Functionalization of Jute and Jute-Cotton Fabrics through Flame-retardant Finish

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Research Article

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Abstract

The ligno-cellulosic Jute fiber, which holds the second largest volume among the natural cellulosic fibers after Cotton. This study focuses on the determination of the flame-retardance (FR) properties of pure Jute and Jute-Cotton fabrics treated with Pyrovatex CP New at concentrations of 90% (owf), M:L: 1:7. A significant improvement in flame-retardancy was determined on both fabrics. After the ignition period, the recorded flame spread time was zero second on both FR treated fabrics; on the other hand, it was measured 21 seconds and 28 seconds to burn the entire length (15cm) of untreated Jute and Jute-Cotton fabrics, respectively. Within these flame-spread times, the length of the char was 2.1 cm and 2.57 cm in the Jute and Jute-Cotton fabrics, respectively. The physio-mechanical properties dropped remarkably after the FR finish in both the warp and weft directions of both fabrics. The SEM images determined the deposition of flame-retardant finishes on the fabric surface. FTIR characterization showed that the inherent properties of the fibers were not affected by the flame-retardant chemical. The TGA analysis showed that the early decomposition occurred on both FR treated fabrics and hence formed more char than the untreated samples. A significant improvement in residual mass (more than 40%) was observed in both fabrics after FR treatment. The detected formaldehyde content on the FR treated samples was much higher; however, it was still in the limit of the allowed formaldehyde content present in textiles that are designed for outerwear and not worn next to the skin. The findings reported in this study show the potential application of Pyrovatex CP New to jute-based materials.

1.0 Introduction

Jute is a ligno-cellulosic fiber that contains the primary elements hemicellulose (22–24%), cellulose (58–60%) and lignin (12–14%), as well as several minor constituents. Because of the variances in the chemical composition, the thermal behavior of various components changes. Thermal behavior and fire-retardant finish have been the subject of some exploratory research in previous studies (Banerjee SK 1986; Varma IK et al. 1988; Basak et al. 1993; Samanta 1995, 2011a, b). To limit the number of casualties and injuries caused by fire, the backing of jute carpet, decorative jute furnishing fabrics, and the brattice cloth for mines have been made fire-resistant. Fire-retardant fabrics are now used in a variety of applications, including floor coverings, floor mats, carpets, military uniforms, hospital furniture, hospital curtains, and industrial ventilation, among others (Weil and Levchik 2008). Higher chemical add-on, visible decrease in tensile strength, and yellowing are the main issues with the fire-protective finish treatment of jute-based fabrics. Furthermore, the majority of these fire-retardant compositions are not durable or semi-durable and require substantial dosages of relevant chemicals (Samanta 1995).

In England, the first attempts to create fire-resistant fabric began in 1735. The mechanism of the fire-retardant effect of several fire-retardant chemicals acting on cellulose was discussed by the earlier authors (Horrocks 1968; Barker 1979). There are numerous publications on cotton's flame-retardancy; however, there are few studies on jute. Some early researchers published on the temporary flame retardancy of Jute using borax-boric acid with di-ammonium phosphate (Banerjee SK 1986), potassium-sodium tartarate (Rochelle Salt) as a fire-retardant agent for Jute cited in a review study by Pal et al. (Pal
et al. 2020), ammonium sulfamate (AS) with urea to improve the flame-retardancy of Cotton (Lewin and Mark 1997) and Jute (Kumar Samanta et al. 2015). Despite significant disadvantages, halogenated, phosphorus-based fire retardants and sulfur-based flame-retardants have been used to improve the flame resistance of wood (Liodakis et al. 2006; Dobele et al. 2007), cotton (S. M. Mostashari* and and S. Z. Mostashari 2008), and synthetic (Markarian Jennifer 2005; Chen et al. 2006; Fei et al. 2008) textiles.

