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Research article

Sustainable development of three distinct starch based bio-composites reinforced with the cotton spinning waste collected from fiber preparation stage

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ABSTRACT

Composites are new materials that combine two or more distinct components with diverse properties to create a new material with improved properties. The goal of this endeavor was to use fiber preparation wastes, or waste from cotton spinning mill blow room and carding, to produce bio composites based on starch. The matrix was prepared using the starches of potatoes, maize, and arrowroot, and any remaining reinforcing material was used. A hand layup technique was used to make the bio-composites. Tensile, bending, density, water absorbency, and SEM testing were among the studies used to illustrate the starch-based biodegradable materials. The maximum tensile strength of 0.49 MPa is displayed by sample AB. The resistive bending force of 3.71 MPa is greatest in Sample AB. The most uniform combination of reinforcing material (wastage cotton) and matrix is seen in PB's SEM picture. Among the samples, AB had the greatest density value, measuring 0.35 g/cm3. The sample PC had the highest absorption findings in both water and the 5 % HCl combination because carding waste had more fiber than blow room and fiber absorbs more water. The resultant bio-composites made of starch had the potential to replace Styrofoam.

1. Introduction

Cotton spinning is highly dependent on the global textile industry as cotton yarn is a crucial raw material used in the production of many textile products, such as clothes, household textiles, and fabrics [1]. The primary causes of changes in the demand for cotton yarn include the following: population growth, global economic conditions, fashion trends, industrial needs, the cost of substitute fibers, regional considerations, technical developments, sustainability and environmental concerns, and trade regulations [2]. An enormous variety of final goods are made from the 27 million tons of cotton that are produced each year [3]. With today's technology Cotton fiber is spun using ring, rotor, air-jet, and friction spinning systems to create cotton yarn [4]. The carding process wastes around 8–12 % of the cotton fibers, which are then transformed into yarn. The combing process increases this proportion to 15–20 % [5–7]. Hard waste and soft waste are the two categories into which these wastes are divided. Relatively open-structured trash that may be used

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immediately in an early feed stage is referred to as soft waste. The production of soft waste occurs from the blow chamber to the ring frame. You may produce lower category yarn again with these supple remnants. Garbage containing fibers that are sealed and require additional processing before they can be repurposed with soft trash is known as hard waste. These wastes are produced throughout the weaving process, ring frame, winding, and weaving preparation [8]. In 2020, the projected global production of cotton yarn was 28.95 million metric tons. Assuming an average waste rate of 3 %, the amount of yarn spinning waste discarded annually comes to about 869, 500 metric tons [9]. Even though these solid wastes can be recycled or used to make other sorts of commodities, they are often disposed of in landfills in many developing country enterprises [10,11]. They thus contribute to greenhouse gas emissions issues and need a significant quantity of landfill area [11]. Recycling trash from spinning and weaving becomes more and more important over time since it is good for the environment and the economy. Valuable spinning and weaving waste may be recycled or reused to save raw material costs, increase material utilization efficiency, and increase profitability [8].

There were some disadvantages to expanded polystyrene foam, frequently marketed under the name Styrofoam, especially with regard to the environment [12]. Foods, electronics, and other fragile things are often packed in plastic, especially polystyrene or Styrofoam, to preserve and protect them [13]. Single-use packaging poses a risk to the environment and public health when thrown out since it can become urban or marine trash. Plastic is a pollutant that may be found in water sources all around the world and is estimated to make up between 60 and 95 percent of marine waste [14]. This plastic waste is being consumed by fish and other marine life [15]. A study of 29 flooded locations in Swiss nature reserves found microplastic contamination in 90 % of the soil in floodplains [16]. Aside from this, some of its drawbacks include restricted reusability, hard recycling, and non-biodegradability [17]. Numerous actions are being done to replace Styrofoam [18]. Modern industry and commerce require the development of biodegradable polymers since synthetic plastics have detrimental environmental consequences [19]. Scientists have developed a range of starch-based composites for a number of applications [20]. To make biodegradable polymers, renewable biomass is employed to provide protein, cellulose, chitosan, and starch [21]. The majority of the rise in bioplastics is predicted to reduce carbon dioxide emissions, plastic waste, and fossil fuel use. These polymers' biodegradability not only has positive societal effects but also attracts corporations and academics to the subject of biodegradable packaging [22]. Nearly 50 % of the bioplastics used in commerce are made from starch. Bioplastics based on starch are simple to produce and are often used in packaging [23,24]. For the purpose of creating packing materials, starch is combined with glycerol and frying oil as a plasticizer due to its exceptional tensile properties [25]. Pure starch has a white hue. The starch powder doesn't have a particular taste or scent. Moreover, pure starch is insoluble in both alcohol and cold water. In starch, two different kinds of molecules are present: linear and helical amylose and branching amylopectin [26]. In this investigation, three distinct kinds of starches were employed. These three forms of starches' chemical make-up is mentioned below Table 1.

Cornstarch, which comes from the cereal maize, is a renewable and sustainable resource [29]. Because of its biodegradability, it can be used as a sustainable alternative to synthetic materials in the creation of composites. Because cornstarch is a plant-based component, using it in composites rather than petroleum-based alternatives can help decrease carbon emissions. Its capacity to flow and soften allows it to be molded into a variety of forms [29–31]. Potato starch is primarily composed of two polysaccharides, amylose and amylopectin, which are closely packed together [32]. Because it may decompose naturally, it is a more environmentally friendly option than composite materials. When exposure to moisture or humidity is a concern, such as in outdoor structures or packaging, potato starch composites can exhibit good moisture resistance [33–35]. Arrowroot starch works well as an adhesive when mixed with natural fibers like cellulose, bamboo, or jute [21]. Aside from improving the mechanical properties of the composite, its superior adherence strengthens the bond between the matrix and the reinforcing fibers. Since arrowroot starch-based composites frequently have low densities, they are useful when weight reduction is essential [36,37].

