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An Approach to Develop Waste Plastic and Natural Fiber (Jute Fiber, Rice Straw) Based Composite Material.

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Abstract:

The increasing demand for sustainable Martials can be fulfilled by recycling the plastic waste. Natural fiber inclusion for composite material development carries high prospect. This study investigates the physical (density, water absorptivity, Digital microscopic view) and mechanical (Tensile test, bend test, impact test) properties of recycled plastic waste composites incorporating 20% natural fiber (rice straw, jute fiber) along with 80 % plastic. Mechanical and physical testing was conducted to evaluate tensile strength, flexure strength, impact energy density, water absorptivity and digital microscopic view aiming to identify composite formulations that balance performance and environmental benefits. We found the combination with 80% and 20% plastic waste jute fiber provide maximum tensile behavior. Whereas the second combination with 20% rice straw offers maximum flexure strength characteristics. This work will significantly contribute to prevent agricultural land pollution while providing an eco-friendly, sustainable material with affordable cost.

Keywords- (WPC) Waste Plastic Composite Material, Waste Plastic, Natural Fiber, Physical properties, Mechanical Properties, Eco-friendly, sustainable material.

1. Introduction

Plastic introduced in the 20th century, gained popularity due to its durability, flexibility, and affordability. Due to this, its production rose from 1.5 million tons to 335 million tons from 1950 to 2016; however, only a small portion was recycled [1]. 407 million tons of plastic were produced in 2015, of which 79% ended up in landfills or were released directly into the natural environment, harming wildlife and entering the food chain as microplastics [2]. At the same time, the world produces nearly 140 billion metric tons of agricultural waste annually, consisting of materials such as jute fiber, date palm fiber, areca nut shells, and rice husks [3]. These agricultural residues are often burned or discarded, leading to pollution and wastage of resources, even though they hold great potential for value-added and sustainable applications [3], [4]. Both plastic and agricultural wastes pose major management challenges, yet they also provide valuable opportunities for innovative recycling methods and the development of sustainable materials.

The development of a composite material made from recycled plastic and agricultural waste could be a great solution to reduce both. Conventional disposal methods, such as incineration, open burning, and landfills, both waste valuable resources and contribute to environmental pollution and greenhouse gas emissions [5]. By converting the wastes into a composite, it can reduce the carbon footprint, greenhouse gas emissions, and pressure on landfills [6]. This type of plastic-based composite exhibits improved mechanical, thermal, and resistive properties and is also cost-effective [7]. These properties of the composite material sometimes yield better results than those of conventional materials like wood and plastics. A composite made from agricultural waste can be a better alternative to wood and plastic.

Recently research on various natural fibers and agricultural wastes includes jute [10], hemp [11], flax [12], kenaf [13], bamboo [14], betel nut husk[15], rice husk [16], rice straw[17], sugarcane bagasse [18], corn husk [19], coconut shell [20], wood flour[21], banana fiber [22], and pineapple leaf fiber [23] used as reinforcements. These materials are readily available, low-cost, and help solve waste management problems. Also, they have these limitations in Mechanical properties (affordable, locally available, and safe).

This paper distinguishes itself by systematically investigating the mechanical properties of WPC composites reinforced with a novel blend of agricultural waste fibers, including jute and rice straw.

To solve this problem, we experimentally prepared material with different recipes and also predicted the outcome using simple Mechanical testing. We found that a combination of 1 part plastic waste (80%+) and 20% jute fiber provides the maximum tensile behavior. However, (Combination: 2 - plastic waste 80% + rice straw fiber 20%) offers the maximum flexural strength.

2. Materials and methodology

2.1 Materials:

The fundamental components for this composite study were sourced directly from the local environment, ensuring that the methodology aligns with the principles of utilizing readily available waste and agricultural byproducts. The material selection was divided into two main categories: reinforcing fiber materials and the polymer matrix. All collected materials underwent rigorous preparation steps to optimize their properties for effective compounding and fabrication.

