the wool fiber. It consists of a series of washes with soap and soda ash and several rinses at varying temperatures. Scouring operations vary for different types and qualities of wool (Gong and Wright, 2002).

1.1.3 Bur Picking and Carbonizing: These are also processes for wool. They are methods for removing bits of burs, sticks and other vegetable matter remaining in wool after scouring. Bur picking is a series of mechanical actions in which the wool is carried over toothed rollers where the opening operations continue and the is passed over a rack. Carbonizing is the process of removing vegetable matter (such as burs, twigs, straw and seeds) picked up and held in the fleece during the time it was growing on the animal. Carbonizing is usually done after scouring by treatment with weak sulfuric or hydrochloric acid, or with salts that become acids when heated. Heating to 93 to 104 °C causes charring of the acid-treated vegetable matter without harming the wool (Gong and Wright, 2002).

1.1.4 Opening and Blending: These two steps, carried on simultaneously, are necessary for cotton and wool and may be used for other staple length fibers. The steel bands holding together the bales of cotton must be cut and the tightly packed cotton lifted out in quantities that can be opened up into fluffy masses in early operations. Wool that comes from the scouring rooms or after bur picking or carbonizing, already fairly well opened. Blending, as the name indicates, is the mixing of fibers from different bales, bags, or suppliers to insure uniformity of a large output of yarn. For successful blending, fibers must be of approximately the same length, diameter, density and moisture content (Gong and Wright, 2002).

1.1.5 Tinting: This process is the adding of a nonpermanent color to one or more types of fibers in a blend in order to identify the fiber or fibers in further processing. This step is necessary to check the uniformity of the blend at various stages of yarn processing and to identify fibers in the waste, which also has commercial value (Gong and Wright, 2002).

1.1.6 Picking and Cleaning: These steps continue, through an additional machine, the opening and removing of trash and such materials. A great deal of cleaning occurs in the opening, shaking, beating and other mechanical movements to which the fibers are subjected as they move along (Gong and Wright, 2002).

1.1.7 Carding: The objective of carding is to separate completely the individual fibers from each other and to put many in a parallel arrangement; at the end of the process, a continuous, gossamer-thin sheet of uniform thickness is delivered to a funnel-like gadget that forms the sheet into a continuous, soft, 2 cm thick strand called a “card sliver.” During carding, further opening and cleaning of the fibers occur and short and tangled bunches of fibers are carried off as waste (noils) (Gong and Wright, 2002).

1.1.8 Combing: This is a process used to produce yarns for a limited number of fabric types in which smooth yarns of long fibers and with considerable twist, are used. Worsteds and voiles are examples. Combing results in still further elimination of short fibers and quite thorough straightening of all fibers that remain, so that all are lined up parallel to the strand length (Gong and Wright, 2002).

1.1.9 Drawing, Spinning and Winding: Carried on together, these are various parts of the same process. Two to six card slivers, or rovings, are fed into the machines together, to insure further uniformity and to facilitate further blending and paralleling of the fibers. Drawing is similar to the processes with which you are already familiar for drawing (stretching) the man-made fibers in orienting the molecules, but it is for a different purpose. Spinning inserts a small amount of twist as drawing progresses and is necessary in order to hold the fibers together; the shorter the fibers the more twist is required. Winding on bobbins, spools, or other holders is necessary to take up the slack in yarns as they are drawn and spun (Gong and Wright, 2002).

1.1.10 Throwing: The making of silk filament yarns is called throwing. Reel silk filaments can be combined into yarns immediately. Short, staple-length silk fibers must be spun. Short outside fibers of the silkworm’s cocoon, the inner fiber from the cocoon and the fiber from pierced cocoon are known as frison and are made into spun silk yarn. Fiber are cut into fairly uniform lengths, combed and twisted into yarns in the same way that other staple fibers are spun (Collier *et al.*, 2009).

## 1.2 Texturizing Processes

The texturizing processes are primarily those applicable to the man-made fibers and particularly to the thermoplastic fibers. The history of such yarns is said to be tied to man's search for a substitute for wool; textured yarns are also a result of attempts to overcome the transparency and slipperiness of thermoplastic filament yarns and the pilling tendency of spun yarns (Hearle *et.al.*, 2001).

1.2.1 Twist texturing: The basis of twist-texturing is to twist a yarn as highly as possible, set it by heating and cooling and then untwist it. In order to relieve the torque, the filaments snarl into pig-tails, which cause a large yarn contraction. The yarn can be stretched to over five times its fully contracted length before the filaments are straightened out. The recovery power is strong. Fabrics can be highly stretched, but come back when released (Hearle *et al.*, 2001).

1.2.2 Jet-screen texturing: False-twist texturing depends on setting fibers in one geometry and then changing to another, which generates stress that can be relieved by buckling. Another principle is to set fibers in the required crimped form. False-twist texturing is extensively described in the public domain, because the advances made by fiber producers and machinery makers had to be sold to the many throwster companies and this spawned considerable academic research (Hearle *et.al.*, 2001).

1.2.3 Air-jet texturing: The third significant texturing process in current use, air-jet texturing, operates by mechanical interlocking and not by heat-setting. It can therefore be applied to any continuous-filament yarn, including rayon, glass and the new high-performance fibers, as well as nylon, polyester and polypropylene. The basis of the method is that yarn is overfed into the compressed air jet-stream, so that loops are forced out of the yarn. The loops need to be locked into the yarn and this can be achieved by twisting the yarn at the take-up (Hearle *et al.*, 2001).

## 2. Principle of staple fiber spinning process

Goswami *et al.* (1997) pointed out that staple fibers have a very wide range of physical properties, most of which have some effect on the methods used in processing them into yarn. Before processing, flax fibers may be 3 ft long, whereas some cottons are less than half an inch. Supplies of man-made fibers are free from extraneous physical or chemical impurities, whereas bales of cotton or wool contain many types of impurity from which the fibers must be separated. The principle of yarn making consists of converting a stock of fibers into yarn whose composition, color, count and twist are specified. Irrespective of differences in machinery used for different fibers, the operations that are principle to the spinning process are:

### 2.1 Opening, cleaning and mixing

The early stages of opening, cleaning and mixing usually occur together, the detailed procedures being determined by the state in which the fiber stock is received in the mill (Goswami *et al.*, 1997).

### 2.2 Sliver formation

The next essential practical requirement in processing is to form a sliver. There is no basic, fundamental reason why this should be so; if after a thorough opening, cleaning and mixing, fibers could be continuously extracted in sequence from the bulk and assembled in a sufficiently uniform strand, at the correct rate to constitute a yarn of the desired count, the need for sliver formation and the subsequent processes of attenuation would disappear. The sliver is usually formed on a carding machine and carding is an important operation in most yarn making sequences; cotton, cotton waste, worsted, semi-worsted, woollen, jute and flax tow system all employ carding machines when using either natural or man-made fibers. To form a sliver, the feed of fibers must be separated almost to single fiber formation on the card so that they can be reassembled side by side. This very complete fiber separation also

enables the carding machine to perform a very efficient cleaning operation (Goswami *et al.*, 1997).

### 2.3 Sliver attenuation - drafting

Except in the woolen and cotton waste condenser systems of spinning, card sliver has many thousands of fibers in its cross section, whereas most single yarns that are required will have about 100 or fewer. The sliver must therefore be attenuated, or drawn finer and this is done by passing it through drafting rollers. The simplest arrangement would consist of two pairs of rollers through which the sliver is passed. The simple arrangement requires that the distance separating the roller nips must be comparable with the length of the longest fiber in the sliver. Drafting therefore results in attenuation of the sliver, parallelization of fibers and mixing caused by the attendant doublings (Goswami *et al.*, 1997).

### 2.4 Formation of the yarn

When the strand of fibers has been reduced to the specified linear density (count), it must be given sufficient strength to enable it to be fabricated into a cloth of some kind. This has been traditionally accomplished by twisting it; the amount of twist inserted is determined by the count, the fiber properties and the purpose for which the yarn is to be used. Warp yarns, where maximum strength and elasticity are required in the weaving process, have more twist inserted in them than do weft yarn from the same fiber, since the prime requirement for a weft yarn is covering power which is greater for a more softly twisted bulky yarn; nor is the weft yarn subjected to as much mechanical treatment – abrasion and repeated stretching-during weaving (Goswami *et al.*, 1997).

## 2.5 Packaging of the yarn

The yarn produced must be wound on some form of package to enable it to be stored and transported in a tidy and convenient way. This necessary provision has no effect on yarn structure; therefore, no particular attention is paid to it here. It merely note that the forms of packages on which yarn is produced at the spinning machine are determined by the type of spinning process used. The size of the package in use determines the frequency of doffing and, on ring –spinning machines, the maximum spindle speed that can be employed; it also governs the number of knots that must be tied in the yarn in later operations. Such consideration are concerned with productive efficiency rather than yarn quality (Goswami *et al.*, 1997).

### 3. Staple yarn spinning

The world's staple yarn is produced by one or other of the following systems (Lord, 2003):

#### 3.1 Cotton spinning

The steps in cotton yarn spinning are as follows:

3.1.1 Bale breaking.

3.1.2 Mixing by stack system or by blending in hoppers.

3.1.3 Opening and cleaning or scotching.

3.1.4 Carding on carding engine with flat cards after which slivers are formed.

3.1.5 Drawing by roller drafting first by doubling without net drafting and then with attenuation on the speed frames by bobbins and flyer spindles.

3.1.6 Spinning with roller drafting on ring frame or mule. Cotton waste yarns are carded and spun on the woolen or condenser system. Staple rayon is made into yarns by any of the systems of spinning, provided the fiber length and thickness are carefully chosen.

### 3.2 Worsted spinning

The sequence of operations for the production of worsted yarns, with long parallel fibers, may be divided into two main classes, for the very long hairs and those of medium length; the latter is subdivided into the English or Bradford system and the French or Continental system (Collier and Tortora, 2001).

3.2.1 Long wools spinning: The steps in long wools spinning are as follows:

- a) Opening
- b) Scouring
- c) Removal of vegetable matter.
- d) Blending and oiling.
- e) Preparation by several processes of gilling into slivers.
- f) Combing by the Lister or Noble comb.
- g) Top finishing by mixing in two or three gillings.
- h) Drawing, first by gilling without net draft and then by flyer and bobbin.

- i) Spinning by flyer, cap or ring with roller drafting.

3.2.2 Medium wools spinning (English system): The steps in medium wools spinning are as follows:

- a) to d) as above
- b) Carding on a worsted carding engine- sliver formation.
- c) Backwashing in soap, followed by drying, oiling and gilling.
- d) Gilling
- e) Combing on noble comb.
- f) Drawing in about 8 stages, as with e) above
- g) Spinning, as with f) above

3.2.3 Medium and short wools spinning (Continental system): The steps in medium and short wools spinning are as follows:

- a) to d) as above
- b) Card on worsted card.
- c) Combing on heilman comb.
- d) Backwashing, but without oiling.
- e) Drawing by 8 or 10 stages of porcupine drawing.

f) Spinning by worsted mule, i.e. roller drafting with all twisting on the run out.

### 3.3 Woollen spinning

The steps in woollen spinning are as follows:

3.3.1 a) to d) as above

3.3.2 Carding and condensing into a roving.

3.3.3 Spinning on woolen mule, with delivery rollers, by spindle drafting, followed by spindle twisting. It is also possible to spin woolen yarns on the ring frame, by using a tube to insert false twist between the drafting rollers and the ring spindle.

### 3.4 Silk spinning

The steps in silk spinning are as follows:

3.4.1 Reeling silk filaments into hanks from the cocoons which are immersed in hot water to soften the gum; six cocoons are reeled together.

3.4.2 Sorting

3.4.3 Winding on to bobbins.

3.4.4 Cleaning or softening the sericin.

3.4.5 Throwing by bobbin and flyer system during which the continuous filament are twisted to form “single”.

3.4.6 Doubling several singles.

3.4.7 Throwing with twist in the opposite direction to the first throwing.

3.4.8 Steaming to set the twist, followed by reeling. Spun silk from silk waste, is made into yarns by carding and spinning by methods which closely resemble the worsted system.

### 3.5 Flax spinning

Flax spinning is divided into two classes, namely, line yarns and tow yarns.

3.5.1 Line yarns spinning: The steps in line yarns spinning are as follows:

a) Piecing and roughing, i.e. sorting to size and preliminary hackling.

b) Hackling or combing, with the separation of tow.

c) Sorting according to quality.

d) Spreading or hand-feeding into special gill boxes or spread boards, and the drafting into slivers of a ribbon like nature.

e) Drafting by several process of gill drawing with doubling, followed by drafting by gill, boxes to roving.

f) Wet spinning by roller drafting and flyer and bobbin system.

3.5.2 Tow yarns spinning: The steps in tow yarns spinning are as follows:

- a) Blending by mixing from stacks.
- b) Carding on roller and clearer carding engine.
- c) Drawing and doubling in gill boxes.
- d) Combing on Heilman comb.
- e) Drawing and doubling in gill boxes, followed by drafting roving.
- f) Dry spinning with roller drafting and either ring spinning or flyer and bobbin.

#### **4. Bast fiber spinning processes**

##### **4.1 Conversion of stem to sliver**

Lord (2003) noted that the process of converting flax, jute and hemp consists of hackling, preparation and spinning. The first step is to (a) split and separate the fibers that are gummed together at the start of the process, (b) disentangle them and (c) parallelize them as far as possible. The remaining broken, shorter, raveled fibers form a tow, which is a byproduct of the process and regarded as inferior. Yarns are also made from this tow. Fiber bundles of similar quality are fed to spreading frames which transport sheets of fibers to a drawframe for a gilling operation similar to that already described.

## 4.2 Spinning bast fibers

Spinning can be done using one of two systems. The dry spinning system is used for coarse yarns; a roving stage similar to those already described is used to produce an intermediate product. Sometimes another flyer spinning system is used to produce the final yarn and sometimes a ring frame is used. Wet spinning is used for finer yarns. The rove (roving) is passed through a trough containing hot water and the rest of the spinning is carried out wet. The water dissolves the gummy substances and provides freedom for the fiber to slide in a controlled fashion in drafting, with the result that evenness is much improved (Lord, 2003).

In base to tip, Nagano and Hiroi (2005) present their theories concerning the universality and regional nuance of bast (and leaf) fiber spinning and weaving amongst various east Asian cultural groups. A wide variety of both tree and herbaceous species, including hemp (*Cannabis sativa*), kudzu (*Pueraria thunbergiana*), linden (*Tilia sp.*), paper mulberry (*Broussonetia sp.*), ramie (*Boehmeria nivea*), wild nettle (*Boehmeria sp.*), wisteria (*Wistaria floribunda*) and abaca/plantain (*Musa sp.*) are covered in this *tour de force* of bast fiber knowledge. Technically, abaca and plantain are leaf fibers rather than bast fibers, but they are processed in much the same manner. The authors also deviate from botanical norms by referring to herbaceous fiber plants as "grass-bast" plants and woody fiber plants as "tree-bast" plants, but their intent is easily understood.

In addition, Gillow and Sentence (1999) concerned the bark cloth in Indonesia and Polynesia the inner bark of the paper mulberry tree, *Broussonetia papyrifera*, is used to make cloth, while in Central Africa the preferred source is a species of fig tree, *ficus natalensis*. In Central Africa, a sheet of bark is removed from the tree, steamed to soften it and then placed over a log and beaten with grooved wooden mallets until the fibers become felted together.

## 5. Hand spinning of staple yarn in Thailand

Traditional of staple yarn spinning has been performed by hand, using hand tools. The two methods widely used are as follows:

### 5.1 Cotton yarn spinning

Worldwide cotton is a fiber of significant economics importance. For many years it has been used more than any other single fiber. The major uses of cotton are in the production of community fabrics in Northeast Part of Thailand. The steps in cotton yarn spinning are as follows:

5.1.1 Opening and cleaning the fibers by hand using a tool called gin.

5.1.2 Rolling to make a long fiber strand by hand using tool called the gong.

5.1.3 Spinning to form a yarn by a combination of drawing or drafting and twisting the strand of fibers by hand using a tool called the spinning wheel.

### 5.2 Hemp yarn spinning

The major uses of hemp are in the production of community fabrics in Northern Part of Thailand. The steps of hemp yarn spinning are as follows:

5.2.1 Pounding to remove the lignin which still adheres to the inner bark or strips.

5.2.2 Joining strips of inner barks to make continuous fiber strips by hand.

5.2.3 Spinning to make continuous yarn by hand using a tool called the spinning wheel.

5.2.4 Boiling to remove the lignin, finish and soften the yarns.

### **Characteristics of yarn**

Characteristics of yarn depend on yarn structure and can serve to either enhance or detract from the inherent qualities of the fiber from which the yarn is made and is, therefore, a key consideration in developing and marketing textile products. (Collier *et al.*, 2009) stated that there is a wide variety of structures and processes that can be selected to achieve a desired yarn product. The product developers select yarns for end uses and communication performance specifications to spinning mills or to fabric product producers who will use the yarns. In the global supply chain, where sourcing of yarns is increasingly separated from product manufacturing, a common language for describing yarn characteristics and performance is necessary.

## **1. Classifications of yarns**

### **1.1 Primary classifications of yarns**

1.1.1 Filament yarns: Filament yarns are made from long, continuous strands of fiber. Monofilament yarns, those made from a single filament, find limited use in nylon hosiery in some open-work decorative fabrics and in fabric webbing as well as in a variety of industrial uses. Monofilament yarns can be made by the extrusion of large single filaments from spinnerets. The slit film technique in which a film of synthetic polymer is cut into strips will also make single filaments, each of which can be used as a monofilament yarn (Collier *et al.*, 2009). Multifilament yarns, those made from multifilament fiber, are made more cohesive by twisting them together loosely or more tightly. The amount of twist together with the characteristics of the fiber will determine the appearance and feel of the yarn. For example, a loosely

twisted smooth filament yarn made from a bright fiber would be characterized by marked luster, resistance to pilling and a smooth surface (Collier *et al.*, 2009).

1.1.2 Staple yarns: Staple or spun yarns are made from staple length fibers. Being short, staple fibers must be held together by some means in order to be formed into a long, continuous yarn. Although the multiple processes required to make staple yarn add significantly to the cost of the yarn, the aesthetic qualities such as comfort, warmth, softness and appearance make these yarns highly desirable in many products. Natural fibers, except for silk, are all staple fibers. Silk and manufactured fibers can be cut or broken into staple fibers, so that it is possible to spin any natural or manufactured fiber into a staple yarn (Collier *et al.*, 2009).

## 1.2 Classification of yarns by number of parts

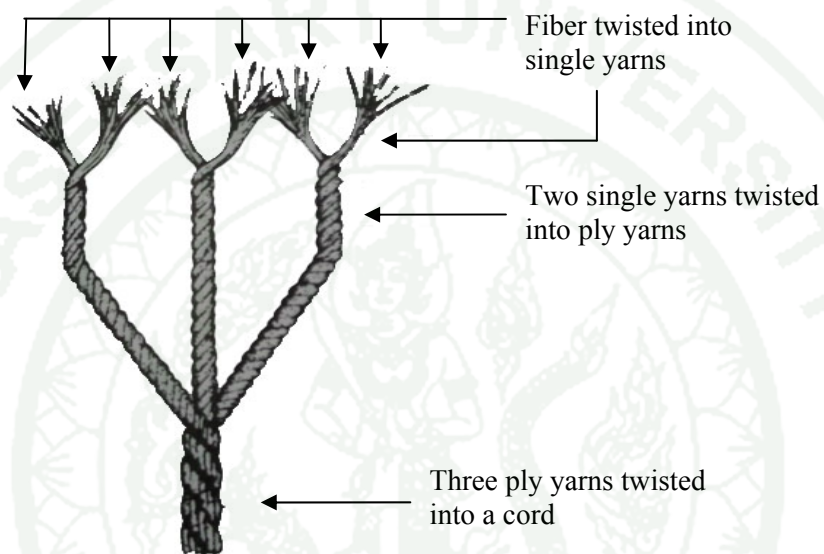
Collier *et al.* (2009) noticed that yarns that have been classified by the number of parts they possess and are divided into single, ply and cord yarns. A single yarn is made from a group of filament or staple fibers twisted together. If a single yarn is untwisted, it will separate into fibers. A single yarn might be identified as either a single yarn of staple fibers or a single yarn of filament fibers.

1.2.1 A single (or one-ply) yarn: A single yarn is a yarn which, if untwisted, will separate into the individual fibers from which it was made. ASTM defines a single yarn as the simplest strand of textile material suitable for operations such as weaving, knitting, etc. A single yarn may be formed from fibers with more or less twist; from filaments with or without twist; from narrow strips of material such as paper, cellophane, or metal foil; or from monofilaments (Saville, 1999).

1.2.2 Ply yarns: Ply yarns are made by twisting together two or more single yarns. If ply yarns are untwisted, they will divide into two or more single yarns, which, in turn, can be untwisted into fibers. Each single yarn twisted into a ply yarn is called a ply (Saville, 1999).

1.2.3 Cord yarns: Cord yarns are made by twisting together two or more ply yarns. Cord yarns can be identified by untwisting the yarn to form two or more ply yarns. Cord yarns are used in making ropes, sewing thread and cordage and are woven as decorative yarns into some heavyweight novelty fabrics.

Figure 2 is a diagrammatic sketch showing all three types of yarn.



**Figure 2** Diagrams of single, ply and cord yarns.

**Source:** Collier *et al.* (2009)

### 1.3 Classification of yarns by decorative effects

Simple yarns are those yarns with uniform size and regular surface. They have varying degrees of twist, ranging from loose to moderate, tight or hard twist. Single, ply and cord yarns can all be simple yarns if their components are uniform in size and have a regular surface. Fancy yarns are made to create interesting decorative effects in the fabrics. They are classified as follows:

1.3.1 Boucle yarns: They are ply yarns. An effect yarn forms irregular loops around a base yarn or yarns. Another yarn binds or ties the effect yarn to the base. Some sources use the terms loop or curl yarns interchangeable with boucle.

1.3.2 Ratine yarns: They are similar to boucle in construction. The loops in ratine yarns are spaced evenly along the base yarn. Snarl yarns are another type of loop yarn in which two or more single yarns under different tension are twisted together.

1.3.3 Flake, flock, or seed yarns: They are made of loosely twisted yarns that are held in place either by a base yarn as it twists or by a third or binder yarn.

1.3.4 Nub yarns: They are ply yarns in which an effect yarn is twisted around a base yarn a number of times in a small area to cause an enlarged bump or “nub”. Sometimes a binder yarn is used to hold the nubs in place.

1.3.5 Slub yarns: The yarns may be either ply or single yarns of staple fibers. The slub effect is created by varying the twist in the yarn; allowing areas of looser twist to be created. This produces a long, thick, soft area in the fabric called a slub.

1.3.6 Spiral, or corkscrew, yarns: They are made of two plies, one soft and heavy, the other fine. The heavy yarn winds around the fine yarn.

1.3.7 Chenille yarns: These yarns consist of a cut pile which may be made of a variety of fibers helically disposed around the two axial threads that secure it. Chenille yarns are traditionally used in the manufacture of furnishing fabrics and trimmings, fashion knitwear and as decorative threads in many types of broad and narrow fabrics.

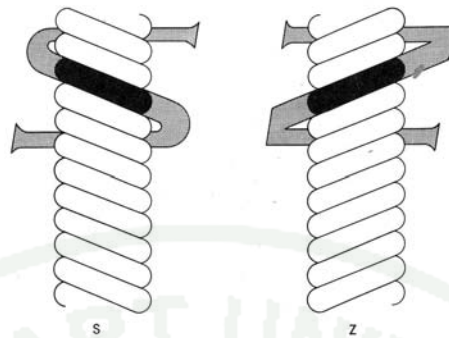
## 2. The Properties of yarns

### 2.1 Yarn strength

The strength of a yarn is governed partly by the strength of the individual fiber of which it is made up and partly by the degree to which these cling together and resist drawing or slipping over each other as the yarn is pulled lengthwise. From fiber to fiber the tensile strength varies considerably but the textile industry requires that it shall be at least 1 gram per denier.