In a study that was published, maize starch served as the primary matrix preparation material and was reinforced with spinning filter waste [38]. A biocompatible arrowroot starch and fiber composite was created [39]. Films made of sugar palm starch reinforced with sugar palm nano fibrillated cellulose were created [40]. The uniqueness of this study was guaranteed by the fact that no researcher has previously tried to integrate spinning line filter wastes with arrowroot and potato starch produced matrix.

The aim of this study was to create novel composite materials using distinct starch sources and evaluate their suitability as a possible substitute for Styrofoam in packaging applications. After the composite was created using a manual lay-up technique, morphological and mechanical analysis of the bio composites was conducted.

Table 1
Amylose and amylopectin concentrations in different kinds of starch.

Parameters	Corn Starch	Arrowroot Starch	Potato Starch
Moisture (%)	10.821	13.11 ± 0.25	15.981 ± 0.36
Ash Content (%)	0.323	0.161 ± 0.05	0.162 ± 0.05
Fat (%)	0.322	0.252 ± 0.04	0.291 ± 0.10
Protein (%)	0.381	0.831 ± 0.02	4.542 ± 0.28
Fiber (%)	0.102	0.031 ± 0.01	0.471 ± 0.01
References	[20]	[27]	[28]

2. Materials and methods

2.1. Materials

2.1.1. Cotton waste collection

The materials used for reinforcement were gathered from Al haj Karim Textile Ltd. located in Manikganj, Dhaka, Bangladesh. Because of the variations in the quantity of waste and short fibers, the characteristics of blowroom and carding waste were varied. The short fibers were isolated from both wastes using the Shirley Trash Analyzer. The waste from blowers included 44 % garbage and linters and around 56 % short fiber with a 4.3 Mic value (fiber fineness). Similarly, carding wastes included 26 % trash and linters along with around 74 % short fiber with a 3.6 Mic value (fiber fineness). Trash and linters, as seen in Fig. 1, were the primary reinforcing materials once the short fibers were separated. Where Fig. 1 (a) waste collected from blow room and Fig. 1 (b) the waste from Shirley Trash Analyzer machine.

2.1.2. Corn and arrowroot collection

In local markets, corn flour is commonly referred to as corn starch. Local markets also sell arrowroot on a business basis. The Shah Smrity Market in Mirpur-1, Dhaka, was the source of both cornstarch and arrowroot starch.

2.1.3. Potato starch extraction

In order to extract the starch from the potatoes, potatoes were gathered at the Mirpur-1 local market in Dhaka. After being sliced into smaller pieces, the potatoes were mixed to create a homogeneous paste. It was combined with a small quantity of water to form a paste, which was subsequently sieved through a strainer set over a basin. It was processed into a smooth powder after drying [41].

2.2. Method

2.2.1. Fabrication of bio composite

The matrix material of each sample was reinforced with 15 % weight proportion of gathered cotton waste. Together with water (70 % w/w), glycerol (2.5 % w/w), vinegar (2.5 % w/w), and starch (10 % w/w) as plasticizers, these three starches were mixed to form a paste [20]. To make the matrix, all of the ingredients were heated to 70 °C until the starch began to gelatinize. It took two or 3 min for the starch to gelatinize. After it had gelatinized, the waste materials were added. There was no need for heat to facilitate the mixing of the wastes because the process was conducted at room temperature. The hand layup process was utilized to manufacture the composites, maintaining evenness, and 5 kg of dead weight was applied to provide a flat form. The same process was used to create six distinct types of samples, Fig. 2(a–f) which were identified by the letters PB, PC, CB, CC, AB, and AC. It was then allowed to cool and sun-dried for ten days. Fig. 2 displayed pictures of the samples that were eventually generated.

Fig. 3 below shows the working process flow diagram that was used to create each sample.

The below Table 2 showed the sample details with its abbreviation.

2.2.2. Characterization

2.2.2.1. Tensile strength. In compliance with ASTM D638 tensile tests were conducted on dog-bone-shaped samples [21] employing the USA-made, 60000-pound capacity universal testing machine (UTM). The sample's dimensions were 7.2 mm in thickness, 20 mm in breadth, and 100 mm in length. The measurements were taken using a gauge length of 50 mm and width of 12.5 mm, with a crosshead speed of 10 mm/min after conditioning at 25 °C and 65 % relative humidity. For the purpose of measuring the average outcome, three replicates from each sample were evaluated.

2.2.2.2. Flexural strength. The ASTM D790 three-point bending test technique was applied using a UTM [42] norm for figuring out flexural strength. The samples measured 82.8 mm × 35.3 mm × 8.1 mm and were subjected to a crosshead speed test at 1.4 mm/min.

