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A Comprehensive Investigation of Woolenization Process Effect on Jute Yarn Quality

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Article

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ABSTRACT

Jute, a renowned biodegradable and sustainable textile fibre, plays a pivotal role in environmentally conscious textile production. The purpose of this study was to investigate the effects of the woolenization process on the qualitative attributes of jute yarn, such as yarn evenness, and tensile and functional properties, with a special focus on the development of wool-like properties. Yarn samples were meticulously prepared from white jute fibre, categorized into three distinct count groups (C8, C10, and C12), and subjected to four treatment categories: untreated (U), woolenized (W), bleached (B), and dyed (D). The results showed that the woolenization process impoverished yarn evenness, with a significant 15.2% increase in CVm for WC8, 74% and 88.6% increase in Thin (-50%)/Km and Thick (+50%)/Km, respectively, for WC10. For tensile properties, a 27% reduction in tenacity and 176.5% remarkable elongation improvement were noted for samples WC10 and WC12, respectively. Furthermore, the development of wool-like properties was noteworthy in functional properties, including a 38.8% increase in Specific Volume Index (SVI), and a 12.8% reduction in moisture content was marked for WC8. The woolenization process also had an adverse effect on jute yarn count and quality ratio, with a deterioration of 12.5% and 32.2% marked for sample WC10, respectively. The results suggest that the bleaching process performed after woolenization negatively impacts yarn evenness. However, dyeing after woolenization and bleaching can enhance overall yarn quality. The outcome of this study will promote the use of natural fibre, and jute over synthetic and natural wool fibres.

KEYWORDS

woolenization, jute yarn, evenness, tensile properties, yarn quality

INTRODUCTION

The annual output of the global wool industry is approximately 2 million tons with a projected market growth of $53.4 billion by 2030. The textile sector consumes 60% of total production [1]. However, wool fibre contributes more to greenhouse gas emissions (GHGs) than jute fibre and is considerably more

expensive [2]. However, amid rising environmental concerns, there is a burgeoning interest in sustainable, eco-friendly fibres like jute for potential applications [3,4]. The prospect of substituting wool with jute, a biodegradable and renewable fibre, through woolenization to impart wool-like properties, is gaining traction in the textile industry.

Jute is a cash crop in Bangladesh but is also stiff and coarse compared to wool yarn [5]. Numerous efforts have been made to improve the jute's flexibility, crimpability, softness, etc., to enhance key property spinnability to produce fine yarn [6,7]. Jute contains mostly cellulose (58.21--64.21%) along with hemicellulose (21.0 - 22.0/24%), lignin (12.0 - 14.0%), pectin (0.2 -1.5%), proteins or nitrogenous matter, etc. 0.80-1.9, Ash 0.7 - 1.2 and waxy components (0.10 - 1.0%) in its chemical structure. The latter substances are quite difficult to remove [8-10]. These seriously affect the fibre's soft, flexible, and elastic ability. Jute fibres are typically characterized by an ultimate length of 0.8-6 mm, a fineness of 1.3-4.0 tex, a density of 1.4-1.5 g.cm-3, tenacity 30-45 gf/tex, elongation 1.0-1.8%, thermal conductivity 427.3 m.Wm-1.K-1 [11].

The woolenization process physically develops a high degree of crimp or waviness by treating the jute fibre or yarn with a strong alkali, and that crimp imparts "wool-like" properties like the softness to touch, thermal insulation, and bulkiness [12-15]. Woolenization on jute yarn has changed physical and chemical properties remarkably. The yarn becomes supple and develops crimp significantly. The nature of crimp in jute fibre varies depending on the concentration of NaOH solution, liquor ratio, and treatment parameters such as temperature and time[16,17]. Various authors reported that the characteristics of crimp are related to the varieties and morphology of jute [17,18]. Conversion from cellulose I to cellulose II is mainly responsible for developing crimp in jute fibre [19,20]. Longitudinal shrinking of the fibre and swelling of intra-crystalline due to NaOH were also responsible for crimp development in jute fibre. Yarn's physical properties are vital for post-spinning operations [21].

Sheep or synthetic fibre-based wool are both not environmentally friendly. Consequently, in terms of ecology, the economy, and climate change, the transformation of biodegradable jute fibre into a wool-like product is of paramount importance. There is immense scope to use woolenized jute yarn in textile garments. Nevertheless, despite the abundance of research on treatments to enhance the crimp development of jute fibre, there is a dearth of studies examining methods to improve the crimp development of jute yarn. This research work focuses on and attempts to establish jute yarn as a sustainable and renewable natural raw material source in the course of woolenization treatment in textile garments applications. In this context, this research work is very important. In summary, the novelty of

this research lies in its focus on the woolenization of jute yarn (as opposed to fibre), and its emphasis on the sustainability and potential applications of woolenized jute yarn in the textile industry.