2.1.1. Fiber Materials: Sourcing and Pre-Treatment

The reinforcing elements comprised two distinct natural fibers: rice straw and jute fiber, both highly abundant in the locality. Rice straw was collected directly from nearby paddy fields immediately following the rice harvest. This direct procurement ensured the material was fresh and allowed for a significant volume to be collected with ease. Once collected, the straw underwent an initial mechanical preparation, where it was manually cut to a specific, uniform length of approximately 6 mm.

This crucial sizing step was performed to facilitate consistent dispersion within the polymer matrix and to ensure compatibility with the composite processing equipment. The jute fiber, a common local commodity, was procured from a trusted local supplier. Similar to rice straw, the raw jute fibers were also meticulously cut into smaller pieces to achieve the desired aspect ratio for effective mechanical interlocking with the plastic matrix. The careful and precise sizing of both fibers was paramount for achieving homogeneous composite properties.

2.1.2. Matrix Material: Low-Density Polyethylene (LDPE) Waste

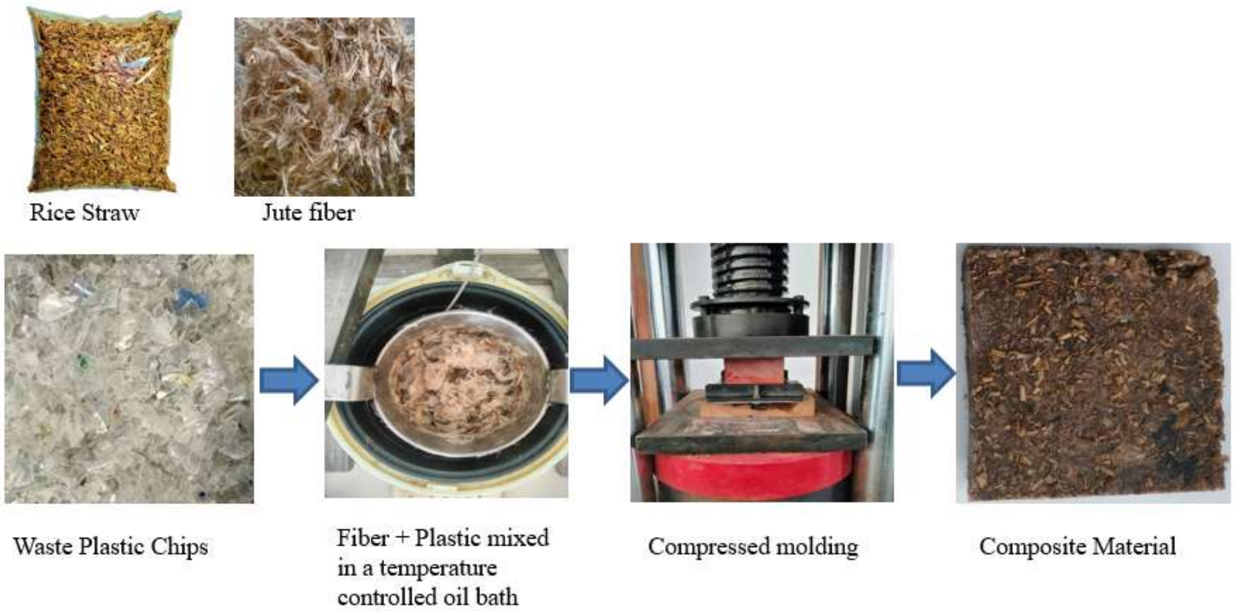
The matrix material selected was Low-Density Polyethylene (LDPE) waste, chosen due to its ubiquitous presence in the country’s waste stream and its inherent thermoplastic properties, which make it ideal for recycling and compounding. The LDPE waste was sourced primarily from local landfill stock and supplemented with material from nearby plastic recycling factories. The collected plastic pellets or fragments were thoroughly rinsed multiple times with water. This extensive washing was essential to remove dirt, was mechanically squeezed to remove excess moisture, and then subjected to open-air sun drying.