### 2.2 Yarn twist

Collier *et al.* (2009) pointed out that all staple yarns and some filament yarns have twist applied to them to hold the fibers together. The degree of twist given to a yarn affects a number of aspects of its appearance, behavior and durability. The amount of twist in a given yarn can be measured. Twist may be expressed as turns per meter (tpm), turns per centimeter (tpcm), or turns per inch (tpi). Although the direction of twist in yarn is of concern primarily to fabric producers. The direction of twist in yarns and other textile strands is indicated by the capital letters “S” and “Z”. Yarn has S twist if, when the yarn is held in a vertical position, the visible spirals or helices around its central axis conform in direction of slope to the central portion of the letter “S” and “Z” twist if the visible spirals or helices conform in direction of slope to the central portion of the letter “Z”. Where two or more yarns, either single or plied, are twisted together, the letters “S” and “Z” are used in a similar manner to indicate the direction of the last twist inserted. In other words, “S” twist is a clockwise-twisted yarn and “Z” twist yarn is counter-clockwise- twisted. Figure 3 illustrates S and Z twist yarns (Saville, 1999).



**Figure 3** Diagrams of S and Z twist yarns.

**Source:** Saville (1999)

The effects of Twist are given below.

2.2.1 The bulkiness of yarns is related to twist. As a general rule, increasing twist decreases apparent yarn size (Collier *et al.*, 2009).

2.2.2 Strength increases in staple yarns as twist increases up to a certain point. Beyond this point, the strength of the yarn begins to decrease and yarns with exceptionally high, tight twist may become brittle and weak (Collier *et al.*, 2009).

2.2.3 Elasticity is increased if yarns are twisted tightly. Tightly twisted yarns are known as crepe yarns, which are generally very fine. The twist of crepe yarns is so high that they curl up unless they are held under tension, as they would be on a loom during weaving (Collier *et al.*, 2009).

2.2.4 More tightly twisted yarns shed soil more easily. Because their surface is smoother, there are fewer loose fiber ends to attract and hold soil. In yarns made from absorbent fibers, absorbency is lower in more tightly twisted yarns (Collier *et al.*, 2009).

2.2.5 Abrasion resistance is increased by tighter twist. This is a logical result because in a more tightly twisted yarn, many fibers are held in such a way that they appear on the surface, then into the center of the yarn and then back to the surface again. As a result, more fibers are subject to a relatively even distribution of abrasion. Loose surface fibers in low-twist yarns also snag and pull up, creating points of wear (Collier *et al.*, 2009).

### 2.3 Yarn size, number, or count

Saville (1999) noticed the yarn number, also sometimes known as yarn count or yarn size, refers (roughly) to diameter and (specifically) to linear density. Because the textile industry requires some means for distinguishing between yarns of different sizes, standards of measurement have been established. There are different systems of measurement for cotton-type yarn, wool-type yarn and still other systems for filament yarns.

2.3.1 Direct numbering systems: The direct methods of measurement rely on the measurement of fixed lengths of yarn. A specified length of yarn is measured and this length is weighed. The measures used are tex or denier. As explained earlier, tex is the weight in grams of a 1-kilometer (1,000-meter) length of yarn and denier is the weight in grams of 9,000 meters of yarn. Yarns may also be specified in *decitex*, which is the weight of 10,000 meters. In all these measures, the higher the number, the coarser the yarn. The size of filament yarns may be designated by giving the denier or tex of the total yarn or by the denier per filament (dpf). A yarn with a denier of 50 is twice as coarse as a yarn with a denier of 25 (Elsasser, 2005).

2.3.2 Indirect numbering systems: Indirect methods of yarn numbering rely on the measurement of fixed weights of yarn. Each system establishes a number of hanks (skeins) of yarn that make up either a pound or a kilogram of yarn weight. Pounds are used for measurements in the English System and kilograms for measurements in the Metric System. The size of the hanks used is different for the different natural fibers, with the measures being as follows: cotton count equals the

number of hanks of 840 yards in 1 pound; linen count equals the number of hanks of 300 yards in 1 pound; woolen count equals the number of hanks of 1,600 yards per pound; worsted count equals the number of hanks of 560 yards per pound. In an indirect system, the larger the number, the smaller the yarn (Elsasser, 2005).

Collier and Epps (1999) noticed that the yarn size of fine are 6-10 tex, medium 12-20 tex and heavy 30-60 tex. Therefore, yarn made from low density fibers are more bulky than yarns of the same count made from fibers of higher density.

### **Processing of Fabric**

Aldermen (2004) investigated the steps necessary in going from the cloth taking shape in his mind to having a fabric in his hands. The first step was deciding what weave structure will provide the desired characteristics. Selection of appropriate fiber, yarn size and style are important for determining the fabric structure.

#### **1. Structures of fabrics**

The textile components studies thus far come together in the making of fabrics. According to ASTM, a fabric is a “planar structure consisting of yarn or fiber”. Planar implies a structure in which the length and width are much higher than the thickness. Fabrics can take many forms and be constructed in a variety of ways, ranging from the mating together of fibrous materials to the intricate interlacing of a complex yarn system such as specific fabric structures and processes and the effect of structure on fabric properties (Collier *et al.*, 2009).

##### **1.1 Fabric construction methods**

The primary classifications of fabrics are briefly described as follows (Collier *et al.*, 2009):

1.1.1 Woven fabrics: Weaving of fabrics consists of interlacing yarns at right angles. By varying the pattern of interlacing, a wide variety of different fabric constructions can be produced. Woven fabrics do not have much stretch unless elastic fibers or stretchable yarns are used.

1.1.2 Looped fabrics: Fabrics can be constructed from one or more continuous yarns by the formation of a series of interconnected loops. Knitting is the best known type of looping construction. Crochet is another. Knits are stretchable because the loops can be elongated.

1.1.3 Knotted fabrics: Some fabric are created by knotting yarns together. Lace, nets, macrame and tatting are examples of this construction method.

1.1.4 Nonwoven fabrics: Webs of fibers can be held together into a fabric by interlocking fibers without the necessity of first forming yarns. Felt and bark cloth, older fabric-making techniques, are also constructed from webs of fibers but are not technically defined as nonwovens.

1.1.5 Stitch-through fabrics: Stitch through or stitch bonding is a technique for constructing fabrics in which two sets of yarns or masses of fibers are stitched together into a fabric structure by another set of yarns.

1.1.6 Braided fabrics: Fabrics may be created by plaiting together yarns or strips of fabrics. The components are interlaced in a diagonal pattern over and under one another to form a flat or tubular fabric of relatively narrow width.

1.1.7 Films: Films are polymeric sheets. Because they are not made from fibers, they are not considered to be true textiles even though they are often used in products that have traditionally been made from textiles such as shower curtains or upholstery. They are sometimes laminated to textiles and, therefore, may be part of the structure of some textile products.

1.1.8 Textile composites: These materials generally consist of one or more textile components impregnated with or embedded in a resin matrix. Textile composites are generally used for high-technology products for industry, the military, and aerospace.

## 1.2 Basic weave fabrics

Three types of weave structure are woven on simple loom and also form the basis of even the most complex weaves. Known as basic weave, these are the plain weave, the twill weave and the satin weave. Woven fabrics, more so than other fabrics are given names that summarize a number of structure features: weight, fiber type, yarn type, yarn count, fabric count and color or pattern. Types of basic weaves are as follows (Collier *et al.*, 2009):

1.2.1 Plain weave: The plain weave is the simplest of the weaves and the most common. It consists of interlacing warp and filling yarns in a pattern of over one and under one. The filling yarn moves over the first warp yarn, under the second, over the third, under the fourth and so on. In the next row, the filling yarn goes under the first warp yarn, over the second, under the third and so on. Plain weave fabrics are constructed from many fibers and in weights ranging from light to heavy. Weaves may be balanced or unbalanced. Decorative effects can be achieved by using novelty yarns or yarns of different colors.

1.2.2 Twill weave: Twill fabrics are readily identified by the diagonal lines that the weave creates on the surface of the fabric. Because there are fewer interlacings, the yarns in twill fabrics can be spaced closely together, packed tightly, and held firmly in place. The simplest twill weave is created by the warp yarn crossing over two filling yarns, then under one, over two, under one and so on. In the next row, the sequence begins one yarn down. The area in which one yarn crosses over several yarns in the opposite direction is called a float.

1.2.3 Satin weave: Satin- weave fabrics are made by allowing yarns to float over a number of yarns from the opposite direction. Interlacings are made at intervals such as over four, under one; over seven, under one; or over eleven, under one. Harnesses are also called shafts; hence, these satin fabrics may be called five-shaft satin, eight-shaft satin, or twelve-shaft satin.

### 1.3 Basic knitted fabrics

Knitted fabrics are formed by interlocking loops of yarns. The interlocking of these loops can be done by either vertical or horizontal movement. When the yarns are introduced in a crosswise direction, at right angles to the direction of growth of the fabric and run or interlock across the fabric, the knit is known as a weft knit. The basics of knitted fabrics can be classified as follows (Collier *et al.*, 2009):

1.3.1 Weft knits: The most important difference among weft-knitting machines is the number of needlebeds and the number of sets of needles used. On these bases, weft knits are divided among those made on each of these machines (Collier *et al.*, 2009):

a) Jersey, or single, knits: Machine with one needlebed and one set of needles are called jersey machines or single-knit machine. The loops formed by the jersey machine are formed in one direction only, which gives a different appearance to each side of the fabric. The basic fabric produced by this machine is known alternately as a plain, single, or jersey knit; the terms are interchangeable.

b) Two-bed knits: A two-bed knit fabric is any knitted cloth or garment that has been produced on any type of opposed bed knitting machine with two sets of needles of any range of fineness or coarseness. The fabrics produced include purl knits and rib knits. A rib knits fabric is characterized by lengthwise ribs formed by wales alternating on the face and back of the cloth. The simplest purl fabric is made by alternating courses so every other course is drawn to the opposite side of

the fabric, thereby producing a fabric with the same appearance on both sides. The raised courses produce a somewhat uneven texture.

c) Three-dimensional knits: The techniques employed for full-fashioned garments are also being used to produce three-dimensional knitted structures. Complex shapes that serve as reinforcement in molded parts for industrial applications can be knitted.

1.3.2 Warp knits: Collier *et al.* (2009) investigated warp knitting. In warp knitting, each yarn is looped around one needle at a time. Warp yarns wound on a warp beam are threaded through metal guides with holes. The guides are attached to a guide bar, which moves sideways as well as forward and back so the yarn are carried both lengthwise and, to a limited extent, diagonally.

a) Tricot: Tricot machines account for the largest quantity of warp yarn knits. Tricot fabric is knit flat. On the face side, the walls create the appearance of a fine, lengthwise line. On the back side, crosswise ribs appear in a horizontal position.

b) Simplex knits: Simplex knitting machines create warp knits similar to tricot but with a denser, thicker texture- a sort of double-knit tricot. Simplex knits are used in products requiring heavier fabrics, such as women's gloves and handbags and simulate suede textured apparel fabrics.

c) Raschel knits: Raschel knit can range from finely knitted laces to heavy-duty fabrics. Elaborately patterned surface effects can also be achieved with the Raschel machine. The fabrics have lengthwise rows of loops held together by laid-in yarn and may, to the eye, have the appearance of woven goods or lace.

## 2. Techniques used in fabric productions

Technique used in fabric production had been a domestic system, a cottage industry with textile spun, knitted and woven in the home. The vast majority of cloth being woven or knitted from yarn spun fiber. And, while much production may be very technologically advanced, hand-produced textiles are still made in many countries exactly as they were many, many years ago (Wilson, 2001).

### 2.1 Weaving processes

Collier *et al.* (2009) noticed that present-day looms can be divided into two major classifications: those that produce cloth in flat form and those that produce cloth in tubular form. Looms that produce flat woven cloth are predominant. Crowfoot *et al.* (2004) stated that new looms were introduced and used together with older, traditional looms. The earliest type of loom known from England is the warp-weighted loom which, by the 10<sup>th</sup> century, had been in use for over a millennium, these are the weaving steps as follows (Collier *et al.*, 2009):

2.1.1 Preparing the warp yarns for weaving: Before their use on the loom, warp and filling yarns must be prepared for weaving. The essential characteristics of suitable warp and filling yarns differ. Warp yarns undergo greater stress and abrasion during weaving than do filling yarns; therefore, warp yarn must be strong enough to withstand these pressures. Warp yarns must be clean, free from knots and uniform in size.

2.1.2 Preparing the filling yarns for weaving: Yarn that is to be used for the filling must be packaged in some form that allows it to be unwound easily for transport through the shed. In shuttle looms the device that carries the yarn across the shed is called a shuttle and is made up of a wooden carrier into which a quill, or pirn, is placed. The filling yarn is wound onto the quill from larger packages of yarn.

2.1.3 Basic motion of weaving: Once the filling yarns have been prepared and the warp yarns have been set into place, the loom goes through a repeated series of motions to form the fabric, which are the weaving operations as follows (Collier *et al.*, 2009):

a) Shedding: Shedding is raising the harnesses through which different warp yarns are threaded creates an open area, called a shed, between the set of wraps.

b) Picking: While the shed is open, the yarn is transported across the opening, laying a filling yarn, or pick, across the width of the loom. In shuttle looms, the knocking of the shuttle up against the stop box at each side of the loom is responsible for much of the noise associated with weaving.

c) Beating up: Beating up is done by the reed that pushes the newly inserted filling yarn close against the woven fabric. This again can be a noisy step in the weaving process.

d) Taking up/letting off: As the woven fabric is formed, it must be moved or taken up on the cloth beam to make room for the formation of more fabric.

## 2.2 Knitting process

Collier *et al.* (2009) considered the advances in knitting production techniques. The knitting industry may be divided into four branches; knitted fabric, knitted outerwear, knitted hosiery and knitted underwear and nightwear. Knitted fabric mills produce a wide variety of fabrics in either flat or circular form that can be cut and sewn into apparel and other items. The steps in formation of loops with the latch needle are as follows:

2.2.1 The old loop is held on the stem of the needle. The latch is open.

2.2.2 The hook grasps the yarn to begin formation of a new loop.

2.2.3 The needle falls, the old loop rises, closing the latch of the needle.

2.2.4 The old loop is cast off.

2.2.5 The needle rises and the new loop slides down to the stem of the needle, pushing the latch open again and the needle is ready to repeat the cycle.

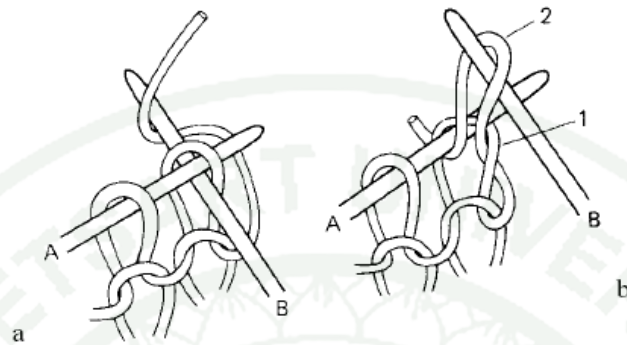
### 2.3 Hand pin knitting

Spencer (2001) stated that the term knitting describes the technique of constructing textile structures by forming a continuous length of yarn into columns of vertically intermeshed loops.

2.3.1 Hand pin knitting: Hand pin knitting is weft knitting, using the fingers to produce open loop structures, may well have been practiced long before the use of hand-held pins. Hand pin knitting was first recorded in religious paintings in 1350 in Northern Italy. It then spread through the rest of Europe.

2.3.2 The principles of hand knitting using two pins: The left-hand pin retains the previously formed row of loops (course). The right-hand pin A is used to draw through and retain the next course of loops, one at a time. Pin B has drawn the newly formed loop 2 through loop 1 of the previous course. Pin A then releases loop 1, which hangs from loop 2, which itself is hanging from pin B. At the start of the next row (course), the pins may change hands and the action continued. If this happens, the fabric will be turned around and the next course of loops will mesh through from the opposite side of the fabric. Each course of loops will be drawn through the heads of the previous course of loops, in the *same direction* in the fabric.

As the pins are straight and pointed, skill is required to ensure that the loops do not slip off the end and cause *drop stitches* (Spencer, 2001).



**Figure 4** Hand pin knitting.

**Source:** Spencer (2001)

### 3. Characteristics of fabrics

Wilson (2001) stated that every textile product is designed: that is, it is made specifically to some kind of plan. Design decisions are made at every stage in the manufacturing process; what fibers should be used in a yarn, what yarn in a fabric, what weight of fabric should be produced, what colours should the yarn or fabric be produced in, what fabric structures should be used and what finishes applied. These decisions may be made by engineers and technology in the case of industrial or medical textiles where performance requirements are paramount, or more often in the case of apparel, furnishings and household textiles, by designers trained in aesthetics, technology and marketing.

### 3.1 Weave structure of fabrics

The designers found in the textile and clothing industries are frequently involved throughout the design process, from initial identification of a need /requirement, through research, generation of initial design ideas, design development and testing product specifications. What these textiles have in common, how they are different fabrics: some of them are heavy, some light, some of them sheer, some opaque, stiff, soft. In spite of their obvious differences, they have one important characteristic as follows (Wilson, 2001).

3.1.1 Durability factors: Two of the most important fabric variables affecting strength of woven fabrics on the contribution to strength of fibers and yarns are weave and fabric count. The more interlacings in a fabric, the higher the fabric count. Fabric weave with a high number of interlacings: The effect of weave can be altered by changing the fabric count of a woven fabric. Yarn and fabric structure work together in determining elongation and recovery of textile fabrics. In woven fabric construction, the aspect of crimp distribution seems to be particularly important in durability. Weave also enters into abrasion resistance. In fabrics with floats, yarns and fibers are free to move absorb energy and are less consistently exposed to abrasants. For this reason, twills and some tightly woven satin fabrics show superior abrasion resistance (Collier *et al.*, 2009).

3.1.2 Appearance: Drape, or the ability of fabric to form pleasing folds, is related to bending and shearing behavior, which are in turn affected by yarn and fabric properties. Shearing is the deformation of a structure in which a rectangle becomes lozenge shaped. In woven fabrics, this result from movement of yarn from what one might call a normal position, in which they run horizontally and vertically and interlace at right angle, to other positions, in which the interlacing is deformed away from a ninety degree angle. In general, woven fabrics with few interlacings wrinkle less than do other fabrics. Dimensional stability problems are often related to unreleased stresses introduced during fabric manufacturing. Shrinkage can also be affected by fabric count in woven fabric (Collier *et al.*, 2009).

3.1.3 Confort factors: Collier *et al.* (2009) noted that fabric construction plays an important role in regulating temperature and moisture around the body. Pile or napped constructions are especially good for cold weather because the yarns or fibers perpendicular to the surface provide numerous small spaces for the dead air that increases insulation. Moisture vapor transmission and water repellency affect comfort. Most fibers are not naturally water repellent but must be given special treatments to render them so.

In these and other products, fiber, yarn and fabric structure can be seen to work together to created the desired effect.

### 3.2 Knit structure on fabric performance

Collier *et al.* (2009) considered the quality of knitted sold and the performance of any individual knit may differ markedly from that of other knits, therefore some general guidelines for the care of knitted goods can be observed. The characteristics that consumers seem to encounter most often in the performance of knitted fabrics are in the areas of dimensional stability, snagging and pilling as follows:

3.2.1 Dimensional stability: One reason for the popularity of knits of wearing apparel is their comfort. The looped construction of knit fabrics permits the fabric to give with the body as it moves. But the stretchiness of knit also in dimensional stability. Consumer have complain about shrinkage, stretching and distortion of knits, although interlock and double knit fabric are usually more stable and display little or no shrinkage. Similarly, fabric with weft or warp inserted yarns are more stable. Shrinkage or growth of fabric during wear and care can render an apparel or household textile item both unappealing and unusable. Consequently a required level of dimensional stability is often specified when selected fabric for textile products.

3.2.2 Durability: Strength of knitted fabrics is considered to be less important for durability than it is in woven goods. Knitted fabrics are easily stretched to accommodate changes of shape as a result of stresses imposed in wear and care. In knits the loops in the structure can be deformed horizontally or vertically, increasing the stretch in both directions. A major problem in the durability of knits is the runs that can be develop in weft knits when one of the loops is broken. If stronger fibers and yarns are used in these knits, they will be less likely to run.

3.3.3 Apparence: Collier *et al.* (2009) noticed that knitted fabrics have good flexibility and are easily extended. Warp knits do not shear as easily as weft knits. The ability of a fabric to shear easily, is an important factor in the appearance of textiles. Theses quality must be taken into account by designers. In general, knits wrinkle less than do other fabrics. This is because loosely constructed fabrics allow more fiber redistribution and motion. However, knitted fabrics, because of their greater extensibility, are more likely to lose their shape in laundering.

### **Physical testing of textiles**

Park and Shore (2004) stated that physical tests on fibers, yarns or fabrics may be required for the following purposes: to assess the raw material and the effects of subsequent processes, as part of a product development project, to establish a product specification, as a customer service, to ensure that the product conforms to a purchasing or sales specification and the investigation of faults, complaints and processing problems.

Collier and Tortora (2001) stated that the products must be tested to determine whether they meet established standards. Two groups in the United States have been closely involved in developing testing methods. The American Association of Textile Chemists and Colorists (AATCC). This groups is composed of persons from the textile wet processing industry, textile chemists, others working in various segments of the textile industry and educators. Tests established by ASTM are focused more specifically on physical testing and the testing of fabric construction.

In addition, Saville (1999) noticed the reasons for textile testing, the testing of textile products is an expensive business. A laboratory has to be set up and furnished with a range of test equipment. There are many methods of testing for textiles. Many of the tests carried out on textile materials are intended to measure the same property but because of their different approach or type of equipment used, different results may occur.

## **1. Fiber testing**

A textile fiber is a peculiar object. It does not have a truly fixed length, width, thickness, shape and cross-section. Growth of natural fibers or production factors of manmade fibers are responsible for this situation. An individual fiber, if examined carefully, will be seen to vary in cross-sectional area along its length. This may be the result of variations in growth rate, caused by dietary, metabolic, nutrient-supply, season, weather, or other factors influencing the rate of cell development in natural fibers. Surface characteristics also play some part in increasing the variability of fiber shape. The scales of wool, the twisted arrangement of cotton, the nodes appearing at intervals along the cellulosic natural fibers, etc. Standard atmosphere for testing is the atmosphere in which physical tests on textile materials are performed. It has a relative humidity of  $65 \pm 2$  percent and a temperature of  $20 \pm 2^\circ \text{C}$  (Saville, 1999).

### 1.1 Fiber length

The "length" of cotton fibers is a property of commercial value as the price is generally based on this character. To some extent it is true, as other factors being equal, longer cottons give better spinning performance than shorter cotton. But the length of a cotton is an indefinite quantity, as the fibers, even in a small random bunch of a cotton, vary enormously in length (Saville, 1999).

Standard test methods for fiber length widely used include the ASTM D 5332 -92 standard test method for fiber length and length distribution of cotton fibers and the ASTM D 5103 standard test method for length and length distribution of manmade staple fibers (Collier and Epps, 1999). Staple fibers can be classified according to the length as short (<26 mm), medium (26-29 mm), long (30-38 mm), and extra long (39 mm and over) (Taylor, 1997).

## 1.2 Fiber fineness

Fiber fineness is another important quality characteristic which plays a prominent part in determining the spinning value of natural fibers such as cotton and wool. If the same count of yarn is spun from two varieties of cotton, the yarn spun from the variety having finer fibers will have a larger number of fibers in its cross-section and hence it will be more even and strong than that spun from the sample with coarser fibers. Fineness denotes the size of the cross-section dimensions of the fiber. Direct determination of the area of cross-section is difficult and laborious for some fibers, therefore fiber fineness is usually expressed as linear density.

Standard test methods for fiber linear density widely used include standard test methods (Collier and Epps, 1999) as follows; the ASTM D 1448 standard test method for micronair reading of cotton fibers, the ASTM D 1577 standard test method for linear density of textile fibers, the ASTM D 2130 standard test method for diameter of wool and other animal fibers by microprojection and the ASTM D 1282 standard test method for resistance to airflow as an indication of average fiber diameter of wool top, card sliver and scoured wool. Cotton fiber usually range from 12 to 20  $\mu\text{m}$  in diameter and fineness is a factor in fiber quality. Coarse wool fibers may be 40 to 50  $\mu\text{m}$  in diameter (Collier and Epps, 1999).

