Development of Water-Repellent Jute Fabric as a Sustainable Solution for Bag Production

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GRAPHICAL ABSTRACT

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This study explored a sustainable solution for creating water-repellent jute fabrics as an eco-friendly alternative to plastic-based shopping bags. After treating jute fibers to a mixture of the agents NUVA N2114 (fluorinated acrylate copolymer), Acetic Acid, and Arkophob DAN (polycarbodiimide-based crosslinking agent), a fabric that repellent water and preserving the natural texture was developed. The fabrics after the treatment passed the spraying test with good results, thus offering a great prospect in the realistic application of the concept of the environmentally friendly textile products. Besides enhancing the application of jute, this study also fosters local farming and green options in the global material sector. It is a small step toward greener choices, using the strength of natural fibers to meet modern needs.

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Keywords: Sustainable solution; Water repellent jute; Shopping bags; Ecologically friendly; Green options

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INTRODUCTION

Plastic and polyethylene bags have been widely used by people around the world for many years. Millions of landfills are reaching their capacities with plastic wastes. These landfills take up trillions of hectors of land and release hazardous gases, as well as carbon dioxide and methane as they decompose, in addition to releasing highly toxic leachates (Madara *et al*. 2016). Because of this detrimental environmental impact, there is a growing need for eco-friendly alternatives to plastics. The jute (*Corchorus* plant) fiber is also known as the "golden fiber" of Bangladesh. This study aimed to develop jute-based composite fabric materials using a water repellent chemical solution. By harnessing the unique properties of jute fiber, which is biodegradable and environmentally friendly, the objective was to create water-repellent composite materials to produce sustainable bags (Shah *et al*. 2021).

This study acknowledges the inherent potential of jute as a renewable resource and endeavors to restore its market value while addressing environmental concerns. By incorporating innovative techniques and technologies, a jute-based composite material that possess water-repellent properties would enhance its functionality while maintaining its eco-friendliness. The successful development of these type of composite materials will revive jute's market value and offer a sustainable solution for jute-based shopping bag production. By minimizing the reliance on plastic and polyethylene and utilizing jute fibers, this research presents a promising avenue for economic growth and environmental conservation in Bangladesh (Jahan *et al*. 2019).

For optimal growth, jute plants need warm to moderate temperatures (20 to 40 °C), high relative humidity (70% to 80%), and grassy soil. They also need 125 to 150 mm of rainfall per month. Jute is grown on plantations and harvested when the plant reaches maturity (Rahman 2010; Ullah *et al*. 2017). To make it easier to harvest the fibers, the plants then are usually retted in slowly flowing water. If necessary, alternative methods for eliminating the fibers without retting can be employed. After drying, the jute fibers are sold for additional processing (Rahman 2010; Ullah *et al*. 2017). Jute fiber has three components: top, middle, and bottom. The middle section of the jute fiber generally exhibits better tensile characteristics than the top and bottom sections (Shahinur *et al*. 2021). Jute fibers are frequently used to make yarn, and jute yarn is used to make jute fabrics. Figure 1 displays some data and statistics regarding the jute fiber.

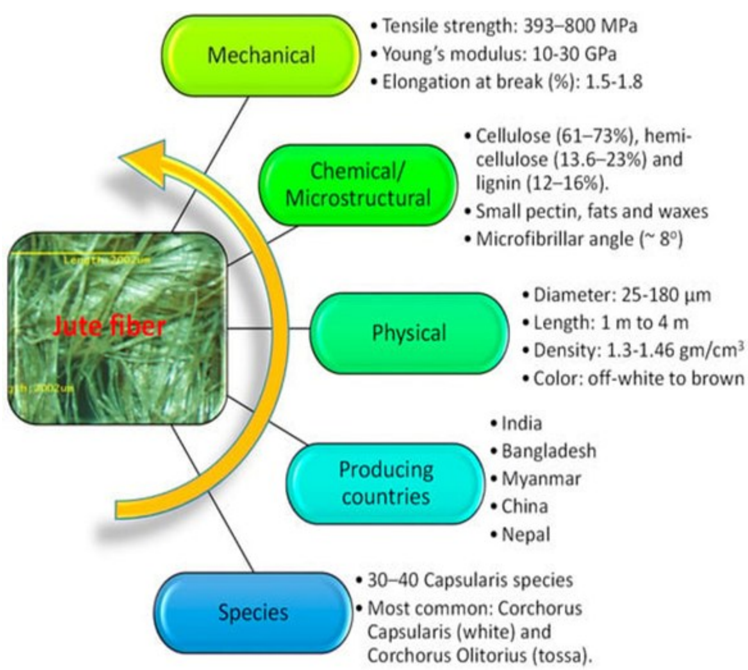

Fig. 1. Facts about jute (Rana and Jayachandran 2000; Dhanasekaran and Balachandran 2008; Shahinur *et al*. 2015; Burrola-Núñez *et al*. 2018)

