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Utilization Of Jute Waste into Polybutylene Succinate-Based Biocomposites and Analysis of Mechanical Properties and Biodegradability

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ABSTRACT

A polybutylene succinate (PBS) composite reinforced with natural jute (*Corchorus olitorius*) fibers (20-50 micrometers) was investigated for its mechanical properties and biodegradability. This study aims to investigate the effects of fiber additions and size variations on composite performance and environmental sustainability. The PBS80/JF20 composite with 80 µm jute particles demonstrated the lowest MFI at 26 g/10 min, significantly lower than that of pure PBS ($p<0.05$), indicating reduced flowability. Tensile strength decreased with the addition of jute fiber, reaching 21.4 MPa with 50 µm particles. Density was also reduced, with the lowest recorded at 1.27 g/cm³ in PBS95/Jute5 ($p<0.05$). The composites with 80 µm fibers exhibited a slightly higher weight loss (9.5%) compared to those with 50 µm fibers (6.8%), likely due to insufficient interfacial adhesion in larger fibers, making them more susceptible to microbial degradation. Results indicate that adding natural jute fibers into the PBS matrix leads to significant decreases in melt flow index, tensile strength, and impact energy, while significantly enhancing density, water absorption, and biodegradability with respect to neat PBS. Further analysis of fiber sizes revealed that increasing fiber size (from 50 to 80 µm) results in a non-significant decrease in melt flow index, tensile strength, density, and impact energy, water absorption and biodegradation rates. These findings suggest that while the addition of natural fibers compromises mechanical properties, it significantly improves the environmental attributes of the composites like water absorption and biodegradation ($p<0.05$). Fibers with a smaller diameter are preferable for maintaining mechanical integrity, while fibers with a larger diameter enhance biodegradability. The paper provides valuable insights into the development of a biocomposite material that balances mechanical performance with environmental sustainability.

Key Words	Biocomposites, Agro-waste, Biodegradation, Mechanical properties, Jute, Corchorus olitorius, Poly(butylene succinate)
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1. Introduction

Jute caddies, known as jute processing waste, produce 40,000 tonnes annually in India (Nayak et al. 2011). It consists of non-spinnable fibers, batching oil, machine oil, grease, and bark from the jute plant. This waste has traditionally been disposed of in landfills or burned for boiler fuel however, both methods are harmful to the environment (Hallerman 2019; Barai et al. 2020; Khandaker et al. 2024). These by-products can, however, be transformed into valuable resources through various approaches.

Jute fibers (*Corchorus olitorius*) waste can be repurposed into biodegradable composites, reducing dependence on synthetic materials and decreasing plastic pollution. Automobile manufacturers use jute fiber composites in parts like the structural bonnet of off-road vehicles (Alves et al. 2010; Naik et al. 2022). Moreover, jute waste can be reused in cement panels reinforced with recycled jute fibers (Ferrandez-García et al. 2020). This will improve properties, density, flexural strength, and thermal conductivity. Jute waste is also beneficial to the agricultural sector because it produces biodegradable geotextiles that control soil erosion (Islam & Ahmed 2012).It is also used to develop biodegradable thermoplastic polyurethane semi-transparent films (Islam et al. 2024).

Developing of eco-friendly fungicides from plant extracts, including jute, offers a sustainable solution to agricultural practices (Islam & Ahmed 2012; Hallerman 2019; Barai et al. 2020). In addition to contributing to sustainable development, jute waste can be converted into useful products, reducing environmental pollution, promoting a circular economy, and supporting rural livelihoods (Shanmugam et al. 2021). The ecological benefits and innovative potential of jute waste utilization are driving forces for further research and development in this field (Rajan et al. 2022).

As mentioned above, developing new materials that meet specialized performance requirements while minimizing environmental impact is becoming an increasingly significant part of the research process with technological advancement (Regin et al. 2024). A promising class of such materials is polymer biocomposites, which combine a biopolymer matrix with a biodegradable filler to produce properties that are not possible with either component alone (Christian 2016; Elnashar et al. 2023a; Elnashar et al. 2023b). In this era, biocomposites are gaining attention due to their both economic and environmental benefits (Gurunathan et al. 2015; Bhat et al. 2021; Andrew & Dhakal 2022). As a result of using biodegradable materials, plant fibers, and agro-industrial waste, biocomposites are a viable solution for reducing plastic waste and repurposing materials that would otherwise be disposed of in landfills or burned (Ortega et al. 2021; Moshood et al. 2022).

Poly(butylene succinate) (PBS) is a biodegradable aliphatic polyester, notable for its high processing ability, superior heat transfer characteristics, robust strength, and good compressive properties (Rafiqah et al. 2021; Aliotta et al. 2022; Barletta et al. 2022). These attributes make

PBS a suitable candidate for a wide range of commercial applications, including biomedical devices and food packaging, due to its biodegradability and non-toxicity (Łopusiewicz et al. 2021; Rafiqah et al. 2021; Mtibe et al. 2023). However, the relatively high cost of PBS limits to its widespread industrial use (Rafiqah et al. 2021).

