CHARACTERISTICS OF TREATED BAMBOO/COTTON BLEND YARN PRODUCED FROM RING AND ROTOR SPINNING TECHNIQUES

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DEDICATION

To my beloved parents, Nor Anuwar and Nik Aida Musnie. I am forever grateful for your endless encouragement, motivation, love, care, and prayers. Without you, I would not have achieved my goals. To my lecturers, thank you for your invaluable guidance and support throughout this journey. To my friends, thank you for making this journey memorable with your friendship. I thank all of you from the bottom of my heart for your unwavering support and best wishes.

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ABSTRACT

Natural bamboo fibres are coarse and stiff, requiring chemical treatment to reduce their high chemical composition and enhance their textile application, where fine and soft fibres are greatly valued. Cotton fibres are widely used in textile manufacturing due to their comfort and durability. However, the deficiency lies in unsustainable cultivation practices. The blending of bamboo and cotton fibre is beneficial as it combines the desirable qualities of both fibres and producing more environmentally friendly textile products. Three types of treatment were studied to investigate the characteristics of bamboo fibres treated under various chemical treatment conditions. The first type of treatment investigated the effects of varying NaOH concentrations and soaking times. The second type of treatment examined the effects of different NaOH concentrations with constant soaking time and addition of softening treatment. Finally, the third type of treatment studied the effect of constant NaOH concentration with further chemical treatment on bamboo fibre. To examine the morphology of fibre, sliver, and yarn, scanning electron microscope (SEM) was used. The process of making 50:50 treated bamboo/cotton yarn involved several steps, including opening, carding, rotor spinning, and ring spinning. Treatment type 3 produced the most promising fibre for yarn production, with a fineness of 11.2 tex and tenacity of 12.6 cN/tex, resulting in a spinnable 50:50 treated bamboo/cotton yarn. The treated bamboo/cotton ring-spun yarn exhibited the best performance as it promoted higher tensile strength, Young's modulus and tenacity of 58.77 MPa, 8.51 MPa, and 3.66 cN/tex, respectively compared to the rotor-spun yarn.

ABSTRAK

Gentian buluh semula jadi bersifat kasar dan keras. Rawatan kimia perlu dilakukan untuk mengurangkan komposisi kimianya yang tinggi untuk menghasilkan gentian berkualiti yang lebih halus dan lembut. Gentian kapas banyak digunakan dalam pembuatan tekstil kerana sifatnya yang lembut dan tahan lama. Namun, amalan penanamannya tidak mampan. Penggabungan gentian buluh dan kapas adalah menguntungkan kerana ia menggabungkan kualiti yang diingini daripada kedua-dua gentian dan menghasilkan produk tekstil yang lebih mesra alam. Tiga jenis rawatan kimia telah dikaji untuk mengkaji ciri-ciri gentian buluh yang dirawat di bawah pelbagai keadaan rawatan kimia. Jenis rawatan 1 mengkaji kesan kepekatan NaOH yang berbeza dan waktu rendaman yang berbeza. Jenis rawatan 2 mengkaji kesan kepekatan NaOH yang berbeza dengan masa rendaman yang malar dan penambahan rawatan pelembut. Akhirnya, jenis rawatan 3 mengkaji kesan kepekatan NaOH yang malar dengan rawatan kimia tambahan pada gentian buluh. Untuk mengkaji morfologi gentian, *sliver*, dan *yarn*, Pengimbasan Mikroskop Elektron (SEM) digunakan. Proses penghasilan *yarn* dengan 50% komposisi buluh yang dirawat dan 50% komposisi kapas melibatkan beberapa langkah, termasuk pembukaan, *carding*, pintalan *rotor*, dan *ring*. Gentian yang terbaik untuk penghasilan *yarn* adalah gentian rawatan 3, dengan kehalusan 11.2 tex dan ketegangan 12.6 cN/tex menghasilkan *yarn* campuran buluh-kapas yang boleh dipintal. *Yarn ring* buluh-kapas menunjukkan prestasi terbaik kerana ia menghasilkan kekuatan regangan, modulus Young, dan ketegangan yang lebih tinggi iaitu 58.77 MPa, 8.51 MPa, dan 3.66 cN/tex, berbanding dengan *yarn rotor*.