### 1.3 Fiber maturity

Fiber maturity is another important characteristic of cotton and is an index of the extent of development of the fibers. As is the case with other fiber properties, the maturity of cotton fibers varies not only between fibers of different samples but also between fibers of the same seed. The causes for the differences observed in maturity, is due to variations in the degree of the secondary thickening or deposition of cellulose in a fiber. Fibers in a sample would indicate some defect in the plant growth (Saville, 1999). Standard test methods used include ASTM D 1442 : maturity of cotton fibers (sodium hydroxide swelling and polarized light procedure) and ASTM D 3818 : linear density and maturity index of cotton fibers (IIC- Shirley Fineness/Maturity Tester) (Collier and Epps, 1999).

### 1.4 Fiber density

Density and specific gravity are terms that are used in relation to the weight of fiber. The terms are similar, but each has a somewhat different technical definition. Density is the ratio of mass of a substance to a unit of volume. In the case of fiber, density is expressed as grams per cubic centimeter (Collier *et al.*, 2009).

Manufactured fibers are usually characterized by their linear density: that is, the weight of specified length of fiber. The SI unit, tex is the weight in grams of 1,000 m of fiber; denier is the weight of 9,000 m. Linear density is determined by weight a precisely cut length of fiber (ASTM D 1577). Because most fiber are less than one tex, single fibers are usually designated in decitex (0.1 tex) or denier units. Microfibers less than one denier or decitex are increasingly popular because of their feel and drape (Collier and Epps, 1999). Moreover, Franck (2005) concluded that the linear density of plant fibers were as follows: coir 50 tex, jute 1.4-3.0 tex, kenaf 1.9-2.2 tex, flax 0.2-2.0 tex, hemp 0.3-2.2 tex, abaca 4.2-44.4 tex and pineapple 1.5-2.3 tex.

## 1.5 Fiber strength

The different measures available for reporting fiber strength are breaking strength, tensile strength and tenacity or intrinsic strength. Coarse fibers generally give higher values for fiber strength than finer ones. The value so obtained is known as intrinsic strength or tenacity. Tenacity is found to be better related to spinning than the breaking strength. The strength characteristics can be determined either on individual fibers or on a bundle of fibers (Saville, 1999).

1.5.1 Single fiber strength: The tenacity of fibers are dependent upon the following factors; chain length of molecules in the fiber, orientation of molecule, size of the crystallites, distribution of the crystallites, gauge length used, the rate of loading, type of instrument used and atmospheric conditions. The mean single fiber strength determined is expressed in units of "grams/tex". The unit for tenacity has the dimension of fiber length and hence this property is also expressed as the "breaking length", which can be considered as the strength of the specimen equivalent in weight to the breaking load (Saville, 1999). Standard test methods for determination of tensile properties of single textile fibers include the standard test method ASTM D 3822-01 tensile behavior, a single fiber test.

1.5.2 Bundle fiber strength: In practice, fibers are not used individually but in groups, such as in yarns or fabrics. Thus, bundles or groups of fibers come into play during the tensile break of yarns or fabrics. Furthermore, the correlation between spinning performance and bundle strength is at least as high as that between spinning performance and intrinsic strength determined by testing individual fibers. The testing of bundles of fibers takes less time and involves less strain than testing individual fibers (Saville, 1999). The standard test method ASTM D 1445: breaking strength and elongation of cotton fibers (flat bundle method) and ASTM D 2524: breaking tenacity of wool fibers, flat bundle method, 1/8 in (3.2 mm gage) length were widely used (Collier and Epps, 1999).

Morton and Hearle (2008) classified the HVI tenacity value of cotton as follows: very weak tenacity (<20 grams per tex), weak tenacity (21-23 grams per tex), average tenacity (24-26 grams per tex), strong tenacity (27-29 grams per tex) and very strong tenacity (>30 grams per tex).

## 2. Yarn testing

Park and Shore (2004) considered the yarn quality a modern spinning plant will carry out on-line monitoring of yarn quality parameters such as evenness, thick and thin analysis and weight variation. A quality factor for yarns is the number of steps involved in processing (Collier and Epps, 1999). Yarn testing is determined by machine that is a various type of testing such as linear density, twist, strength. ASTM Standard and the others describes a method for designating the various features of yarns to help suppliers and manufactures communicate.

### 2.1 Linear density

Linear density is determined by weighing specified length of yarn and converting . The thickness or diameter of a yarn is one of its most fundamental properties. However, it is not possible to measure the diameter of a yarn in any meaningful way. This is because the diameter of a yarn changes quite markedly as it is compressed. Most methods of measuring the diameter of yarn, apart from optical ones, involve compressing the yarn as part of the measurement process. Standard test methods used to determine linear density of yarn (yarn number), ASTM D1907, include the two systems of linear density designation in use: the direct and the indirect as follows:

2.1.1 Direct system: The direct system of denoting linear density is based on measuring the weight per unit length of a yarn. The main systems in use are: Tex – weight in grams of 1000 meters, Decitex - weight in grams of 10,000 meters and Denier - weight in grams of 9000 meters.

2.1.2 Indirect system: The indirect system is based upon the length per unit weight of a yarn and is usually known as count because it is based on the number of hanks of a certain length which are needed to make up a fixed weight. This is the traditional system of yarn linear density measurement and each branch of the industry has its own system based on the traditional length of hank associated with the locality and the type of yarn manufactured.

## 2.2 Crimp

This distortion is known as crimp and before the linear density of the yarn can be determined the crimp must be removed and the extended length measured. The crimp tester is a device for measuring the crimp-free length of a piece of yarn removed from a fabric. The instrument consists of two clamps, one of which can be slid along a scale and the other which is pivoted so as to apply tension to the yarn. The sample of yarn removed from the fabric is placed in the clamps.

In addition, the Shirley crimp tester is the machine for crimp testing. When yarn is removed from a fabric it is no longer straight but it is set into the path that it took in the fabric. This distortion is known as crimp and before the linear density of the yarn can be determined the crimp must be removed and the extended length measured. The crimp tester is a device for measuring the crimp-free length of a piece of yarn removed from a fabric. The instrument consists of two clamps, one of which can be slid along a scale and the other which is pivoted so as to apply tension to the yarn.

## 2.3 Twist

Twist is primarily introduced into a staple yarn in order to hold the constituent fibers together, thus giving strength to the yarn. The effects of the twist are twofold: as the twist increases, the lateral force holding the fibers together is increased so that more of the fibers can contribute to the overall strength of the yarn. Secondly as the twist increases, the angle that the fibers make with the yarn axis

increases, so preventing them from developing their maximum strength which occurs when they are oriented in the direction of the applied force. A twist test, ASTM D1423, the amount of twist in a given yarn can be measured and expressed as turns per meter (tpm), turns per centimeter (tpcm), or turns per inch (tpi). Booth (1964) concerned that twist is the measure of the spiral turns given to a yarn in order to hold the constituent fibers or threads together. A coarse yarn with 20 tpi has vastly different twist characteristics to a fine yarn with 20 tpi. Yarn twist parameter of amount of twist is designated as TPI (turns per inch) which affects appearance and durability of the yarns for spun yarn as follows: low twist 2-12 tpi, high twist 20-30 tpi and for filament yarns as usually low twist 0.5-1 tpi.

## 2.4 Yarn evenness

Yarn evenness can be defined as variation in weight per unit length of the yarn or as the variation in its thickness. There are a number of different ways of assessing it (Saville, 1999).

2.4.1 Visual examination: Yarns to be examined are wrapped onto a matte black surface in equally spaced turns so as to avoid any optical illusions of irregularity. The black-boards are then examined under good lighting conditions using uniform non-directional light. Generally the examination is subjective but the yarn can be compared with a standard if one is available; the ASTM produce a services of cotton yarn appearance standards. Motorized wrapping machines are available: in these, the yarn is made to traverse steadily along the board as it is rotated, thus giving a more even spacing (Saville, 1999).

2.4.2 Cut and weight methods: This is the simplest way of measuring variation in mass per unit length of a yarn. The method consists of cutting consecutive lengths of the yarn and weighing them. For the method to succeed, however, an accurate way of cutting the yarn to exactly the same length is required (Saville, 1999).

2.4.3 Uster evenness tester: The uster evenness tester measures the thickness variation of a yarn by measuring capacitance. The yarn to be assessed is passed through two parallel plates of a capacitor whose value is continuously measured electronically. The presence of the yarn between the plates changes the capacitance of the system which is governed by the mass of material between the plates and its relative permittivity. A diagram should be plotted of the actual variations in mass per unit length along the length of the yarn. The percentage CV or U value gives an overall number for yarn irregularity and hence is the most widely used of the measurements that the instrument makes. The U value was the only value calculated by the older uster equipment and is equal to percentage of mean deviation. The upper limit of CV which is acceptable for a yarn varies with the different types of yarn. Different spinning systems, count and end uses have different upper limits and knowledge of these can only be gained from experience of what is acceptable in a given application. Uster produces a volume of 'statistics' which lists the measured values of unevenness for the main types of yarn and for a range of counts for each type, so that measured values can be compared with expected values (Saville, 1999).

2.4.4 Spectrogram: Theoretically, if the CV of a yarn were zero, then the spectrogram would consist of a straight line. However, If the yarn has a completely random distribution of staple fibers, as in the case of the limiting CV value, then the staple length  $L$  has an effect on the spectrogram (ASTM International, 2005).

## 2.5 Hairiness

Yarn hairiness is in most circumstances an undesirable property, giving rise to problems in fabric production. Therefore it is important to be able to measure it in order to control it. However, it is not possible to represent hairiness with a single parameter because the number of hairs and the length of hairs both vary independently. Theoretically a yarn may have a small number of long hairs or a large number of short hairs or indeed any combination in between. The problem is determining which combination should be given a higher hairiness rating. Measurements of hairiness are very dependent on the experimental configuration used

such as the number and type of guides the yarn passes over and also the method chosen for detecting the hairs (Saville, 1999).

## 2.6 Yarn bulk

The WRONZ Bulkometer test gives an indication of the covering power of a yarn when it is incorporated into finished products such as knitwear or textured filament yarns. A large amount of continuous filament yarn has its bulk and stretch increased by some from of crimping process so that it may have the same covering power as staple fiber yarn and approximately the same texture. Tests for yarn stretch, which is related to yarn bulk, usually measure the difference in length between the straightened yarn and the contracted yarn (Saville, 1999).

Filament yarns are smooth and silky, an appearance that is enhanced by the low twist. Bulked filament yarns have the appearance of spun yarns, being rougher and less lustrous than flat filament yarns (Collier and Epps, 1999).

## 2.7 Friction

A yarn which is being knitted or woven into a fabric or wound onto a package runs around many guides during the process. Each one cause a drag on the yarn due to friction. Changes in the friction. Properties of the yarn can cause an increase or decrease in this drag and hence tension in the yarn. This can give rise to problems in that too much or too little yarn is fed to a process or the yarn is too tight or too slack spectrogram (ASTM International, 2005).

## 2.8 Yarn strength

The strength of an extension result from a sample of yarn taken from different parts of a package can be very variable. Yarn made from staple fibers is worse in this respect than yarn made from continuous filaments owing to the fact that the number of fibers in the cross-section of a staple fiber yarn is variable. This means

that in order to get a reasonable estimation of the mean strength of a yarn a large number of tests have to be carried out on it (ASTM D2256-2256).

Yarn strength can be measured on either single yarns (ASTM D 2256-2002) or on yarn skeins. Classification according to strength of yarn strength for a staple yarn varies as follows: weakest yarns about 10 cN/tex, best yarns 30 cN/tex (Lord, 2003).

### 3. Fabric testing

Collier *et al.* (2009) considered the specifications from conception and design to selection of the most appropriate materials for specific products. The International System of Units is the standard used for reporting measurements of textile properties, such as ASTM, ISO and SI. Basic physical properties of fabrics, along with methods for measuring them are as follows:

#### 3.1 Fabric weight

Weight is one of the most important characteristics, especially for woven, knitted and nonwoven fabric. Fabric weight is usually expressed as ounces per square yard or grams per square meter. For both of these systems, the higher the number, the heavier the fabric. The metric measure is used internationally and is the standard in the scientific literature dealing with textiles. Fabric weight is a function of the weight and thickness of the yarns used and how closely they are packed in the fabric structure (Collier *et al.*, 2009).

Weights may range widely. Fabrics weighing less than one ounce per square yard would be very light weight, two or four ounces per square yard are light weight. Medium-weight fabrics are five to seven ounces per square yard and heavyweight fabrics range from nine to eleven ounces. The weighting fabrics greater than fourteen ounces are classified as very heavyweight (Collier *et al.*, 2009).

On the other hand, fabric weight is determined by weighing fabric specimens of predetermined size on a balance. ASTM D 3776 recommends different specimen sizes for commercial testing and laboratory testing. Fabric weights in grams/meter<sup>2</sup> or ounces/yard<sup>2</sup> is calculated from the weight of the area measured. Ranges for fabric weights are as the very light weight fabric <35 (g/m<sup>2</sup>), light weight 70-100(g/m<sup>2</sup>), medium weight 170-240 (g/m<sup>2</sup>), heavy weight 300-375(g/m<sup>2</sup>) and very heavy weight >475(g/m<sup>2</sup>) (Collier and Epps,1999).

### 3.2 Fabric thickness

Fabric thickness is a key characteristic in determining product end use, especially where comfort is concerned and therefore, it is essential to specify thickness when considering a selection of fabrics. Thickness is measured by gauges that compress the fabric under a standard weight and is reported in thousandths of an inch or in millimeters (Collier *et al.*, 2009).

Collier and Epps (1999) classified the fabric according to thickness as thin fabric (<0.20 mm. thick), medium fabric (0.23-0.46 mm. thick) and thick fabric (>0.47 mm. thick).

### 3.3 Fabric width

Fabric widths will vary with the size of the machine on which they are made. Some weaving, knitting and nonwovens machines can produce fabric several meters wide. Other fabrics, such as braids or ribbons, are purposely constructed in narrow widths. Some fabrics are knitted in tubes, with a diameter appropriate for the end use, such as socks or T-shirt. A buyer will specify a fabric width necessary for making the final textile product (Collier *et al.*, 2009).

### 3.4 Fabric count

The closeness of the weave is expressed as the fabric count. Sometime called thread count, this is the number of yarns in one inch or centimeter of warp and in one inch or centimeter of filling. When the number of yarns in the warp is similar to the number of yarns in the filling, the weave is said to be a balanced weave. The fabric count is often expressed in numerical form as 80 x 64, indicating that there are 80 warp yarns per inch and 64 fillings per inch. When warp and filling are perfectly balanced, or equal, the count may be state as 80 square, meaning there are 80 yarns per inch in the warp and 80 yarns per inch in the filling.

Fabric count is usually measured with a calibrated, square magnifying glass called either a linen tester or a pick glass. The glass is marked off in fraction of an inch or in centimeters and the number of warp and filling yarns beside these calibrations can be viewed in magnified form with the glass and counted (Collier *et al.*, 2009). Moreover, Collier and Epps (1999) classified fabric according to fabric count as low count (10×10 – 40×40 yarns/inch), medium count (45×45 – 65×65 yarns/inch) and high count (>75×75 yarns/inch).

### 3.5 Fabric symmetry

When fabrics are used to construct apparel, home furnishing, or other textile products, differences in appearance from front to back or top to bottom become important. A fabric that has the same appearance on both front and back is reversible. If the two sides are different, it is not reversible. For fabric that are not reversible, the side to be displayed in the finished textile is termed the face of the fabric and the other side is the back. In addition, contain constructions look different along the length of the fabric depending on which end is considered the top (Collier *et al.*, 2009).

### 3.6 Abrasion resistance

In fabric structures where one set of yarns is predominant on the surface, the abrasion resistance of the fibers in that yarn would be a very important factor in durability. Yarn with high twist and even diameter resist abrasion better than those with low twist and/or uneven diameter. Yarn with loops, knots, or slubs, often used because of their attractive texture, are especially subject to abrasive wear. Heavier yarns result in thicker fabrics that are more abrasion resistant. Abrasion resistance can be determined on several different type of abrasion-testing machine. The results of tests run on different machine cannot be compared, as each machine tests with a different motion and each holds the fabrics in different positions. Some instruments determine only flat abrasion, while others can measure resistance to edge and flex abrasion (Collier *et al.*, 2009).

Standard test methods for abrasion resistance widely used include the ASTM D 3884, ASTM D 3885, ASTM D 3886, ASTM D 4157, ASTM D 4158, ASTM D 4966 and AATCC 93. They all use a flat or nearly flat fabric configuration. Beside, AATCC 93 which is a tumble abrasion test in which the fabric continuously changes its configuration during the test.

### 3.7 Fabric strength

The fabric strength evaluations are made in terms of breaking strength, tear strength, or bursting strength. Breaking strength, the force required to break a woven fabric when it is pulled under tension, is measured on a tensile testing machine. Tearing strength of a fabric, expressed in pound or grams, is the pressure required to continue a tear or a rip already begun in a woven fabric. Bursting strength is the force required to rupture a fabric. This is commonly used to evaluate the strength of knitted and nonwoven fabrics (Collier *et al.*, 2009). Moreover, Collier and Epps (1999) pointed out that plain weave has a high breaking strength, twill weave has a medium breaking strength and satin weave has a low breaking strength. Two standard test methods for fabric breaking strength differ in the form of the specimens

prepared for testing. The ASTM D 5034 is for the Grab Test and the ASTM D 5035 is for the Strip Test (Collier and Epps, 1999).

### 3.8 Hand and drape

In contrast to fabric color, where objective judgment is effective and used for color measuring instrumentation, objective decision making is becoming the norm. The determination of what is or is not a satisfactory fabric hand is extremely difficult. The AATCC has a standard evaluation for fabric hand. Drape and hand of fabrics can be measured objectively by the Drapemeter, the Kawabata Evaluation System for fabrics (KES) and the Fabric Assurance by Simple Testing (FAST) system (Collier *et al.*, 2009).

### 3.9 Sensorial confort

Collier *et al.* (2009) considered that the sensorial confort is related to surface and softness properties of fabrics. Surface properties can be measured on the Kawabata Surface Tester. Allergies and adverse reaction to abrasion and roughness are really in the realm of medical testing. In addition to the Kawabata and FAST system, there is an ASTM method to determine bending resistance. A strip of fabric is moved off the edge of a platform until it touches the angled side of the platform. The longer the length of fabric it takes to touch the side, the stiffer is the fabric.

## Related research

Cong *et al.* (2006) studied the chemical composition, wood characteristic, fiber morphology and pulping performance of paper mulberry. The results showed that the contents of Klason lignin and pectin of the bast were 12.0% and 11.7%, respectively. The extraction contents of cool/hot water and 1% NaOH were several times higher than that of populus tomentosa. The average length of the phloem was 7.45 mm and the average length of the xylem was 0.58 mm. The pulp yield was 49.7% when the xylem was cooked with NaOH-AQ process ISO brightness, 65.7%,

could be achieved when the pulp with  $\text{KMnO}_4$  value of 16.6 was bleached with 8.0% active chlorine and the breaking length of the pulp was 6.03 km. Adopting two impregnation stages, APMP with 72.5% ISO brightness could be produced by using the xylem as raw material, the breaking length of the pulp with  $49^\circ$  SR was 4.65 km.

Lei *et al.* (2007) studied the chemical compositions, fiber morphology and physical pulping characteristics of *Broussonetia papyrifera* bark produced in dry-hot valley of the Jinshajiang River were analyzed. The results were as follows: The lignin content was low and the holocellulose content was high in the bast part of the bark. The fiber of the bark was of great utilization value for its cellulose content reached 43.06%. The fiber length ranged from 3.3 mm to 16.94 mm with the average length 9.37 mm and the ratio of fiber length to width was 509, indicating the bark fiber should be an excellent raw material for long-fiber making. According to the laboratory measurements, the pulp yield was 42.47%, the hardness (the Kappa value) was 6.70, the burst resistance index was 2.23 kPa·m/g, the tearing index was 34.53 m N·m/g, the folding endurance value was 192, and the tension resistance value was 27.67 N·m/g. These indexes showed that the bark of *Broussonetia papyrifera* produced in dry-hot valley of the Jinshajiang River was well suitable for pulp making.

Min *et al.* (2007) studied the feasibility of *Broussonetia papyrifera* pulping. The evaluation was based on fiber morphology, chemical compositions and pulping properties. And the KP-AQ method suiting for pulping was made out. The L9 (34) orthogonal experiment was planned. The results were as follows: The holocellulose content was 82.09%, the Klason lignin content was 18.57%, the average length of fibers was 863  $\mu\text{m}$ , the length-width ratio was 51.3 and the ratio of cell wall thickness to cavity diameter was 0.37, so it was feasible for *Broussonetia papyrifera* to pulp. The alkali content was primary influencing factor of pulping, the next was retention time, the last was sulfidity and the best conditions of pulping were 18% alkali content, retention lasting 90 minutes and 24% sulfidity.

Sittidilokratna *et al.* (2007) concerned the screening of pectinase producing bacteria and assessment of the effectiveness for biopulping of paper mulberry bark of the pectinase of the highest producer. Pectinase producing bacteria identified in this studied included 3 isolates of *Erwinia carotovora* sub sp. *carotovora*, 2 of *Erwinia chrysanthemi* and 7 of *Bacillus* sp. They were different in their ability to produce PG, PAL and PL. Moreover, treatment of paper mulberry bark with crude pectinase suggested the application of pectinases to produce high quality fiber from wood bark.

Rongji *et al.* (2009) noticed the a kind of cellulose whiskers were extracted from the branch-barks of mulberry (*Morus alba* L.) by an alkali treatment at 130 °C and subsequently a sulfuric acid hydrolysis. AFM image showed that the diameter of obtained whiskers was ranged from 20 to 40 nm. The chemical compositions analysis, FT-IR, XRD results indicated that the hemicellulose and lignin were removed extensively in the cellulose whiskers, with a crystallinity of 73.4%. The TGA curves implied a two-stage thermal decomposition behavior of cellulose whisker due to the introduction of sulfated groups into the crystals in the sulfuric acid hydrolysis process. The obtained whiskers may have the potential applications in the fields of composites as a reinforcing phase, as well as in pharmaceutical and optical industries as additives.

Liu *et al.* (2010) studied the pectins extracted from mulberry branch bark, a byproduct of the sericulture industry. A single-factor experiment was used to optimize the production conditions. Under optimal conditions, the galacturonic acid yields from bark with and without epidermis were  $61.73 \pm 1.39\%$  and  $35.12 \pm 0.24\%$ , respectively. The extracted pectins mainly consisted of galacturonic acid with a trace amount of neutral sugars and the total galacturonic acid content in the pectins extracted from the bark without epidermis reached  $85.46 \pm 2.76\%$ . Pectins extracted from bark without epidermis had a higher degree of esterification ( $71.13 \pm 1.67\%$ ) than those extracted from bark with epidermis ( $24.27 \pm 2.89\%$ ). Pectin solution from bark without epidermis showed higher apparent viscosity, suggesting its higher gelation ability. Thus, the mulberry branch bark is a potential source of pectin with different degrees of esterification.

Memon *et al.* (2011) conducted the research on the lamination of the mulberry paper with biodegradable films can ameliorate the usability, corresponding to the modernisation and green products. Meticulously, the laminating machine was designed and created in this research, with the size 98 x 118 x 126 centimeters. The machine consisted of the roller driver and the infrared heater. The laminate film was pulled by the roller driver and be passed the latex glue and infrared heater. Subsequently, the film was coated on the mulberry paper by the rubber roller. The experimental results showed that the best lamination was at speed 3.72 m/min. In addition, the biodegradable film was 40  $\mu\text{m}$  thick and it's tensile strength was 40.22 MPa. Tensile strength of normal mulberry paper was 37.07 MPa, but 79.14 MPa after the lamination. The laminated mulberry-paper was more attractive, strengthening and lotus effect. The surface became smooth, easily to print and to clean out the dirt.