Except for cotton, limited studies were conducted on natural fibers, but the studies by Yusuf (Yusuf 2018) on linen, hemp, silk & wool and on flame-retardancy of jute by Mehta & Hoque (Mehta 1982). Dorez et al. investigated the effects of the content of cellulose, hemicellulose, and lignin on the pyrolysis and combustion of natural fibers (Dorez et al. 2014a). Previous studies reported the application of different organophosphates and other chemicals in Jute (Reddy et al. 2007; Klingshirn 2007; Matei et al. 2008) and in a recent study, Samanta et al. have successfully investigated the effect of nano-zinc oxide as a flame-retardant finish on Jute fabric (Samanta et al. 2017) and Roy et al. reported the durable flame-retardancy on Jute (Roy et al. 2018).

The chemical composition of cellulose-based fibers varies according to their origin (i.e., seed, leaf, cane, fruit, wood, bast, and grass). At temperatures above 170–200°C, most natural fibers begin to degrade. The main fiber components, cellulose, lignin, and hemicellulose, all behave differently. Hemicellulose pyrolysis occurs rapidly between 220 and 315°C. Lignin forms char, which protects the integrity of the textile surface by acting as a layer of fire insulation. Increased char formation during the burning process indicates flame retardancy. It is difficult to decompose lignin due to its low decomposition rate, while a high cellulose content can result in increased fiber flammability (Dorez et al. 2014b; Salmeia et al. 2016). Many scientists have studied the improvement of the flame-retardance of cellulose fibers by using different kinds of flame-retardants (Dorez et al. 2013; Lazko et al. 2013; Freivalde et al. 2014; Afzal et al. 2017). However, it frequently has a negative impact on the mechanical (Lam et al. 2011a, b; Yang et al. 2012b, a) and comfort (Guin et al. 2014; Lam et al. 2014; Poon and Kan 2016) properties of the textile product and may even be allergenic. Therefore, selecting the most appropriate treatment and chemical concentration of flame retardant is essential (Tang et al. 2017b, a).

Previous researchers conducted several studies on the application of Jute fibers in composites (M. Khabir Uddin et al. 1997; A. Bismarck et al. 2000; Mohanty et al. 2000; Mishra et al. 2007; Khan et al. 2010), but very few were determined the flame-retardancy of Jute fabrics for technical textiles. Therefore, this study aims to impart flame-retardant finishing on 100% Jute and Jute-Cotton fabrics treated with a phosphorous-based commercial flame-retardant (FR). Jute-Cotton fabric was selected for this study as there is no previously reported work citing the use of flame-retardants on Jute-Cotton.

**2.0 Experimental**

**2.1 Materials**
All experiments were carried out using two different plain-woven fabrics consisting of 100% Jute (290 GSM, EPI: 22, PPI: 16) and Jute-Cotton (Warp: Cotton and Weft: Jute; 340 GSM, EPI: 52, PPI: 26), purchased from Mony Jute Company, Dhaka, Bangladesh.

2.2 Chemicals and Reagents

A phosphorous-based commercial flame-retardant chemical, PYROVATEX CP New (N-methylol dimethylphosphonpropionamide) and cross-linking agent KNITTEX FFRC (a modified dihydroxyethylene urea) were purchased from the local agent of Huntsman (Swiss Color, Bangladesh). All chemicals were used as received.

2.3 Fabric Pretreatment:

Before flame-retardant finish treatment, to remove impurities, both fabrics were scoured and bleached using Caustic soda (100 g/kg), hydrogen peroxide (80 g/kg), at a liquor ratio of 1:10. The pretreatment process was run for 30 minutes at 50°C. Finally, the treated fabrics were neutralized using acetic acid for 10 minutes.

2.4 Flame-Retardant Finishing Treatment

100% Jute and Jute-Cotton fabrics were treated with PYROVATEX CP NEW according to our previous work (Most Setara Begum et al. 2022) using the exhaust method at 90% (owf) concentration with the material-to-liquor ratio 1:7 in an open bath at room temperature for 1 hour. The KNITTEX FFRC crosslinking agent was used at 30 g/L. Phosphoric Acid (25%) was used to control pH (3.5-6). Finally, the treated samples were dried in air.