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LIST OF SYMBOLS AND ABBREVIATIONS

ε	-	Strain
Δl`	-	Change in length
σ	-	Stress
μm	-	Micrometre
A1	-	Treatment type 1 of bamboo fibre at condition 1
A2	-	Treatment type 1 of bamboo fibre at condition 2
A3	-	Treatment type 1 of bamboo fibre at condition 3
A4	-	Treatment type 1 of bamboo fibre at condition 4
ASTM	-	American Society for Testing and Materials
B1	-	Treatment type 1 of bamboo fibre at condition 5
B2	-	Treatment type 1 of bamboo fibre at condition 6
B3	-	Treatment type 1 of bamboo fibre at condition 7
B4	-	Treatment type 1 of bamboo fibre at condition 8
C1	-	Treatment type 2 of bamboo fibre at condition 1
C2	-	Treatment type 2 of bamboo fibre at condition 2
C3	-	Treatment type 2 of bamboo fibre at condition 3
$C_6H_5Na_3O_7$	-	Trisodium citrate
CH_3COOH	-	Acetic Acid
CN	-	Cotton fibre

CV	-	Coefficient variation
D1	-	Treatment type 2 of bamboo fibre at condition 4
D2	-	Treatment type 2 of bamboo fibre at condition 5
D3	-	Treatment type 2 of bamboo fibre at condition 6
EN	-	Treatment type 3 of bamboo fibre at condition 1
et al.	-	et alia, and others
FTK	-	Faculty of Engineering Technology
HCl	-	Hydrogen Chloride
H_2O_2	-	Hydrogen Peroxide
Lo	-	Original length
MOE	-	Modulus of elasticity
MPa	-	Megapascal
MRB	-	Malaysia Rubber Board
MTIB	-	Malaysia Timber Board Malaysia
$MgCl_2$	-	Magnesium Chloride
NaOH	-	Sodium Hydroxide
NaOCl	-	Sodium Hypochlorite
Na_2CO_3	-	Sodium carbonate
Na_2SO_4	-	Sodium sulfate
$Na_5P_3O_{10}$	-	Sodium tripolyphosphate
PALF	-	Pineapple Leaf Fibre
SEM	-	Scanning electron microscope
Tex	-	Yarn weight in gram for 1000 meters
UN	-	Untreated bamboo fibre

USDA	-	United States Department of Agriculture
UTHM	-	Universiti Tun Hussein Onn Malaysia
UTM	-	Universal Testing Machine
UV	-	Yarn weight in gram for 1000 meters
$Zn(NO_3)_2$	-	Zinc nitrate

CHAPTER 1

INTRODUCTION

1.1 Research background

Owing to growing environmental concerns and the depletion of non-renewable resources, researchers are striving to replace traditional non-renewable materials with sustainable eco-friendly materials that can be recycled or biodegradable (Sakthivel et al., 2021). Every part of the textile industry, from fibre cultivation and manufacturing to transportation and life cycle assessment is concerned with long-term viability and environmental responsibility (Aishwariya, 2018). The investigation of various natural fibres as possible substitutes for artificial fibres has been carried out in depth to meet the criteria of economic, environmentally beneficial, and renewable natural resource use (Tong et al., 2018). Recently, attempts have been made to produce textile fibre from bamboo (Kaur et al., 2019; Rocky & Thompson, 2020; Wu et al., 2021).

In the textile industry, the market for natural bamboo fibres extracted directly from bamboo through the degumming process (retting), has escalated due to its excellent properties such as biodegradability, antibacterial functions, and anti-odour (Chauhan et al., 2013). Currently, three main bamboo fibre extraction methods are used, namely mechanical extraction, chemical extraction, and combined chemical and mechanical extraction (Rocky & Thompson, 2018; Shinde et al., 2018). Regenerated cellulose fibres, such as tencel lyocell, modal rayon, viscose rayon, and bamboo rayon, are usually considered the most significant fibres in terms of textiles and the environment (Basit et al., 2018). By far, the viscose process is predominantly used to create fibres from bamboo but the properties of natural bamboo fibres in the bamboo viscose products may have been lost. Viscose rayon produced from the bamboo has different characteristic from natural bamboo (Nayak & Mishra, 2016).Due the presence of bamboo-kun and dendrocin, mechanically processed bamboo fibres are known to be resistant to pest and fungal infections. However, fibres obtained from regenerated cellulose of bamboo plant fail to retain them (Zhang et al., 2015).

Bamboo textiles have not yet achieved their full potential and cleaner production processes are emerging. The quality of textile material is determined by the characteristics of the raw material, for example its chemical structure and construction as well as its physical properties (Šajn & Zupin, 2017). For centuries, the construction industry has benefited primarily from the use of bamboo. However, in recent years, various sectors, such as textile, pulp and paper, medicinal, arts and design, aerospace, and food and beverage, have begun to explore and utilise all aspects of the bamboo plant (Akinlabi et al., 2017).