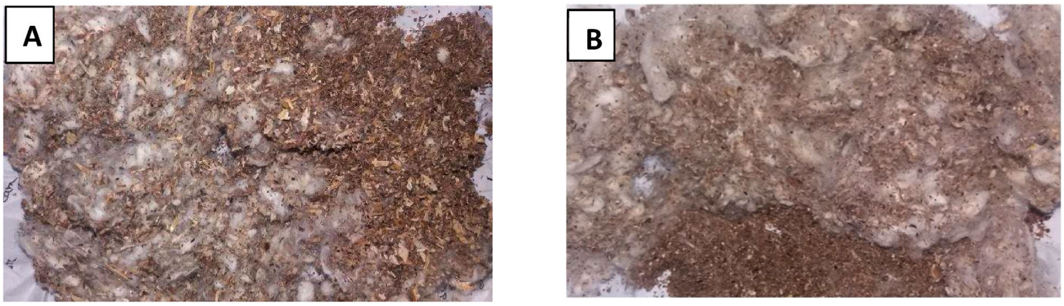

Fig. 1. a. Blow-out room waste b. after utilizing Shirley Trash Analyzer, carding waste.

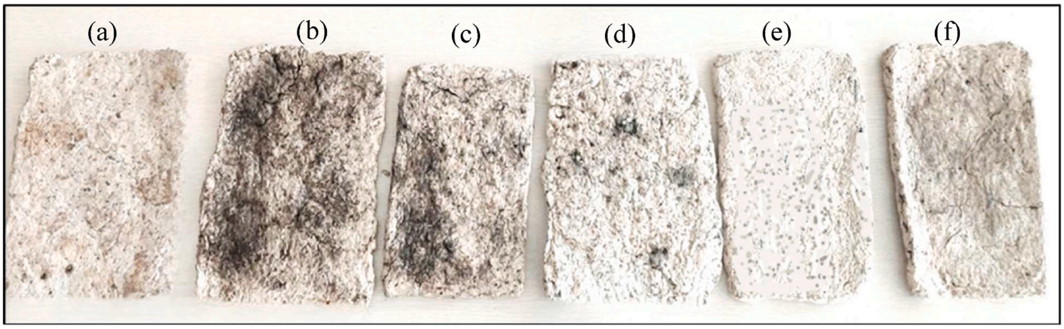

Fig. 2. Finished item following preparation (a) C_B, (b) A_C, (c) A_B, (d) P_B, (e) P_C, (f) C_C.

For the purpose of measuring the average outcome, three replicates from each sample were evaluated.

2.2.2.3. Density measurement. ASTM D4052 was used to compute the weight (m) and volume (v) of the composite samples [43] a technique where their density was calculated using 1 cm by 1 cm dimensions. The thickness was measured using a BSW Aluminum Vernier Caliper (Brand: BSW, Size/Dimension: 50–300 Mm, UK) with an accuracy of ± 0.02 mm. The average thickness value from 10 random measurements was computed for each composite. The composite densities were calculated using the equation.

$$\rho\left(\frac{g}{cm^3}\right) = \frac{m}{v} \tag{1}$$

Here in equation (1), ρ = sample's density expressed in grams per cubic centimeter, m = sample's mass expressed in grams and v = sample's volume expressed in cubic centimeters.

2.2.2.4. Water and acid absorption. Through the measurement of a coupon's total mass change after exposure to a certain environment, the ASTM D5229 [44] The moisture content is tracked over time using the water absorbency or moisture content test technique. Equation (2) is applied to calculate the liquid absorption percentage. All samples were trimmed to 3.5 cm in length and 2 cm in breadth for this test method. Next, fill a glass beaker with 250 ml of water. Currently, weigh the sample dry mass after it has been measured in a dry state, soaked in water ten times for 1 min, and then weighed every minute. In a similar manner, for each sample. The remaining methods for this test procedure are the same as the previous one, except 5 % HCl is to be used in place of 250 ml of water. Fig. 4 depicted the testing process's preparation. Based on the volume of water on the surface before to being weighed, a formula was developed to determine the mass gain in percentage after immersion.

$$Increase\ in\ mass(percent) = \frac{Conditioned\ mass - Dry\ mass}{Dry\ mass} \times 100\% \tag{2}$$

2.2.2.5. SEM analysis. The SEM image was taken in order to study the morphological characteristics of the interactions between the matrix and filler. That machine's operating specifications were secondary electron imaging mode and 10 KV accelerating voltage. There was a 20 ×mm working distance and 500× the magnification. The gadget has the HITACHI SU1510 model number.

3. Results and discussion

3.1. Tensile strength

The strain was shown on the x-axis as a percentage, and the stress was shown on the y-axis as megaPascals (MPa). The material's reaction to applied pressures is demonstrated by the graph in Fig. 5, which indicates that as strain increases, stress also tends to increase. Sample PB displayed the maximum stress value, measuring 0.48 MPa, which is equivalent to a 1.2 % strain. With a stress of 0.46 MPa and a strain of 1.2 %, PC is in close second. With equivalent strains of 1.5 % and 1.3 %, samples CB and CC displayed somewhat lower stress values of 0.44 MPa and 0.42 MPa, respectively. Sample AB showed the least amount of stress out of all the samples, with a strain of 1.1 % at 0.36 MPa.

With a value of 0.49 MPa, sample AB had the maximum tensile strength, as shown in Fig. 6. AC, which has a tensile strength of 0.46 MPa, comes next. At 0.37 and 0.38 MPa, respectively, PB and CB's tensile strengths were somewhat lower.