EXPERIMENTAL

Materials and Methods

Materials

In this experiment, white tossa jute fibre with an average fibre diameter of 28.12 µm and fibre strength of 36.72 g/tex was chosen to produce three Jute yarn samples.

Sample Preparation: A total of thirty-six yarn samples were produced, encompassing four distinct treatment categories: untreated (U), woolenized (W), bleached (B), and dyed (D). Within each category, yarns were further categorized into three count groups: C8 (276 tex or 8 Ib./spyndle), C10 (345 tex or 10 Ib./spyndle), and C12 (413 tex or 12 Ib./spyndle), as illustrated in Figure 1.

Fibre Processing and Spinning

Fibre processing and spinning were conducted at the Bangladesh Jute Research Institute (BJRI) laboratory. Initially, 50 kg of jute fibres were processed into slivers through a series of machines, including a jute softener with 25% emulsion application (after that, it was piled for 48 hr), breaker card with 240 kg/hr, a finisher card with delivery speed 135kg/hr, and 1st draw frame with 4.0 draft, 2:1 doubling, delivery speed 65 kg /hr/head, 2nd draw frame with 6.3 draft, 3:1 doubling, delivery speed 31 kg/hr/head, 3rd and finisher draw frame with 4.8 draft, 3:1 doubling, sliver count 3.6 Ktex, delivery speed 13 kg/hr/head. Subsequently, the drawn slivers were transformed into yarn of 276 tex (tpi, 4.55), 345 tex (tpi, 3.75), and 413 tex (tpi, 3.45) in a spinning machine (James Mackie, Ireland) with flyer rpm 3800.

Woolenization, Bleaching, and Dyeing

The yarn samples underwent a woolenization process, followed by bleaching and dyeing treatments. The details of these processes are outlined in Table 2.

Woolenization Process: The yarn samples were immersed in a woolenization bath containing NaOH (sourced from Mark, India), a sequestering agent (provided by Clariant), and a wetting agent (also from Clariant). This woolenization process was carried out at room temperature for 30 min, maintaining a liquor ratio of 1:20 (M:L). Following woolenization, the yarns were subjected to a hot wash for 5 min.

Subsequently, the yarns were neutralized with acetic acid for 4 min and underwent another washing cycle. The samples were then mechanically squeezed and dried for around 5 min.

Table 1. Principal fibre properties

Grade	Ultimate Length (mm)	Density (g/cm^3)	Diameter (um)	Strength (g/tex)	Elongation (%)
White tossa	2.4	1.31	28.12	36.72	1.6

Bleaching and Dyeing

For bleached and dyed treatment categories, the woolenized yarn samples were subjected to a bleaching process employing H_2O_2 (50% w/v), Lissapol™ BN 200L (manufactured by Croda), and sodium silicate. This bleaching process was conducted for 1 hr at a temperature range of 80-85 °C, utilizing an enzyme as a peroxide killer. Following bleaching, the yarn samples were dyed using a basic dye known as Sandocryl Red C-4 G at a concentration of 1% owm (on the weight of the material). The dyeing process was continued for 1 hr at a temperature of 95 °C. The meticulous execution of these processes ensured the proper preparation and treatment of the yarn samples for subsequent analysis and evaluation.