Twisting is the main method of binding fibres together to produce yarn and increase its tensile strength (Shuvo, 2020). When it comes to the textile industry, ring spinning machines are used to twist staple fibres into yarn (spun yarn) while also winding it into bobbins for storage. Ring spinning is the earliest modern spinning methods (Majumdar, 2013). Spun yarns can be made from a single type of fibre or from a combination of different types of fibres. In the textile industry, it is quite popular to combine synthetic fibres (which may have high strength, lustre, and fire-retardant features) with natural fibres (which have excellent water absorption and skin-comforting qualities). Cotton-polyester and wool-acrylic fibre mixes are the most extensively utilised fibre combinations (Qin, 2016). Fibre characteristics must be evaluated in a certain order of importance with respect to the product and the spinning process.

To determine the spinnability of textile material, the fineness, length, and tenacity of the fibres are essential for considerations (Jais et al., 2020). Rocky & Thompson (2020) demonstrated that natural bamboo fibres produced by chemical treatment were homogeneous, fine, and spinnable when combined with a cotton blend. The lignin component in the bamboo gives it its rigidity and yellow colour. Since lignin is resistant to a variety of alkalis, different treatments will not be able to remove all lignin content (Shinde et al., 2018). Natural bamboo fibre may be used for textile applications, particularly spinning. However, it is important to pay close attention to the structure and properties of bamboo (Malaysian species) as well as the extraction procedure used to obtain finer fibres before utilising them. Efficient treatment of bamboo fibre properties will be beneficial in the production of spinnable blend yarn of bamboo and cotton fibres. Thus, the primary aim of this research is to explore the development of treated bamboo/cotton yarns and evaluate the properties of the produced yarns.

1.2 Problem statement

The average number of fibres in the cross-section of the yarn greatly influences its uniformity. Hence, the finer the fibres, the more uniform the yarn for a particular yarn count, and the finer the count that can be spun for a given number of fibres in the yarn cross-section (Azeem et al., 2019). Fineness is considered as the dominant factor in determining the limiting count which could be spun from a given quality of cotton. Thus, it is necessary to investigate the possibility of utilising coarse fibre to produce yarn with better productivity. The nature of natural bamboo fibres is coarse and stiff which limits their use in the textile industry, where fine and soft fibres are highly valued (Prakash, 2020). Compared to other natural fibres, bamboo fibres have a significantly higher chemical composition. He et al. (2021) inferred that bamboo fibres with high lignin content are rough and stiff, and do not meet the requirements of textile fibres, thus lignin removal is required to improve bamboo fibre properties.

Lignocellulosic fibres, such as like jute and banana, have been treated with eco-friendly biocatalysts followed by bleaching with hydrogen peroxide for fibre surface modification (Chattopadhyay et al., 2020). Researchers have also developed several eco-friendly processes for extracting bamboo fibres without the use of harsh chemicals, such as NaOH and Na_2S, although not all of them produce fibres suitable for yarn (Rocky & Thompson, 2018). Mechanical extraction and chemical treatment of fibres as part of the fibre modification process can be performed to break the molecular structure or diminish certain chemicals in the microfibrils that impart toughness to the fibre (Rocky & Thompson, 2018; Zimniewska, 2022).

Individual bamboo fibres are much shorter in length when they are divided into their individual fibres, although they appear to be continuous in the bamboo culms between nodes (Rocky & Thompson, 2018). Short bamboo fibres are normally not spinnable owing to the abundance of shorter fibres in the wick leaving the fibre bundle due to reduced spinning triangle and do not twist into the yarn, but instead protrude from the yarn. Therefore, bundles of fibres have longer lengths and could be cut into staple lengths to minimise length variations (He et al., 2021). Studies reported that the short-staple spinning technique allows a maximum fibre length of 70 mm in the drafting zone of the ring frame and speed frame (Chattopadhyay et al., 2020). The appropriate length of short staple fibres as an input is to ensure that the fibre length variation can be minimised in the preparatory stage and can be processed in the drafting zone to a certain specified length (Chattopadhyay et al., 2020). Blending low-spinnability fibres with cotton fibre for spinning is a standard approach for producing good-quality yarns for apparel applications (Abdullah et al., 2020). The blending of fibres helps utilise the unique properties of individual fibres and produce yarn with superior characteristics (Chattopadhyay et al., 2020).