Takasaki *et al.* (2011) examined the molecular orientation of paper and mechanical properties of prepared paper yarn by twisting strips of paper made from various ratios of mulberry bast and Manila hemp. The molecular orientation of paper in direction of the strip was highest for paper with a mulberry bast weight ratio of 30 wt% as measured by a microwave molecular orientation analyzer. In contrast, the paper yarn sample with a mulberry bast weight ratio of 100 wt% showed a low molecular orientation of paper in direction of the strip. For mechanical properties, paper yarn with mulberry bast weight ratio of 30 wt% had the highest strength and young's modulus and the lowest elongation. These results show that the mechanical properties of the paper yarn depend on the molecular orientation of the paper in direction of strip.

Choi *et al.* (2012) found that Fumigants, including methyl bromide and ethylene oxide, are generally used for the preservation of the Korean cultural heritage, especially paper products like letters and books. However, the use of fumigants is banned because of their harmful effects on humans and the environment. Gamma irradiation is being considered as an alternative for the sterilization of insects and fungi in organic products. Therefore, they investigated the sterilization effects of radiation and its effect on the mechanical properties of the Korean traditional paper-

Hanji. Treatment doses of 9 kGy and 8 kGy of gamma irradiation inactivated 5 log units of *Aspergillus niger* and *Bacillus cereus* spores inoculated on Hanji, respectively. The gamma irradiations up to an absorbed dose of 50 kGy resulted in no significant changes in the tensile strength, bursting strength and appearance of Hanji. These results confirmed that radiation treatment disinfects the Korean traditional paper efficiently without changing its properties and that this treatment could be used to prevent the damage of Korean ancient archives by molds and fungi.

Sato Duarte *et al.* (2012) studied the characteristics of the fibers of species *Bactris setosa* (tucum) used by close-knit social groups, located in Sorocaba-Brazil, in basket-making technique. This fiber “tucum” was softer and more delicate than other leaf fibers and also very long, about 370 mm in length. The laboratory test results showed that *Bactris setosa* (tucum) presented a longitudinal view closer to that of sisal and abaca. The average breaking force of the fiber was 246.27 cN, higher than the one found in the literature. Regarding the values of stretching, they concluded that ‘tucum’ fiber was very close to that of linen. When compared with other vegetable fibers, Tucum’ fiber was superior in terms of tenacity. *Bactris setosa* was similar to other vegetable textile fibers and demonstrated a good potential for application in textile activities.

Reddy and Rhim (2014) studied the separation of crystallized nanocellulose (CNC) from paper-mulberry (*Broussonetia kazinoki* Siebold) bast pulp by sulfuric acid hydrolysis method. They were blended with agar to prepare bionano composite films. The effect of CNC content (1, 3, 5 and 10 wt% based on agar) on the mechanical, water vapor permeability (WVP) and thermal properties of the nano composites were studied. Changes of the cellulose fibers in structure, morphology, crystallinity and thermal properties of the films were evaluated using FT-IR, TEM, SEM, XRD and TGA analysis methods. The CNC was composed of fibrous and spherical orelliptic granules of nano-cellulose with sizes of 50–60 nm. Properties of agar film such as mechanical and water vapor barrier properties were improved significantly ( $p < 0.05$ ) by blending with the CNC. The tensile modulus and tensile strength of agar film increased by 40% and 25%, respectively, in the composite film

with 5 wt% of CNC and the WVP of agar film decreased by 25% after formation of nano composite with 3 wt% of CNC. Therefore, the CNC obtained from the paper-mulberry bast pulp can be used as a reinforcing agent for the preparation of bio-nano composites and they have a high potential for the development of completely biodegradable food packaging materials.

Punsuvon and Kobayashi (n.d.) pointed out that the bast from paper mulberry (*Broussonetia papyrifera*) is a widely applied traditional raw material for small scale paper mills in South East Asia, mainly Thailand, Myanmar, Vietnam, South China, Taiwan, Korea and Japan. The classical pulping using caustic soda requires high cost investment of waste water from pulping and bleaching. Steam explosion is a technique to separate cellulosic fibers from hemicellulose, lignin and pectic substance with reasonable yield and purity. From view point of environmental conservation, this pulping method was applied to paper mulberry bast with combination of H<sub>2</sub>O<sub>2</sub>/KOH bleaching of the pulp thus obtained. As the wastewater from bleaching can be applied to a fertilizer, this process, therefore, consists of zero emission. It was found that the bast was pulped under very mild condition: in experiment, 150 g of the of 5 elevated temperature levels between 180-220°C for 5 min in a steam explosion batch reactor gave the yields of 48-61%. The dark pulp was beached with 2 stage H<sub>2</sub>O<sub>2</sub>/KOH. The optimum conditions were 190°C for 5 min. Physical and chemical analyses after bleaching showed that the steam explosion could replace the traditional pulping.

Anapanurak and Puangsin. (n.d.) studied the optimum conditions and proper chemicals in pulping process of paper mulberry. Paper mulberry inner bark was first soaked in water for 24 hours. After that, water was mostly removed by squeezing the bark and 7% by weight of varied chemicals (NaOH KOH, Ca(OH)<sub>2</sub> or their mixture (3:2:2)) were added at the ratio of liquor to bark 10:1. The bark was then boiled at 100 °C for an hour and further bleached with hydrogen peroxide. For bark boiled in NaOH, it was bleached only one time whereas the ones boiled in KOH, Ca(OH)<sub>2</sub> or their mixture were bleached for two, two and one time, respectively. The results showed that the mixture of NaOH, KOH and Ca(OH)<sub>2</sub> (3:2:2) could be used as an alternative for NaOH in pulp production. The strength and physical properties of pulp

obtained from this method as tensile index, burst index, tear index, folding resistance, brightness and opacity were 38.76 N.m/g, 4.21 kPa.m<sup>2</sup>/g, 65.67 mN.m<sup>2</sup>/g, 1,210.81, 75.89% and 78.09%, respectively.



## MATERIALS AND METHODS

### Materials

#### 1. Paper Mulberry Bark

The materials used for this study were eighteen kilograms of paper mulberry (*Broussonetia papyrifera* (L.) Vent.) inner bark, between 6 to 12 months old, from the Mea Fah Luang Foundation, in Chiangrai province (Figure 5).



**Figure 5** Paper mulberry barks.

#### 2. Equipment

Equipment used to determine the characteristics and physical properties of paper mulberry fiber, yarn and fabric were as follows:

##### 2.1 Equipment used for preparing of paper mulberry fiber

- 2.1.1 Tank 1-1.5 m in length, 1-1.5 m width and .25-.5 m in depth
- 2.1.2 Knife
- 2.1.3 Basket
- 2.1.4 Balance

### 2.1.5 Rope

## 2.2 Equipment used for spinning of paper mulberry yarn

### 2.2.1 Hand reel

### 2.2.2 Wood pound

### 2.2.3 Scissors

### 2.2.4 Pot

### 2.2.5 Stove

## 2.3 Equipment used for weaving and knitting paper mulberry fabrics

### 2.3.1 Hand looms, 24 inch sizes width

### 2.3.2 Pins needles, No. 6

## 2.4 Equipment used for testing of the characteristics and physical properties of paper mulberry fiber

### 2.4.1 Scanning electronic microscope

### 2.4.2 Fiber length tester

### 2.4.3 Linear density tester

### 2.4.4 Moisture content tester

### 2.4.5 Instron tensile tester

### 2.4.6 Balance

## 2.5 Equipment used for testing of the characteristics and physical properties of paper mulberry yarn

### 2.5.1 Microscope

### 2.5.2 Balance

### 2.5.3 Linear density tester

### 2.5.4 Twist tester

### 2.5.5 Instron tensile tester

## 2.6 Equipment used for testing of the characteristics and physical properties of paper mulberry fabric

### 2.6.1 Microscope

### 2.6.2 Thickness tester

### 2.6.3 Balance

### 2.6.4 Pick Glass

### 2.6.5 Instron tensile tester

## Methods

### 1. Preparation of Paper Mulberry Fiber

#### 1.1 Preparation of paper mulberry barks

The preparation of paper mulberry barks was carried out in three stages.

1.1.1 Removed of the cortex or barks by hand decortication.

1.1.2 Scraped the cortex to remove most of the outer barks from the woody stem, the parenchyma in the bast layer and some of the gums and pectins.

1.1.3 Washed 2 to 3 times, then the barks were completely dried out.

#### 1.2 Preparation of paper mulberry fibers for testing

The preparation of paper mulberry fibers were carried out by separated method which occurred in three stages:

1.2.1 Sprayed water on the dry barks to soften them.

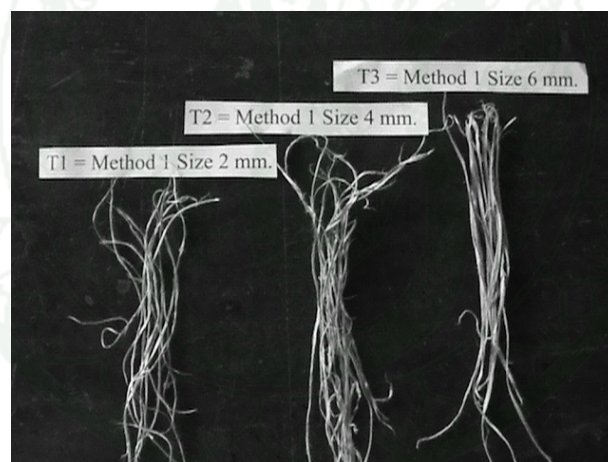
1.2.2 Separated the barks into bundle fibers by hand.

1.2.3 Separated the bundle fibers into single fibers.

### 1.3 Preparation of paper mulberry fibers for yarn spinning

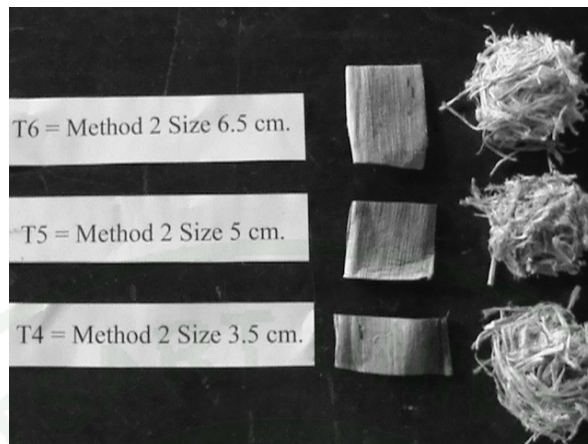
The inner barks were divided into two parts. Each of the two parts was used for each of the two different hand spinning methods developed.

1.3.1 Preparation of paper mulberry bundle fibers for the modified hemp spinning method: Separated the inner barks into strips in three sizes width; 2 mm, 4 mm and 6 mm, as shown in Figure 6.



**Figure 6** Paper mulberry strips in three sizes width.

1.3.2 Preparation of paper mulberry fibers for the modified cotton spinning method: Cut-off the inner barks in three sizes length; 3.5 cm, 5 cm and 6.5 cm, and separated into bundle fibers by hand, as shown in Figure 7.



**Figure 7** Paper mulberry barks in three sizes length.

## 2. Testing of Paper Mulberry Fiber

The characteristics and physical properties of the paper mulberry fibers were determined according to ASTM standard testing methods as follows:

2.1 Fiber length was tested according to ASTM D 5332-92 Standard Test Method for Fiber Length and Length Distribution of Cotton Fibers (ASTM International, 2005).

2.2 Fiber density was tested according to ASTM D 1577-07 Standard Test Methods for **Linear Density of Textile Fibers** and determined using a Scanning Electronic Microscope (ASTM International, 2005).

2.3 Moisture content was tested according to ASTM D2654-89a Standard Test Methods for Moisture in Textiles (ASTM International, 2005).

2.4 Fiber tenacity was tested according to ASTM D 3822-01 standard Test Method for Tensile Properties of Single Textile Fibers (ASTM International, 2005).

The samples were conditioned in a standard laboratory atmosphere for testing ( $27\pm 1$  °C and  $65\pm 2$  % RH) for 24 hours.

### **3. Spinning of Paper Mulberry Yarns**

The two hand spinning methods developed for the paper mulberry yarns were the modified hemp spinning method and the modified cotton spinning method.

#### **3.1 The modified hemp spinning method (MH)**

The yarn spinning method was developed by modifying the hemp spinning method widely used in the Northern Part of Thailand. This method was experimented using three size paper mulberry bark strips: 2 mm, 4 mm, and 6 mm.

#### **3.2 The modified cotton spinning method (MC)**

This processing of paper mulberry yarn spinning was modified from the traditional hand spinning method of cotton yarn which widely used in the Northeast Part of Thailand. This method was experimented using three fiber length: 3.5 cm, 5 cm, and 6.5 cm.

### **4. Testing of Paper Mulberry Yarns**

The characteristics and physical properties of the paper mulberry yarns were determined according to ASTM standard testing methods as follows:

4.1 Yarn count was tested according to ASTM D1059 - 01 Standard Test Methods for Yarn Number Based Short-Length Specimens (ASTM International, 2005).

4.2 Yarn twist was tested according to ASTM D1423 - 02 Standard Test Methods for Twist in Yarn by Direct-Counting (ASTM International, 2005).

4.3 Yarn appearance was determined using a scanning electronic microscope and according to ASTM D2255 - 02 Standard Test Method for Grading Spun Yarns for Appearance (ASTM International, 2005).

4.4 Yarn breaking strength and elongation were tested using an Instron Tensile Tester according to ASTM D 2256 - 02 Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method (ASTM International, 2005).

## **5. Weaving of Paper Mulberry Fabrics**

The paper mulberry yarns were experimentally woven on the Thai hand loom in plain weave construction. The processes of weaving were as follows:

5.1 Shedding: This was raising the harnesses through which different warp yarns threaded created an open area.

5.2 Picking: While the shed was open, the filling yarn was transported across the opening, laying across the width of the loom.

5.3 Beating up was done by the reed that pushed the newly inserted filling yarn close against the woven fabric.

5.4 Taking up/letting off: As the woven fabric was formed, it must be moved or taken up on the cloth beam to make room for the formation of more fabric.

This weaving was done using the harness No. 24 (12 warp yarns per inch).

## **6. Knitting of Paper Mulberry Fabrics**

Knitting of paper mulberry fabrics were done in the hand knitting process by hand-knit in weft-knit construction; fives steps in the formation of loops with the pin needles were as follows:

6.1 The left-hand pin A retained the previously formed row of loops (course).

6.2 The right-hand pin B was used to draw through and retained the next course of loops.

6.3 Pin B had drawn the newly formed loop 2 through loop 1 of the previous course. Pin A then released loop 1, which hung from loop 2, which itself was hanging from pin B.

6.4 At the start of the next row (course), the pins might be changed to the other hands as the action continues.

The hand knitted fabrics were produced using two No. 6 pins needles.

## **7. Testing of Paper Mulberry Woven and Knitted Fabrics**

The characteristics and physical properties of the paper mulberry fabrics were determined according to ASTM standard testing methods as follows:

7.1 Fabric thickness was tested according to ASTM D1777 - 96 Standard Test Methods for Thickness of textile Materials (ASTM International, 2005).

7.2 Fabric weight was tested according to ASTM D 3776 - 96 Standard Test Methods for Mass per Unit Area (weight) of fabric (ASTM International, 2005).

7.3 Woven fabric count was tested according to ASTM D 3775 - 03a Standard Test Methods for Warp End Count and Filling Pick count of Woven fabric (ASTM International, 2005).

7.4 Fabric strength was tested according to ASTM D 5034 – 95 Standard Test Methods for Breaking Strength and Elongation of Textile Fabric (ASTM International, 2005).

7.5 Fabric surface texture was tested using the Scanning Electron Microscope (Saville, 1999).

The samples were conditioned in the standard laboratory atmosphere for testing ( $27\pm 1$  °C and  $65\pm 2$  % RH) for 24 hours.

## **8. Experiment Plan and Data Analysis**

### **8.1 The experiment plan**

The experiment to determine the effect of spinning methods of paper mulberry yarn was Completely Randomized Design (CRD). There were totally six spinning methods as follows:

8.1.1 Modified hemp spinning method (MH) using 2 mm strip

8.1.2 Modified hemp spinning method (MH) using 4 mm strip

8.1.3 Modified hemp spinning method (MH) using 6 mm strip

8.1.4 Modified cotton spinning method (MC) using 3.5 cm fiber

8.1.5 Modified cotton spinning method (MC) using 5 cm fiber

### 8.1.6 Modified cotton spinning method (MC) using 6.5 cm fiber

Five replications of experiment were conducted.

## 8.2 Data analysis

Mean and Standard Deviation were used and calculated for each treatment and the Analysis of Variance (ANOVA) and Least Significant Ranges (LSR) were used for comparing the differences of the mean values at .05 confidence level. Therefore the best yarn from the six spinning methods for paper mulberry fabrics could be determined.

## 9. Hypothesis

9.1 Hypotheses for testing the effect of spinning methods upon the physical properties of paper mulberry yarns.

9.1.1 The paper mulberry yarns spun by different methods did not have different count.

9.1.2 The paper mulberry yarns spun by different methods did not have different twist.

9.1.3 The paper mulberry yarns spun by different methods did not have different breaking strength.

9.1.4 The paper mulberry yarns spun by different methods did not have different elongation.

9.2 Hypotheses for testing the effect of spinning methods upon the physical properties of paper mulberry woven fabrics.

9.2.1 The paper mulberry woven fabrics made from the yarns spun by different methods did not have different thickness.

9.2.2 The paper mulberry woven fabrics made from the yarns spun by different methods did not have different weight.

9.2.3 The paper mulberry woven fabrics made from the yarns spun by different methods did not have different weft count.

9.2.4 The paper mulberry woven fabrics made from the yarns spun by different methods did not have different strength (warp).

9.2.5 The paper mulberry woven fabrics made from the yarns spun by different methods did not have different strength (weft).

9.2.6 The paper mulberry woven fabrics made from the yarns spun by different methods did not have different elongation (warp).

9.2.7 The paper mulberry woven fabrics made from the yarns spun by different methods did not have different elongation (weft).

9.3 Hypotheses for testing the effect of spinning methods upon the physical properties of paper mulberry knitted fabrics.

9.3.1 The paper mulberry knitted fabrics made from the yarns spun by different methods did not have different thickness.

9.3.2 The paper mulberry knitted fabrics made from the yarns spun by different methods did not have different weight.

9.3.3 The paper mulberry knitted fabrics made from the yarns spun by different methods did not have different count (course).

9.3.4 The paper mulberry knitted fabrics made from the yarns spun by different methods did not have different count (wale).



## RESULTS AND DISCUSSION

This research focuses on characteristics and properties of paper mulberry fiber, yarn and fabric. The objectives were: to determine the characteristics and physical properties of paper mulberry fiber, to develop the spinning processes of paper mulberry yarn, to determine the characteristics and physical properties of paper mulberry yarns and to experimentally produce the paper mulberry fabrics by weaving and knitting and determine the characteristics and physical properties of the paper mulberry fabric produced. The research result can be categorized into 4 sections as follows:

Section 1 : Characteristics and physical properties of the paper mulberry fiber

Section 2 : Paper mulberry yarn spinning methods

Section 3 : Characteristics and physical properties of the paper mulberry yarns

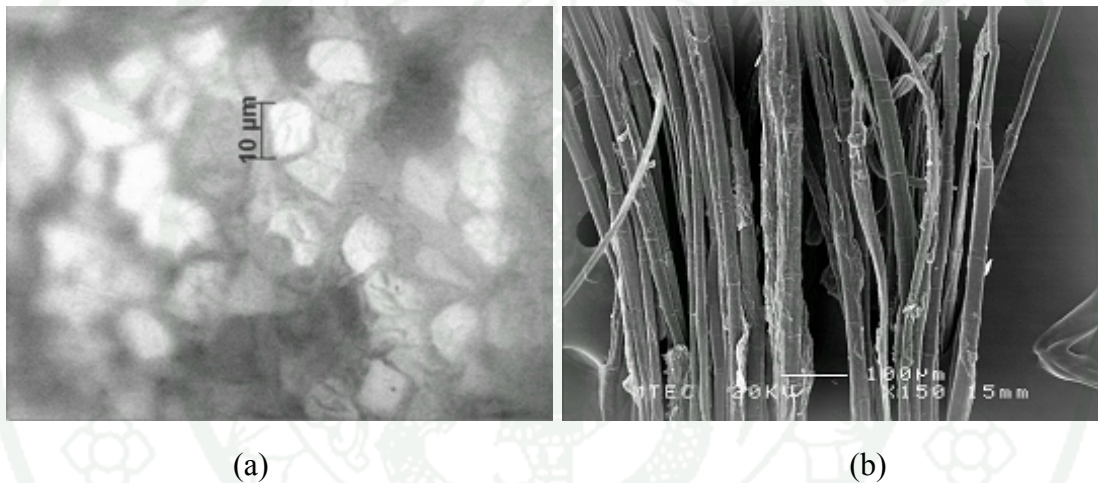
Section 4: Characteristics and physical properties of the paper mulberry fabrics

### **Characteristics and Physical Properties of the Paper Mulberry Fiber**

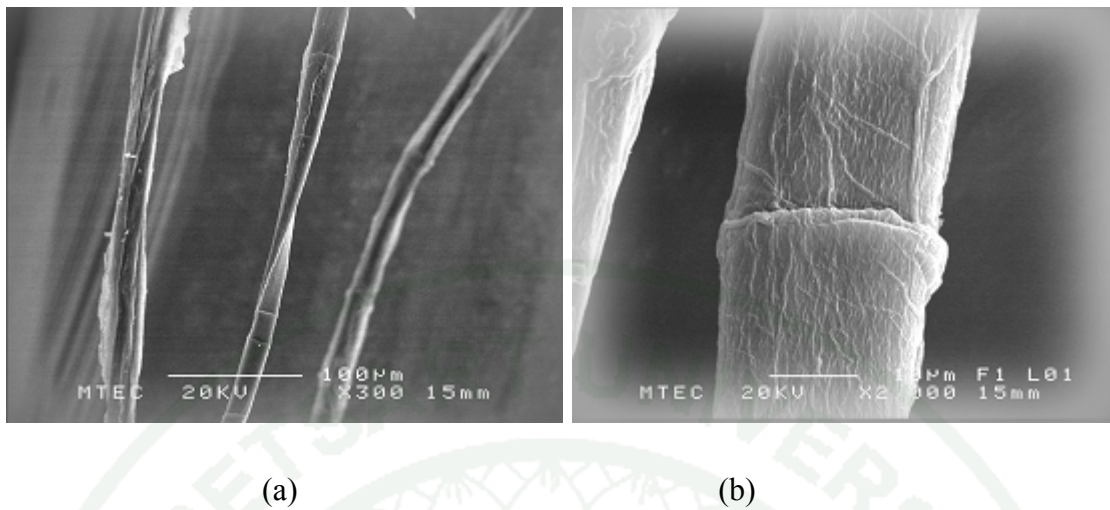
The process of preparing paper mulberry fiber begins with strayed water on the dry paper mulberry bark. And then, separated the bark into bundle fiber by hand, and utilized in this study. The results show characteristics and physical properties of paper mulberry fibers as follows:

## 1. The Characteristics of the Paper Mulberry Fiber

When studying the characteristics of paper mulberry fiber using a scanning electronic microscope with 150x times magnifying power, it was found that the cross-sectional image of the fiber showed clusters of fibers with the average diameter of 10 micrometers for each of the fibers. The fiber had rounded corners with lumen in the middle as shown in Figure 8 (a). When looking along the length, the fiber had an uneven texture as shown in Figure 8 (b), where as Figure 9 shows the node that appears on the fiber periodically.



**Figure 8** Cross-section of paper mulberry fiber -150x (a) and longitudinal section of paper mulberry fiber-150x (b).



**Figure 9** A node on a paper mulberry single fiber in (a) 300x and (b) 2000x.

Evidently, the characteristics showed that the diameter of paper mulberry fiber was considerably close to those of hemp fiber (10-30 micrometers), jute fiber (6-26 micrometers) and flax fiber (12-16 micrometers) (Hemachandra, 2010).

According to, Franklin (1937) the paper mulberry fiber was a thick-wall shaped fiber, where the ends were pointed, blunt and scalloped in form. There were dislocations and cross-marking within the fiber, which was enveloped in a thin and transparent membrane. The cross section of the fiber affects other properties within the fiber in addition. Collier and Tortora (2001) found that, the cross-sectional view was a practical way in which to view the three-dimensional form of a fiber. Cross sections were often used as a means of comparison to the physical appearance of these fibers. It was best observed under a microscope.