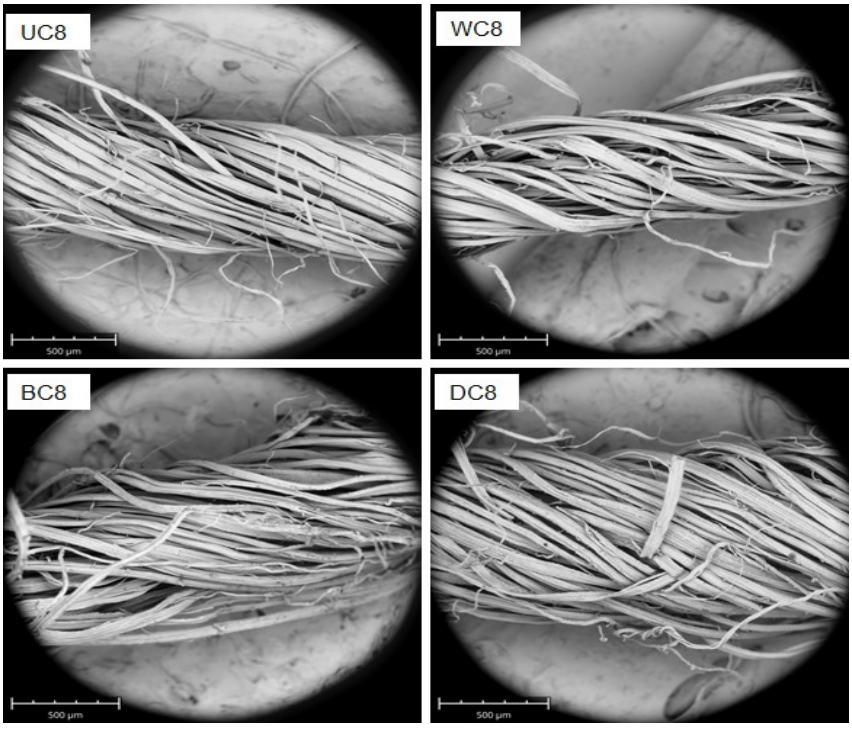


Figure 1. Scanning Electron Microscope (SEM) images of yarn samples

Table 2. Process details

Process	Woolenization	Bleaching	Dyeing
Chemical variable	CS - 15%, SEA - 1cc/L,WA - 1cc/L	HP – 12%, SOS – 5%, WA – 2cc/L	BD – 1%, SOA – 0.5 g/L, Slt – 10 g/L
Non-Chemical variable	M: L - 1:20, Temp - RT, Time - 30 min	M: L - 1:50, Temp – 80-85 ^{0}C, Time - 60 min	M: L - 1:50, Temp –95 ^{0}C, Time - 60 min

*CS-Caustic soda, SEA-Sequestering agent, WA-Wetting agent, HP-H_2O_2, SOS-Sodium silicate, BD-Basic Dye, SOA-Sodium acetate, Slt-Salt, RT-Room Temperature.

Characterization

Fibre properties

Fibre diameter and density were measured according to ISO 137-1985 on the Fineness and Content Analysis System FYI-YG002C, China. Bundle strength and elongation were measured according to ISO 3060 on the MAG Fibrostelo F0501 (CRL), India, and the fibre weight was measured according to ISO 14362 in EP 125 SM electronic balance.

Yarn evenness properties

After yarn production, all samples were stored under standard laboratory conditions (20 ± 2 °C and 65 ± 2% RH) for 24 hr before testing as per ISO 139. Yarn count was measured according to D1907M-12(2018) by the skein method. Yam evenness properties indicate regularity in yarn shape and mass distribution. The four indicators of yarn evenness, CVm%, Thin (-50%)/Km, Thick (+50%)/Km, and Neps (+200%)/Km were measured on the Uster Tester 5 following the ISO 16549 method.

Yarn tensile properties

Yarn tensile properties reveal the resistance force against pre-selected load. Yarn tenacity (G/TEX) and elongation (%) were measured according to the ASTM D2256-90 method on the Mesdan Lab AUTODYN II single-end tester.

Yarn functional properties

The important functional properties, such as wool-like properties and moisture content, are the important parameters to assess the woolenization effects. Yarn bulkiness is the primary tool to assess wool-like properties. We measured yarn bulkiness by specific volume index, SVI%. Yarn samples weighing approximately 1g were immersed in 10 ml toluene. Toluene is inert and not absorbed by the fibre.

Therefore, changes in specific volume by immersing yarn represent yarn bulkiness. After immersion, changes in specific volume index were calculated according to the following formula;

$$|SVI\%| = \frac{(V_x - V_0)/g}{V_0} X\ 100 \quad (1)$$

*V_x=Volume after immersion of the yarn samples, V_0= Volume before immersion yarn samples, g= Weight of yarn sample in grams.

Wool-like properties keep the body warmer through insulation. In this context, the reduced moisture content of yarn that facilitates heat insulation is another indicator of woolenization. Moisture content was measured by Mesdan Humy Tester III according to ASTM D2654-22. Moreover, as wool fibre shows more elongation, a remarkable increase in elongation will correspond to wool-like properties. Finally, we measured quality ratio (QR%), an analytical index of jute yarn quality, generally used in the jute spinning industry, from the following formula:

$$|QR\%| = \frac{\text{Tensile strength (lbs)}}{\text{Jute count (lbs/spyndle)}} X\ 100 \quad (2)$$

RESULTS AND DISCUSSION

Yarn evenness properties

Experimental data on yarn evenness is shown in Table 3. Moreover, results in terms of CVm%, Thin ((-50%)/km, Thick (+50%)/km and Neps (+200%)/km were illustrated in Figure 2.