Jute is sometimes treated with various media to improve its functional qualities (Shahinur *et al.* 2021). Additionally, jute is a sustainable raw material for chemical products, such as carboxymethyl cellulose (CMC), microcrystalline cellulose (MCC), pulp, and composite products for structural applications (beam, plate, bar), as well as conventional textile products including hessian, nursery pots, shopping bags, sacking, and carpet backing cloth (CBC). Jute fiber is superior to many natural or synthetic fibers in terms of sustainability and mechanical qualities (Chandekar *et al.* 2018). The greatest effort has been focused on the development of thermosets and thermoplastic-based fiber-reinforced composites as structural materials. By using less synthetic polymer ingredients, the addition of jute fibers to a synthetic polymer matrix could increase its strength while also promoting environmental sustainability.

Despite the fact that jute fibers have been the subject of extensive research and that pertinent review papers have been published (Faruk *et al*. 2012; Pujari *et al*. 2014; Singh *et al*. 2018; Ashraf *et al*. 2019; Gogna *et al*. 2019, Rabbi *et al*. 2020; Sanivada *et al*. 2020; Shelar and Narendra Kumar 2021), the cited studies focused primarily on jute as a sustainable raw material for the development of composite materials.

Jute is lauded as the second most organic, environmentally friendly, and biodegradable fiber after cotton (Song *et al*. 2021). It can be a great substitute where strength, heat conductivity, and expense are major considerations. These days, research on jute fiber-reinforced polymer composites is crucial (Mishra and Biswas 2013; Ahmadi and Dastan 2017; Sinha *et al*. 2017; Ilman and Hestiawan 2018; Panigrahi *et al*. 2018, Selver *et al*. 2018). Jute fiber is typically utilized for basic and low-end textile items. The environment and the cost would both be substantially improved if the characteristics of jute were changed to better suit high-value and advanced textiles. Cellulose (45% to 71.5%), hemicelluloses (13.6% to 21%), and lignin (12% to 26%) make up jute (Sinha *et al*. 2017; Selver *et al*. 2018). Lignin provides mechanical support because it contains numerous aromatic rings (Radzi *et al.* 2023; Selver *et al*. 2018). Gum is any substance other than cellulose that impairs jute's fineness, flexibility, and smoothness (Sinha *et al*. 2017).

For natural fibers, alkaline treatment commonly is carried out using sodium hydroxide (NaOH) within a specific concentration range. Such processing is widely employed to modify surface and structural characteristics. This treatment, often referred to as mercerization when performed under defined NaOH conditions, disrupts the original hydrogen-bonded network of cellulose. Although the initial swelling and rearrangement of cellulose breaks some hydrogen bonds, an approximately equivalent number of new hydrogen bonds are formed upon structural reorganization. As a result, the key effects of alkaline treatment arise not merely from changes in fiber diameter or aspect ratio, but also from improvements in surface roughness, removal of hemicellulose and lignin, increased fiber fibrillation, and enhanced interfacial adhesion with polymer matrices (Cavallaro *et al*. 2017). In order to study the thermal and mechanical properties of jute fibers using vacuum-assisted resin infusion, various surface treatments of jute fibers have been reported recently, including silane treatment, alkali treatment, and octane and alkali treatment of jute fibers and their corresponding jute fiber-reinforced composites (Liu *et al*. 2010). In a different study, the surface characteristics of jute fabric-reinforced composites with a polyester matrix were improved by the application of two well-known textile finishing agents, fluorocarbon and micro-silicone, and their flexural, tensile, and interlaminar shear strengths were examined (Dilfi *et al*. 2018).

Recently, there has been an increase in interest in creating environmentally friendly and sustainable materials, and jute composites have been shown to be a viable choice. Natural fiber made from the *Corchorus* plant is cheap, readily available, and biodegradable. But in order to fully realize its potential and customize it for a variety of uses, scientists and producers have been investigating the application of other matrices, including as thermosets, thermoplastics, and bio-based polymers.