## 2. The Physical Properties of the Paper Mulberry Fiber

The research investigated four aspects of paper mulberry fiber's physical properties: fiber length, fiber density, moisture content and tenacity. The data were obtained by using ASTM standard testing methods (Saville,1999),as shown in table 1.

**Table 1** Physical properties of the paper mulberry fiber.

<b>Fiber Type</b>	<b>Fiber length (mm)</b>	<b>Fiber density (tex)</b>	<b>Moisture content (%)</b>	<b>Tenacity (cN/tex)</b>	<b>Elongation (%)</b>
Single fiber	10.20	0.95	8.14	4.85	4.50
Bundle fiber	42.27	13.04	10.66	15.90	11.21

Table 1 shows that the fiber length, the density, the moisture content, the tenacity and the elongation of the single fiber were less than those of the bundle fiber. The length of the paper mulberry single and bundle fibers were similar to flax fiber. Therefore the paper mulberry single fiber was classified as short (<26 mm) while the bundle fiber was classified as extra long fiber (>39 mm) (Taylor, 1997).

The density of the paper mulberry single fiber was 0.95 tex whereas that of the bundle fiber was 13.04 tex. Collier and Epps (1999) suggested that since the density of most fibers are less than one tex, therefore single fibers are usually designated in decitex (0.1 tex) or denier units. The density of the paper mulberry fiber was less than one tex and, therefore similar to flax (0.2-2.0 tex) (Franck, 2005) .

The moisture content of the paper mulberry single fiber was 8.14% and that of the bundle fiber was 10.66%. These were similar to that of cotton (8-11%) but was lower than that of flax (12%). Franck (2005) noticed the moisture content of other bast fibers: hemp 8%, ramie 12% and sisal 10.57%. The paper mulberry fiber could adsorb water similar to the other bast fibers. Therefore, it could be classified as hydrophilic fiber.

The tenacity of the paper mulberry single fiber was 4.85 cN/tex and that of the bundle fiber was 15.90 cN/tex. Franck (2005) pointed out that flax which its tenacity is 5.5-6.5 cN/tex, is one of the strongest natural fibers. Therefore, the paper mulberry fiber was classified as strong fiber when compared with the others.

The elongation of paper mulberry single fiber was 4.50% and that of bundle fiber was 11.21% while that of flax is 3.3%. Thus percentage elongation of paper mulberry fiber was higher than that of flax.

## **Paper Mulberry Yarn Spinning Methods**

### **1. The Two Developed Spinning Methods**

#### **1.1 The modified hemp spinning method**

This was a hand spinning method, developed from the hemp spinning method widely used in Northern Thailand. The process consisted of four steps as follows:

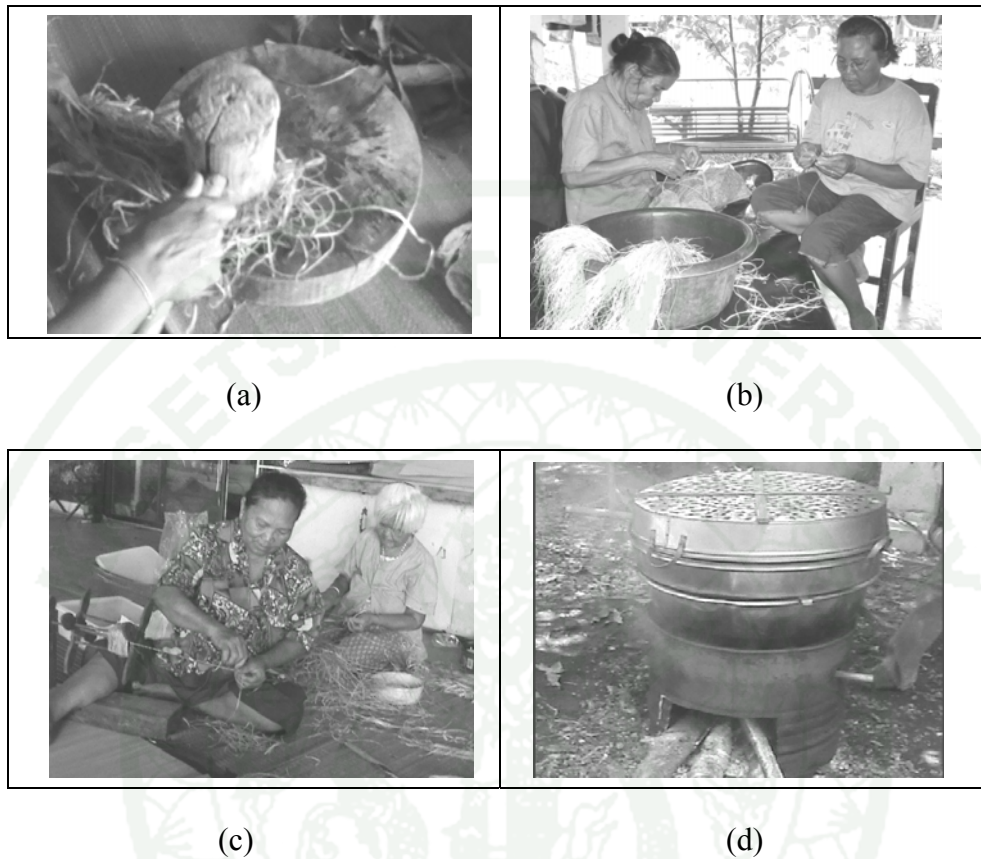
1.1.1 Pounding to further soften and affine the strips and remove lignin.

1.1.2 Joining strips of inner barks to make continuous fiber strips; using the Thai traditional method by hand.

1.1.3 Hand spinning to make continuous yarn.

1.1.4 Boiling: This process was done the last time to remove the lignin, finish and soften the yarn.

Figure 10 shows the steps of the modified hemp spinning processes.



**Figure 10** The steps of the modified hemp spinning method (a) pounding strips, (b) joining strips, (c) hand spinning and (d) boiling the yarns.

This method was experimented using paper mulberry barks with different width (2, 4, 6 mm).

## 1.2 The modified cotton spinning method

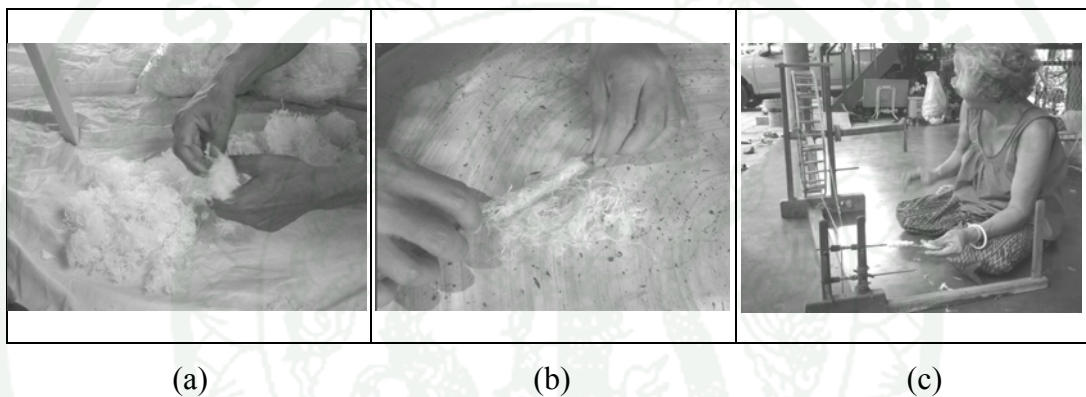
This method modified from the technique originated in the cotton spinning method widely used in Northeast Thailand. The process consisted of three steps as follows:

1.2.1 Cleaning or scotching to soften and increase the fineness of the bundle fibers.

1.2.2 Rolling of the bundle fibers to make a long strand of a sliver using the Thai traditional hand method.

1.2.3 Spinning to form a yarn by a combination of drawing or drafting and twisting the prepared strands of fiber. A spinning wheel was used to mechanize the spinning process. And the rollers were used to draft the fiber bundle and rotate the spindles.

Figure 11 shows the steps of the modified cotton spinning processes.



**Figure 11** The steps of the modified cotton spinning method (a) cleaning or scotching, (b) rolling bundle fibers and (c) spinning to yarns.

This method was experimented using paper mulberry fibers with different length (3.5, 5, 6.5 cm).

## 2. Yield of Paper Mulberry Yarns

**Table 2** The yield of paper mulberry yarns from different spinning methods.

Yarn Spinning Methods	Yield of Paper Mulberry Yarns		
	Length (M)	Weight (g)	Waste (g)
MH with 2 mm strip	978	960	40
MH with 4 mm strip	935	970	30
MH with 6 mm strip	908	975	25
MC with 3.5 cm fiber	950	950	50
MC with 5 cm fiber	964	958	42
MC with 6.5 cm fiber	970	965	35

From Table 2, the data shows that in terms of yarn length the MH using 2 mm bark strips could produce the longest yarn (978 meters), whereas, the MH using 6 mm strips had the highest weight of yarn (975 grams). This method also had the least waste (25 grams).

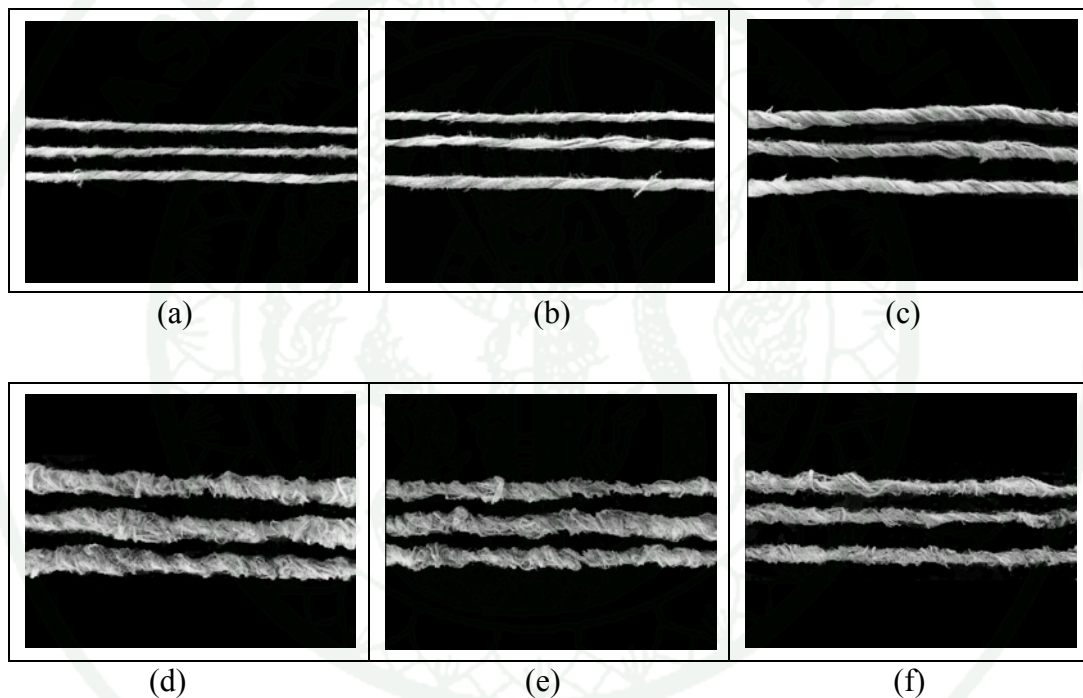
In terms of production, the best method of spinning yarn from the paper mulberry fiber was the MH using 6 mm strips. However, when compare among the MH, it was found that the spinning method using 2 mm strips was the best one. But among the MC, the spinning method using 6.5 cm long fibers was the best one. The MH is appropriate for community enterprise and farmers in the North and the MC is appropriate for community enterprise and farmers in the Northeast. These two developed methods could be used for spinning paper mulberry yarns.

## Characteristics and Physical Properties of the Paper Mulberry Yarns

The yarns obtained from the six spinning methods were investigated in two aspects of characteristics and four aspects of physical properties as follows:

### 1. The Characteristics of the Paper Mulberry Yarns

#### 1.1 The longitudinal section of the paper mulberry yarns produced

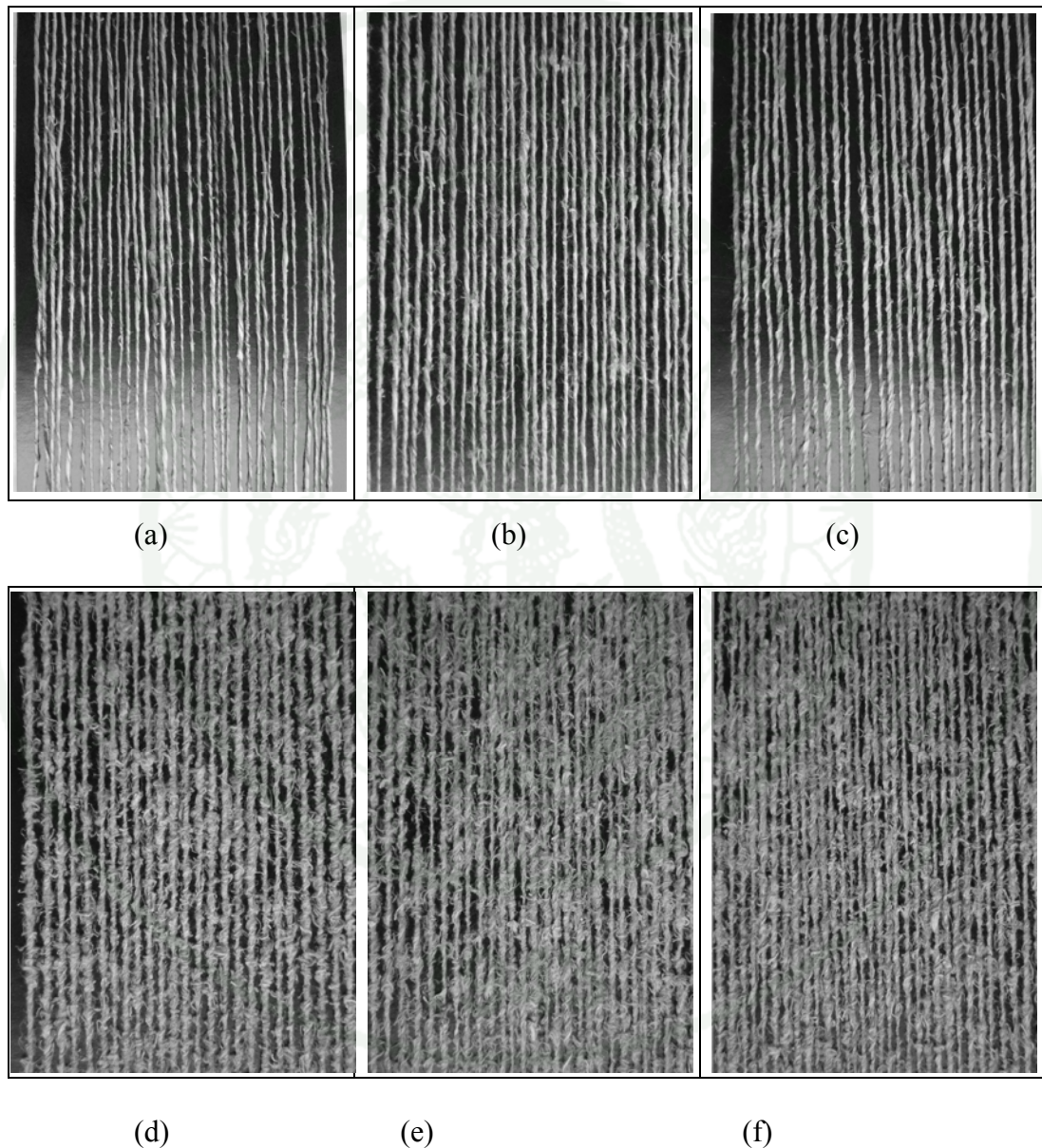


**Figure 12** Longitudinal section of the yarn spun by different methods (a) modified hemp (MH) with 2 mm strip, (b) modified hemp (MH) with 4 mm strip, (c) modified hemp (MH) with 6 mm strip, (d) modified cotton (MC) with 3.5 cm fiber, (e) modified cotton (MC) with 5 cm fiber and (f) modified cotton (MC) with 6.5 cm fiber.

The images of the paper mulberry yarns produced (Figure 12) show that the MH could produce much smoother yarns than the MC. The finest yarn was produced from the MH using 2 mm strips. In contrast, the yarns produced from the

MC had more fuzzy and rough texture. They looked like novelty yarns. Therefore, they should be used as filling yarns.

### 1.2 The evenness of the paper mulberry yarns produced



**Figure 13** The evenness of the paper mulberry yarns spun by different methods (a) modified hemp (MH) with 2 mm strip, (b) modified hemp(MH) with 4 mm strip, (c) modified hemp (MH) with 6 mm strip, (d) modified cotton (MC) with 3.5 cm fiber, (e) modified cotton (MC) with 5 cm fiber, and (f) modified cotton (MC) with 6.5 cm fiber.

Figure 13 shows that the paper mulberry yarns spun by the MH (a), (b) and (c) were fuzzy and uneven in texture, which could be categorized at grade C level. Whereas, the yarns spun by the MC (d), (e) and (f) were more fuzzy and uneven in texture. As a result, they were categorized at below grade D level.

Moreover, the MH cloud produce yarns with smoother surface than the MC. However, the paper mulberry yarns could produce different texture fabrics. Therefore, it might be suitable for household fabrics.

## 2. Physical Properties of the Paper Mulberry Yarns

The study investigated the following aspects of the yarn's physical properties: yarn count, yarn twist, yarn breaking strength and elongation, using the ASTM standard test. The results are shown as follows:

### 2.1 Yarn count

**Table 3** Means of yarn count of the paper mulberry yarns produced by different spinning methods.

Yarn Spinning Methods	Yarn Count (tex)
MH with 2 mm strip	963.48
MH with 4 mm strip	1310.14
MH with 6 mm strip	1683.88
MC with 3.5 cm fiber	1271.70
MC with 5 cm fiber	1150.68
MC with 6.5 cm fiber	1022.78

From Table 3, the data shows that the yarn spun by MH with 6 mm strips was the heaviest (1683.88 tex). Followed by the yarn spun by MH with 4 mm strips (1310.14 tex). Meanwhile, the yarns spun by MH with 2 mm strips was the smallest (963.48 tex).

It was noted that the MH using a 6 mm strips yielded the heaviest yarn since it was spun from the widest strips. Besides, the MH with 2 mm strips has smallest size because it was spun from the narrowest strips but when compare with the yarn standard (Collier and Epps, 1999) it was noted as the heaviest size as well. It could be concluded that all the paper mulberry yarns produced were heavy size.

Different methods showed to produce the yarns with different count. Variation analysis of the means yarn count revealed that different spinning methods resulted in different yarn count at .01 level (Table 4). Therefore, the hypothesis 9.1.1 which stated that the paper mulberry yarns spun by different methods did not have different count was rejected.

**Table 4** Variations analysis of the means yarn count of the paper mulberry yarns spun by different methods.

Source of Variation	df	SS	MS	F	p
Treatment	5	1671737.43	334347.49	35.04	0.00
Error	24	228984.08	9541.00		
Total	29	47566867.41			

**Table 5** The analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn count of the paper mulberry yarns spun by different methods.

Yarn Spinning Methods	Yarn Count (tex)
MH with 6 mm strip	1683.88 <sup>a</sup>
MH with 4 mm strip	1310.14 <sup>b</sup>
MC with 3.5 cm fiber	1271.70 <sup>bc</sup>
MC with 5 cm fiber	1150.68 <sup>c</sup>
MC with 6.5 cm fiber	1022.78 <sup>d</sup>
MH with 2 mm strip	963.48 <sup>d</sup>

$p \leq .05$

Table 5 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn count of the yarns spun by different methods. It was found that the MH with 6 mm strips produced the highest yarn count and was statistically different from the others at .05 level.

The count of the yarn produced by MH with 4 mm bark strips was statistically different from the count of the yarns produced by the MC with 5 and 6.5 cm fibers and the yarn produced by the MH with 2 mm bark strips at .05 level.

The count of the yarns produced by the MC with 3.5 and 5 cm fibers were statistically different from the count of the yarn produced by the MC with 6.5 cm fibers and the yarn produced by the MH with 2 mm bark strips at .05 level.

While the MC with 6.5 cm fibers and the MH with 2 mm strips yielded the lowest yarn count and were not statistical different at .05 level.

## 2.2 Yarn twist

**Table 6** Means of yarn twist of the paper mulberry yarns produced by different spinning methods.

Yarn Spinning Methods	Yarn Twist (turns/inch)
MH with 2 mm strip	5.60
MH with 4 mm strip	4.60
MH with 6 mm strip	5.00
MC with 3.5 cm fiber	10.80
MC with 5 cm fiber	9.80
MC with 6.5 cm fiber	8.80

From Table 6, the data shows that the yarn spun by the MC with 3.5 cm fibers had the highest yarn twist (10.80 turn/inch). Followed by the yarn spun by MC with 5 cm fibers (9.80 turns/inch). In contrast, the yarn spun by the MH with 4 mm strips had the lowest yarn twist (4.60 turn/inch).

It was found that the yarn spun by the MC with 3.5 cm fibers yielded the highest twist as it was produced from the shortest fibers and therefore needed more twist. While the MH with 4 mm strips had the lowest twist since it was spun from the narrow bark strips. Thus, the paper mulberry yarns produced were the low twist ones (Booth, 1964).

Different methods showed to produce the yarns with different twist. Variation analysis of the means yarn twist (Table 7) revealed that different spinning methods resulted in different yarn twist at .01 level. Therefore, the hypothesis 9.1.2 which stated that the paper mulberry yarns spun by different methods did not have different twist was rejected.

**Table 7** Variation analysis of the means yarn twist of the paper mulberry yarns spun by different methods.

Source of Variation	df	SS	MS	F	p
Treatment	5	180.57	36.11	67.71	0.00
Error	24	12.80	0.53		
Total	29	193.37			

**Table 8** The analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn twist of the paper mulberry yarns spun by different methods.

Yarn Spinning Methods	Yarn Twist (turns/inch)
MC with 3.5 cm fiber	10.80 <sup>a</sup>
MC with 5 cm fiber	9.80 <sup>b</sup>
MC with 6.5 cm fiber	8.80 <sup>c</sup>
MH with 2 mm strip	5.60 <sup>d</sup>
MH with 6 mm strip	5.00 <sup>d</sup>
MH with 4 mm strip	4.60 <sup>d</sup>

$p \leq .05$

Table 8 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn twist of the yarns spun by different methods. It was found that the MC with 3.5 cm fibers produced the highest yarn twist and was statistically different from the others at .05 level.

The twist of the yarn produced by MC with 5 cm fibers was statistically different from the twist of the yarns produced by the modified cotton spinning method with 6.5cm fibers and the MH with 2 mm strips, 6 mm strips and 4 mm strips at .05 level.

The twist of the yarn produced by the MC with 6.5 cm fibers was statistically different from the twist of the yarn produced by the MHs with 2 mm strips, 6 mm strips and 4 mm strips at .05 level.

While the MHs with 2 mm strips and 4 mm strips and 6 mm strips yielded the lowest yarn twist and were not statistical different at .05 level.

### 2.3 Yarn breaking strength

**Table 9** Means of yarn breaking strength of the paper mulberry yarns produced by different spinning methods.

Yarn Spinning Methods	Yarn Breaking Strength (cN/tex)
MH with 2 mm strip	264.22
MH with 4 mm strip	352.71
MH with 6 mm strip	551.06
MC with 3.5 cm fiber	36.14
MC with 5 cm fiber	83.44
MC with 6.5 cm fiber	66.39

From Table 9, the data shows that the paper mulberry yarn spun by the MH with 6 mm strips had the highest breaking strength (551.06 cN/tex). Followed by the yarn spun by MH with 4 mm strips (352.71cN/tex). Whereas, the paper mulberry yarn spun by the MC with 3.5 cm fibers had the lowest breaking strength (36.14 cN/tex).