2.5 Flammability Test:

The untreated and flame-retardant (FR) treated fabrics were tested using a vertical flammability test. The specimen size was kept 15 cm in length and 5 cm in width and exposed to a standard flame at 90° vertically using a Bunsen burner for 10 seconds of ignition time; the flame source is then removed and left for further burning. Afterwards, the flame spreading time, after glow time and char length was recorded. All tests were repeated three (03) times.

2.6 Physio-mechanical Properties Analysis:

The effect of the flame-retardant finish on the physio-mechanical properties of the treated fabrics was determined by the tensile strength test, the tearing strength test, and elongation at break. For the tensile strength test and the elongation at the break, the maximum force was determined using the grab method (EN ISO 13934-2). The tear force was determined using the single tear method (EN ISO 13937-2(auto-stop)). All tests were repeated three (03) times.

The weight gain of the samples was measured by using Eq. (1) and expressed as a percentage.

\[
\text{Weightgain} (\%) = \frac{W_2-W_1}{W_1} \times 100 \quad \text{Eq. 1}
\]
where, \( W_1 \) and \( W_2 \) indicate the oven-dry weight of the fabric samples before and after FR treatments, respectively.

### 2.7 Surface Characterization:

The surface topography characterization of the fabric samples was examined using a scanning electron microscope (SEM, SU 1510, Hitachi, Japan) by using the Carbo filament technique without coating. An Attenuated Total Reflection-Infra Red (ATR-IR) mode (JASCO 4700, Japan) was used to study the chemical composition changes by FR treatment on both fabrics.

### 2.8 Thermal Properties Analysis:

Thermal Gravimetric Analysis (TGA) was performed under a nitrogen atmosphere with a NETZSCH (Jupiter STA 449 F3) Thermogravimetric Analyzer Instrument. A 10 mg sample was heated from room temperature to 600\(^\circ\)C at 10\(^\circ\)C/min.

### 2.9 Formaldehyde Test:

The free formaldehyde content on the Jute and Jute-Cotton fabric samples was determined by using ISO 14184-1, analyzed using the UV-VIS Spectrophotometer. Formula to calculate the amount of formaldehyde extracted for each sample (\( w_F \)), to the nearest mg/kg, using Eq. 2:

\[
w_F = \frac{\rho \times 100}{m} \quad \text{Eq. 2}
\]

Where, \( \rho \) is the concentration of HCHO in solution, in mg/L, as read in the calibration graph, \( m \) is the mass of the specimen, in grams.

### 3.0 Results And Discussion

#### 3.1 Determination of Flammability:

According to the findings of our previous study (part I), (Most Setara Begum et al. 2022) the treatment condition was optimized at a 1:7 material to liquor ratio for a 90% (owf) concentration of Pyrovatex CP New on Jute fabrics. Apparently, the Jute-Cotton fabric was treated with the same parameters, and the performance was measured.

Figures 1 and 2 represent the vertical flammability properties and digital images of 90% Pyrovatex CP New (1:7) treated Jute and Jute-Cotton fabrics, respectively. Both treated fabrics exhibited good FR ability in terms of flame-spread time and char length. It was observed that after the flame source was removed, the flame spread time was less than one second on the FR treated Jute-Cotton fabric, whereas it was zero on the FR treated Jute fabric. The after-glow time on 100% Jute fabric remained zero, while it was two seconds for the Jute-Cotton fabric. Similarly, a slightly higher char length (2.73cm) was determined on the Jute-Cotton fabric than on 100% Jute (2.2cm). On the contrary, both untreated fabrics were completely (15.0 cm) burned spreading the flame for 21.6 seconds and after glowing for 14.6 seconds on
pure jute and 28 seconds and 17.6 seconds, respectively, on the Jute-Cotton fabrics (Fig. 1). These findings show a significant improvement in flame-retardance in the Jute-based materials used in this study and therefore meet the requirements for FR ability of decorative fabrics (B1 rating, ≤5s) in support of the previous findings (2006; Li et al. 2022).