CVm%

It was observed that overall, CVm% increased due to the woolenization process compared to control samples, with a slight improvement after the bleaching and dyeing process. The significant deterioration was with a rise of 15.2% for WC8 than the control sample. Among the treated samples, the lowest CVm 25.16%, was observed for dyed sample DC12, while control sample UC12 had 25.34%, respectively. The highest CVm% was observed for bleached yarn sample WC10 (30.86%), followed by BC10 (29.92%).

Thin (-50%)/km

The woolenization process increased thin fault (-50%)/km compared to the control group, and sample WC10 revealed the highest thin fault 1077.3 (74% increase) with CV 63.8%, whereas the lowest thin/km was 619.0 for the control sample UC10 with CV 11.3%. However, thin faults were decreased in bleached and dyed yarn samples. Moreover, coarser yarn exhibited fewer thin faults than finer yarn.

Thick (+50%)/km

Thick faults (+50%)/km increased after the woolenization process, and the highest value was 1123.4 with 63.8% CV for the WC10 sample and 88.6% increase compared to UC10. However, a downtrend was observed in the bleaching and dyeing process except in sample BC12, where thick/km upped to 1128.6. Of the three count groups, the finer count had more thick faults than the coarser yarn. It was noticed that variation within the mean value increased after each chemical treatment, and bleaching added the highest CV%, ranging from 57.2 to 96.3.

Table 3. Yarn evenness and tensile properties

Sample	U			W			B			D		
Count	C8	C10	C12	C8	C10	C12	C8	C10	C12	C8	C10	C12
CVm	26.4	28.1	24.3	30.4	30.9	25.4	26.9	29.9	25.3	25.2	28.9	25.2
(%)	(1.1)	(3.3)	(4.6)	(5.3)	(8.3)	(4.4)	(8.3)	(9.3)	(4.0)	(8.9)	(10.2)	(3.6)
Thin	514.6	619.0	832.0	812.5	1077.3	931.5	446.0	619.0	879.4	371.4	569.0	849.4
(-50%)	(11.2)	(11.3)	(20.6)	(16.3)	(63.8)	(10.2)	(17.3)	(56.3)	(38.0)	(18.3)	(48.7)	(65.7)
Thick	687.3	595.6	547.2	985.7	1123.4	664.6	682.8	877.3	1128.6	517.2	828.5	732.1
(+50%)	(41.6)	(43.3)	(60.7)	(56.3)	(63.8)	(44.7)	(57.2)	(96.3)	(87.9)	(58.3)	(78.7)	(95.7)
Neps	79.0	58.0	25.0	33.0	45.0	21.0	74.0	188.0	230.0	85.0	156.0	120.0
(+200%)	(35.6)	(29.5)	(71.4)	(90.4)	(96.9)	(91.4)	(29.6)	(82.2)	(40.1)	(27.5)	(72.3)	(63.3)
Tenacity	8.9	14.1	15.2	8.2	10.3	13.4	8.1	10.9	13.9	7.8	9.7	11.6
(g/tex)	(12.1)	(9.5)	(9.8)	(13.2)	(9.6)	(9.3)	(12.9)	(14.6)	(14.8)	(16.8)	(17.6)	(17.7)
Elongation	3.0	3.4	3.4	5.9	6.9	9.4	5.6	7.0	8.6	7.9	8.4	9.2
(%)	(3.1)	(2.7)	(3.5)	(3.2)	(3.0)	(3.7)	(4.3)	(4.8)	(3.6)	(3.5)	(3.5)	(3.6)

* Values in parenthesis denote CV% of three readings of each parameter

Neps (+200%)/km

Overall, the woolenization process improvised the Neps/km very well for three count groups (33,45, 21 for C8, C10, and C12, respectively), but bleaching impoverished sharply, followed by the dyeing process.