Natural bamboo fibre and regenerated (viscose) bamboo fibre are two types of textile bamboo fibre. The viscose technique is primarily utilised to produce bamboo fibres. However, the quality of natural bamboo fibres has been lost in the process, resulting in bamboo viscose products that lack the characteristics of genuine bamboo fibres (Ali et al., 2021). Meanwhile, more environmentally friendly manufacturing methods are being used. To preserve the natural quality of bamboo fibres, it is crucial to explore a mechanical process combined with chemical treatment to achieve a satisfactory level of fibre extraction. A comparative study of chemical treatment conditions for the development of viable natural bamboo fibres in the textile industry is important. It is required to determine the potential of treated bamboo fibre properties to produce blended yarn via ring and rotor spinning techniques.

1.3 Research objectives

This study embarks the following objectives:

i. To analyse the physical and tensile properties of bamboo fibres subjected to different chemical treatment conditions.
ii. To produce treated bamboo/cotton blended yarn using ring and rotor spinning techniques.
iii. To evaluate the physical and tensile properties of treated bamboo/cotton blended yarns produced via ring and rotor spinning techniques.

1.4 Research scope

The scope of this study includes:

i. Bamboo species are supplied by Hangterra Bamboo Sdn. Bhd.

ii. A single species, Schizostachyum grande (buluh semeliang), was investigated in this study. The fibres are randomly extracted from the top, middle, and bottom of each bamboo culm section.

iii. The decorticator machine is used as the mechanical fibre extraction method for bamboo.

iv. The extracted bamboo fibres are hand-combed with a hackling tool to remove short fibres, impurities, and neps, and to parallelise the fibres.

v. Three types of chemical treatments are conducted on bamboo fibres. In the first treatment, treated bamboo fibres are treated at 4 and 8 wt.% NaOH concentrations for soaking times of 6, 12, 18, and 24 hours. The second treatment involves bamboo fibres treated with 20% and 25% NaOH concentrations for 2 hours and soaked in commercial softener. In the third treatment, the fibres are treated at 10% NaOH concentrations for 24 hours and then soaked in 10% CH_3COOH for 24 hours. After that, the fibres are soaked in 3% NaOCl for 15 minutes, followed by soaking in 5% H_2O_2 for 15 minutes, washing and neutralising in 10% $MgCl_2$ for 24 hours. All treated fibres are dried at room temperature. Evaluation of treated fibre includes morphology (SEM), diameter (ASTM D2130-90), fineness (ASTM D1577) and tensile properties (ASTM C1557-14).

vi. Weight ratio of 50:50 treated bamboo/cotton blended sliver were formed.

vii. The sliver is produced using a carding machine. The main cylinder speed, doffer speed, output speed, and input speed are all maintained at 327.6 rpm, 1.69 rpm, 1.03 m/min, and 0.03 m/min, respectively.

viii. Physical properties analysis of sliver includes morphology (SEM), fineness, and evenness.

ix. Treated bamboo/cotton ring-spun yarn is produced using a ring spinning machine. The electronic settings remain constant at 5,600 rpm spindle speed, 900 twists per metre, 8 total draft, and Z twist. Treated bamboo/cotton rotor-spun yarn is produced using a rotor spinning machine. The electronic settings remain constant at 40 mm rotor diameter, 56,134 rpm rotor speed, 3,614 rpm opening roller speeds, and delivery speeds of 56.5 m/min.

x. The physical and tensile properties of yarn are investigated.

xi. Physical properties analysis of yarn includes morphology (SEM), diameter (ASTM D2130-90), and fineness (ASTM 1907).

xii. Tensile properties are determined according to ASTM D2256 for breaking strength, elongation, Young's modulus, stress strain and tenacity.

xiii. The research was conducted at three different locations: the Faculty of Engineering Technology, Bamboo Research Centre, Universiti Tun Hussein Onn Malaysia, Pagoh, Johor; the Faculty of Applied Sciences, Textile Research Centre, Universiti Teknologi MARA, Shah Alam, Selangor; and the Pineapple Waste Production Centre in Pekan Nanas, Pontian, Johor.