3.2 Physio-Mechanical Properties Analysis:

The weight gain after the FR treatment was 23.6% and 28.8% for the Jute and Jute-Cotton fabrics, respectively. The extent of physio-mechanical damage was determined through the loss of tensile and tear strength and elongation at break measurements. Figure 3 shows the results of the tensile strength in the warp and weft directions of the Jute and Jute-Cotton fabrics. It can be observed from the figure that the tensile strength decreased significantly in the FR-treated fabrics compared to the untreated fabrics in both directions. About 23% strength loss was observed in the warp direction of the Jute fabrics, while about 21% loss was observed in the weft direction of the same fabrics. On the contrary, the maximum tensile strength loss of approximately 32% was found in the warp direction on Jute-Cotton fabrics, however, a relatively minimal loss was observed (7%) in the weft direction of the Jute-Cotton fabric. These results correspond to a greater strength loss in Jute than in cotton by flame-retardant treatment, since a negligible strength loss was found in the weft direction of the Jute-Cotton fabric. A similar finding was reported in previous research (Lam et al. 2011a, c). Such a reduction in tensile strength can be associated with the use of a cross-linking agent in the flame-retardant finish bath. The cross-linking agent is composed of melamine resin and formaldehyde, which can decrease the strength of cross-linked fibers (Kang 1998; Yang et al. 2000, 2005).

Similarly, tear strength loss was determined on the FR treated Jute fabrics in both warp and weft directions. Although the strength loss trend remains almost similar (Fig. 4a) as the tensile, the strength loss was more than twice in the weft direction (23%) than in the warp (10%). On the other hand, a notable tear strength loss was observed in the warp direction (19%) of the Jute-Cotton fabric after FR treatment, which is almost double that of Jute fabrics in the same direction. Thirteen percent (13%) strength loss was observed in the weft direction of the same fabric (Fig. 4b). Consequently, a similar tear strength loss trend was observed in the warp direction of Jute and the weft direction of Jute-cotton fabrics and vice versa. Such findings coincide with previous research (Lam et al. 2011a, c; Tang et al. 2017b). This happens as the yarns adhere to each other due to the cross-linking agent in the flame-retardant finishing, thus reducing the yarn mobility and tearing strength (Saville 1999).

Figure 5 illustrates the elongation at maximum force applied on the untreated and FR treated fabrics. A significant loss of elongation was observed on the FR treated fabrics in both the warp and weft directions of the Jute and Jute-Cotton fabrics. The maximum loss of elongation (24%) was found in the warp directions of the Jute and Jute-Cotton fabrics, while almost similar results as 12% and 10% were found in the weft directions of the Jute and Jute-Cotton fabrics, respectively. The variances among the initial and final elongation loss on warp and weft directions of Jute-Cotton fabrics can be due to the variances of yarn that is used in both directions. The technical reason behind this elongation loss on the FR treated
fabric can be due to the variation of twist set in the yarns, the resultant crimp on each set of yarns generated from the compactness of weave structures used on both fabrics. Furthermore, the increased cohesiveness between fibers and between yarns can result in a lower elongation for FR treated fabrics and this finding coincides with the previous study (Tang et al. 2017b).

### 3.3 Surface Chemical Composition and Surface Morphology Analysis:

The SEM images of the untreated and treated Jute and Jute-Cotton fabrics are shown in Fig. 6. It can be observed that the untreated samples showed a smooth surface while the images of both FR treated Jute and Jute-Cotton samples exhibit some irregular and rough surfaces, indicating that the surface deposition of flame-retardant chemicals on the fiber occurred during the treatments.