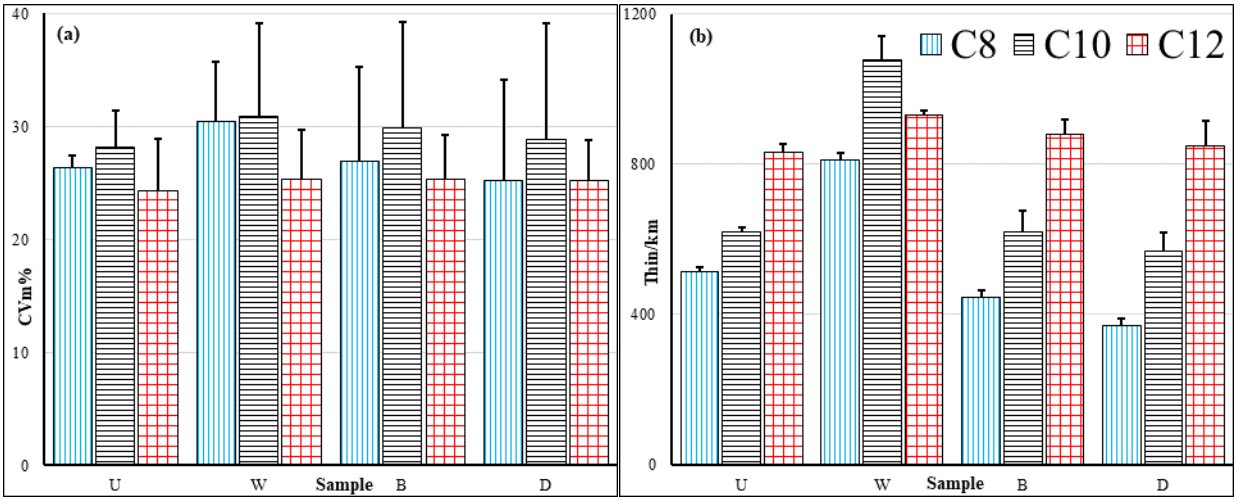
The lowest Neps/km was found 21 and 25 for treated WC12 and control sample UC12, respectively. The highest Neps/km was found at 230 and 79 for treated BC12 and control sample UC8, respectively. Primarily, uncontrolled and random removal of impurities from control samples by woolenization with alkali impoverished yarn evenness properties, like CVm%, Thin (-50%)/km, Thick (+50%)/km, and Neps (+200%)/km. Furthermore, bleaching and dyeing, the oxidative reduction process with various uncontrolled factors intensified the unevenness attribute. The high CV% of mean unevenness was produced primarily due to the lack of a levelling system and the machine's mechanical condition; both are technically unsatisfactory.

Tensile properties

Tenacity in g/tex (Ten) and elongation in % (Elg) are two important parameters of tensile properties measured and presented in Table 3.

Tenacity

Overall, the woolenization process deteriorated yarn tenacity compared to control samples (Figure 3a); after the bleaching and dyeing process, the deterioration intensified. The highest deterioration 31.6% in tenacity was found for the samples DC8 and UC8, representing 14.12 and 9.72 g/tex, respectively. However, in the woolenization process, the significant deterioration was 27.0% for WC10 compared to the control sample UC10.



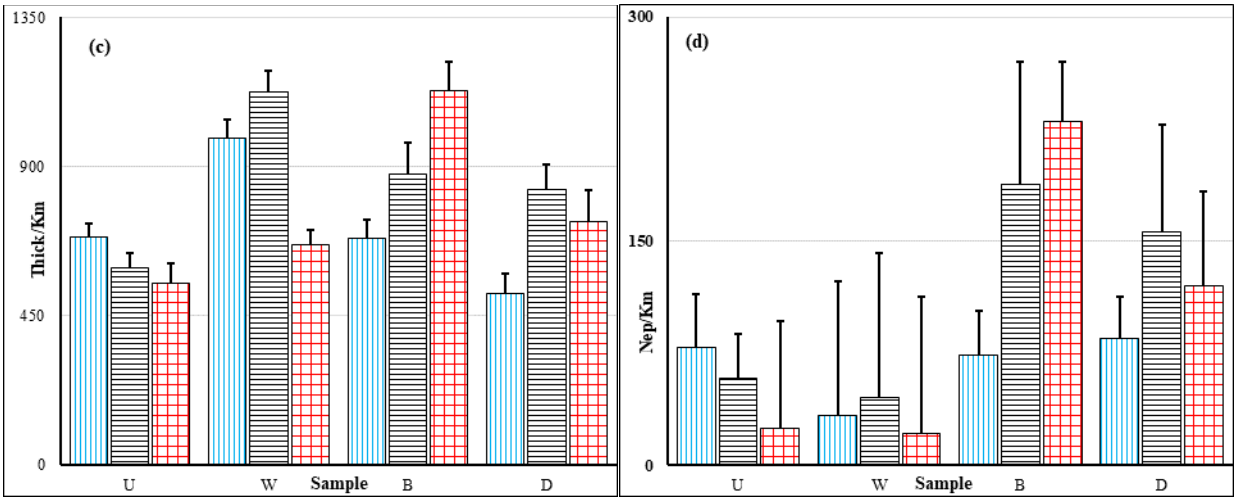


Figure 2. Yarn evenness properties (a) CVm%, (b) Thin (-50%)/km, (c) Thick (+50%)/km, (d) Neps (+200%)/km