In response to these challenges, researchers and engineers have been actively exploring the application of water-repellent coatings or treatments to jute composites. These coatings are designed to create a hydrophobic barrier on the surface of the composite, preventing or reducing the ingress of water molecules into the jute fibers. Commonly used water-repellent materials include silicone-based compounds, fluoropolymers, and nanoparticle-based coatings. The application of water-repellent coatings serves several crucial purposes. Firstly, it enhances the durability of jute composites by shielding the fibers from moisture-related damage. This results in composites that exhibit improved dimensional stability and resistance to swelling, which is vital for maintaining structural integrity in various applications.

Water-repellent treatments also extend the application range of jute composites. They become suitable for use in outdoor construction materials, where exposure to rain and humidity is frequent, or in marine environments, where resistance to saltwater is essential. Additionally, these treated composites can be used in furniture and other products where resilience to high hum or sporadic spillage is required.

EXPERIMENTAL

Materials

Jute fabric was obtained from a local market in Bangladesh. This fabric was used as base material and is biodegradable. Archroma commercial water-repellent agent NUVA N2114 was used to obtain durable hydrophobic characteristics to the jute fabric without compromising breathability. In order to ensure the NUVA N2114 finish to the fabric, a crosslinking agent, Arkophob DAN was used, which improves the durability of the water-repellent finish. The pH of treatment bath was set using acetic acid. All the chemicals used were of reagent grade and were purchased from local chemical suppliers in Bangladesh. A singeing machine (to clean the surface), digital electronic balance (to accurately weigh the chemical), pH meter (to check the acidity of the solution), padding machine for the uniform application of the chemical solution and stenter machine (drying and setting) were used in the process of conducting the treatment. NUVA N2114 is a fluorinated acrylate copolymer (C6-based fluorochemical), and Arkophob DAN is a polycarbodiimide-based crosslinking agent that reacts with hydroxyl groups in cellulose and the fluoropolymer.

Treatment of the Jute Fabric

To eliminate the protruding fibers and make the surface level in order to have a good adherence of the finish, a singeing process was adopted, which imparted water-resistance in the fabric. This jute material was subsequently padded through a mixture of a special formula blend that consisted of the NUVA N2114, acetic acid, and Arkophob DAN. The experiment was repeated by varying the concentration and process conditions, and an optimal recipe was obtained. The fabric after padding was dried and cured in the stenter machine at temperature 155 to 165 °C and 2 min to ensure that chemicals were well bonded to the fiber surface. During curing (155 to 165°C), NUVA N2114 forms a thin fluorocarbon film that lowers surface energy. Arkophob DAN crosslinks with cellulose hydroxyl groups, anchoring the fluoropolymer firmly and improving wash durability and repellency.

Fig. 2. Jute fabric treatment flow chart

Table 1. List of Raw Materials, Quantity, and Instruments

Raw Materials	Quantity (g/L)	Instruments
NUVA N2114	100, 120, 140	1. Padder 2. Stenter
Acetic acid	0.5-1	
Arkophob DAN	10	

Each jute fabric sample was passed twice through the padding mangle at 2 bar pressure and 1.5 m/min speed, ensuring uniform impregnation of the finishing solution. The wet pick-up was maintained at approximately 80% ± 5%.