2.2 Methodology:

The waste plastic and natural fiber composite preparation involved sourcing and processing the raw materials. Waste plastics, such as high-density polyethylene (HDPE), polyethylene terephthalate (PET), or low-density polyethylene (LDPE), were collected, cleaned to remove impurities, and then shredded or pelletized for compounding. Meanwhile, the natural fibers—jute and rice straw—were prepared by cutting the jute into 5-10 mm lengths. The rice straw was chopped, cleaned, and dried to ensure a consistent moisture level, promoting better mixing and preventing steam formation during high-temperature processing. All materials were stored in controlled, low-humidity conditions until the compounding process to preserve their quality and prevent moisture absorption.

2.2.1. Preparation of Composite material

Figure 1 illustrates the preparation methods and all involved steps. Initially, different types of raw materials were collected. Then those materials were cut to size. For plastic waste, it was collected, cut into pieces, rinsed with water, and dried in the sun. The plastic was mixed with various fibers as shown in the figure. The resulting mixture was melted in a muffle furnace. Subsequently, the melted mixture was poured into a mold and pressed at 10 KN using a compression testing machine.



Rice Straw

Jute fiber

Waste Plastic Chips

Fiber + Plastic mixed in a temperature controlled oil bath

Compressed molding

Composite Material

Figure 1: Making of composite Material

Composites of the WPC material with varying compositions were prepared to achieve optimal results. Tests can be conducted using a UTM machine. Two combinations were used to make the composite material. Combination 1: 80% plastic waste + 20% jute fiber. Combination 2: 80% waste plastic + 20% rice straw. Additionally, a 100% waste plastic sample was prepared for comparison.

2.2.2. Physical Testing

Density Test: The density test for waste plastic and natural fiber composites measures the material's mass per unit volume, which is important for lightweight applications. The test is usually performed using the Archimedes Principle (e.g., ASTM D792), where the sample is weighed in air (Wa) and then submerged in a known liquid (Wl). Adding low-density natural fibers (such as rice husk or jute fiber) generally lowers the overall composite density (ρ) compared to the pure plastic matrix, often leading to increased porosity and reduced moisture stability. The density is calculated with the following formula**:**

$$\rho = \frac{Wa}{V} \qquad (2.1)$$

Where V is the volume of the sample, which is determined by the difference between the weight in air and the weight when submerged (W_a - W_l), relative to the density of the immersion liquid (ρ_{liquid}). For a solid of mass m, weight $W_{a,}$ and volume V:

$$\rho = \frac{Wa}{V} = \frac{Wa}{Wa - Wl} \times \rho_{liquid} \qquad (2.2)$$

Water Absorption test:

The Water Absorption (WA) test is an important method for characterizing waste plastic and agri-waste composites. It measures how much moisture the material absorbs when submerged, which affects its dimensional stability, mechanical performance, and durability in humid conditions. Since agri-waste (such as natural fibers) is hydrophilic and plastic is hydrophobic, the WA value indicates the quality of fiber-matrix adhesion and the presence of voids or porosity within the composite. Poor adhesion allows water to easily penetrate fiber-plastic interfaces and voids, resulting in high WA and possible thickness swelling. The test typically involves immersing pre-conditioned, weighed samples (Wd, dry weight) in distilled water for a set period (e.g., 24 hours or until saturation), then re-weighing them (Ww, wet weight) after removing surface water. The water absorption percentage (WA) is calculated with the following formula (often following standards like ASTM D570 or D5229):

$$WA\% = \frac{Ww - Wd}{Wd} X\ 100\% \qquad (2.3)$$

2.2.3. Mechanical Testing

Tensile test: The tensile test is a fundamental mechanical characterization of waste plastic and agri-waste composites, used to determine the tensile strength and modulus (stiffness) by measuring the maximum stress a material can withstand before fracture when subjected to a controlled uniaxial pulling force. This property is crucial for structural applications and directly reflects the effectiveness of the fiber-matrix interfacial adhesion and the degree of dispersion and orientation of the agri-waste reinforcement (e.g., rice husk, coconut shell fibers). The test typically follows standards like ASTM D638 or ISO 527, using dumbbell-shaped specimens pulled at a constant rate until failure. The Tensile Strength (σ_{Ts}) is the calculated maximum engineering stress reached during the test, given by the ratio of the maximum load (F_{max}) applied to the initial cross-sectional area (A):

$$\sigma_{Ts} = \frac{\mathrm{Fmax}}{A} \qquad (2.4)$$

Bend Test:

The Flexural (Bend) Test is an essential mechanical evaluation of waste plastic and agri-waste composites, used to determine the material's behavior under bending load, resulting in the Flexural Strength and Flexural Modulus (a measure of stiffness). This test simulates common loading conditions for composite materials used as structural or non-structural panels and is highly sensitive to fiber-matrix adhesion, porosity, and the overall integrity of the composite. It is typically performed as a three-point or four-point bending test (for example, following ASTM D790 or ISO 178), where a rectangular specimen is supported at two points and loaded at the center or two interior points until failure. The Flexural Strength (σf) for a rectangular bar in a three-point bend test is calculated as the maximum stress at the outer surface (at the point of break) using the following equation:

$$\sigma_f = \frac{3\mathrm{FmaxL}}{2bd^2} \qquad (2.5)$$

Where F_{max} is the maximum load applied, L is the support span length, b is the specimen width, and d is the specimen thickness.

Impact test:

The impact test, often performed using standardized methods like Charpy or Izod, is essential for evaluating the toughness of composite materials made from waste plastic and agricultural waste. It measures their resistance to fracture under sudden, high-speed loading. Adding agricultural waste fibers (such as rice husk or wheat straw) as reinforcement or filler into a plastic matrix (like recycled PET or polypropylene) creates a complex failure mechanism. While the hydrophobic nature of the plastic and weak interfacial bonding with the hydrophilic agricultural waste can often reduce overall impact strength compared to virgin material, chemical treatments or optimal fiber loading can improve fiber-matrix adhesion. This enhancement can boost the material's ability to absorb energy by encouraging mechanisms like fiber pull-out and crack deflection. The test result, known as Impact strength (Ei), is determined by the energy absorbed during fracture (E absorbed) and the cross-sectional area A of the specimen at the notch, typically expressed through the fundamental relationship.

$$E_i = \frac{\mathrm{Eabsorbed}}{A} \qquad (2.6)$$

Thus, an increase in E_i for the waste-based composite indicates a successful, tougher, and more durable material for sustainable applications.

3. Result and discussion

This research focuses on waste plastic and natural fiber-based composites. We conducted various mechanical and physical tests, such as density, water absorption, tensile, microscopic examination, bending, and impact tests to justify our work. All tests were completed successfully, and we obtained significant results. All test analyses are discussed below.

3.1. Density of developed composite:

The observed differences in (Table 1) composite density—where the 20% Jute Fiber + 80% Waste Plastic composite is found 0.928 gm/cm^3 which is denser than pure waste plastic density found 0.895 gm/cm^3, but the 20% Rice Straw + 80% Waste Plastic composite density is found 0.849 gm/cm^3 which is less dense—are primarily dictated by the significant variations in the intrinsic specific density and morphology of the two natural fibers relative to the plastic matrix. Consequently, substituting the lighter plastic with the denser jute fiber naturally increases the overall composite density. Conversely, rice straw is a lightweight, porous material with a lower intrinsic density and a higher internal void content due to its hollow structure (lumen). When this lighter, more porous material is incorporated into the plastic, it introduces a greater volume of low-density material and potential micro-voids, resulting in a measurable decrease in the overall composite density compared to the pure plastic matrix.

Plastic 80 %+ 20 % fiber	volume in cm^3	Weight in gm	**Density ρ in gm/cm^3**
jute fiber 20 %	3.71	3.44	**0.928**
rice straw 20%	3.63	3.08	**0.849**
Raw Plastic 100 %	3.47	3.11	**0.895**

Table 1: Density of developed composite compare along with 100% waste plastic.