Lastly, at 0.36 MPa, CC's tensile strength was the lowest of all the samples. The cotton waste from blow rooms had more debris, which improved the composite's tensile strength. Because the PC sample matrix was evenly combined with carding cotton waste, the PC sample's tensile strength was greater than the PB sample's.

With an elastic modulus of 40.83 MPa, Sample AB had the highest of all the samples, according to Fig. 7.

CB, who had an elastic modulus of 38 MPa, came next. PC exhibited an elastic modulus of 34.17 MPa, which was somewhat lower than that of CC and PB, which were 32.72 MPa and 30.83 MPa, respectively. The fluctuation in elastic modulus values for several

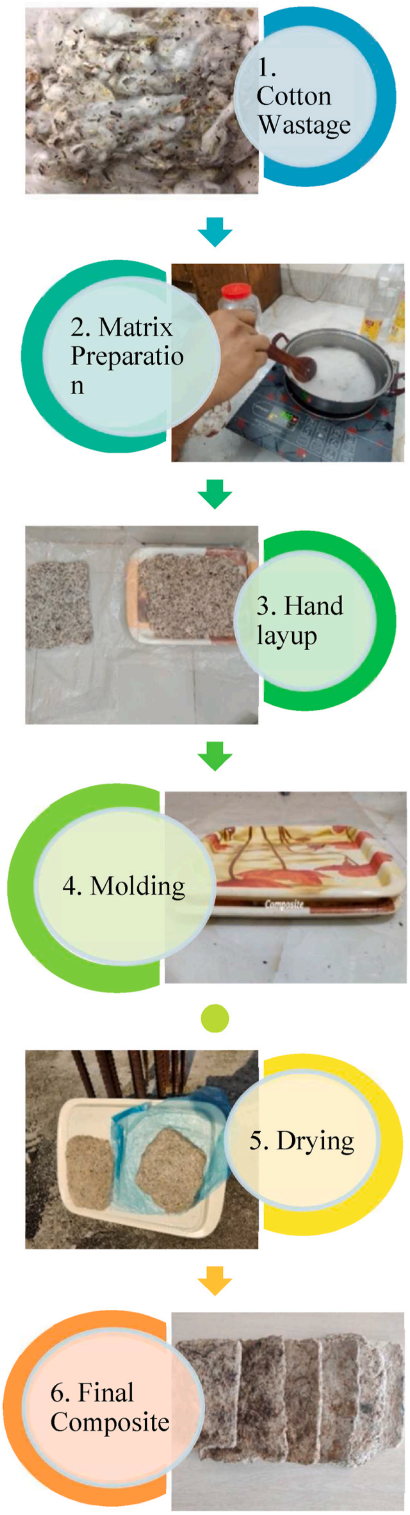

Fig. 3. Flow chart for manufacturing composites.

composite materials at different manufacturing stages was depicted in a bar diagram. With sample AB having the highest modulus and sample PB having the lowest, it offers insights into the mechanical characteristics and stiffness of the composites.

Out of all the samples, sample AC showed the most elongation at break in Fig. 8, measuring 1.3 %. PB and AB, both of which have an elongation at break of 1.2 %, come next. The elongation of CB and CC was somewhat lower, with break values of 1 % and 1.10 %, respectively. Sample AC has the largest elongation at break, whereas samples CB and CC have somewhat lower values. This gives information on the flexibility and stretch capabilities of the composites. Carding cotton waste is made up of longer, more uniform fibers that are less elongated because of their stiffness than blow room cotton waste, which is made up of shorter fibers with better flexibility and elongation potential.

The mechanical properties of reinforced composite materials are influenced by the quantity of reinforcement, matrix qualities, and mutual interfacial wettability [45]. When fiber was added to the composites, a potent combination of polysaccharides, cellulose fibers, and starch significantly increased the composites' tensile modulus and strength [46]. The Ab sample performed better than the other produced samples in terms of tensile strength, young's modulus, and elongation % because the blowroom waste had a tiny quantity of trash particles in addition to the fiber, which enhanced the sample's performance. Cornstarch was weaker than the other two starches

Table 2
Exemplary Illustration.

Sample ID	Composition (Wastage)	Composition (Matrix)
P_B	Blow Room	Potato Starch
C_B	Blow Room	Corn Starch
A_B	Blow Room	Arrowroot Starch
P_C	Carding	Potato Starch
C_C	Carding	Corn Starch
A_C	Carding	Arrowroot Starch

Fig. 4. Test of water absorbency.

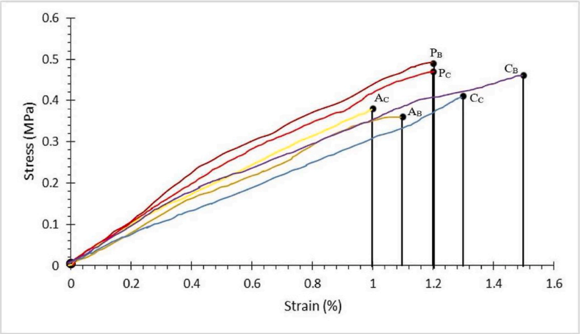

Fig. 5. Stress-strain curve representation for bio composites.