Each spinning method yielded the yarn with different breaking strength. The hemp spinning methods yielded the yarns with much higher strength than the cotton spinning methods.

Different methods showed to produce the yarns with different breaking strength. Variation analysis of the means yarn breaking strength (Table 10) revealed that different spinning methods resulted in different yarn breaking strength at .01 level . Therefore, the hypothesis 9.1.3 which stated that the paper mulberry yarns spun by different methods did not have different breaking strength was rejected.

**Table 10** Variations analysis of the means yarn breaking strength of the paper mulberry yarns spun by different methods.

Source of Variation	df	SS	MS	F	p
Treatment	5	1025120.01	205024.00	265.77	0.00
Error	24	18514.77	771.45		
Total	29	1043635.89			

**Table 11** The analysis of Least Significant Ranges (LSR) to measure the mean difference of breaking strength of the paper mulberry yarns spun by different methods.

Yarn Spinning Methods	Yarn Breaking Strength (cN/tex)
MH with 6 mm strip	551.06 <sup>a</sup>
MH with 4 mm strip	352.71 <sup>b</sup>
MH with 2 mm strip	264.22 <sup>c</sup>
MC with 5 cm fiber	83.44 <sup>d</sup>
MC with 6.5 cm fiber	66.39 <sup>de</sup>
MC with 3.5 cm fiber	36.14 <sup>e</sup>

$p \leq .05$

Table 11 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn breaking strength of the yarns spun by different methods. It was found that the MH with 6 mm strips produced the highest yarn breaking strength and was statistically different from the others at .05 level.

The breaking strength of the yarn produced by MH with 4 mm bark strips was statistically different from the breaking strength of the yarns produced by the MH with 2 mm strips and the MC with 5 cm fibers, 6.5 cm fibers and 3.5 cm fibers at .05 level.

The breaking strength of the yarns produced by the MH with 2 mm strips was statistically different from the breaking strength of the yarn produced by the MC with 5 cm fibers, 6.5 cm fibers and 3.5 cm fibers at .05 level.

The MC with 5 cm fibers was statistically different from the breaking strength of the yarn produced by the modified cotton spinning methods with 3.5 cm fibers at .05 level.

Moreover, the MC with 6.5 cm fibers and 3.5 cm fibers yielded the lowest yarn breaking strength and were not statistical different at .05 level.

The result showed the difference of the modified spinning methods that the yarns spun by the MH have a higher breaking strength than the MC because the MH produced from the long fiber spinning method whereas the MC that produced from the short fiber spinning method with the result that could be different of breaking strength fabric.

#### 2.4 Yarn elongation

**Table 12** Means of yarn elongation of the paper mulberry yarns produced by different spinning methods.

<b>Yarn Spinning Methods</b>	<b>Yarn Elongation (%)</b>
MH with 2 mm strip	13.33
MH with 4 mm strip	17.07
MH with 6 mm strip	25.36
MC with 3.5 cm fiber	14.05
MC with 5 cm fiber	19.41
MC with 6.5 cm fiber	17.80

Table 12, the data shows that the yarn spun by the MH with 6 mm strips had the highest elongation (25.36%). Followed by the yarn spun by MC with 5 cm fibers (19.41%). Meanwhile, the yarn spun by the MH with 2 mm strips had the lowest elongation (13.33%).

It was interesting that the MH with the 6 mm strips also had the highest count and the highest strength (Table 3 and Table 9).

Different methods showed to produce the yarns with different elongation. Variation analysis of the means yarn elongation revealed that different spinning methods resulted in different yarn elongation at .01 level (Table 13). Therefore, the hypothesis 9.1.4 which stated that the paper mulberry yarns spun by different methods did not have different elongation was rejected.

**Table 13** Variations analysis of the means yarn elongation of the paper mulberry yarns spun by different methods.

Source of Variation	df	SS	MS	F	p
Treatment	5	471.81	94.36	162.36	0.00
Error	24	13.95	0.58		
Total	29	485.76			

**Table 14** The analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn elongation of the paper mulberry yarns spun by different methods.

Yarn Spinning Methods	Yarn Elongation (%)
MH with 6 mm strip	25.36 <sup>a</sup>
MC with 5 cm fiber	19.41 <sup>b</sup>
MC with 6.5 cm fiber	17.80 <sup>c</sup>
MH with 4 mm strip	17.07 <sup>c</sup>
MC with 3.5 cm fiber	14.05 <sup>d</sup>
MH with 2 mm strip	13.33 <sup>d</sup>

$p \leq .05$

Table 14 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of yarn elongation of the yarns spun by different methods. It was found that the MH with 6 mm strips produced the highest yarn elongation and was statistically different from the others at .05 level.

The elongation of the yarn produced by MC with 5 cm fibers was statistically different from the elongation of the yarns produced by the MC with 6.5 cm fibers, the MH with 4 mm strips, the MC with 3.5 cm fibers and the MH with 2 mm strips at .05 level.

The elongation of the yarns produced by the MC with 6.5 cm fibers and the MH with 4 mm strips were statistically different from the elongation of the yarns produced by the MC with 3.5 cm fibers and the MH with 2 mm strips at .05 level.

While the MC with 3.5 cm fibers and the MH with 2 mm strips yielded the lowest yarn elongation and were not statistical different at .05 level.

The yarn spun by the MH with 6 mm strips (the widest strip) consisted of long fibers. That was why it had higher elongation than the yarns produced from the other size strips and the yarn produced from the MC methods.

## 2.5 The conclusion of the yarn characteristics and physical properties

It can be concluded that in terms of characteristics, the modified hemp spinning methods with 2, 4 and 6 mm strips could produce finer and smoother yarns and less fuzzy and uneven than the modified cotton spinning method with 3.5, 5 and 6.5 cm fibers. (Table 15)

In terms of physical properties, the yarn from the MH using 6 mm strips could produce the highest count, highest breaking strength, highest elongation and was statistically different from the others at .05 level. (Table 15)

Therefore, the MH with 6 mm strips seemed to be the best spinning method for paper mulberry fiber.

**Table 15** Characteristics and physical properties of the paper mulberry yarns produced by different spinning methods.

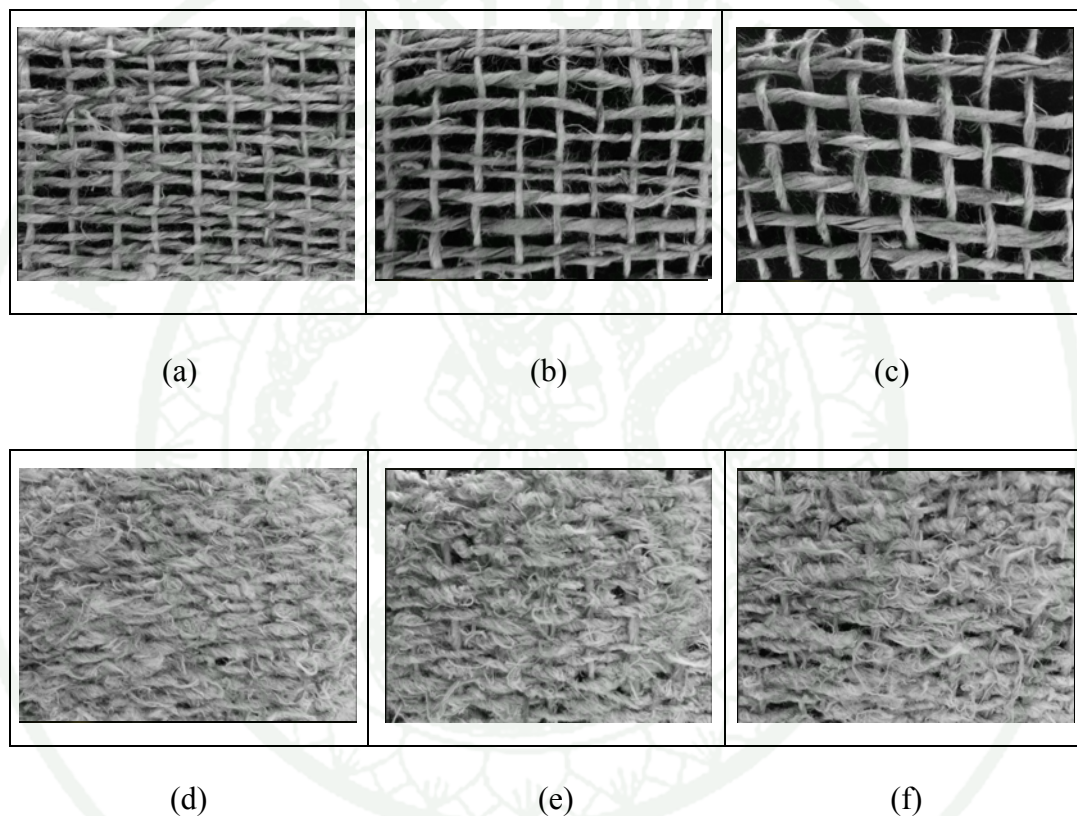
Yarn Spinning Methods	Characteristics		Physical Properties			
	longitudinal section	Evenness	Yarn Count (tex)	Yarn Twist (turns/inch)	Yarn Breaking Strength (cN/tex)	Yarn Elongation (%)
MH with 2 mm strip	Smooth	Uneven (grade C)	963.48 <sup>d</sup>	5.60 <sup>d</sup>	264.22 <sup>c</sup>	13.33 <sup>d</sup>
MH with 4 mm strip	Smooth	Uneven (grade C)	1310.14 <sup>b</sup>	4.60 <sup>d</sup>	352.71 <sup>b</sup>	17.07 <sup>c</sup>
MH with 6 mm strip	Smooth	Uneven (grade C)	1683.88 <sup>a</sup>	5.00 <sup>d</sup>	551.06 <sup>a</sup>	25.36 <sup>a</sup>
MC with 3.5 cm fiber	Fuzzy and rough	Uneven (below grade D)	1271.70 <sup>bc</sup>	10.80 <sup>a</sup>	36.14 <sup>e</sup>	14.05 <sup>d</sup>
MC with 5 cm fiber	Fuzzy and rough	Uneven (below grade D)	1150.68 <sup>c</sup>	9.80 <sup>b</sup>	83.44 <sup>d</sup>	19.41 <sup>b</sup>
MC with 6.5 cm fiber	Fuzzy and rough	Uneven (below grade D)	1022.78 <sup>d</sup>	8.80 <sup>c</sup>	66.39 <sup>de</sup>	17.80 <sup>c</sup>

p ≤ .05

## Characteristics and Physical Properties of the Paper Mulberry Fabrics

### 1. The Characteristics of the Paper Mulberry Woven Fabrics

The characteristics of paper mulberry woven fabric produced from different yarns are shown in Figure 14



**Figure 14** The paper mulberry woven fabrics made from different yarns (a) modified hemp (MH) with 2 mm strips spun yarn, (b) modified hemp (MH) with 4 mm strips spun yarn, (c) modified hemp (MH) with 6 mm strips spun yarn, (d) modified cotton (MC) with 3.5 cm fibers spun yarn, (e) modified cotton (MC) with 5 cm fibers spun yarn and (f) modified cotton (MC) with 6.5 cm fibers spun yarn.

Figure 14 shows characteristics of the paper mulberry woven fabrics made from the yarns obtained from MH (a), (b) and (c) and the yarns obtained from the MC (d), (e) and (f).

It can be seen that the yarn obtained from the MH with 2 mm strips (a) could produce the woven fabric with more density than the others since it was the smallest one. In contrast, the paper mulberry woven fabrics made from the MC spun yarns (d), (e) and (f) were fuzzier and thicker fabrics.

This results of the yarns spun by the MH that could produced from the long fiber with the result that was easily to spun and easily to twist the yarn which cause smooth the yarn. While the MC could produced from the short fiber with the result that the hairiness in yarn.

## 2. Physical Properties of the Paper Mulberry Woven Fabrics

The woven fabrics made from the yarns produced by the six spinning methods were investigated in five aspects: fabric thickness, fabric weight, woven fabric count, fabric strength and elongation, using the ASTM standards. The results are shown as follows:

### 2.1 Fabric thickness

**Table 16** Means of fabric thickness of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Thickness (mm)
MH with 2 mm strip	3.11
MH with 4 mm strip	3.77
MH with 6 mm strip	4.13
MC with 3.5 cm fiber	4.19
MC with 5 cm fiber	3.40
MC with 6.5 cm fiber	2.29

Table 16 shows that the paper mulberry woven fabric made from the yarn obtained from the MC with 3.5 cm fibers had the highest thickness (4.19 mm). Followed by the yarn woven fabric from the spun by the MH with 6 mm strips (4.13 mm). While, the woven fabric made from the yarn obtained from the MC with 6.5 cm fibers was the lowest thickness (2.29 mm).

Therefore, all of paper mulberry woven fabrics were thick fabrics ( $>0.47$  mm thick) (Collier and Epps, 1999).

Different yarns tended to produce fabrics with different thickness. Variation analysis of the means woven fabric thickness (Table 17) revealed that different yarns resulted in different thickness at .01 level. Therefore, the hypothesis 9.2.1 which stated that the paper mulberry woven fabrics made from the yarns spun by different methods did not have different thickness was rejected.

**Table 17** Variations analysis of the means fabric thickness of the paper mulberry woven fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	12.93	2.56	15.86	0.00
Error	24	3.91	0.16		
Total	29	16.84			

**Table 18** The analysis of Least Significant Ranges (LSR) to measure the mean difference of thickness of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Thickness (mm)
MC with 3.5 cm fiber	4.19 <sup>a</sup>
MH with 6 mm strip	4.13 <sup>a</sup>
MH with 4 mm strip	3.77 <sup>b</sup>
MC with 5 cm fiber	3.40 <sup>b</sup>
MH with 2 mm strip	3.11 <sup>c</sup>
MC with 6.5 cm fiber	2.29 <sup>d</sup>

$p \leq .05$

Table 18 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of thickness of the woven fabrics made from different yarns. It was found that the yarn from the MC with 3.5 cm fibers and the yarn from the MH with 6 mm strips produced the highest thickness fabrics and were statistically different from the others at .05 level.

The thicknesses of the woven fabrics made from the yarns spun by the MH with 4 mm strips and the MC with 5 cm fibers were statistically different from the thicknesses of the fabrics made from the yarns spun by the MH with 2 mm strips and the MC with 6.5 cm fibers at .05 level.

Meanwhile, the thicknesses of the woven fabrics made from the yarns spun by the MH with 2 mm strips was statistically different from the thicknesses of the fabric made from the yarns spun by the MC with 6.5 cm strips at .05 level.

## 2.2 Fabric weight

**Table 19** Means of fabric weight of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Weight (g/m <sup>2</sup> )
MH with 2 mm strip	6.34
MH with 4 mm strip	7.00
MH with 6 mm strip	4.52
MC with 3.5 cm fiber	7.67
MC with 5 cm fiber	5.88
MC with 6.5 cm fiber	7.59

Table 19 shows that the woven fabrics made from the yarns spun by the MC with 3.5 cm fibers was the heaviest (7.67 g/m<sup>2</sup>). Followed by the fabric made from the yarn spun by MC with 6.5 cm fibers (7.59 g/m<sup>2</sup>). While, the woven fabrics made from the yarns spun by the MH with 6 mm strips was the lightest (4.52 g/m<sup>2</sup>).

Therefore, the paper mulberry woven fabrics produced were all light weight (<35 g/m<sup>2</sup>) (Collier and Epps, 1999) even though they were classified as thick fabrics.

Different yarns tended to produce fabrics with different weight. Variation analysis of the means woven fabric weight (Table 20) revealed that different yarns resulted in different fabric weight at .01 level. Therefore, the hypothesis 9.2.2 which stated that the paper mulberry woven fabrics made from the yarns spun by different methods did not have different weight was rejected.

**Table 20** Variations analysis of the means fabric weight of the paper mulberry woven fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	35.42	7.08	85.82	0.00
Error	24	1.98	0.08		
Total	29	37.36			

**Table 21** The analysis of Least Significant Ranges (LSR) to measure the mean difference of weight of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Weight (g/m <sup>2</sup> )
MC with 3.5 cm fiber	7.67 <sup>a</sup>
MC with 6.5 cm fiber	7.59 <sup>a</sup>
MH with 4 mm strip	7.00 <sup>b</sup>
MH with 2 mm strip	6.34 <sup>c</sup>
MC with 5 cm fiber	5.88 <sup>d</sup>
MH with 6 mm strip	4.52 <sup>e</sup>

$p \leq .05$

Table 21 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of weight of the woven fabrics produced by different yarns. It was found that the yarns from MC with 3.5 cm fibers and 6.5 cm fibers produced the heaviest fabric and were statistically different from the others at .05 level.

The weight of the woven fabric made from the yarn spun by the MH with 4 mm strips was statistically different from the weight of the fabrics made from the yarns produced by the MH with 2 mm strips, the MC with 5 cm fibers and the MH with 6 mm strips at .05 level.

The weight of the woven fabrics made from the yarn spun by the MH with 2 mm strips was statistically different from the weight of the fabric made from the yarn spun by the MC with 5 cm fibers and the MH with 6 mm strips at .05 level.

Moreover, The woven fabrics weight made from the yarn spun by the MC with 5 cm fibers was statistically different from the weight of the fabric made from the yarn spun by the MH with 6 mm strips at .05 level.

### 2.3 Fabric weft count

**Table 22** Means of fabric weft count of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Woven Fabric Weft Count (yarns/inch)
MH with 2 mm strip	12.20
MH with 4 mm strip	12.20
MH with 6 mm strip	8.80
MC with 3.5 cm fiber	13.60
MC with 5 cm fiber	15.60
MC with 6.5 cm fiber	18.20

Table 22, shows that the woven weft fabric made from the yarn spun by the MC with 6.5 cm fibers has the highest weft count (18.20 yarns/inch). Followed by the fabric made from the yarn spun by the MC with 5 cm fibers (15.60 yarns/inch). While, the woven fabric made from the yarn spun by the MH with 6 mm strips has the lowest weft count (8.80 yarns/inch).

Therefore, the paper mulberry woven fabrics produced low count. Since they had less than  $10 \times 10 - 40 \times 40$  yarns/inch (Collier and Epps, 1999).

Different yarns tended to produce fabrics with different count. Variation analysis of the means woven fabric weft count (Table 23) revealed that different yarns resulted in different fabric weft count at .01 level. Therefore, the hypothesis 9.2.3 which stated that the paper mulberry woven fabrics made from the yarns spun by different methods did not have different weft count was rejected.

**Table 23** Variations analysis of the means fabric weft count of the paper mulberry woven fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	259.77	51.95	107.49	0.00
Error	24	11.60	0.48		
Total	29	271.37			

**Table 24** The analysis of Least Significant Ranges (LSR) to measure the mean difference of count of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Woven Fabric Weft Count (yarns/inch)
MC with 6.5 cm fiber	18.20 <sup>a</sup>
MC with 5 cm fiber	15.60 <sup>b</sup>
MC with 3.5 cm fiber	13.60 <sup>c</sup>
MH with 2 mm strip	12.20 <sup>d</sup>
MH with 4 mm strip	12.20 <sup>d</sup>
MH with 6 mm strip	8.80 <sup>e</sup>

$p \leq .05$

Table 24 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of weft count of the woven fabrics produced by different yarns. It was found that fabric made from the yarns spun by the MC with 6.5 cm fibers had the highest weft count and was statistically different from the others at .05 level.

The weft count of the woven fabric made from the yarn spun by the MC with 5 cm fibers was statistically different from the count of the fabrics made from the yarns spun by the MC with 3.5 cm fibers, the MH with 2 mm strips, 4 mm strips and 6 mm strip at .05 level.

Meanwhile, the weft count of the woven fabrics made from the yarn spun by the MC with 3.5 cm fibers was statistically different from the count of the fabric made from the yarns spun by the MH with 2 mm strips, 4 mm strips and 6 mm strips at .05 level.

Moreover, the weft count of the woven fabrics made from the yarns spun by the MH with 2 mm strips and 4 mm strips were statistically different from the count of the fabric made from the yarn spun by the MH with 6 mm strips at .05 level.

#### 2.4 Fabric strength in warp direction

**Table 25** Means of fabric strength in warp direction of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Strength in Warp Direction (cN/tex)
MH with 2 mm strip	581.51
MH with 4 mm strip	493.53
MH with 6 mm strip	293.32
MC with 3.5 cm fiber	97.82
MC with 5 cm fiber	106.27
MC with 6.5 cm fiber	114.86

Table 25 shows that the woven fabrics made from the yarn spun by the MH with 2 mm strips had the highest strength in warp direction (581.51cN/tex). Followed by the woven fabrics made from the yarn spun by the MH with 4 mm strips (493.53 cN/tex). In contrast, the woven fabrics made from the yarn spun by the MC with 3.5 cm fibers has the lowest strength (97.82 cN/tex).

Different yarns tended to produce fabrics with different strength in warp direction. Variation analysis of the means woven fabric strength in warp direction (Table 26) revealed that different yarns resulted in different strength at .01 level. Therefore, the hypothesis 9.2.4 which stated that the paper mulberry woven fabrics

made from the yarns spun by different methods did not have different strength (warp direction) was rejected.

**Table 26** Variations analysis of the means fabric strength in warp direction of the paper mulberry woven fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	1136561.79	227312.38	13944.36	0.00
Error	24	391.23	16.30		
Total	29	1136953.02			

**Table 27** The analysis of Least Significant Ranges (LSR) to measure the mean difference of strength in warp direction of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Strength in Warp Direction (cN/tex)
MH with 2 mm strip	581.51 <sup>a</sup>
MH with 4 mm strip	493.53 <sup>b</sup>
MH with 6 mm strip	293.32 <sup>c</sup>
MC with 6.5 cm fiber	114.86 <sup>d</sup>
MC with 5 cm fiber	106.27 <sup>e</sup>
MC with 3.5 cm fiber	97.82 <sup>f</sup>

$p \leq .05$

Table 27 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of strength in warp direction of the woven fabrics produced by different yarns. It was found that the yarns spun by the MH with 2 mm strips produced the highest strength fabric and was statistically different from the others at .05 level.

The strength in warp direction of the woven fabric made from the yarn spun by the MH with 4 mm strips was statistically different from these of the fabrics made from the yarns spun by the MH with 6 mm strips and the MC with 6.5 cm fibers, 5 cm fibers and 3.5 cm fibers at .05 level.

The strength in warp direction of the woven fabric made from the yarn spun by the MH with 6 mm strips was statistically different from the strength of the fabrics made from the yarns spun by the MC with 6.5 cm fibers, 5 cm fibers and 3.5 cm fibers at .05 level.

Moreover, the strength in warp direction of the fabric made from the yarn spun by the MC with 6.5 cm fibers was statistically different from these of the fabrics made from the yarns spun by the MC with 5 cm fibers and the MC with 3.5 cm fibers, at .05 level.

Finally, the strength of the fabric made from the yarn spun by the MC with 5 cm fibers was statistically different from the strength of the fabrics made from the yarn spun by the MC with 3.5 cm fibers, at .05 level.

## 2.5 Fabric strength in weft direction

**Table 28** Means of fabric strength in weft direction of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Strength in Weft Direction (cN/tex)
MH with 2 mm strip	125.92
MH with 4 mm strip	204.54
MH with 6 mm strip	158.10
MC with 3.5 cm fiber	95.10
MC with 5 cm fiber	115.82
MC with 6.5 cm fiber	132.35

Table 28 shows that the woven fabric made from the yarn spun by the MH with 4 mm strips had the highest strength in weft direction (204.54 cN/tex), followed by the fabric made from the yarn spun by the MH with 6 mm strips (158.10 cN/tex). Whereas the woven fabric made from the yarn spun by the MC with 3.5 cm fibers had the lowest strength (95.10 cN/tex).

Different yarns tended to produce fabrics with different strength in weft direction. Variation analysis of the means woven fabric strength in weft direction (Table 29) revealed that different yarns resulted in different strength at .01 level. Therefore, the hypothesis 9.2.5 which stated that the paper mulberry woven fabrics made from the yarns spun by different methods did not have different strength in weft direction was rejected.