PBS composites with natural fibers not only reduce production costs; but also minimize the environmental impact. These composites leverage renewable resources, decrease reliance on fossil fuels, and promote a reduction in plastic waste due to their biodegradability (Moshood et al. 2022). Consequently, PBS composites offer a more sustainable alternative for various industries, contributing to a greener and more eco-friendly future (Mochane et al. 2021; Vázquez-Núñez et al. 2021; Barletta et al. 2022). Therefore, researchers focused on making PBS composites with natural fibers and agro-industrial wastes, aiming to reduce production costs while harnessing renewable resources.

Several natural fibers have been reported to be suitable for this purpose, including almond shell flour, rice husks, wheat bran, bamboo fibers and sugarcane rind fibers. They offer low cost, availability, low density, a renewable and sustainable nature, biocompatibility, and environmental friendliness. Biocomposites prepared from natural fibers can exhibit enhanced mechanical, thermal, and tribological properties. In recent years, PBS has become a more readily available biodegradable material, allowing researchers to develop biodegradable composites made of PBS and natural fibers (Quiles-Carrillo et al. 2018; Yap et al. 2020; Jansiri et al. 2021; Sasimowski et al. 2021).

In recent studies, natural fibers are effective as reinforcement in polymer biocomposites. PBS composites containing almond shell flour have been shown to increase tensile strength, although elongation at break and tensile modulus were affected. The previous studies reported that biodegradation of PBS composites can be enhanced by sugarcane natural fibers (Quiles-Carrillo et al. 2018; Yap et al. 2020; Chamas et al. 2021; Jansiri et al. 2021). The impact of rice husk and date palm fibers waste on the mechanical and biodegradable properties of biocomposites has also been studied which showed important trade-offs between increased biodegradability and enhanced mechanical performance (Quiles-Carrillo et al. 2018; Yap et al. 2020; Chamas et al. 2021; Jansiri et al. 2021).

A variety of factors influence the mechanical properties of biocomposites, including their fillers, processing conditions, and natural fiber dispersion (Mohammed et al. 2023). Consequently, selection of these factors is crucial when selecting natural fibers for biocomposite materials. Utilising agrowaste as a filler in biocomposites has gained significant importance due to its potential to improve the physical, mechanical, thermal, and thermo-mechanical properties (Fayomi et al. 2020; Talabi et al. 2024).

Agro-waste materials, including plant fibers, agricultural residues, and food processing by-products, can enhance the strength, stiffness, toughness, and thermal stability of biocomposites, making them attractive for various applications (Das et al. 2022). Moreover, incorporating agro-waste in biocomposites can yield economic and environmental benefits by reducing landfill waste and reliance on petroleum-based materials (Maraveas 2020; Ortega et al. 2021;

Phiri et al. 2023). Recent research highlights the diverse applications and enhanced properties of biocomposites. The addition of cassava pulp to poly(butylene succinate) (PBS) improves biodegradability and mechanical properties (Nithikarnjanatharn & Samsalee 2022).

Studies on poly(lactic acid) (PLA) composites filled with Dalbergia sissoo wood waste show significant improvements in physical, mechanical and thermal properties (Singh et al. 2021). Agro-flour filled PBS composites exhibit favourable biodegradability and mechanical performance (Sasimowski et al. 2023). PLA/PBS blends with cellulose fiber demonstrate potential for packaging applications. Hemp fibers and shives in PBS-based composites offer biodegradability, while bamboo and kenaf fibers enhance mechanical properties, revealing versatility and environmental benefits (Dönitz et al. 2023).

The present research study aims to develop and characterize composite materials composed of poly(butylene succinate) (PBS) bioplastic and fine jute fiber (JF) filler, focusing on their mechanical, surface morphological, and biodegradability properties. Biocomposites with varying JF content (0 to 20 wt%) will be synthesized to assess how different filler concentrations influence the material's properties. The goal is to identify the optimal jute fiber content that enhances the material's performance while maintaining superior biodegradability. This will contribute to sustainable material development and offering potential applications in environmentally friendly products.

2. MATERIAL AND METHOD

2.1 Collection of material /sample

In this study, a commercial injection grade of poly(butylene succinate) (PBS) (B3C03) from BioPBS Pvt Ltd, Gujarat, India, was used as the matrix material. This PBS has melting temperature in the range of 120-200°C, a density of 1.25-1.50 g/cm³, and a melt flow rate of 5 g/10 min at 120°C with a 2.0 kg load. The jute fibers filler was sourced from a local agricultural farm in Jaipur (Rajasthan), India.

2.2 Processing of sample

Before incorporation, the jute fibers were washed and dried at 80°C for 15 hours. Jute fibers of various sizes ranging from 50 μm to 80 μm were mixed with the melted PBS matrix at varying concentrations, with a maximum of 20% jute fiber content.