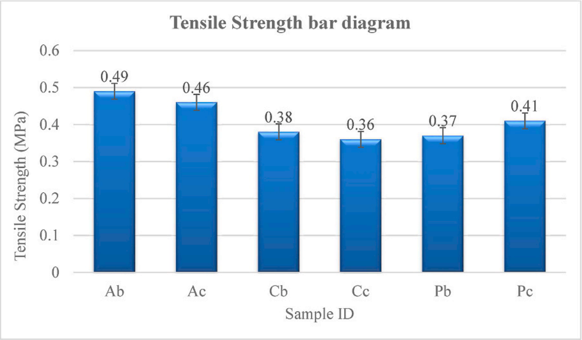

Fig. 6. Diagram of the Bio Composites' tensile strength bar.

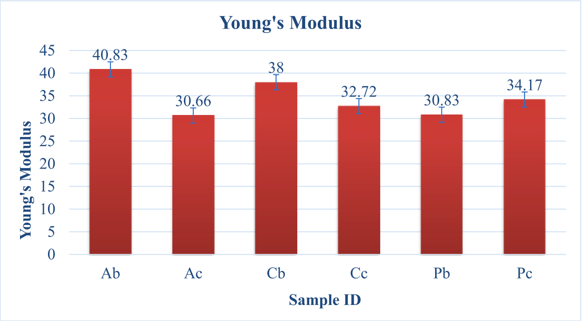

Fig. 7. Young's modulus bar chart for bio-compatible materials.

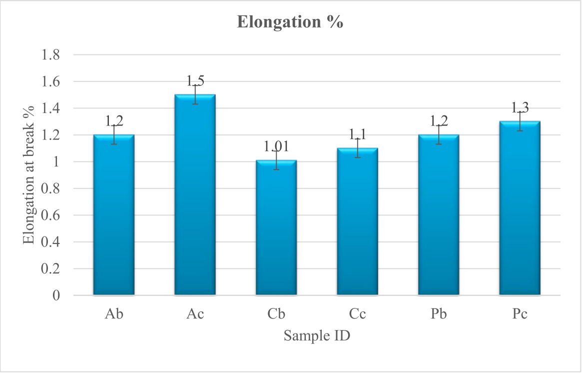

Fig. 8. Bio composites' elongation properties.

in comparison, which validated the mechanical behavior of the sample data [47]. Samples made from potato starch behaved more moderately than the other two.

3.2. Flexural strength

A three-point flexural test determines a composite material's flexural or bending strength, which determines the force needed to bend it. The load is tested, causing the middle and upper layers to compress and the lowest layer to stretch. Strong attachment between the fibers and matrix is necessary for the flexural test to yield positive findings. Bending strength, which is force per unit area, is always higher than tensile strength [48].

The bending load of six distinct samples was displayed below in Fig. 9. Fig. 9 clearly illustrates that, out of the six samples, the composite made of arrowroot and blow room waste exhibits the best outcome, while the composite made of potato starch and carding waste exhibits the lowest value. Because their molecules are more closely packed, finer-textured starches create stronger bioplastics. Additionally, blow room waste has more hard debris and irregularly shaped fibers, which strengthens the binding between it and arrowroot. PB (2.33 MPa) is 9.013 % more than PC (2.12 MPa), AB (3.71 MPa) is 16.98 % more than AC (3.08 MPa), and CB (3.16 MPa) is 16.77 % more than CC (2.63 MPa) according to the figure.

Similar factors mentioned in the tensile test may also be responsible for the improvement in the flexural capabilities of the composites. The addition of fiber—which was discovered from the arrowroot binder with the blowroom waste—served as reinforcement and significantly enhanced interfacial adhesion, which was related to this outcome. Stress was transferred from the fiber to the matrix [49]. The stress was distributed evenly and efficiently along the fibers as a result of their function as load carriers and the tension that was transmitted from the matrix along them, enhancing the mechanical characteristics [50]. A weaker contact between the material and matrix in this case may have reduced the flexural strength of the PC samples.

3.3. SEM analysis

SEM micrographs of these surfaces were collected in order to have a better understanding of the internal architecture of the composites and the interfacial bonding between the fiber surface and matrix surface [51]. This SEM revealed that the dark area of the picture indicates the matrix, which is starch, the irregular little droplet represents the waste particle of the wasted cotton, and the irregular lines represent the reinforcing material (wastage cotton) [Fig. 10].

SEM images of the external surfaces of composites comprising *Pc*, PB, AB, Ac, *Cc*, and CB were displayed in Fig. 11(a–f). While samples *Pc*, *Cc*, and Ac of the appropriate quantity of fiber had somewhat uneven fiber distribution in the matrix, samples PB, AB, and CB of the recommended amount of fiber demonstrated satisfactory adhesion between the reinforcement (cotton fiber) and starch (the matrix). Because PB sample matrix starch often has smaller particle sizes and a more uniform distribution, it exhibits a very excellent homogeneous mixing compared to other methods. This helps to create a smoother and more homogenous mixture when it is employed as a bio plastic [52]. Blow-room cotton waste for reinforcement materials has more trash than carding waste, and garbage promotes fiber-matrix adhesion. Compared to blow-room, carding waste has more fiber. For this reason, blow-room reinforcing material bonds and mixes with the matrix more homogeneously than carding cotton waste composite. As a result, higher fiber-matrix adhesion is seen when carding composite materials PC, AC, and *Cc* because of excessive fiber.

3.4. Density

Fig. 12 mentioned the densities of *Pc*, PB, AB, Ac, *Cc*, and CB composites. Among the samples, AB has the maximum density, while *Pc* displays the lowest density. A denser composite structure may be produced by using cotton waste from blow room machines, which may contain shorter and more compressed fibers. In general, arrowroot starch is denser than potato and maize starch. Compared to maize and potato starches, arrowroot starch was present in greater amounts. Using carding cotton waste, which often consists of longer and more uniform fibers, may also result in a less compacted composite structure and a somewhat lower density.