**Table 29** Variations analysis of the means fabric strength in weft direction of the paper mulberry woven fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	36693.38	7338.68	3129.77	0.00
Error	24	56.28	2.35		
Total	29	36749.66			

**Table 30** The analysis of Least Significant Ranges (LSR) to measure the mean difference of strength in weft direction of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Strength in Weft Direction (cN/tex)
MH with 4 mm strip	204.54 <sup>a</sup>
MH with 6 mm strip	158.10 <sup>b</sup>
MC with 6.5 cm fiber	132.35 <sup>c</sup>
MH with 2 mm strip	125.92 <sup>d</sup>
MC with 5 cm fiber	115.82 <sup>e</sup>
MC with 3.5 cm fiber	95.10 <sup>f</sup>

$p \leq .05$

Table 30 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of strength in weft direction of the woven fabrics produced by different yarns. It was found that the yarns from the MH with 4 mm strips produced the fabric with the highest strength in weft direction and was statistically different from the others at .05 level.

The strength in weft direction of the woven fabric made from the yarn spun by the MH with 6 mm strips was statistically different from the strength of the fabrics made from the yarn spun by the MC with 6.5 cm fibers, the MH with 2 mm strips, the MC with 5 cm fibers and 3.5 cm fibers at .05 level.

The strength in weft direction of the woven fabric made from the yarn spun by the MC with 6.5 cm fibers was statistically different from the strength of the fabrics made from the yarns from the MH with 2 mm strips, the MC with 5 cm fibers and 3.5 cm fibers at .05 level.

The strength in weft direction of the woven fabric made from the yarn spun by the MH with 2 mm strips was statistically different from the strength of the fabrics made from the yarn spun by the modified cotton spinning method with 5 cm fibers and the MC with 3.5 cm fibers, at .05 level.

Moreover, the fabric strength in weft direction of the fabric made from the yarn spun by the MC with 5 cm fibers was statistically different from that of the fabric made from the yarn spun by the MC with 3.5 cm fibers at .05 level.

The strength in weft direction of the fabrics made from the weft yarns that spun by the MH methods were higher because these yarns had higher yarn count than the yarns produced by the MC methods.

## 2.6 Fabric elongation in warp direction

**Table 31** Means of fabric elongation in warp direction of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Elongation in Warp Direction (%)
MH with 2 mm strip	7.36
MH with 4 mm strip	11.03
MH with 6 mm strip	7.54
MC with 3.5 cm fiber	17.63
MC with 5 cm fiber	19.25
MC with 6.5 cm fiber	16.25

Table 31 shows that the woven fabric made from the yarn spun by the MC with 5 cm fibers had the highest elongation in warp direction (19.25%), Followed by the fabric made from the yarn spun by the MC with 3.5 cm strips (17.63 %). Meanwhile the woven fabric made from the yarn spun by the MH with 2 mm strips was the lowest elongation (7.36%).

Different yarns tended to produce fabrics with different elongation in warp direction. Variation analysis of the means woven fabric elongation in warp direction (Table 32) revealed that different yarns resulted in different elongation at .01 level. Therefore, the hypothesis 9.2.6 which stated that the paper mulberry woven fabrics made from the yarns spun by different methods did not have different elongation in warp direction was rejected.

**Table 32** Variations analysis of the means fabric elongation in warp direction of the paper mulberry woven fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	681.82	136.36	590.95	0.00
Error	24	5.54	0.23		
Total	29	687.36			

**Table 33** The analysis of Least Significant Ranges (LSR) to measure the mean difference of elongation in warp direction of the paper mulberry woven fabrics produced by different yarns.

Spinning Method of the Yarn Used	Fabric Elongation in Warp Direction (%)
MC with 5 cm fiber	19.25 <sup>a</sup>
MC with 3.5 cm fiber	17.63 <sup>b</sup>
MC with 6.5 cm fiber	16.25 <sup>c</sup>
MH with 4 mm strip	11.03 <sup>d</sup>
MH with 6 mm strip	7.54 <sup>e</sup>
MH with 2 mm strip	7.36 <sup>e</sup>

$p \leq .05$

Table 33 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of elongation in warp direction of the woven fabrics produced by different yarns. It was found that the yarn spun by the MC with 5 cm fibers produced the fabric with highest elongation in warp direction and was statistically different from the others at .05 level.

The elongation in warp direction of the woven fabric made from the yarn spun by the MC with 3.5 cm fibers was statistically different from these of the fabrics made from the yarns spun by the MC with 6.5 cm fibers, the MH with 4 mm strips, 6 mm strips and 2 mm strips at .05 level.

The elongation in warp direction of the woven fabrics made from the yarn spun by the MC with 6.5 cm yarn was statistically different from these of the fabrics made from the yarns spun by the MH with 4 mm strips, 6 mm strips and 2 mm strips at .05 level.

Moreover, the woven fabrics of elongation in warp direction made from the yarn spun by the MH with 4 mm strips was statistically different from that of the fabrics made from the yarns spun by the MH with 6 mm strips and 2 mm strips at .05 level.

The result showed that the fabrics made from the yarns spun by the MC methods had higher elongation in warp direction than the fabrics made from the yarns spun by the MH methods since the yarns spun by the MC methods had higher twist than the yarns spun by the MH methods, therefore, they could elongate more.

## 2.7 Fabric elongation in weft direction

**Table 34** Means of fabric elongation in weft direction of the paper mulberry woven fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Elongation in Weft Direction (%)
MH with 2 mm strip	6.51
MH with 4 mm strip	10.75
MH with 6 mm strip	9.58
MC with 3.5 cm fiber	7.42
MC with 5 cm fiber	4.93
MC with 6.5 cm fiber	4.35

Table 34 shows that the woven fabrics made from the yarn spun by the MH with 4 mm strips had the highest elongation in weft direction (10.75%). Followed by the fabric made from the yarn spun by the MH with 6 mm strips (9.58 %). While, the woven fabric made from the yarn spun by the MC with 6.5 cm fibers had the lowest elongation (4.35%).

Different yarns tended to produce fabrics with different elongation in weft direction. Variation analysis of the means woven fabric elongation in weft direction (Table 35) revealed that different yarns resulted in different fabric elongation in weft direction at .01 level. Therefore, the hypothesis 9.2.7 which stated that the paper mulberry woven fabrics made from the yarns spun by different methods did not have different elongation in weft direction was rejected.

**Table 35** Variations analysis of the means fabric elongation in weft direction of the paper mulberry woven fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	160.09	32.02	203.45	0.00
Error	24	3.78	0.16		
Total	29	163.87			

**Table 36** The analysis of Least Significant Ranges (LSR) to measure the mean difference of elongation in weft direction of the paper mulberry woven fabrics made from different yarns

Spinning Method of the Yarn Used	Fabric Elongation in Weft Direction (%)
MH with 4 mm strip	10.75 <sup>a</sup>
MH with 6 mm strip	9.58 <sup>b</sup>
MC with 3.5 cm fiber	7.42 <sup>c</sup>
MH with 2 mm strip	6.51 <sup>d</sup>
MC with 5 cm fiber	4.93 <sup>e</sup>
MC with 6.5 cm fiber	4.35 <sup>f</sup>

p ≤ .05

Table 36 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of elongation in weft direction of the woven fabrics produced by different yarns. It was found that the yarn spun by the MH with 4 mm strips produced the fabric with the highest elongation in weft direction which was statistically different from the others at .05 level.

The elongation in weft direction of the woven fabric made from the yarn spun by the MH with 6 mm strips was statistically different from these of the fabrics made from the yarns spun by the MC with 3.5 cm fibers, the MH with 2 mm strips, the MC with 5 cm fibers and 6.5 cm fibers at .05 level.

Meanwhile, the elongation in weft direction of the woven fabrics made from the yarn spun by the MC with 3.5 cm fibers was statistically different from those of the fabrics made from the yarns spun by the MH with 2 mm strips, the MC with 5 cm fibers and 6.5 cm fibers at .05 level.

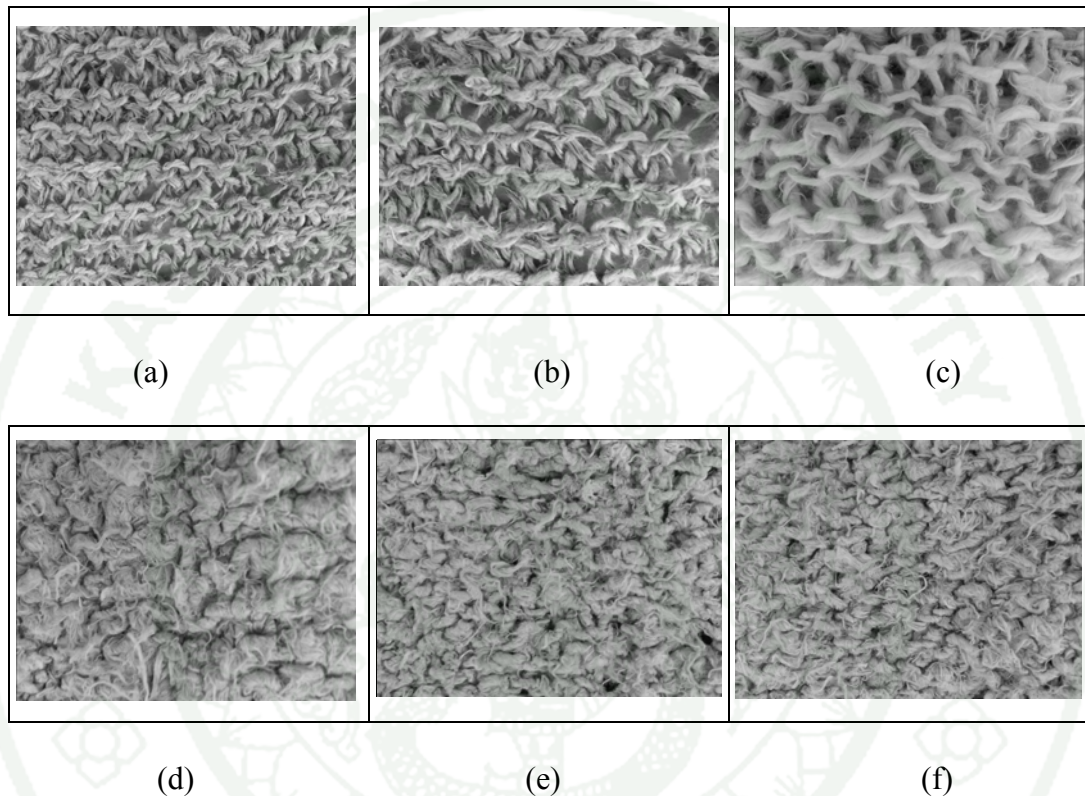
The elongation in weft direction of the woven fabrics made from the yarn spun by the MH with 2 mm strips was statistically different from these of the fabrics made from the yarns spun by the MC with 5 cm fibers and 6.5 cm fibers at .05 level.

Moreover, the woven fabrics of elongation in weft direction made from the yarn spun by the MC with 5 cm fibers was statistically different from that of the fabric made from the yarn spun by the MC with 6.5 cm fibers at .05 level.

It can be concluded that the fabric made from the yarns spun by the MH methods tended to have higher elongation in weft direction than the fabrics made from the yarns produced by the MC methods.

### 3. The Characteristics of the Paper Mulberry Knitted Fabrics

The characteristics of the paper mulberry knitted fabrics made from different yarns are shown in Figure 15.



**Figure 15** The paper mulberry knitted fabrics made from different yarns (a) modified hemp (MH) with 2 mm strip spun yarn, (b) modified hemp (MH) with 4 mm strip spun yarn, (c) modified hemp (MH) with 6 mm strip spun yarn, (d) modified cotton (MC) with 3.5 cm fiber spun yarn, (e) modified cotton (MC) with 5 cm fiber spun yarn and (f) modified cotton (MC) with 6.5 cm fiber spun yarn.

Figure 15 shows characteristics of the paper mulberry knitted fabrics made from different yarns. These found that the yarn from the MH with 2 mm strips could produce the more density knitted fabric (a) than the others. While, the paper mulberry knitted fabrics made from the yarn spun by the MC with 3.5 cm fibers (d) was more rough and fuzzy than the others.

The knitted fabrics made from the yarns spun by the MH (a), (b) and (c) were smoother than the others. Whereas, the knitted fabrics made from the yarns spun by the MC (d), (e) and (f) were more fuzzy than the others. The texture of the knitted fabrics depended on the texture of the yarns.

#### 4. Physical Properties of the Paper Mulberry Knitted Fabrics

The knitted fabrics made from the six different yarns were investigated in three aspects physical properties: fabric thickness, fabric weight and knit fabric count, using the ASTM standards. The results are shown as follows:

##### 4.1 Fabric thickness

**Table 37** Means of fabric thickness of the paper mulberry knitted fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Thickness (mm)
MH with 2 mm strip	2.95
MH with 4 mm strip	3.97
MH with 6 mm strip	4.30
MC with 3.5 cm fiber	5.28
MC with 5 cm fiber	4.61
MC with 6.5 cm fiber	3.68

From table 37, the data shows that the knitted fabric made from the yarn spun by the MC with 3.5 cm fibers had the highest thickness (5.28 mm). Followed by the fabric made from the yarn spun by the MC with 5 cm fibers (4.61 mm). While, the knitted fabric made from the yarn spun by the MH with 2 mm strips had the lowest thickness (2.95 mm).

The knitted fabric made from the yarn of the MC with 3.5 cm fibers had the highest thickness because the yarn used was more fuzzy than the others. Therefore, all of the paper mulberry knitted fabrics produced were thick fabrics (>0.47 mm thick) (Collier and Epps, 1999).

Different yarns tended to produce fabrics with different thickness. Variation analysis of the means knitted fabric thickness (Table 38) revealed that different yarns resulted in different fabric thickness at .01 level. Therefore, the hypothesis 9.3.1 which stated that the paper mulberry knitted fabric made from the yarns spun by different methods did not have different thickness was rejected.

**Table 38** Variations analysis of the means fabric thickness of the paper mulberry knitted fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	18.63	3.73	31.56	0.00
Error	24	2.83	0.12		
Total	29	21.46			

**Table 39** The analysis of Least Significant Ranges (LSR) to measure the mean difference of thickness of the paper mulberry knitted fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Thickness (mm)
MC with 3.5 cm fiber	5.28 <sup>a</sup>
MC with 5 cm fiber	4.61 <sup>b</sup>
MH with 6 mm strip	4.30 <sup>bc</sup>
MH with 4 mm strip	3.97 <sup>cd</sup>
MC with 6.5 cm fiber	3.68 <sup>d</sup>
MH with 2 mm strip	2.95 <sup>e</sup>

$p \leq .05$

Table 39 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of thickness of the knitted fabrics made from different yarns. It was found that the yarn from the MC with 3.5 cm fibers produced the fabric with the highest thickness which was statistically different from the others at .05 level.

The thickness of the knitted fabric made from the yarns spun by the MC with 5 cm fibers was statistically different from the thickness of the fabrics made from the yarns spun by the MH with 4 mm strips, the MC with 6.5 cm fibers and the MH with 2 mm strips at .05 level.

The thickness of the knitted fabric made from the yarn spun by the MH with 6 mm strips was statistically different from the thickness of the fabrics made from the yarns spun by the MC with 6.5 cm fibers and the MH with 2 mm strips at .05 level.

The thickness of the knitted fabric made from the yarn spun by the MH with 4 mm strips was statistically different from the thickness of the fabrics made from the yarns spun by the MH with 2 mm strips at .05 level.

Meanwhile, the thickness of the knitted fabrics made from the yarn spun by the MH with 4 mm strips and the MC with 6.5 cm fibers were statistically different from the thickness of the fabrics made from the yarn spun by the MH with 2 mm strips at .05 level.

#### 4.2 Fabric weight

**Table 40** Means of fabric weight of the paper mulberry knitted fabrics made from different yarns.

Spinning Method of the Yarn Used	Fabric Weight (g/m <sup>2</sup> )
MH with 2 mm strip	9.54
MH with 4 mm strip	10.57
MH with 6 mm strip	10.50
MC with 3.5 cm fiber	12.22
MC with 5 cm fiber	10.81
MC with 6.5 cm fiber	10.81

Table 40 shows that the knitted fabric made from the yarn spun by the MC with 3.5 cm fibers was the heaviest (12.22g/m<sup>2</sup>). Followed by the fabrics made from the yarn spun by MC with 5 cm fibers and 6.5 cm fibers (10.81 g/m<sup>2</sup>). The knitted fabric made from the yarn spun by the MH with 2 mm strips was the lightest (9.54 g/m<sup>2</sup>). Therefore, the paper mulberry fabrics were classified as very light weight fabrics (Collier and Epps,1999).

Different yarns tended to produce fabrics with different weight. Variation analysis of the means knitted fabric weight (Table 41) revealed that different yarns resulted in different fabric weight at .01 level. Therefore, the hypothesis 9.3.2 which stated that the paper mulberry knitted fabrics made from the yarns spun by different methods did not have different weight was rejected.

**Table 41** Variations analysis of the means fabric weight of the paper mulberry knitted fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	18.62	3.72	31.57	0.00
Error	24	2.83	0.12		
Total	29	21.45			

**Table 42** The analysis of Least Significant Ranges (LSR) to measure the mean difference of weight of the paper mulberry knitted fabrics produced by different yarns.

Spinning Method of the Yarn Used	Fabric Weight (g/m <sup>2</sup> )
MC with 3.5 cm fiber	12.22 <sup>a</sup>
MC with 5 cm fiber	10.81 <sup>b</sup>
MC with 6.5 cm fiber	10.81 <sup>b</sup>
MH with 4 mm strip	10.57 <sup>b</sup>
MH with 6 mm strip	10.50 <sup>b</sup>
MH with 2 mm strip	9.54 <sup>c</sup>

p ≤ .05

Table 42 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of weight of the knitted fabrics made from different yarns. It was found that the yarn from the MC with 3.5 cm fibers produced the fabric with the highest thickness which was statistically different from the others at .05 level.

The weight of the knitted fabrics made from the yarns spun by the MC with 5 cm fibers, 6.5 cm fibers, the MH with 4 mm strips and 6 mm strips were statistically different from the weight of the fabric made from the yarn spun by the MH with 2 mm strips at .05 level.

The result showed that the heavier fabric was those made from the yarns spun by the MC methods. This might be because the yarns produced from the MC methods had more density of fibers than the yarns spun by the MH methods, therefore, resulting higher weight fabrics.

#### 4.3 Fabric count: course/inch

**Table 43** Means of fabric count (course/inch) of the paper mulberry knitted fabrics made from different yarns.

Spinning Method of the Yarn Used	Knitted Fabric Count (Course/inch)
MH with 2 mm strip	4.00
MH with 4 mm strip	4.20
MH with 6 mm strip	3.00
MC with 3.5 cm fiber	5.00
MC with 5 cm fiber	4.40
MC with 6.5 cm fiber	5.00

Table 43 shows that the knitted fabric made from the yarns spun by the MC with 3.5 cm fibers and 6.5 cm fibers had the highest count (5.00 course/inch). Followed by the fabric made from the yarn spun by MC with 5 cm fibers (4.40 course/inch). While, the knitted fabric made from the yarn spun by the MH with 6 mm strips had the lowest count (3.00 course/inch). Therefore, the paper mulberry fabrics could be classified as low count fabric.

Different yarns tended to produce fabrics with different fabric count (course). Variation analysis of the means knitted fabric count (course) (Table 44) revealed that different yarns resulted in different count at .01 level. Therefore, the hypothesis 9.3.3 which stated that the paper mulberry knitted fabrics made from the yarns spun by different methods did not have different count (course) was rejected.

**Table 44** Variations analysis of the means fabric count (course/inch) of the paper mulberry knitted fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	13.87	2.77	33.28	0.00
Error	24	2.00	0.08		
Total	29	15.87			

**Table 45** The analysis of Least Significant Ranges (LSR) to measure the mean difference of fabric count (course/inch) of the paper mulberry knitted fabrics produced by different yarns.

Spinning Method of the Yarn Used	Knitted Fabric Count (Course/inch)
MC with 3.5 cm fiber	5.00 <sup>a</sup>
MC with 6.5 cm fiber	5.00 <sup>a</sup>
MC with 5 cm fiber	4.40 <sup>b</sup>
MH with 4 mm strip	4.20 <sup>bc</sup>
MH with 2 mm strip	4.00 <sup>c</sup>
MH with 6 mm strip	3.00 <sup>d</sup>

$p \leq .05$

Table 45 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of count (course/inch) of the knitted fabrics made from different yarns. It was found that the yarn from the MC with 3.5 cm fibers and 6.5 cm fibers produced the fabrics with the highest count and were statistically different from the others at .05 level.

The count (course/inch) of the knitted fabric made from the yarns spun by the MC with 5 cm fibers and the MH with 4 mm strips were statistically different from the count of the fabrics made from the yarn spun by the MH with 2 mm strips and 6 mm strips at .05 level.

Meanwhile, the count of the knitted fabrics made from the yarns spun by the MH with 4 mm strips and 2 mm strips were statistically different from the count of the fabric made from the yarn spun by the MH with 6 mm strips at .05 level.

## 4.4 Fabric count : wale/inch

**Table 46** Means of fabric count (wale/inch) of the paper mulberry knitted fabrics made from different yarns.

Spinning Method of the Yarn Used	Knitted Fabric Count (Wale/inch)
MH with 2 mm strip	6.40
MH with 4 mm strip	5.00
MH with 6 mm strip	5.00
MC with 3.5 cm fiber	4.00
MC with 5 cm fiber	4.80
MC with 6.5 cm fiber	5.00

Table 46 shows that the knitted fabric made from the yarn spun by MH with 2 mm strips had the highest count (6.40 wale/inch), Followed by the fabrics made from the yarn spun by the MH with 4 mm strips and 6 mm strips and the MC with 6.5 cm fibers (5.0 wale/inch). Whereas, the knitted fabric made from the yarn spun by the MC with 3.5 cm fibers had the lowest count (4.00 wale/inch). Therefore, the paper mulberry fabrics produced could be classified as low count fabric.

Different yarns tended to produce fabrics with different count (wale/inch). Variation analysis of the means knitted fabric count (wale/inch) (Table 47) revealed that different yarns resulted in different count at .01 level. Therefore, the hypothesis 9.3.4 which stated that the paper mulberry knitted fabrics made from the yarns spun by different methods did not have different count (wale/inch) was rejected.

**Table 47** Variations analysis of the means fabric count (wale/inch) of the paper mulberry knitted fabrics made from different yarns.

Source of Variation	df	SS	MS	F	p
Treatment	5	14.97	2.99	17.96	0.00
Error	24	4.00	0.17		
Total	29	18.97			

**Table 48** The analysis of Least Significant Ranges (LSR) to measure the mean difference of count (wale/inch) of the paper mulberry knitted fabrics made from different yarns.

Spinning Method of the Yarn Used	Knitted Fabric Count (Wale /inch)
MH with 2 mm strip	6.40 <sup>a</sup>
MH with 4 mm strip	5.00 <sup>b</sup>
MH with 6 mm strip	5.00 <sup>b</sup>
MC with 6.5 cm fiber	5.00 <sup>b</sup>
MC with 5 cm fiber	4.80 <sup>b</sup>
MC with 3.5 cm fiber	4.00 <sup>c</sup>

$p \leq .05$

Table 48 shows the result of analysis of Least Significant Ranges (LSR) to measure the mean difference of count (wale/inch) of the knitted fabrics made from different yarns. It was found that the yarn from the MH with 2 mm strips produced the fabric with the highest count and was statistically different from the others at .05 level.

The count (wale/inch) of the knitted fabrics made from the yarns spun by the MH with 4 mm strips and 6 mm strips, the MC with 6.5 cm fibers and 5 cm fibers were statistically different from the count of the fabric made from the yarn spun by the MC with 3.5 cm fibers at .05 level.



## CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

The objectives of this research were to determine the characteristics and physical properties of paper mulberry fiber, to develop the spinning processes for paper mulberry yarn, to determine the characteristics and physical properties of the paper mulberry yarns and to experimentally produce the paper mulberry fabrics by weaving and knitting and determine the characteristics and physical properties of the paper mulberry fabric produced. The research findings from the experiments can be concluded as follows:

#### 1. The characteristics and physical properties of paper mulberry fiber

It was found that the cross-sectional image of the fiber showed clusters of fibers with an average diameter of 10 micrometers for each of the fibers. The fiber had rounded corners with lumen in the middle. The fiber had an uneven texture and a node that appears on the fiber periodically. It was considerably close to hemp fiber and was a smaller diameter when compared to jute fiber.