In this study, PBS pellets were dried in a hot air oven at 80°C for 15 hours to remove moisture. Jute fibers with diameters ranging from 50 μm to 80 μm, were mixed with PBS to create composites with various weight ratios, from PBS100JUTE0 to PBS80JUTE20. The mixing process involved a twin-screw extruder operating at 150°C and a screw speed of 50 revolutions per minute, ensuring thorough blending of the PBS and jute fiber particles. After extrusion, the biocomposite strands were pelletized and cooled using a cold air circulation system. These pellets were then moulded into biocomposite plates using a hand-operated injection machine, applying a pressure of 5 MPa at 150°C for two minutes. The injection rate for forming the biocomposites ranged from 20 cm³/s to 50 cm³/s, facilitating uniform sample production for further testing and analysis (Singh et al. 2021).

2.3 Melt flow index

The melt (flow) index has become a widely established criterion for extrudability of thermoplastic materials, especially polyolefins. It is standardised as the weight of polymer (polyolefin) extruded in 10 min at a constant temperature (190 °C) through a tubular die of specified diameter (0.0825 inches) (Van Krevelen & Te Nijenhuis 2009). In this study, the Melt Flow Index (MFI) was measured as per ASTM D1238 standards (ASTM D1238-20). The measurement was performed using a melt flow index instrument (P.S.I Sales Pvt. Ltd., MFI-421/16) at 150°C with a load of 2.5 kg. The MFI value reported is the average of three independent measurements.

2.4 Composite Characterizations

2.4.1 Mechanical Testing

The mechanical evaluation will include tensile strength, compressive characteristics, and overall durability. Tensile strength and Young's modulus were measured according to the standard ASTM D638 (ASTM D638 [no date]). A universal testing machine (UTM) was used to evaluate the mechanical properties, with a cross-head speed of 50 mm/min and a load cell that could measure up to 10 kN. The test specimens were made according to the dimensions specified in the standard, with a total length of 115 mm, a thickness of 3.2 mm, and a middle length of 33 mm in the shape of dumbbells. An Izod impact strength test was conducted on PBS/JF biocomposite specimens according to the ASTM D256 standard (43), with the samples kept at room temperature. The test was conducted using a pendulum impact tester. In the present study, hardness was measured for the PBS/JF composites according to the ASTM D 2240 (44) international standard. The Shore D hardness value was determined using specimens with a length of 63.5 mm and a thickness of 3.2 mm.

2.4.2 Biodegradability Properties

The biodegradability was examined through natural soil burial tests, assessing the degradation of the biocomposites by determining weight loss. The rectangular specimens with dimensions of 50 mm in length, 2 mm in thickness, and 10 mm in width were fabricated by injection moulding method with injection temperature and pressure of 170-190°C and 25MPa. The prepared samples were buried in soil for 50 days according to the method described by Kim et al. (48). The specimens were placed and buried in the backyard at a depth of 25 cm below the surface of the topsoil. After being buried for the mentioned time: 0, 7, 15, 25, 30, 40, and 50 days (48), the specimens were taken out and washed with distilled water before being dried in an oven with hot air at 50 °C for one day. The percentage of weight loss was then calculated using a digital scale and the result was determined using the following equation:

$$W_{loss}= W_{initial}-W_{final} / W_{initial} \times 100 \% \qquad (1)$$

Where initial and last represent the initial day and final day of the composite buried in the soil for testing.

2.4.3 Water absorption properties

In this study, the gravimetric method was used to determine the density and water absorption of pure PBS and PBS/JF composites. Three samples were tested for water absorption. The samples were weighed accurately on a scale and then submerged in water to determine their volume. For the water absorption test, test samples of biocomposites were soaked in water for 15 days. The samples were then allowed to drain for a minute before being dried with a towel and air dried until they were completely surface-dry. The experiment was run in triplicates. The weight of each sample (Wt) was recorded, and the volume of water absorbed was calculated. The water absorption (WA) performance of PBS/JF biocomposite samples was evaluated by measuring the difference in weight between the composite and the pure PBS sample using the following equation.

$$Biocomposite\ W_{absorption} = \frac{W_{final} - W_{initial}}{W_{initial}} * 100 \tag{2}$$

2.4.4 Density Determination of PBS/Jute fiber composite

Density was determined according to the ASTM D 1895-17 (2017) standard. Five replicates were used for density determination. The density of the sample was calculated using the following equation:

$$\text{Density (g/cm}^3\text{)} = m/v \tag{3}$$

where, m represents mass and v for volume (Saffian et al. 2021).

2.5 Statistical analysis

The results are presented as mean ± SD of three replicates. Statistical analysis was done by One way ANOVA. Further, significant results ($p<0.05$) were compared by post-hoc test like Tukey's Multiple Comparison Test and pairwise T-Test significant (ANOVA Calculator | AAT Bioquest [no date]). For statistical analysis, two way ANOVA is also performed to compare the result of PBS with its jute composites using SPSS software.

3 RESULT AND DISCUSSION

3.1 Melt Flow Index

The melt flow index (MFI) of PBS/JF biocomposites with jute fiber diameter sizes of 50 to 80 µm was found to be in the range of 25~47 g/10 minutes which is shown in figure 1.