The chemical composition changes of untreated and FR treated pure Jute and Jute-Cotton fabrics are illustrated in Fig. 7. The surface chemical composition of the substrate was determined by FTIR-ATR analysis. These spectra are concentrated in the 4000 to 500 cm$^{-1}$ spectral range. The peaks at 3330, 3338, 3330, and 3338 cm$^{-1}$ in the case of untreated Jute, FR treated Jute, untreated Jute-Cotton, and FR treated Jute-Cotton, respectively, represent hydrogen-bonded (OH) stretching; this is one of the signature bands of the spectrum connected with the α-cellulose in fiber (Obi Reddy et al. 2009; Seki et al. 2013; Chandrasekar et al. 2017; Jothibasu et al. 2020). Similarly, the peaks at 2896 and 2903 cm$^{-1}$ for both untreated and FR treated Jute and Jute-Cotton fabrics, respectively. These peaks represent the presence of the aldehyde group; the existence of CH and CH$_2$ in cellulose and hemicellulose was shown by stretching and bending C-H (Paiva et al. 2007; Kommula et al. 2013). This peak is more visible on both FR treated substrates than on the untreated. The peak was apparent at 2363 cm$^{-1}$ and was associated with the C = C group. The visible peaks of both the FR treated substrates at 1665 and 1657 cm$^{-1}$ are shifted from their untreated substrates at 1636 and 1651 cm$^{-1}$ corresponds to the water molecules (H-O-H group) of the natural fibers (de Rosa et al. 2010; Fiore et al. 2011), as well as the carbonyl groups (C = O) present in lignin and hemicellulose (Sgriccia et al. 2008; Sonia and Priya Dasan 2013). Carbonyl stretching modes of the carboxylate anion cause a new peak at 1551 cm$^{-1}$, which is attributed to the carbonyl bond (C = O) (Yang and Yang 2007; Siriviriyanun et al. 2008; Wu and Yang 2009). These spectra show that the treated specimens have been exposed to a flame retardant chemical. The inherent symmetric bending of CH$_2$ in lignin is related to absorbance at 1430 cm$^{-1}$ (Benhamadouche et al. 2021) and centered on wagging CH at 1316 cm$^{-1}$ (Tang et al. 2017c). The sharp peak centered at 1031 cm$^{-1}$ was associated with the C-O group of the hydroxyl ether groups present in the cellulose (Paiva et al. 2007; Tang et al. 2017c). Peaks at 896 and 903 cm$^{-1}$ of untreated and FR treated specimens, respectively showed β-glucosidic linkage and were attributed to O-C-O stretching during C-H deformation of cellulose. In theory, the cellulose of natural fibers is represented by the 700–900 cm$^{-1}$ region (Pappas et al. 2002; de Rosa et al. 2011).

### 3.4 Thermal Properties Analysis:
Figures 8 (a, b) and Fig. 9 (a, b) show the TGA and DTG curves of untreated and flame-retardant treated jute and jute-cotton fabrics, respectively. The main pyrolysis and rapid weight loss stage is observed around 360°C for untreated Jute and Jute-Cotton fabrics, respectively. This stage corresponds to the dehydration and decarboxylation reactions that produce more combustible gases; the region around 400°C corresponds to the decomposition of char formed during the pyrolysis stage (Shafizadeh 1973; Wang et al. 2007). In the low temperature region, a slight weight loss was observed, and this may be due to the moisture present in the samples. Previous research suggested that cellulose is mostly damaged in the amorphous region of the polymer during the primary stage of pyrolysis (Zhu et al. 2004; Lessan et al. 2011). There is significant weight loss from the sample, and cellulose pyrolysis occurs in the crystalline region of the polymers in the second stage. Glucose and various types of combustible gases are the main pyrolysis products formed in this stage (Zhu et al. 2004; Poon and Kan 2015). Studies reported that thermal decomposition of cotton produces combustible and noncombustible volatiles (Chen 1991). A continuous reduction in mass loss occurred at high temperature due to dehydration and decarboxylation along with the discharge of water, carbon dioxide, and carbonyl (Lessan et al. 2011).