The tests of physical properties of the paper mulberry fiber indicated that the fiber length, the density, the moisture content, the tenacity, and the elongation of the single fiber were less than those of the bundle fiber. The paper mulberry single fiber length was classified as a short fiber (10.20 mm) while the bundle fiber was classified as an extra long fiber (42.27 mm). The density of the paper mulberry single fiber was 0.95 tex whereas that of the bundle fiber was 13.04 tex. These could be generally classified as natural sources similar to the other fibers. The moisture content of the paper mulberry single fiber was 8.14% and that of the bundle fiber was 10.66%, whereas the tenacity of the paper mulberry single fiber was 4.85 cN/tex and that of the bundle fiber was 15.90 cN/tex. Moreover, The elongation of the paper mulberry single fiber was 4.50% and that of the bundle fiber was 11.21%.

## **2. The paper mulberry yarn spinning methods**

The two hand spinning methods were developed as follows:

2.1 The modified hemp spinning method: This was developed from the hemp spinning method mainly used in Northern Thailand. The process consisted of four steps: pounding, joining strips of inner bark, hand spinning to make continuous yarn and boiling the yarn.

2.2 The modified cotton spinning method: This method modified from the technique originated in the cotton spinning method widely used in the Northeast of Thailand. The process consisted of three steps: opening the fibers, rolling the fibers into a short strand of fibers, and stretching and spinning to form a yarn.

The two spinning methods were tested using 2, 4, and 6 mm strips for the modified hemp spinning method and 3.5, 5, and 6.5 cm fibers for the modified cotton spinning method. The analysis of the yield of the paper mulberry yarns from different spinning methods showed that in terms of yarn length the modified hemp spinning method using 2 mm bark strips could produce the longest yarn (978 meters), whereas, in terms of weight, the modified hemp spinning method using 6 mm strips could produce the highest weight of yarn (975 grams). This method also had the least waste (25 grams).

## **3. The characteristics and physical properties of the paper mulberry yarns**

It was found that the modified hemp spinning methods could produce much smoother yarns than the modified cotton spinning methods. The finest yarn was produced from the modified hemp spinning method using 2 mm strips. In contrast, the yarns produced from the modified cotton spinning methods were more fuzzy and rough. In terms of yarn evenness, it was found that that the paper mulberry yarns spun by the modified hemp spinning method were bumpy and uneven in texture, and could be categorized at grade C level. Whereas, the modified cotton spinning methods could

produce more bumpy and uneven texture yarns; as a result, they were categorized at below grade D level.

Concerning the physical properties of the paper mulberry yarns, it was found that the yarn spun by the modified hemp spinning method with 6 mm strips had the highest count (1683.88 tex). Meanwhile, the yarns spun by the modified hemp spinning method with 2 mm strips had the lowest count (963.48 tex). All the paper mulberry yarns produced were heavy in size. The yarns spun by different methods statistically had different counts at .01 level.

In terms of yarn twist, it was found that the yarn spun by the modified cotton spinning method with 3.5 cm fibers had the highest yarn twist (10.80 turn/inch). In contrast, the yarn spun with the modified hemp spinning method with 4 mm strips had the lowest yarn twist (4.60 turn/inch). All the yarns produced were low twist ones. The paper mulberry yarns spun by different methods statistically had different twist at .01 level.

In terms of yarn breaking strength, it was found that the paper mulberry yarn spun by the modified hemp spinning method with 6 mm strips had the highest breaking strength (551.06 cN/tex), whereas the paper mulberry yarn spun by the modified cotton spinning method with 3.5 cm fibers had the lowest breaking strength (36.14 cN/tex). The paper mulberry yarns spun by different methods statistically had different breaking strength at .01 level.

In terms of yarn elongation, it was found that the yarn spun by the modified hemp spinning method with 6 mm strips had the highest elongation (25.36%). Meanwhile, the yarn spun by the modified hemp spinning method with 2 mm strips had the lowest elongation (13.33%). The paper mulberry yarns spun by different methods statistically had different elongation at .01 level.

#### 4. The characteristics and physical properties of the paper mulberry fabrics

##### 4.1 The characteristics and physical properties of the paper mulberry woven fabrics

Concerning the characteristics of the paper mulberry woven fabrics, it was found that the woven fabric made from the yarn spun by the modified hemp spinning method with 2 mm strips had more density than the others. The paper mulberry woven fabrics made from the yarn spun by the modified cotton spinning methods were fuzzier and thicker than others.

In terms of fabric thickness, it was found that the paper mulberry woven fabric made from the yarn spun by the modified cotton spinning method with 3.5 cm fibers had the highest thickness (4.19 mm) while the woven fabric made from the yarn spun by the modified cotton spinning method with 6.5 cm fibers had the lowest thickness (2.29 mm). The paper mulberry woven fabrics made from the yarns spun by different methods statistically had different thickness at .01 level.

In terms of fabric weight, it was found that the paper mulberry woven fabrics made from the yarn spun by the modified cotton spinning method with 3.5 cm fibers had the heaviest weight (7.67 g/m<sup>2</sup>). While, the paper mulberry woven fabric made from the yarn spun by the modified hemp spinning method with 6 mm strips had the lightest weight (4.52 g/m<sup>2</sup>). The paper mulberry woven fabrics made from the yarns spun by different methods statistically had different weight at .01 level.

In terms of fabric weft count, it was found that the paper mulberry woven fabric made from the yarn spun by the modified cotton spinning method with 6.5 cm fibers had the highest weft count (18.20 yarns/inch), whereas, the paper mulberry woven fabric made from the yarn spun by the modified hemp spinning method with 6 mm strips had the lowest weft count (8.80 yarns/inch). The paper mulberry woven fabrics made from the yarns spun by different methods statistically had different weft count at .01 level.

In terms of fabric strength, it was found that the paper mulberry woven fabric made from the yarn spun by the modified hemp spinning method with 2 mm strips had the highest strength in warp direction (581.51cN/tex). In contrast, the paper mulberry woven fabric made from the yarn spun by the modified cotton spinning method with 3.5 cm fibers had the lowest strength in warp direction (97.82 cN/tex). The paper mulberry woven fabrics made from the yarns spun by different methods statistically had different strength in warp direction at .01 level. The paper mulberry woven fabric made from the yarn spun by the modified hemp spinning method with 4 mm strips had the highest strength in weft direction (204.54 cN/tex), whereas the paper mulberry woven fabric made from the yarn spun by the modified cotton spinning method with 3.5 cm fibers had the lowest strength in weft direction (95.10 cN/tex). The paper mulberry woven fabrics made from the yarns spun by different methods statistically had different strength in weft direction at .01 level.

In terms of fabric elongation, it was found that the paper mulberry woven fabric made from the yarn spun by the modified cotton spinning method with 5 cm fibers had the highest elongation in warp direction (19.25%), meanwhile the paper mulberry woven fabric made from the yarn spun by the modified hemp spinning method with 2 mm. strips had the lowest elongation in warp direction (7.36%). The paper mulberry woven fabrics made from the yarns spun by different methods statistically had different elongation in warp direction at .01 level. It was also found that the paper mulberry woven fabric made from the yarn spun by the modified hemp spinning method with 4 mm strips had the highest elongation in weft direction (10.75%) while the paper mulberry woven fabric made from the yarn spun by the modified cotton spinning method with 6.5 cm fibers had the lowest elongation in weft direction (4.35%). The paper mulberry woven fabrics made from the yarns spun by different methods statistically had different elongation in weft direction at .01 level.

#### 4.2 The characteristics and physical properties of the paper mulberry knitted fabrics

Concerning the characteristics of the paper mulberry knitted fabrics, it was found that the knitted fabric made from the yarn spun by the modified hemp spinning method with 2 mm strips had more density than the others. On the other hand, the paper mulberry knitted fabrics made from the yarn spun by the modified cotton spinning method with 3.5 cm fibers was more rough and fuzzy than the others.

In terms of fabric thickness, it was found that the paper mulberry knitted fabric made from the yarn spun by the modified cotton spinning method with 3.5 cm fibers had the highest thickness (5.28 mm) while the paper mulberry knitted fabric made from the yarn spun by the modified hemp spinning method with 2 mm strips had the lowest thickness (2.95 mm). All of the paper mulberry knitted fabrics produced were thick fabrics. The paper mulberry knitted fabrics made from the yarns spun by different methods statistically had different thickness at .01 level.

In terms of fabric weight, it was found that the paper mulberry knitted fabric made from the yarn spun by the modified cotton spinning method with 3.5 cm fibers was the heaviest ( $12.22\text{g/m}^2$ ) and the paper mulberry knitted fabric made from the yarn spun by the modified hemp spinning method with 2 mm strips was the lightest ( $9.54\text{g/m}^2$ ). The paper mulberry knitted fabrics made from the yarns spun by different methods statistically had different weight at .01 level.

In terms of fabric count, it was found that the paper mulberry knitted fabric made from the yarns spun by the modified cotton spinning method with 3.5 cm fibers and the modified cotton spinning method with 6.5 cm. fibers had the highest course count (5.00 course/inch). On the other hand, the paper mulberry knitted fabric made from the yarn spun by the modified hemp spinning method with 6 mm strips had the lowest course count (3.00 course/inch). The paper mulberry knitted fabrics made from the yarns spun by different methods statistically had different count (course/inch) at .01 level. It was also found that the paper mulberry knitted fabric

made from the yarn spun by the modified hemp spinning method with 2 mm strips had the highest wale count (6.40 wale/inch) while the paper mulberry knitted fabric made from the yarn spun by the modified cotton spinning method with 3.5 cm fibers had the lowest wale count (4.00 wale/inch).

## **Recommendations**

### **1. General Recommendations**

1.1 The highlight of this research: it was found that the paper mulberry fiber could be spun into yarns and the yarns could be used to produce fabrics. Therefore it should be further developed as a natural fiber for the Thai textile industry.

1.2 In terms of yarn evenness, It was found that the modified hemp spinning methods could produce much smoother yarns. Therefore, these yarns could also produce smoother fabrics. In contrast, the fuzzy fabrics could be produced from the yarns spun by the modified cotton spinning methods, which were more fuzzy and rough.

1.3 In terms of yarn breaking strength, it was found that the paper mulberry yarns spun by the modified hemp spinning methods had high breaking strength. Therefore, those yarns can be used for technical textile and geo textile such as covering fabrics. On the other hand, the paper mulberry yarns spun by the modified cotton spinning methods had low breaking strength, therefore they should be used for home textiles.

1.4 In terms of yarn elongation, it was found that the yarns spun by the modified hemp spinning methods had high elongation. Therefore they should be used for technical textiles such as interior decoration and furniture fabrics.

1.5 The characteristics of the paper mulberry woven fabrics made from the yarns spun by the modified hemp spinning methods had more density and smoothness. Therefore these should be used for geo textile products.

1.6 The paper mulberry woven fabrics made from the yarns spun by the modified cotton spinning methods were fuzzy and thick. Therefore these should be used for aesthetic fabric products such as furniture.

1.7 In terms of fabric strength, it was found that the paper mulberry woven fabric made from the yarns spun by the modified hemp spinning methods had high strength. Therefore these will be useful for outerwear or upholstery applications.

1.8 The characteristics of the paper mulberry knitted fabrics made from the yarns spun by the modified hemp spinning methods had more density. Therefore, these fabrics could also produce high density products. In contrast, the rough and fuzzy fabrics could be produced from the yarns spun by the modified cotton spinning methods, which were more rough and fuzzy.

1.9 In terms of fabric weight, it was found that the paper mulberry knitted fabric made from the yarns spun by the modified cotton spinning methods had heavy weight. Therefore they would be useful for use in household furnishing.

## **2. Recommendations for further study**

2.1 In this research, it was found that the paper mulberry fibers could be spun into yarns by hand spinning methods. Therefore, in a further study, yarn spinning should be experimented with a spinning machine used in the textile industry.

2.2 In the hemp spinning method 2, 4, and 6 mm strips were used. In a further study, it would be interesting to use smaller than 2 mm strips or strips larger than 6 mm.

2.3 In terms of weaving fabrics, it was found that the paper mulberry fabric could be produced by hand loom. Therefore, in a further study, it would be interesting to try a weaving machine in the textile industry.

2.4 In terms of knitted fabrics, it was found that the paper mulberry fabric could be produced by hand knitting. Therefore, in a further study, it would be interesting to try a knitting machine or other hand knitting method such as caroché.

2.5 This research focused on the characteristics and physical properties of the fiber, the yarns, the woven fabrics and the knitted fabrics produced. In a further study, it would be interesting to study the consumers preference of the paper mulberry woven fabrics and the knitted fabrics.

2.6 In further research, other properties of paper mulberry fiber, yarns, and fabrics should be studied. These include dyeing properties and fabric produced by hand.

2.7 This research the materials used for this study were inner bark paper mulberry between 6 to 12 months old. In a further study, it would be interesting to study the younger paper mulberry than this research.

2.8 In this research, woven and knitted fabrics were experimentally produced. In a further study another type of fabric especially nonwoven should be produced.

## LITERATURE CITED

- Alam, S. and G.M. Arifuzzaman. 2007. Chemical Analysis of Okra Bast Fiber (Abelmoschus esculentus) and Its Physico-chemical Properties. **Journal of Textile and Apparel, Technology and Management** 5: 1-9.
- Anapanurak, W. and B. Puangsin. n.d. **Paper Mulberry Pulp Properties by Various Alkaline Processes**. The Research Project for Higher Utilization of Forestry and Agricultural Plant Materials in Thailand (HUFA), Kasetsart Agricultural and Agro-industrial Product Improvement Institute (KAPI), Kasetsart University, Bangkok, Thailand.
- ASTM International. 2005. Standard Test Methods for Testing and Materials. **ASTM Standards Book of Standard** vol. 07.01 (2005): D 76-D 4391.
- Booth, J.E. 1964. **Principles of Textile Testing**. 2<sup>nd</sup> ed. Heywood book Temple Press Books Ltd., London, England.
- Choi, J., Y.Chung, D. KyuShikLee, and J. WoonLee. 2012. Effect of radiation non disinfection and mechanical properties of Korean traditional paper, Hanji. **Radiation Physics and Chemistry** 81: 1051–1054.
- Collier, B.J. and H.H. Epps. 1999. **Textile Testing and Analysis**. Merrill, an imprint of Prentice Hall, Inc., New Jersey, U.S.A.
- \_\_\_\_\_. and P.G. Tortora. 2001. **Understanding Textiles**. 6<sup>th</sup> ed. Prentice-Hall, Inc., New Jersey, U.S.A.
- \_\_\_\_\_, M.J. Bide and P.G. Tortora. 2009. **Understanding Textiles**. 7<sup>th</sup> ed. Pearson Education, Inc., New Jersey, U.S.A.
- Cong, X., H. Wen and Z. Riu. 2006. The Wood Characteristic and Pulping Performance of Plantation Paper Mulberry. **China Pulp & Paper** 09: 1.

- Crowfoot, E., F. Pritchard and K. Staniland. 2004. **Textiles and Clothing**. The boydell Press., London, England.
- Diamond, J. and E. Diamond. 2007. **Fashion Apparel, Accessories, Home Furnishings**. Pearson Education, Inc., New Jersey, U.S.A.
- Elsasser, V.H. 2005. **Textiles Concepts and Principles**. 2<sup>nd</sup> ed. Fairchild publications, Inc., New York, U.S.A.
- Franklin, G.L. 1937. **The preparation of material for maceration**. Tropical Woods. Forest Products Research. No. 40.
- Franck, R.R. 2005. **Bast and other plant fibers**. Woodhead Publishing Ltd., Cambridg, U.S.A.
- Frings, G.S. 1999. **Fashion from Concept to Consumer**. 6<sup>th</sup> ed. Prentice-Hall, Inc., New Jersey, U.S.A.
- Gillow, J. and B. Sentence. 1999. **World Textiles A Visual Guide to Traditional Techniques**. Thames & Hudson Ltd., London, England.
- Gong, R.H. and R.M. Wright. 2002. **Fancy yarns Their manufacture and application**. Woodhead Publishing Ltd and CRC Press LLC., Cambridge, England.
- Goswami, B.C., J.G. Martindale and F.L. Scardino. 1997. **Textile Yarns Technology, Structure, and Applications**. A Wilay-Interscience Publication John Wiley & Sons, Inc., Canada.
- Hearle, J.W.S., L. Hollick and D.K. Wilson. 2001. **Yarn texturing technology**. Woodhead Publishing Ltd., and CRC Press LLC, Cambridge, England.

- Hemachandra, E. 2010. **Fundamentals of Textiles Fiber**. CRC Press LLC.  
Boca Raton, U.S.A.
- Ingamells, W. 1993. **Colour for textiles A user's handbook**. Society of Dyers  
and Colourists. West Yorkshire, England.
- Lawrence, C.A. 2003. **Fundamentals of Spun Yarn Technology**. CRC Press LLC.  
Boca Raton, U.S.A.
- Lei, J., L. Sheng, K. YANG, Z. Yi and Z. Chun. 2007. Analyses on Chemical  
Composition Fiber Morphology and Pulping Properties of *Broussonetia*  
*papyrifera* Bark Produced in Dry-hot Valley of the Jinshajiang River.  
**Journal of Southwest Forestry College** 03: 15.
- Liu , L., J. Cao, J. Huang, Y. Cai, J. Yao. 2010. Extraction of pectins with different  
degrees of esterification from mulberry branch bark. **Bioresource**  
**Technology** 101: 3268–3273.
- Lord, P.R. 2003. **Handbook of Yarn Production Technology, Science and**  
**Economics**. Woodhead Publishing Ltd and CRC Press LLC., Cambridge,  
U.S.A.
- Memon, A., S. Ithisoponakula, S. Pramoonmak, M. lawsuriyontab, D. Leenoic and  
N. Passadeed. 2011. A Development of Laminating Mulberry Paper by  
Biodegradable Films. **Energy Procedia** 9: 598 – 604.
- Min, N., G. Hui and Z. Li-ping. 2007. Fiber Morphology, Chemical Compositions  
and Pulping Properties of Xylem in *Broussonetia papyrifera*. **Nonwood**  
**Forest Research** 04: 12.

- Mongkolsuk, Y., B. Thaiutsa, L. Puangchit and M.Tanasombat. 2004. Development of Cleaner Technology for Pulping and Paper Making of Paper Mulberry, pp. 103-116. **In Proceeding of the 42<sup>nd</sup> Kasetsart University Annual conference.** 3-6 February 2004, Kasetsart University, Bangkok, Thailand.
- Morton, W.E. and J.W.S. Hearle. 2008. **Physical Properties of Textile Fibers.** 4<sup>th</sup> ed. Woodhead Publishing Ltd., and CRC press LLC. Florida, U.S.A.
- Muir, A.D. and N.D. Westcott. 2003. **Flax The genus *Linum*.** Taylor & Francis. London, England.
- Nagano,G. and N. Hiroi. 2005. **Base to Tip: Bast-Fiber Weaving in Japan and Its Neighboring Countries.** Shikosha Publishing Co., Ltd., Kyoto, Japan.
- Park, J. and J. Shore. 2004. **Practical Dyeing.** Society of Dyers and Colourists. West Yorkshire, England.
- Punsuvon, V. 2000. Comparison of Chemical Components in Different Grades of Paper Mulberry Bark, pp. 21- 26. **In Proceeding of the 38<sup>th</sup> Kasetsart University Annual conference,** 1- 4 February 2000, Kasetsart University, Bangkok Thailand.
- \_\_\_\_\_. and Y.Kobayashi. n.d. **The Research Project for Higher Utilization of Forestry and Agricultural Plant Materials in Thailand (HUFA).** Kasetsart Agricultural and Agro-industrial Product Improvement Institute (KAPI), Kasetsart University, Bangkok, Thailand.
- Reddy, J. P. and J.-W. Rhim. 2014. Characterization of bionanocomposite films prepared with agar and paper-mulberry pulp nanocellulose . **Carbohydrate Polymers** 110: 480 - 488.

- Rongji, L. , J. Fei , Y. Cai , Y. Li , J. Feng and J.Yao. 2009. Cellulose whiskers extracted from mulberry: A novel biomass production. **Carbohydrate Polymers**. 76: 94 - 99.
- Sato Duarte, A.Y., R. Santiago de Queiroz., R.A. Sanches., C.R. Garcia and F.G. Dedini. 2012. Ethnobotany of Natural Fiber-*Bactric setosa* (tucum) in a Traditional Rural Community. **Fibers & Textiles in Eastern Europe** (91): 18 - 20.
- Saville, B.P. 1999. **Physical testing of textiles**. Woodhead Publishing Ltd., Cambridge, England.
- Spencer, D.J. 2001. **Knitting Technology**. 3<sup>rd</sup> ed. Woodhead Publishing Ltd., Cambridge, England.
- Sittidilokratna, C., S.Suthirawut, L.Chitradon, V. Punsuvon, P. Vaithanomsat and P. Siriacha. 2007. Screening of Pectinase Producing Bacteria and Their Efficiency in Biopulping of Paper Mulberry Bark. **Science Asia** (33):131-135.
- Tajima, M., B. Thaiutsa, L. Puwangchit, S. Thammincha, M. Tanasombat, P. Suekaew and M. Sommeechai. 2001. Growth and Allometry of of Thai Paper Mulberry (*Broussonetia papyrifera*) and Japanese Kozo (*B. kazinoki*) Grown in 8 Provinces in Thailand, pp. 9. **In Proceeding of the International Symposium on Paper Mulberry and Handmade Paper for Rural Development**. 19-24 March 2001, Kasetsart Agricultural and Agro-industrial Product Improvement Institute (KAPI), Kasetsart University, Bangkok, Thailand.
- Takasaki, M., R. Ogura., H. Morikawa, S.Chino and H.Tsuiki. 2011. Preparation and Properties of Paper Yarn from Mulberry. **Advanced Materials Research** 20 (175-176): 575-579.

- Taylor, M.A. 1997. **Technology of Textile Properties**. 3<sup>rd</sup> ed. Forbes Publications Ltd., London, England.
- Thailand Textile Institute. 2011. **Thai Textile Statistics 2011-2012**. Thti Research Press, Thailand.
- Thammincha, S. 2001. **Proceeding of the International Symposium on Paper Mulberry & Handmade Papers for Rural Development**. Bangkok, Thailand.
- Ujjin, S., S. Niyom, S. Supawadee, S. Prisnar and V. Haruthaithanasan. 2000a. Postharvest Technology of Paper Mulberry Bark, pp. 33. *In Proceeding of the 38<sup>th</sup> Kasetsart University Annual conference*, 1-4 February 2000, Kasetsart University, Bangkok Thailand.
- \_\_\_\_\_, S. Samakprakone, P. Siriacha, Y. Mongkolsuk and V. Haruthaithanasan. 2000b. Fiber Characteristic of Paper Mulberry from Various Clones, pp. 27-38. *In Proceeding of the 38<sup>th</sup> Kasetsart University Annual conference*, 1-4 February 2000, Kasetsart University, Bangkok Thailand.
- Whistler, W.A. and C.R. Elevitch. 2006. **Paper mulberry**. Available Source: [www.traditionaltree.org](http://www.traditionaltree.org), April 03, 2007.
- Wilson, J. 2001. **Handbook of Textile Design, Principles Processes and Practice**. Woodhead Publishing Ltd., Cambridge, England.

## CURRICULUM VITAE

**NAME** : Ms. Sakorn Chonsakorn

**BIRTH DATE** : December 24, 1967

**BIRTH PLACE** : Nakhon Si thammarat, Thailand

<b>EDUCATION</b>	<b>: <u>YEAR</u></b>	<b><u>INSTITUTE</u></b>	<b><u>DEGREE/DIPLOMA</u></b>
	1990	Rajamangala Institute	Bachelor of Home Economics
	1999	Kasetsart University	Master of Home Economics

**POSITION/TITLE** : Assistant Professor

**WORK PLACE** : Faculty of Home Economics Technology,  
Rajamangala University of Technology Thanyaburi

**SCHOLARSHIP/ AWARDS** : Thai Government Scholarship 2005-2014