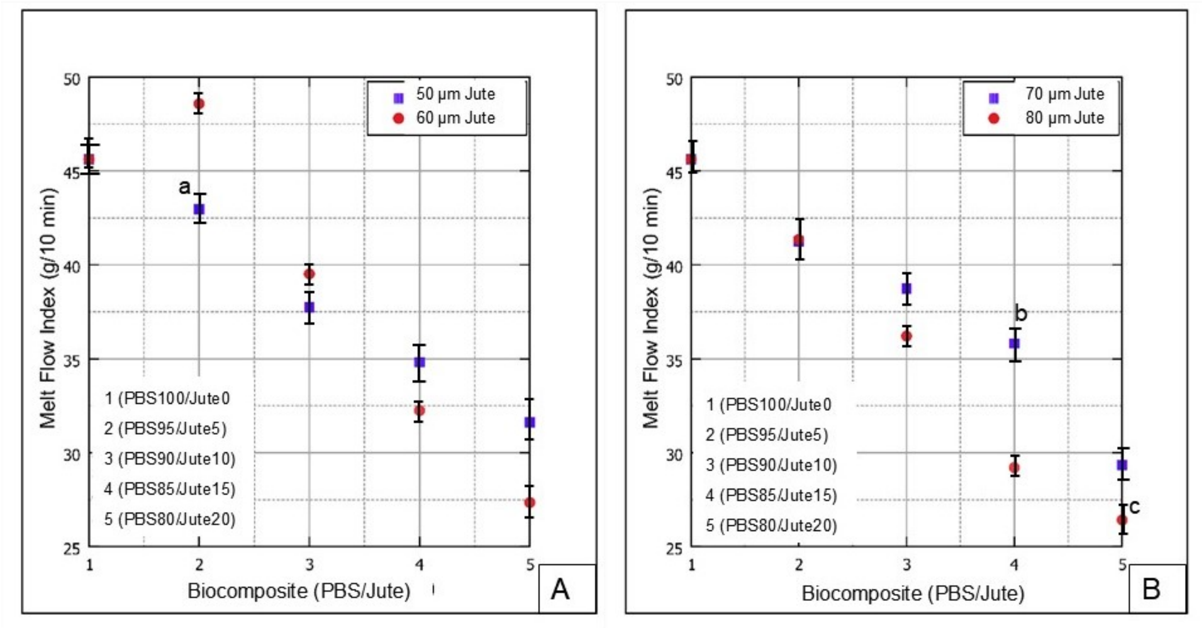

Figure 1: Melt flow index of jute fiber reinforcement biocomposites (A) 50-60 µm (B) 70-80 µm. One-way ANOVA was used to test the treatment effect. Small letters indicate significant differences across treatments tested using post hoc Tukey's HSD test. All values were taken significant at $p < 0.05$.

The results from the Melt Flow Index (MFI) tests reveal a notable decrease in the flow behaviour of PBS plastic following the introduction of jute fibers of different sizes ranging from 50 to 80 microns. Figure 1 illustrates the MFI values for Jute fibers at 50, 60, 70, and 80 µm. Notably, the size of the jute fibers correlates inversely with the MFI values, as depicted in Figures 1(a) and 1(b). Specifically, the MFI is at its lowest when using 80 µm jute fibers, particularly evident in PBS80Jute20 composites. This trend of decreasing MFI with increasing the amount of jute fibers was observed. The minimum MFI was observed when jute fiber percentage reached 20% (PBS80Jute20 composites). However, the size of jute particles did not affect the MFI significantly with respect to the particle sizes. This shows that the selected particle size range did not impose any significant effect on the developed composites.

Jute fibers with a smaller diameter exhibited higher homogeneity and compatibility within the polymer matrix, as demonstrated by their even distribution. This was supported by the result of the melt flow index test which showed that the PBS80/JF20 sample with 80 µm particles had a minimum MFI of 26 g/10 min, significantly lower than that of pure PBS material ($p<0.05$). This difference can be attributed to the mixing of jute fibers, which enhanced the discontinuous mixing of both PBS and jute fibers in the composite. A similar finding was reported in previous studies stating that increased fibers content of the composite resulted in lower MFI (Soleimani et al. 2008).

3.2 Mechanical Properties

The tensile strength and Young's modulus of the PBS/JF biocomposites are shown in Figure 2 which gives an idea of the mechanical properties of composites. The pure PBS exhibited a tensile strength of 27.2 MPa. With particle sizes reduced to 50 µm PBS/JF biocomposites showed a tensile strength between 21 MPa and 27 MPa, with jute fibers accounting for 10 to 20% of the mass. Adding jute fibers to PBS resulted in significant ($p<0.05$) decrease in tensile strength of 21 MPa. At 80 µm particle size, PBS80/Jute20 has low tensile strength. However, the lowest tensile strength 21.4 MPa was reported with the addition of 50 µm particle size of jute fibers (PBS80/Jute 20). This is possibly due to the smaller particle size of jute fibers being more compatible with the matrix composite. However, the selected particles sizes (50-80 µm) was to small to pose significant effect on tensile strength ($p>0.05$). Similarly, in previous reports, it was reported that there is a strong relationship between the tensile strength of composites and the fiber/matrix adhesion; and low adhesion, resulted in a decrease in tensile strength and elongation at break (Liu et al. 2009).