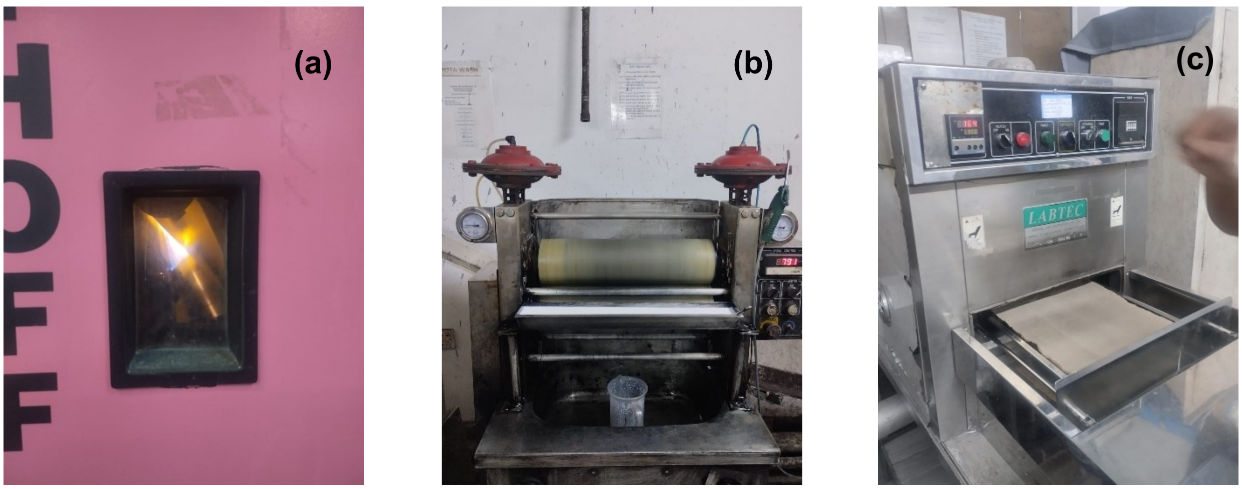

Fig. 3. (a) Singeing (b) Padding and (c) Stentering

Evaluation of Water Repellence

Three testing techniques used were described below:

Spray rating test

The water spray test is a qualitative technique, and it was used to test the water repellence of a fabric to wetting on the surface. It was regularly used to measure the performance of water-repellent finishes on fabric. In the test, a specific volume of distilled water was sprayed on a taut, conditioned fabric specimen mounted in a hoop. The pattern and degree of wetting were then visually compared to a standard rating chart.

Standard test conditions:

i. Specimen Size: 180 mm × 180 mm (7 in. × 7 in.)
ii. Conditioning: Minimum 4 h at 65% ± 2% relative humidity and 21±1 °C (70 ± 2°F)
iii. Water Volume**:** 250 mL of distilled water at 27 ± 1°C (80 ± 2°F)
iv. Spray Time: 25–30 s
v. Apparatus: AATCC Spray Tester
vi. Assessment: Visual comparison to a standard chart

Table 2. Water Spray Test Ratings Table (AATCC 22)

Rating	ISO Equivalent	Description
100	ISO 5	No sticking or wetting of the specimen face
90	ISO 4	Slight random sticking or wetting of the specimen face
80	ISO 3	Wetting of the specimen face at spray points
70	ISO 2	Partial wetting of the specimen face beyond spray points
50	ISO 1	Complete wetting of the entire specimen face beyond spray points
0	–	Complete wetting of the entire face of the specimen

Drop test

This visual test was used to evaluate water repellency. A material with lower surface tension than water was considered water repellent. Water droplets placed on such a surface remained on top and did not penetrate.

Absorption test

The absorbency or spot test was applied to find out the rate at which a fabric absorbed a liquid (usually water). In the procedure, a distilled water drop was applied on the surface of the cloth, and the absorption time of the drop was noted. The fabrics which easily absorbed the droplet were defined as hydrophilic and those that did not absorb easily were regarded as water-repellent.

RESULTS AND DISCUSSION

Drop Test

Under the drop test, one drop of pure water was placed upon the upper part of the untreated and treated jute fabrics. The repellency of the water was determined by the way the droplets behaved. In case of the untreated jute fabric, a water drop was directly absorbed by the surface of the fabric. Such droplets can be seen in Fig. 4, but not in Fig. 5.

Fig. 4. Treated jute fabric

Fig. 5. Untreated jute fabric

This meant that the raw jute fibers were hydrophilic in nature since they are composed of natural cellulose. Conversely, water repellancy was greatly achieved on the treated jute cloth that was subsequently completed by a combination of NUVA N2114, Arkophob DAN, and a crosslink agent. The water droplet stood on the surface in a shape that is close to a sphere, and it had not gone into the fabric during the observation process. This observation can be seen in Fig. 4. This kind of behavior was an indication of a successful change in the surface energy of the fabric making it have lesser affinity to water.

Absorption Test

From the absorption test, it was observed that the region of interest did not absorb the water droplets and was not wetted. Figures. 6 and 7 shows samples after this test. Compared to an untreated jute (Fig. 6), the treated jute was completely dry. It was observed that after 2 min of waiting, the droplets did not penetrate the treated water-repellent layer; the surface was arid. However, as they got wet in the untreated samples, the wet mark was clearly visible, as indicated in Fig. 7.

Fig. 6. Treated jute fabric

Fig. 7. Untreated jute fabric

Spray Rating Test

The spray test results showed that all three treated samples (Samples 1, 2, and 3) provided improved water resistance to jute fabric. With increasing concentrations of Nuva N2114 (100 g/L, 120 g/L, and 140 g/L) and curing at 155 °C and 165 °C, the spray ratings progressively improved, indicating higher levels of water repellency.