3.5. Water and HCl absorption

Every product's absorbency had progressively risen every minute during the water absorption test. In this case, *Pc* began with an absorbency of 327.73 % at the first minute and progressively grew to reach its maximum point in the graph, 436.82 % (Fig. 13). Subsequently, the absorption of PB was 272.55 %, and it climbed steadily to 311.27 %. The absorption for CB was 109.95 % in the first minute and 190.05 % in the tenth.

Below Table 3 showed the water absorbency test result.

Then, in the first minute, CC's absorbency was 224.10 %, and by the tenth minute, it was 263.67 %. Then, in the first minute, AB's absorbency was 139.02 %, while AC's was 224.12 %. In the tenth minute, AB's absorbency was 163.41 %, while AC's was 246.49 %.

The product manufactured from arrowroot starch and blow room waste had the lowest absorbency rate, whereas the product made from potato starch and carding waste had the greatest absorbency rate, according to the data. The blow room waste fiber had more garbage than the carding cotton waste, and the carding cotton waste contained more fiber than the blow room waste. Compared to

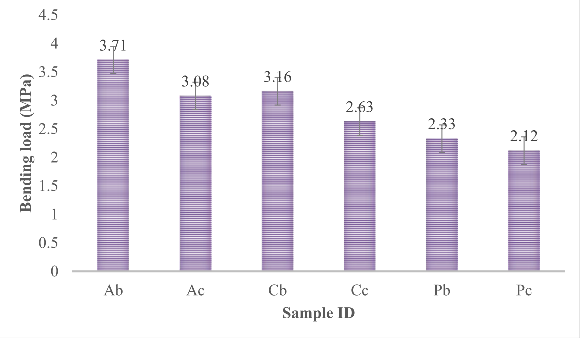

Fig. 9. Column chart for bending strength results.

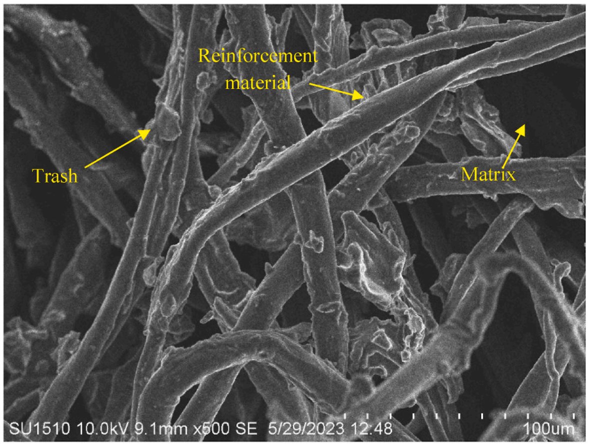

Fig. 10. Sem picture of the cc..

fiber, trash absorbs less water. The capacity of composite materials to absorb water is enhanced by potato starch because amylose has a stronger affinity for water than amylopectin.

In the instance of the HCl treatment, as seen in Fig. 14, the absorbency of each product rose progressively with each passing minute. In this case, PB's absorbency started off at 246.77 % in the first minute and climbed progressively to 288.06 % in the tenth. After then, the PC's absorbency started at 257.89 % and concluded at 361.13 % in the first minute. Once more, CB's absorbency started at 82.08 % and concluded with 170.75 %. Then, CC also steadily rose. After 1 min, its absorbency was 258.30 %, down from 238.22 %. At that point, AB's absorbency was 136.30 %; it grew over time to 173.29 %. Finally, the AC grew progressively as well. The absorption started at 249.01 % and concluded with 271.54 %.

Accordingly, the product of cornstarch with blow room waste had the lowest absorbency rate and the product of potato starch with carding waste (PC) had the greatest absorbency rate.

The entire set of HCl mix water absorption test results was displayed in Table 4.

4. Future prospects

Because hand layup is a manual operation, the composite may have an uneven distribution of fiber and matrix [53]. The next improvement to obtain a smooth surface and fiber reinforcement might be to use compression molding technology as a superior manufacturing technique. This bio composite made of starch might serve as a substitute for Styrofoam (Fig. 15 a, b) and Table 5 highlights the comparison between Styrofoam and the research work samples. The specifications for Styrofoam or polystyrene (EPS) foam are displayed below and contrasted with development examples.

5. Conclusion

The textile industry's waste management problems may be sustainably addressed by combining cotton filter waste from the spinning machine with the produced starch-based bio-composites. The use of cotton filter particles enhanced the bio-composites' mechanical properties, rendering them a feasible substitute for Styrofoam. It highlights the importance of multidisciplinary research and collaboration between the disciplines of materials science and textiles, as well as the potential for cutting-edge approaches to waste management and the development of sustainable materials. The findings were reported in turn as a closing statement-

- The arrowroot sample reinforced with blowroom waste demonstrated exceptional flexural strength (3.71 MPa) and tensile strength (0.49 MPa). Corn and potato starches are less sticky than arrowroot starch. The other created samples did not contain cotton linters or trash particles, which is why the arrowroot matrix adhered to blowroom wastes more successfully.
- Sample AB showed the greatest outcomes. The SEM image showed that PB had the most consistent matrix and reinforcing material mix (wastage cotton).
- With a density of 0.35 g/cm3, AB had the highest density of the other samples.
- The sample PC exhibited the highest absorbance values in both the water and the 5 % HCl combination because the carding waste had more fiber than the blow room, and fiber absorbed more water.