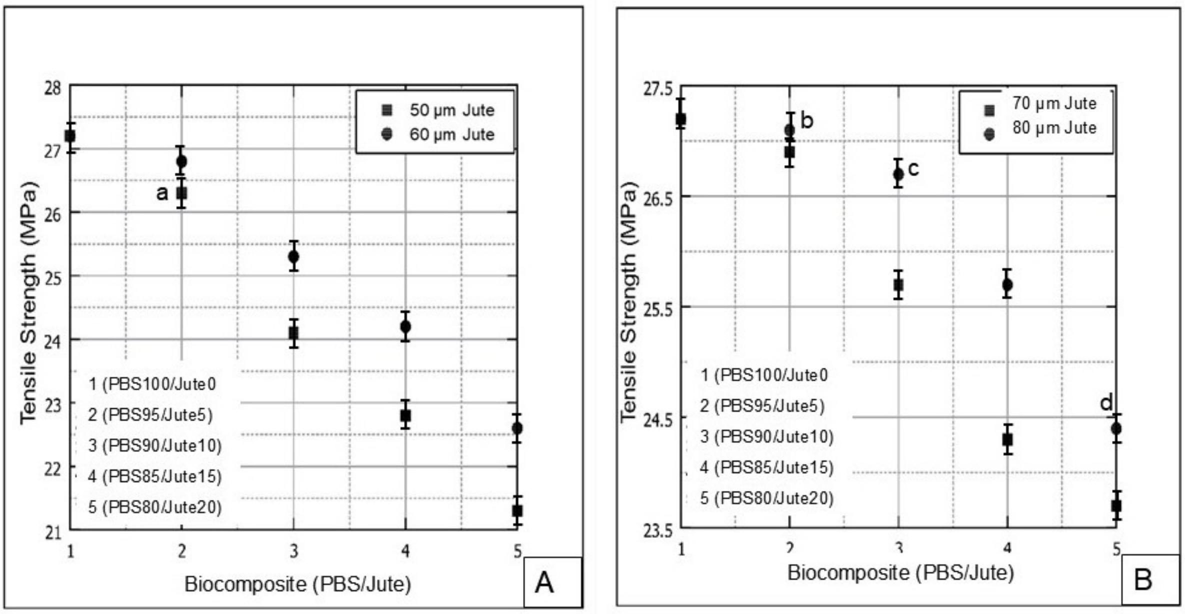

Figure 2: Tensile strength of PBS/jute fiber compositions a) 50 µm and 60 µm jute fibers b) 70 µm and 80 µm jute fibers. One-way ANOVA was used to test the treatment effect. Small letters indicate significant differences across treatments tested using post hoc Tukey's HSD test. All values were taken significant at $p < 0.05$.

The tensile strength of bioplastics decreased as jute fiber percentage increased, regardless of jute fiber size. The tensile strength of pure PBS was superior to that of PBS/JF biocomposites. The decrease in tensile strength of the biocomposites when the jute fiber content increased may be due to the stiff interface between the fibers and matrix, which had less ability to deform (Terzopoulou et al. 2016; Jansiri et al. 2021; Vorawongsagul et al. 2021).

These findings are similar to those reported by (Kim et al. 2005) in their study on rice husk powder mixed with PBS matrix materials. Similarly, our results showed that the tensile strength of the composite increased with decreasing the size of jute fibers.

3.3 Impact Strength and Energy

Impact strength is expressed in terms of impact energy. Impact energy describes the ability of biocomposites to absorb the force of an impact, which is related to the tenacity of biocomposite materials. The addition of jute fibers in PBS led to significant decrease in impact energy and strength of biocomposites ($p>0.05$). As shown in figure 3, impact energy of PBS80/JF20 (2.7 KJ/m^2) biocomposites containing 50 µm jute fibers was non-significantly ($p>0.05$) higher than biocomposites containing 80 µm jute fiber (3.2 KJ/m^2). However, PBS100/Jute0 possessed high impact energy (4.2 KJ/m^2) compared to the jute composite ($p<0.05$).