Elongation

Due to the woolenization process, it was marked that the elongation property was improved greatly than the control sample (Figure 3b). The highest elongation 9.4% of WC12, was found against the control sample UC12 of 3.4% elongation, 176.5%, a remarkable increase in elongation. A material loss like waxing material, pectin, and colouring material from the jute yarn samples with the treatment of NaOH and H_2O_2 reduces the tenacity. Primarily, a high number of thin (-50%)/km produced lower tenacity in woolenized yarn samples. In addition, due to the high variation in mean yarn count, a high variation in tenacity was observed from the error bar diagram. On the other hand, caustic soda causes swelling, and shrinkage and produces soda cellulose that improves fibre spirality and extensibility, ultimately contributing to higher elongation. Furthermore, the bleaching compound's reduction activity had slightly lowered elongation. In the case of dyed yarn, basic dye-fibre bonding and high temperature may contribute to higher elongation.

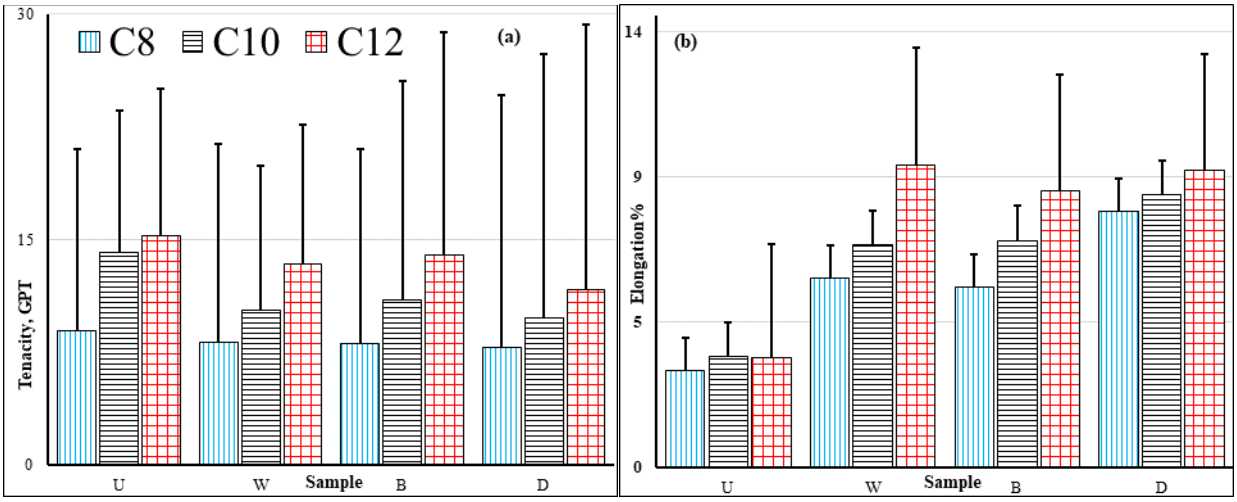


Figure 3. Yarn tensile properties (a)Yarn tenacity, G/TEX, (b) Elongation %

Yarn functional properties

The measured yarn functional properties are presented in Table 4. The prime objective of this study was the development of wool-like properties development, one of the important aspects of yarn functional properties. The findings in yarn wool-like properties were exhibited in Figure 4a and Figure 4b in terms of SVI% and MC%, respectively.

Table 4. Yarn functional properties

Sample	U			W			B			D		
Count	C8	C10	C12	C8	C10	C12	C8	C10	C12	C8	C10	C12
MC	3.9 (1.5)	3.8 (2.0)	3.9 (1.7)	3.5 (2.0)	3.6 (1.7)	3.4 (1.5)	3.4 (1.5)	3.4 (2.1)	3.3 (1.7)	3.7 (2.1)	3.7 (1.7)	3.8 (2.1)
SV	9.4 (2.9)	9.4 (4.6)	9.3 (3.1)	38.8 (2.3)	37.0 (1.5)	37.7 (1.0)	26.1 (5.4)	26.5 (2.4)	18.0 (3.0)	26.3 (2.8)	25.9 (2.3)	25 (3.5)
YC	8.0 (5.5)	10.4 (7.2)	12.1 (5.7)	7.6 (3.1)	9.1 (2.3)	11.8 (1.8)	7.5 (7.2)	9.6 (4.2)	11.7 (4.8)	7.7 (4.1)	9.2 (3.6)	11.6 (4.8)
QR%	68.1	78.2	65.0	62.0	53.0	57.7	61.5	56.6	60.2	60.0	50.0	50.2