1.5 Significance of study

This study contributes to a better understanding of the response of treated bamboo/cotton blended yarn. The following is a summary of those contributions that align with the results discussed in Chapter 4. The study will have a significant impact on academics, community, industry, and government.

i. Academic

Yarn made from a combination of bamboo and cotton fibres is acceptable as a means of diversifying bamboo. It also introduces new value-added textile yarns and an effective means to reduce dependence on cotton and viscose bamboo usage. Cotton and bamboo fibres have distinct properties in terms of diameter, fineness, softness, and strength for blending. This study proposed the utilisation of mechanical and chemical methods as effective bamboo fibre extraction methods for suitable blending. It is envisaged that this combined approach and its impact on changes in fibre properties and fibre separation in bamboo fibres may help in improving the understanding of the influence of fibre properties on yarn properties. The purpose is for the selection of fibre fineness and strength to produce spinnable yarns. If the factors that can largely influence yarn quality, such as length distribution, fineness, and strength, can be effectively controlled, the result of the yarn unevenness test will be affected. The properties of sliver and their impact on the properties of yarn spun on different spinning techniques, such as fineness and evenness, are also important parameters. It has been found that the influence on spinning performance and yarn quality depends on the spinning technique used. Ring spinning is more positive for performance and yarn quality than rotor spinning. The findings of this study could assist researchers to further investigate ways to develop bamboo fibres and maintain machine parameters for a compatible blending to produce good-quality yarn.

ii. Community

An increase in bamboo cultivation will provide an opportunity for income-generating activities for rural residents as well as creating employment for small and medium-sized businesses. This will encourage the realisation of smallholders to grow their plantation to meet their financial demands. Fashion and designers can offer and market their eco-friendly and sustainable wardrobe alternatives, and also meet the increasing expectations of sustainable fashion-conscious customers. Consumers have evolved over time and become more educated about materials and production processes, which has prompted their desire to make socially responsible choices while upgrading their wardrobes with a value tag. In fact, international brands are increasingly focused on the most ethical and transparent approaches, considering the environment and customers.

iii. Industry

This research will contribute to five major thrusts in the Bamboo Industry Development Action Plan 2021-2030 drafted by the Malaysian Timber Industry Board, including policy strengthening, broadening raw material sources; expanding human resources, knowledge, and capacity; boosting innovation, technology, research, development, and commercialisation; improving supply chain and quality assurance; and bolstering the bamboo industry's marketing strategy and smart sharing. Natural bamboo/cotton blend yarns are scarce in the market. Successful commercial cultivation of local bamboo as a natural raw material in the industry adds value to fibre producers and the textile sector, with sustainability as the goal for process improvement. It can also minimise the Malaysian high cost of importing textile fibres such as cotton and man-made fibre. In addition, Malaysia’s bamboo demand has continued to expand over the years, and with proper strategy, the industry's potential to value-added goods with higher prices for export. The traditional manufacturing industry, to original design and brand manufacturing in developing effective bamboo fibres production promote economic growth.

iv. Government

Although the global market for bamboo goods was worth at around US$68 billion (RM288.2 billion) in 2018, Malaysia's economic contribution to the global bamboo market remained minimal, at around RM9 million. With proper government input in policy measures, accomplishment in business would provide huge earnings to the Malaysian government by increasing the export of bamboo products. In fact, it has the potential to be a very resourceful material in Malaysia, which significantly helps to mitigate the negative effects of soil erosion, combat climate change, protect biodiversity, and promote sustainable construction development.

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APPENDIX

LIST OF PUBLICATIONS

i. Anis Amirah Nor Anuwar, Najwa Wajihah Mohd Rusli, Azrin Hani Abdul Rashid, Nazaruddin Mohd Nawi and Abdussalam Al-hakimi Mohd Tahir (2020) Evaluation of Kenaf Fibre for The Development of Kenaf/Polyester Hybrid Yarn, International Journal of Advanced Trends in Computer Science and Engineering, World Academy of Research in Science and Engineering, 9, 295, ISSN:22783091

ii. Anis Amirah Nor Anuwar, Azrin Hani Abdul Rashid, Abdussalam Al-hakimi Mohd Tahir & Mohd Nazrul Roslan (2022) Bamboo as a Potential Textile Fibre in Yarn Manufacturing, Bamboo: Perspective, Technology and Application, UTHM, 22, ISBN:9789672817741

iii. Anis Amirah Nor Anuwar, Azrin Hani Abdul Rashid, Suzi Salwah Jikan, Mohd Nazrul Roslan, Abdussalam Al-hakimi Mohd Tahir, Nurul Husna Zolkifflee & Fathee Aizat Mohd Razal (2022) The Effect of Alkaline Treatment on The Fineness of Schizostachyum Grande Fibre for Textile Applications, International Journal of Integrated Engineering, 14, 37, ISSN:2229-838X

VITA

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