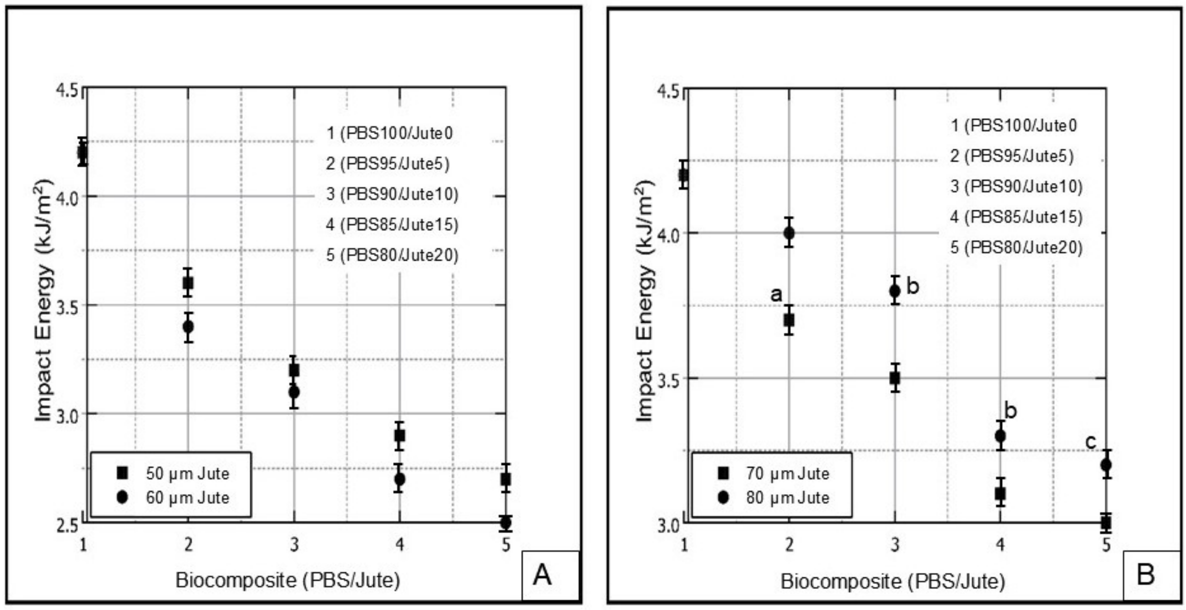

Figure 3 Impact energy analysis of PBS/JF compositions a) 50 µm and 60 µm jute fibers b) 70 µm and 80 µm jute fibers. One-way ANOVA was used to test the treatment effect. Small letters indicate significant differences across treatments tested using post hoc Tukey's HSD test. All values were taken significant at $p < 0.05$.

The impact energy of each PBS/Jute fiber composite was lower than the impact energy of pure PBS, suggesting that pure PBS has good ductility due to its high impact strength. The fracture became more brittle when the concentration of jute fiber in the biocomposites increased up to a maximum of 20%. These results were found to be in contrast with strength of treated jute fibers-based PBS composites developed by (Liu et al. 2009). The figure 3 shows the effect of particle size of jute fibers on PBS-based composites. The highest strength of PBS80/Jute20 was observed with 80 µm particles revealing the strength of the polymer. This is possibly due to the high bonding ability of larger jute particles.

3.4 Density of PBS/Jute fiber composites

The densities of manually injected PBS/JF biocomposites are presented in Table 1. The average density of pure PBS was found to be 1.26 g/cm^3. By injection moulding method, PBS molecules were aligned in the direction of flow, resulting in high density.

The addition of jute fiber with particle sizes of 50 µm to 80 µm resulted in a significant decrease in the density of the PBS matrix with increasing the particle size ($p<0.05$). The lowest density was observed with PBS95/Jute5 i.e. 1.27 g/cm^3 ($p<0.05$) (ANOVA Calculator | AAT Bioquest [no date]).

The non-uniform molecular alignment of the molten polymer and Jute fibers of 80 µm is responsible for the formation of gaps within the biocomposites, leading to a decrease in composite density. In PBS biocomposites, the particle size of the reinforcing material like jute fibers affects the density of composites ($p<0.05$). The small particles tend to have higher densities due to better packing efficiency and reduced porosity. The composite also has enhanced density and mechanical properties due to improved interfacial adhesion and a larger surface area for smaller particles (Saffian et al. 2021).

The highest density was observed with PBS80/Jute20 i.e.1.68 g/cm^3 for 50 µm jute fibers. The trend of increasing density was observed with increasing the amount of Jute fibers. The possible reason is the uniform distribution of high amount of jute fibers throughout the PBS matrix.

Table 1 Density of the PBS/Jute biocomposite

PBS /Jute Ratio	50 µm	60 µm	70 µm	80 µm
PBS100/Jute0	1.26 ± 0.0	1.26 ± 0.0	1.26 ± 0.0	1.26 ± 0.0
PBS95/Jute5	1.35 ± 0.01	1.31 ± 0.01*	1.29 ± 0.01*	1.27 ± 0.01*
PBS90/Jute10	1.49 ± 0.01	1.39 ± 0.02*	1.34 ± 0.02*$	1.32 ± 0.01*$
PBS85/Jute15	1.54 ± 0.01	1.42 ± 0.01*	1.39 ± 0.02*$#	1.37 ± 0.02*$#
PBS80/Jute20	1.68 ± 0.02	1.58 ± 0.01*	1.45 ± 0.01*$#	1.40 ± 0.03*$#

Density (g/cm^3) ($p<0.05$)

* $p < 0.05$ density of 50 µm vs. Density of other particle size (60 /70/80 µm)

$ $p < 0.05$ density of others vs. Density of (PBS90/Jute10)

#$p < 0.05$ density of others vs. Density of (PBS85/Jute15)

3.5 Water absorption

The pure PBS sample showed a non-significant increase (0.25%) in its weight due to absorption of water (Table 2). Water absorption values of PBS/jute fiber composites increased with increasing the size of jute fibers ($p>0.05$) revealing the void spaces in the PBS matrix due to the large size of jute fibers (80 µm). Increasing the amount of jute fibers in the matrix the water absorption increased ($p>0.05$). The possible reason for this is the formation of void spaces in PBS due to the addition of jute fibers (Table 2). However, with respect to PBS, addition of jute fibers resulted in a significant increase in the water absorption properties. Water absorption increased significantly with an increase in content of jute fibers ($p<0.05$) (table 2).