3.2. Water absorptivity of developed composite:

The increase in the water absorptivity for both the 20% Jute Fiber + 80% Waste Plastic composite (3.31%) and the 20% Rice Straw + 80% Waste Plastic composite (7.67%) compared to the pure waste plastic (0.42%) is primarily sees to the hydrophilic nature of the natural fibers introduced into the hydrophobic polymer matrix. The waste plastic matrix alone shows very low water absorption because it lacks these polar groups. Therefore, the incorporation of jute fiber increase in absorption and, even more when rice straw increase. Introduces pathways for water intrusion through the fiber structure itself and, critically, via the exposed fiber surfaces and micro-gaps created at the imperfect fiber-matrix interface. The much higher absorption of the rice straw composite 7.67% compared to the jute composite 3.31% is likely due to the highly porous and hollow internal structure of the rice straw, which provides a greater surface area and internal volume for water storage, leading to superior moisture retention.

Plastic 80 %+ 20 % fiber	Initial weight W_d g_m	Final weight W_w g_m	**Water absorption % in 3 Day =** $\frac{Ww-Wd}{Wd} X\ 100\%$
jute fiber 20 %	18.84	19.463	**3.31**
rice straw 20%	17.01	18.315	**7.67**
Raw Plastic 100 %	14.43	14.49	**0.42**

Table 2: Water absorptivity of developed composite compare along with 100% waste plastic.

3.3. Microscopic view:

The microscopic views of the two composites are shown in figure 2. The 20% Jute Fiber + 80% Waste Plastic composite typically shows densely packed jute bundles that appear more uniform in cross-section. In contrast, the 20% Rice Straw + 80% Waste Plastic composite microstructure exhibits more irregularly shaped straw particles characterized by their hollowness. This open, porous morphology leads to poor impregnation by the plastic melt, resulting in significant micro-voids and large air gaps at the fiber-matrix interface. This structural discontinuity and the high internal surface area of the porous straw explain the composite's lower overall density and its substantially higher water absorption, as water can easily wick into the straw's lumen and travel along the extensive, poorly bonded interface.

20% Jute fiber 20% Rice Straw 100 % waste plastic

Figure 2: Microscopic View of composite

3.4. Tensile test:

From the tensile test, we found (Table 3) that the strength of 20% jute fiber combined with 80% waste plastic is 8.84 MPa, which is higher than the strength of 100% waste plastic, at 8.22 MPa. This is because the jute fiber enhances the composite's strength. On the other hand, the strength of 20% rice straw with 80% waste plastic is 7.33 MPa, which is less than that of 100% waste plastic. Therefore, the jute fiber-based composite shows better tensile behavior. We can also see this in the graph (Figure 3).

Table 3: Tensile strength of developed composite in comparison to 100% waste plastic

Plastic 80 %+ 20 % fiber	Cross-sectional area A mm^2	Max Load P=Kgf	Max Load P=(Kgf*9.81) N	**Tensile strength (P/A) MPa**
jute fiber 20%	70.74	63.77	625.58	**8.84**
rice straw 20%	77.42	57.82	567.21	**7.33**
Raw Plastic 100%	75.01	62.89	616.95	**8.22**

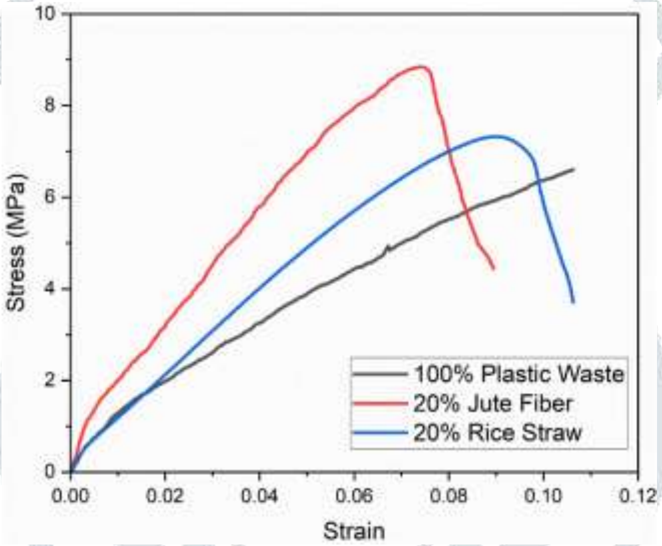


Figure 3: Variation of resistive force with deformation under tensile loading.