All things considered, the various starches had demonstrated their capacity to serve as an appropriate matrix for the biodegradable composites. These composite materials might be made to function as an environmentally friendly substitute for packaging with more study on compression molding or other techniques. Contemporary composite manufacturing techniques might potentially overcome sample flaws like uneven surfaces and ineffective waste material distribution as reinforcing materials.

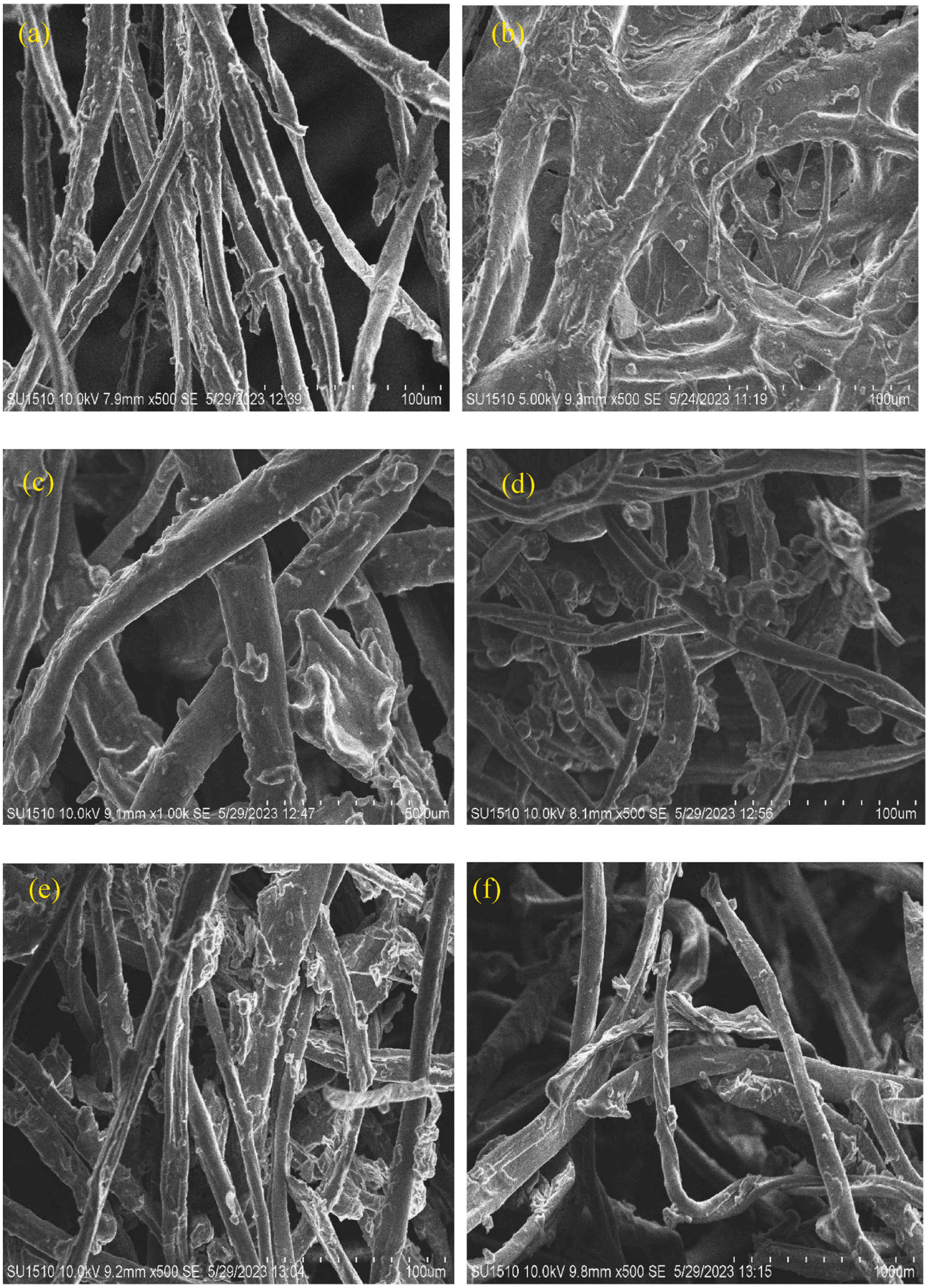

Fig. 11. Surface SEM micrographs: (a) P_C, (b) P_B, (c) *Cc*, (d) C_B, (e) A_B, (f) Ac.

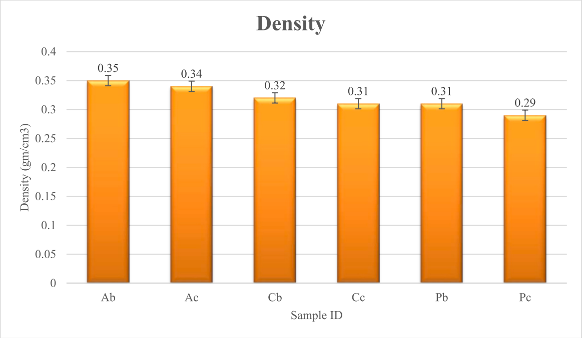

Fig. 12. The composites' density.