According to the DTG curves, the main decomposition peak for untreated Jute occurs at 356.39°C. A similar pyrolysis stage for FR treated Jute are observed in Figs. 8 and 10, but the decomposition peak shifted to lower temperature at 291.35°C. The early thermal degradation can be due to phosphoric acid that is generated during the pyrolysis of phosphorous-containing compounds present in the flame-retardant chemical. This acts as a dehydrating agent leading to a lower decomposition temperature and a higher remaining char yield. Similarly, for untreated Jute-Cotton fabrics, the main pyrolysis and decomposition stage is observed at 356.39°C; on the other hand, the decomposition temperature is observed at 299.29°C for FR-treated Jute-Cotton fabrics. However, the initial decomposition temperature for FR treated fabrics was also reduced from 257.48 to 215.66 and 266.47 to 217.46 for Jute and Jute-Cotton fabrics, respectively.

The initial degradation temperatures, temperature at highest rate of mass loss and final char yields at 600°C are presented in Fig. 10. The figure shows that the FR treated Jute fabric resulted in a higher char residue (41.30%) at 600°C than the untreated Jute (19.80%). A higher char residue at 600°C is also observed for FR treated Jute-Cotton fabrics (40.47%) than that of untreated Jute-Cotton fabrics (18.54%). The residuary weights of these samples are almost constant above 378.57°C and 306.49°C for untreated Jute and FR treated Jute fabrics, while it was 391.91°C and 340.36°C for untreated and FR treated Jute-Cotton fabrics, respectively. These results indicate a significantly higher char formation in the FR treated fabrics than in their untreated pairs. This happens because FR treatment modified the pyrolytic process of cellulosic fabrics and resulted in the formation of char of cellulosic fibers before pyrolysis (Yang et al. 2012a). Earlier studies suggested that the increase in char formation in these temperature regions corresponds to improved FR performance (Kandola 1997). These results of thermal analysis clearly express the significant improvement in flame-retardancy in FR treated fabrics (Yang et al. 2012b).
Based on toxicological data and epidemiological evidence obtained in workplaces, the International Agency for Research on Cancer (IARC) classified formaldehyde as a Group 1 carcinogen for humans in 2004 (NEWS CENTER 2004; Protano et al. 2022). One of the most debilitating dermatological conditions is allergic contact dermatitis caused by clothing. Formaldehyde-containing resins have been used in the clothing industry to make wrinkle-resistant fabrics since 1926 (Stonecipher 1993; Scheman et al. 1998). The industry now claims that the average level of free formaldehyde in US textiles is between 100 and 200 ppm (Fowler Jr 1992). The free formaldehyde measured in the samples in this study was 127 ppm and 119.4 ppm for the Jute and Jute-Cotton fabrics, respectively (Fig. 11). However, a negligible content of formaldehyde is also found in the untreated samples, which may be due to external contamination. The findings in this study meet the requirements for textiles that are not in direct contact (eg. outerwear). The European Ecolabel (Commission Decision 2002/371/EC) and the private Oeko-Tex Standard 100 are two voluntary labeling schemes that consider ecological and consumer protection criteria. In both schemes, the limit for textiles not in direct contact with the skin (eg. outerwear) and decorative materials is 300 mg/kg. Ecolabel established a limit of 30 mg/kg for textiles in direct contact with the skin, while Oeko-Tex Standard 100 established a limit of 75 mg/kg. Furthermore, Oeko-Tex Standard 100 established a limit for baby textiles that should emit less than 20 mg/kg of formaldehyde (Senaldi et al. 2007; United States Government Accountability Office 2010).