Table 3. Spray Rating of Jute Fabric Treated with Nuva N2114

Sample No.	Concentration (g/L)	Chemical	Spray Rating (155 °C)	Spray Rating (165 °C)
01	100	Nuva N2114	80	80
02	120	Nuva N2114	90	90
03	140	Nuva N2114	100	100

In particular, Sample 3, which had been dipped in 140 g/L of Nuva N2114 and cured at 155 and 165 °C, testified a spray value of 100, indicating the highest score in the

AATCC Method 22. This finding validates great hydrophobicity, such that it was hard to detect any wetting on the cloth surface. Additional washability trials (20 washing cycles at 40°C) were conducted for Sample 03. Results showed that treated samples retained above 85% of their initial repellency (spray rating: 90 after 1st wash, 80 after 20th wash).

Fig. 8. Spray rating test

Fig. 9. Different types of bags with treated jute fabric

After successful treatment, various types of jute bags were produced using the treated fabric. These included a pencil bag, a ladies' purse, a laptop bag, and a school bag. The treated material provided enhanced water resistance and durability. The improved bags were priced at double that of an everyday jute bag. Its robustness and capacity to shield the contents from inclement weather justify this cost. As a result, it is expected to attract consumers looking for reliable bags for their daily and weekly shopping trips, ultimately boosting the demand for jute as a primary raw material. This, in turn, will benefit Bangladeshi jute cultivators (Ssegawa and Muzinda 2021).

Manufacturing Cost Analysis

Table 4 indicates the comparison of the manufacturing cost of water-repellent school bags between low GSM and high GSM treated jute fabrics. The two give 1000 bags in 500 yards. Although the price of fabric, spending on treatment and transportation and profit margin are the same, the cost of the fabric is very different, which is 65 BDT when GSM is low and at 150 BDT when GSM is high. Consequently, the low and the high GSM cost per bag is 900 BDT and 980 BDT, respectively.

Table 4. Water Repellent School Bag Manufacturing Cost

Item	Low GSM Fabric	High GSM Fabric
Pieces/Yard	1000 pcs / 500 yards	1000 pcs / 500 yards
Swing	4.94 USD (per pcs)	4.94 USD (per pcs)
Fabric Cost	0.54 USD (per pcs)	1.23 USD (per pcs)
Treatment Cost	0.82 USD (per pcs)	0.82 USD (per pcs)
Transport Cost	0.25 USD (per pcs)	0.25 USD (per pcs)
Profit	0.82 USD (per pcs)	0.82 USD (per pcs)
Total Cost	7.41 USD (per pcs)	8.07 USD (per pcs)

Table 5. Evaluation of Market Feasibility and Economic Impact of Water-Repellent Jute Bag

Product Name	Price (USD)	Biodegradability
Jute bag	0.82-6.59	Good
Canvas bag	2.47-12.35	Good
Cotton grocery bag	0.41-4.12	Good
Polyester shopping bag	1.23-6.59	Poor
Leather bag	4.12-41.18	Good
Nylon backpack	0.82-41.18	Poor
Paper bag	016-1.65	Good
Woven straw beach bag	1.65-8.23	Good
Plastic grocery bag	0.16-1.65	Worst
Water-repellent jute bag	1.23-8.23	Good

In Table 5, a comparison is made of different kinds of bags in terms of price and biodegradability. Compared to the other options, jute, cotton, canvas, paper, leather, and woven straw bags are biodegradable hence environmentally friendly. On the other hand, polyester, nylon, and plastic bags fare the worst in terms of biodegradability. The water-repellent jute bag, priced between 150 to 1000 BDT (1.37 to 9.10 USD), combines eco-friendliness with added functionality, offering a sustainable and practical alternative.

CONCLUSION

1. In conclusion, the quest to enhance the resistance of jute composites to moisture absorption through water-repellent coatings or treatments underscores the commitment of the scientific community and industries to harness the full potential of sustainable materials. These efforts not only extend the range of applications for jute composites but also contribute to the overarching goal of creating eco-friendly and durable materials capable of thriving in a variety of challenging environmental conditions. As research in this field continues, one can anticipate further advancements in water-repellent technologies for jute composites, making them even more versatile and resilient in humid or wet environments.

2. Finally, the development of water-repellent jute-based composites not only offers a sustainable and environmentally friendly solution for bag production but also holds the promise of revitalizing the market value of jute, benefiting the farmers and economy of Bangladesh. By introducing innovative and eco-conscious materials, this research contributes to the broader goal of fostering sustainability and driving new dimensions of innovation in composite materials globally.

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Competing Interests

The authors declare that they have no competing interests.

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