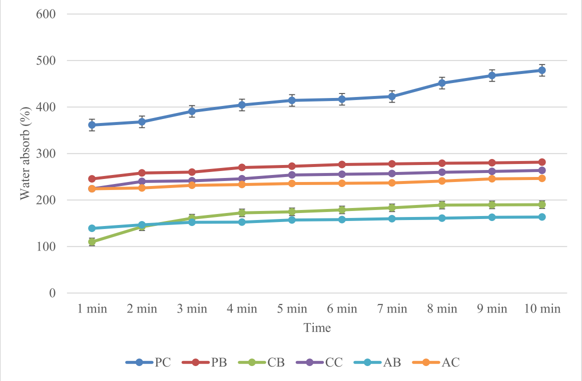

Fig. 13. Graph of water absorbency results.

Table 3
Composites' water absorbency behavior.

	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
P_C	327.7 %	334.1 %	355.1 %	367.7 %	376.8 %	379.1 %	384.6 %	411.4 %	426.4 %	436.7 %
P_B	272.6 %	286.3 %	288.3 %	299.1 %	301.8 %	305.9 %	307.4 %	308.7 %	309.9 %	311.3 %
C_B	109.95 %	142.6 %	161.1 %	172.5 %	174.7 %	178.8 %	183.3 %	189.2 %	189.6 %	190.1 %
C_C	224.10 %	239.8 %	241.4 %	245.7 %	253.8 %	255.5 %	256.9 %	259.8 %	261.6 %	263.7 %
A_B	139.02 %	146.7 %	152.2 %	152.5 %	157.1 %	157.8 %	159.8 %	160.8 %	162.9 %	163.5 %
A_C	224.12 %	225.9 %	231.6 %	233.4 %	235.6 %	235.8 %	236.9 %	240.8 %	245.7 %	246.5 %

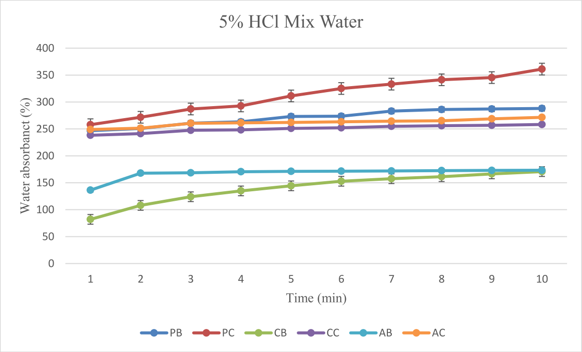

Fig. 14. Water absorbance result graph for 5 % HCl mix.

Table 4
Water absorbency test with 5 % HCl mix.

	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
P_B	246.8 %	250.8 %	260.6 %	263.2 %	273.2 %	273.7 %	283.1 %	286.1 %	287.2 %	288.2 %
P_C	257.9 %	271.7 %	287.1 %	292.8 %	311.4 %	325.2 %	333.3 %	341.4 %	345.4 %	361.2 %
C_B	82.08 %	108.1 %	124.1 %	134.1 %	144.4 %	152.9 %	157.6 %	161.4 %	166.6 %	170.8 %
C_C	238.3 %	241.4 %	247.5 %	248.3 %	250.8 %	252.3 %	254.9 %	255.7 %	256.8 %	258.2 %
A_B	136.30 %	167.7 %	168.5 %	170.6 %	171.3 %	171.6 %	171.8 %	172.5 %	172.8 %	173.3 %
A_C	249.01 %	251.4 %	260.5 %	261.3 %	262.1 %	263.3 %	264.5 %	265.1 %	268.8 %	271.6 %

Fig. 15. (a) Styrofoam [56], (b) Potentially substitute starch-based bio composite.

Table 5
Comparison between Styrofoam and composite samples.

Properties	Styrofoam	A_B	A_C	P_B	P_C	C_C	C_B
Tensile Strength	0.46 MPa	0.50 MPa	0.45 MPa	0.38 MPa	0.42 MPa	0.37 MPa	0.39 MPa.
Bending Strength	11–31 MPa	3.73 MPa	3.09 MPa	2.34 MPa	2.13 MPa	2.64 MPa	3.17 Mpa.
Young's Modulus	22–52 MPa.	40.84 MPa	30.56 MPa	30.84 MPa	34.16 MPa.	32.71 MPa.	39 Mpa.
Elongation At Break	≤1 %	1.21 %	1.52 %	1.22 %	1.31 %	1.11 %	1 %
Density	0.01–0.05 g/cm^3	0.36 g/cm^3	0.35 g/cm^3	0.30 g/cm^3	0.30 g/cm^3	0.31 g/cm^3	0.30 g/cm^3
Water Absorbance	<0.5 %	163.42 % (After 10 min)	246.50 % (After 10 min)	311.28 % (After 10 min)	436.81 % (After 10 min)	263.68 % (After 10 min)	190.06 % (After 10 min)
Reference	[54,55]	Current work					

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On request, data will be made available.

Additional information

For this work, no further information is provided.

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Md. Redwanul Islam: Writing – original draft, Visualization, Supervision, Methodology, Formal analysis, Conceptualization. **Fahmida-E-Karim:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Asif Al Hasan:** Project administration, Data curation. **Tawsisa Dil Afrose:** Project administration, Data curation. **Md Sakib Hasan:** Project administration, Data curation. **Hasib Sikdar:** Project administration, Data curation. **Abu Bakr Siddique:** Supervision. **Hosne Ara Begum:** Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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