Table 2: Water absorption properties of Jute fiber-reinforced matrix

PBS /Jute Ratio	50 µm	60 µm	70 µm	80 µm
PBS100/Jute0	0.25 ± 0.01	0.25 ± 0.01	0.25 ± 0.01	0.25 ± 0.01

PBS95/Jute5	0.38 ± 0.21	1.19 ± 0.31	1.23 ± 0.14	1.32 ± 0.2
PBS90/Jute10	1.45 ± 0.2	1.62 ± 0.23	2.1 ± 0.12	2.20 ± 0.21
PBS85/Jute15	1.89 ± 0.12	2.12 ± 0.24	2.36 ± 0.2	2.47 ± 0.13
PBS80/Jute20	2.18 ± 0.15	2.45 ± 0.12	2.78 ± 0.25	3.22 ± 0.26

P<0.5 significantly different compared to PBS (ANOVA Calculator | AAT Bioquest [no date])

3.6 Biodegradability Study

The percentage of weight loss of PBS and jute fiber biocomposites after being buried in the soil for 0, 7, 15, 25, 30, 40, and 50 days for different particle sizes (50 to 80 µm) is shown in Figure 4. There was a general trend where the percentage of weight loss of PBS/Jute fiber biocomposites increased with increasing jute fiber content in PBS/Jute-based biocomposites.

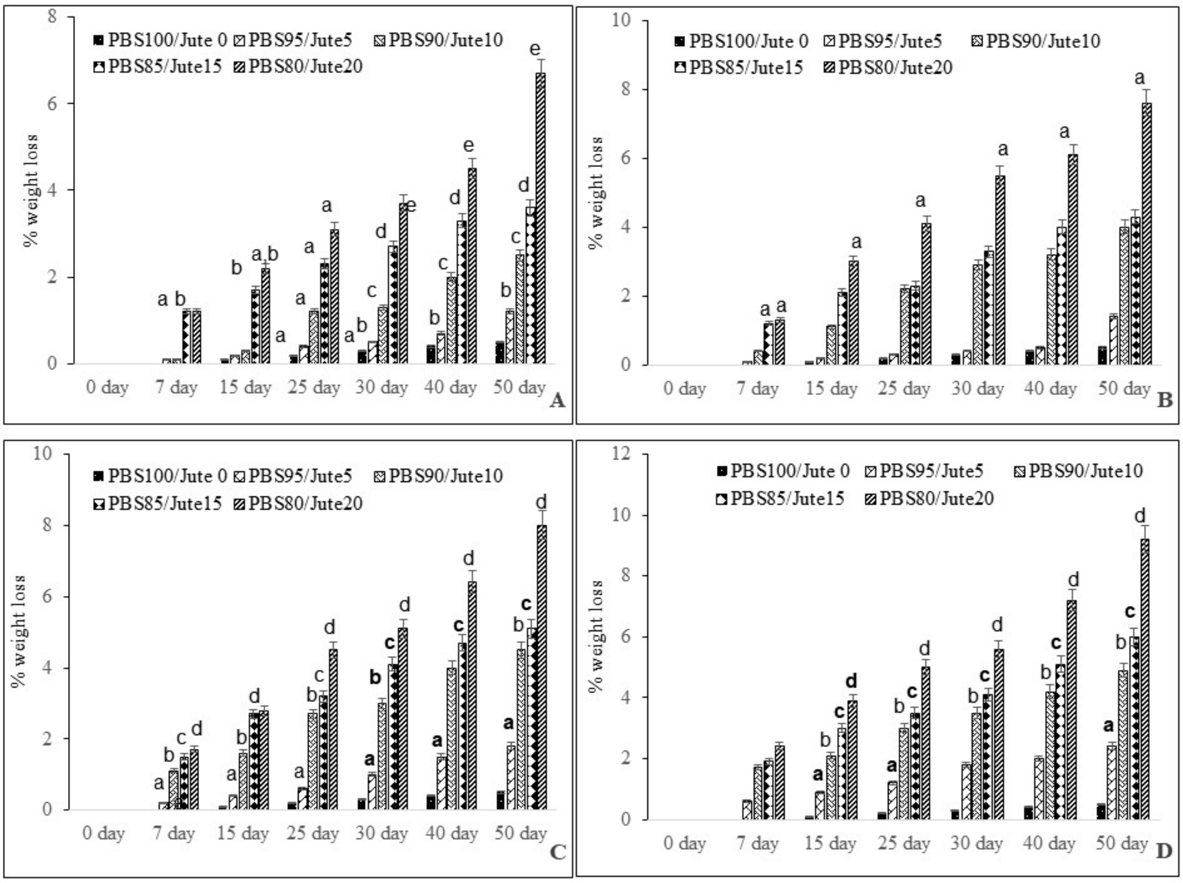

Figure 4: The biodegradability of the PBS/JF composites is shown in figure 4 (a) to 4 (d) for 50 µm to 80 µm jute fibers. Two-way ANOVA was used to test the treatment effect. Small letters indicate significant differences across treatments tested using post hoc Tukey's HSD test. All values were taken significant at $p < 0.05$.