**Conclusion**

The present study investigates the possible opportunity to improve the flame-retardancy properties of jute and jute-cotton fabric by using a commercially available flame-retardant chemical. The thermal stability and FR ability of both fabrics were significantly improved with some loss of physical strengths and properties. The FR treated fabrics showed better char-forming ability during the thermal degradation and combustion stage. FR-treated fabrics showed a significant loss in tensile and tear strength compared to untreated fabrics in both warp and weft directions. The SEM images showed some irregular and rough surfaces in the morphological stage of the fabric, indicating that the surface deposition of flame-retardant chemicals on the fiber occurred during the treatments. The FTIR study revealed that flame-retardant treatment did not affect the natural properties and functional groups on the fiber surface.

The thermogravimetric findings indicate that early decomposition occurred on both FR treated Jute and Jute-Cotton fabrics. Furthermore, at maximum temperature, a significant improvement of the residual mass percentage was also achieved after the flame-retardant treatment on both the Jute and Jute-Cotton fabrics. The TGA results clearly reveal the enhancement of the flame-retardance property on both fabrics after FR treatments. Despite the fact that the formaldehyde content detected in the FR treated samples is quite higher than that under their untreated condition, it still meets the permitted formaldehyde content present in textiles that are designed for external uses and are not worn directly next to the skin.

Lignin in Jute has a tendency to create more char during burning, and char acts as an insulation and inhibits the propagation of the fire. On the contrary, the harsh and brittle nature of Jute fiber is exhibited due to the presence of lignin. To overcome this limitation and hence improve the handle along with the flame-retardant property of fabric, Jute-Cotton combination fabric can act as an influential alternative.
Furthermore, economically Jute fiber is cheaper and the cultivation process is cleaner than that of cotton. The consumption of chemicals, pesticides and water in cotton production is higher, whereas Jute production is associated with minimal uses of chemicals and pesticides. Furthermore, since it grows during the monsoon season, no external water is needed for Jute cultivation. Nevertheless, Jute is still facing challenges in achieving commercial success for potential applications. Therefore, with respect to the environmental aspect of these cellulosic fibers, the jute fiber is more sustainable and promising to meet the requirements for technical applications.

Declarations

Author Contribution Conceptualization, M.S.B. and R.M.; investigation and experimental, M.S.B. and A.K.; writing—original draft preparation, M.S.B.; writing—review and editing, M.S.B. and R.M.; visualization, M.S.B. and R.M.; supervision, R.M. All authors have read and agreed to the published version of the manuscript.

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Consent to participate Not applicable.

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Code availability Not applicable.

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**Figures**

![Flammability Properties of Jute and Jute-Cotton Fabrics](image)

### Figure 1

Flammability Properties of Jute and Jute-Cotton Fabrics (M:L: 1:7, Pyrovatex CP New: 90% owf)
Figure 2

Digital images of Char formation after vertical flammability test of (a) Untreated Jute Fabric, (b) FR Treated Jute Fabric, (c) Untreated Jute-Cotton Fabric and (d) FR Treated Jute-Cotton Fabrics

Figure 3

Tensile Strength of (a) Jute and (b) Jute-Cotton Fabrics
Figure 4

Tear Strength of (a) Jute and (b) Jute-Cotton Fabrics

Figure 5

Elongation at Maximum Force of (a) Jute and (b) Jute-Cotton Fabrics
Figure 6

SEM Images of (a) Untreated Jute, (b) FR Treated Jute; (c) Untreated Jute-Cotton and (d) FR Treated Jute-Cotton Fabrics
Figure 7

FTIR results of Untreated and FR Treated Jute and Jute-Cotton Fabrics
Figure 8

TGA curves (a) and DTG (b) curves of Jute textiles under nitrogen

Figure 9

TGA curves (a) and DTG (b) curves of Jute-Cotton textiles under nitrogen
Figure 10

Thermogravimetric Analysis Data of Jute and Jute-Cotton Fabric Samples
Figure 11

Formaldehyde content measured in the samples