Specific Volume Index %

Overall, a higher specific volume index (SVI%) was developed due to the woolenization process, and an increment in bulkiness indicates an effective woolenization process. The maximum improvement in SVI% was observed for sample WC8, 38.8% compared to 9.4% for sample UC8 (Figure 4a). However, further treatment with bleaching and dyeing process deteriorated the wool-like properties and lowered the SVI%

to about 26%. Regarding the JYC effect, the coarser yarn had a slightly lower SVI % than the finer count yarn. We assume that treating jute yarn with caustic soda produces soda cellulose, causes swelling and develops crimp internally that improves the yarn bulkiness leading to higher SVI%. These phenomena are illustrated in Figure 5.

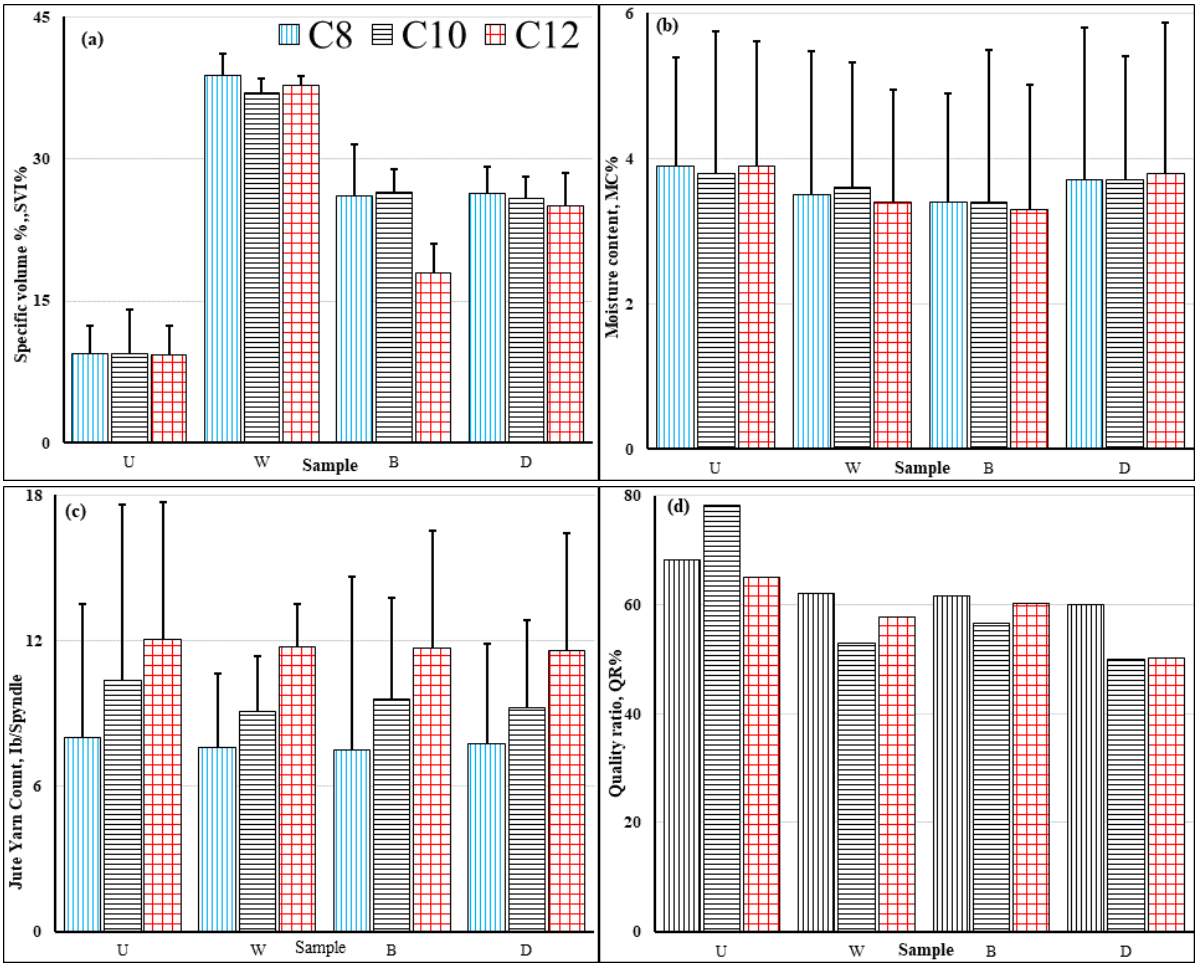


Figure 4. Functional properties (a)Specific volume, SVI %,(b) Moisture content, MC %,(c) Yarn Count, JYC, (d) Quality ratio, QR %