In this study, the weight loss of PBS/Jute fibers-based biocomposites was calculated for different particle sizes of jute fiber after being buried in the ground for 15 days. It was found that PBS/Jute fiber composites with a particle size of 80 µm had a slightly higher percentage of weight loss (9.5%) than those with a particle size of 50 μm (6.8%). This was due to insufficient interfacial adhesion between the jute fibers and the PBS matrix due to large size (80 μm) of jute fibers, resulting in a PBS composite that was easily degraded by microorganisms. However, the effect of fiber size is not significant. It was observed that the weight loss of PBS/Jute fibers biocomposites non-significantly decreased with a decrease in size of jute fibers (50 μm) ($p>0.05$). This was attributed to the superior internal structure of the composite reinforced with finer fibers (Sasimowski et al. 2021).

It was also found that the amount of weight loss was directly proportional to the amount of jute fibers added, with the highest weight loss observed at a jute fiber content of 20% irrespective of fibers sizes (PBS80/Jute20). Biodegradability significantly increased with increasing the jute fiber content with respect to PBS ($p<0.05$). Jute fiber, a natural fiber with hydrophilic properties, facilitates water absorption and increases its biodegradability by making it susceptible to microbial action. The contact between water and PBS increased in the presence of jute fibers, leading to hydrolysis of the polymer and a reduction in weight due to the action of microorganisms in the natural soil burial process. This decrease in weight resulted in the weight loss percentage (Sasimowski et al. 2021; Nithikarnjanatharn & Samsalee 2022).

PBS-based biocomposites made from jute fiber waste have a wide range of applications. Since these composites are biodegradable and promote the circular economy, they play an important role in protecting the environment. Our study shows that the addition of jute fiber waste to PBS significantly enhances mechanical properties such as tensile strength, impact energy, density, and water absorption properties as well as biodegradability. The developed composite will address a key challenge in replacing traditional plastics. In addition to diverting waste from landfills, this approach will reduce dependence on natural resources. Jute waste-based biocomposites can be converted into useful products such as tablewares which promote circular economy. By optimization of biodegradation, lifecycle of these composites can be optimized with minimization of waste. Using jute waste as a filler material in developing PBS-based biocomposites offers several cost advantages over synthetic alternatives. Jute waste, being an agricultural byproduct, is both abundant and relatively inexpensive compared to synthetic fillers such as glass fibers, carbon fibers, or mineral-based reinforcements, which often involve higher processing and transportation costs. Integrating jute waste into biocomposites not only minimizes material costs but also reduces the need for disposal methods like incineration or landfilling, leading to savings in waste management.

Jute based composites are important sectors for biocomposite application such as tablewares. It is a suggested area where the findings of this study can be implemented due to its requirements for sustainability, biodegradability, and moderate mechanical properties. The major advantage of using jute waste processing generally requires lower energy and fewer chemical treatments, decreasing overall manufacturing expenses. In terms of product lifecycle, the biodegradability of jute-based composites can reduce costs associated with end-of-life disposal, especially for products with a limited lifespan. However, challenges in ensuring consistent mechanical properties, due to natural fiber variability, might necessitate additional quality control processes, which could offset some cost savings. Overall, adopting jute waste as a filler enhances the sustainability of biocomposites while providing an economical alternative to synthetic fillers, particularly in applications where moderate mechanical strength and biodegradability are prioritized over high-performance material requirements.

4. Conclusion

This study evaluated the mechanical properties and biodegradability of polybutylene succinate (PBS) composites reinforced with natural jute fibers of varying sizes (50-80 μm). It has been found that the incorporation of jute fibers into PBS matrix non-significantly reduce melt flow index, tensile strength, or impact energy compared to PBS. However, jute fibres based composite significantly increases density and biodegradability when compared with PBS. Fibres size did not impose any significant impact on melt flow index, tensile strength or impact energy. This study also examined the effect of jute fibers' size in the range of 50 to 80 μm to show the impact of larger fiber sizes (80 μm) on the mechanical properties of PBS/jute biocomposites. Larger fiber sizes (80 μm) resulted in non-significant decreases in melt flow index, tensile strength, density, and impact energy. However, a significant increase in water absorption and biodegradation rates was observed with the larger (80 μm) jute fibers. It has been found that adding natural jute fibers to PBS composites do not reduce some mechanical properties ($p>0.05$), but significantly affects environmental performance properties, such as water absorption and biodegradability. The variations in fiber size indicated that smaller fibers may be preferable for maintaining mechanical integrity, whereas larger fibers enhance biodegradability. These insights are valuable for designing and developing sustainable biocomposite materials and balancing mechanical performance with environmental benefits.

Authors' contributions:

1. Abhishek Sharma: Perform experiments, analyse results, write first draft

2. Shweta Kulshreshtha: Origin of concept, Analyse results, write final draft, and reviewed manuscript.

3. Nitesh Singh Rajput: origin of concept, review manuscript.

4. Ashish Goyal: reviewed manuscript and provide guidance.

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