Moisture content

Overall, the woolenization process reduced MC % (Figure 4b), indicating wool-like properties' effectiveness. The maximum decrease in MC % was observed at 12.8% for sample WC8 compared to sample UC8 of MC % at 3.9%, followed by bleached yarn. However, a slight improvement was found for dyed yarn. Alkaline treatment plays a role in enhancing the effectiveness of the woolenization. This results in swelling of the intra-crystalline zone and conversion from cellulose I to cellulose II, which contributed mainly to producing a crimp-like structure of yarn that increased the yarn bulkiness. This bulkiness was

measured by an increase in the specific volume. The alkaline and bleaching process removes unexpected materials from the yarn body, resulting in lower moisture content.

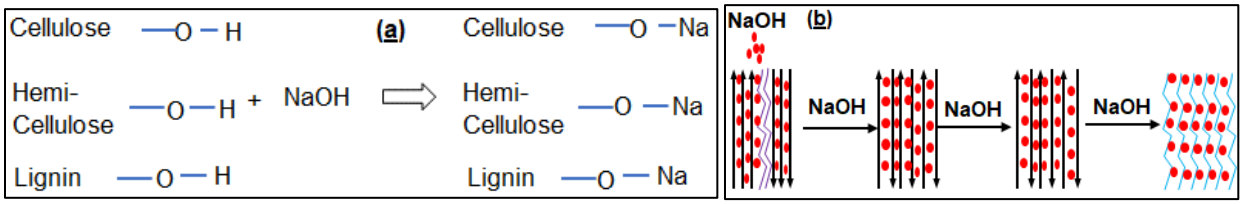


Figure 5. Changes occur in jute yarn for woolenization, (a) chemical scheme, (b) structural scheme

Jute Yarn Count

Overall, every process reduced the treated jute yarn count (Figure 4c). However, a remarkable reduction was observed for the woolenization, with the highest reduction of 12.5% for sample WC10 compared to the control sample UC10. Weight loss of the sample yarn was produced due to chemical treatment. There is a correlation between jute yarn count (JYC) and weight loss.

Quality ratio properties

The quality ratio (QR) % of the produced samples was graphically presented in Figure 4d. It was observed that every treatment shaped the yarn quality ratio, QR % downward. In comparison, the samples of C8 of each treatment exhibited the lowest and samples of C10 and C12 showed the highest deterioration. For example, due to the woolenization process, QR % deteriorated 9.0% and 32.2% for samples WC8 and WC10, respectively. The alkaline process reduced evenness and tenacity. This contributed to the reduction of QR%. Continuous treatment with reducing agents at high temperatures tolled on quality ratio heavily.

CONCLUSION

The main purpose of this study was to examine the effects of the woolenization process on the wool-like properties and the physical and mechanical characteristics of jute yarn. Overall, the results showed that the woolenization process improved the wool-like properties of the jute yarn in terms of SVI %, MC % and Elg %. However, the treatment also reduced JYC, weight, and tenacity compared to the control samples. The bleaching and dyeing process further deteriorated the yarn's physical and mechanical properties. This negative impact was more pronounced for finer yarn. Overall, the woolenization process improved the bulkiness of the yarn moderately. Moreover, we have found high variability in mean results. Jute spinning machinery is not well technology-driven to deliver optimum yarn quality like cotton spinning machinery.

In our observation, besides unfavourable fibre properties, the mechanical condition of machines and lack of technology to spin yarn with optimum quality contributed significantly to the inferior yarn quality.

Author Contributions

Conceptualization – Khan MAS, Jamil ATMK; methodology – Khan MAS, Chowdhury MFM; formal analysis – Chowdhury MFM and Hossain A; investigation – Khan MAS; resources – Khan MAS; writing-original draft preparation – Chowdhury MFM, Hossain A; writing-review and editing – Chowdhury MFM; visualization – Khan MAS, Maniruzzaman M; supervision – Jamil ATMK. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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