3.5. Bend test:

The results from the bend test (Table 4), summarized by the calculated flexural strength, highlight the distinct reinforcing abilities of the two natural fibers within the waste plastic matrix. The 20% Jute Fiber + 80% Waste Plastic composite achieved a flexural strength of 17.82 N/mm², which shows a significant increase over the raw 100% waste plastic strength of 14.10 N/mm². This notable improvement is mainly due to the jute fiber's superior inherent stiffness and its capacity to resist bending deformation, effectively transferring and distributing the applied flexural loads across the material's cross-section. Interestingly, the 20% Rice Straw + 80% Waste Plastic composite also demonstrated a modest gain, with a flexural strength of 17.93 N/mm², slightly surpassing the jute composite. This comparable performance in bending, despite rice straw's low density and high porosity, suggests that the increased bulk volume and irregular shape of the straw—acting as an internal filler—may help constrain the matrix and resist crack propagation under complex stress conditions during bending. However, this effect is generally limited by the fiber's poor interfacial adhesion and tendency for micro-void formation. This is also illustrated in Figure 4.

Plastic 80 %+ 20 % fiber	Cross section area A=(wxt) mm^2	Max Load P=Kgf	Max Load P=(Kgf*9.81) N	**Flexural strength σ =(Mc/I) N/mm^2**
jute fiber 20%	111.10	14.8	145.19	**17.82**

rice straw 20%	101.99	13	127.53	**17.93**
Raw Plastic 100%	99.37	9.96	97.71	**14.10**

Table 4: Flexural strength of the developed composite versus 100% waste plastic

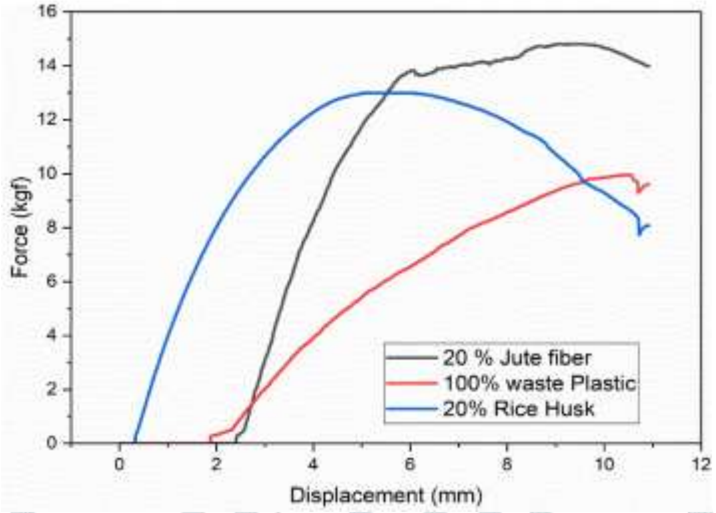


Figure 4: Variation of resistive force with deformation under flexural loading.

3.6. Impact test

Table 5 shows that the impact load for 20% jute fiber combined with 80% waste plastic is 0.206 J/mm², which is higher than the 100% waste plastic strength found to be 0.150 J/mm². The impact load for 20% rice straw combined with 80% waste plastic is 0.111 J/mm², which is lower than the 100% waste plastic strength of 0.150 J/mm². So, adding natural fibers like jute improves the impact load capacity.

Plastic 80 %+ 20 % fiber	Area mm^2	energy J	Impact value J/mm^2
jute fiber 20%	95.15	19.6	0.206
rice straw 20%	95.41	10.6	0.111
Raw Plastic 100%	88.91	13.33	0.150

Table 5: Impact Energy of developed composite compare along with 100% waste plastic

We found a combination: 1 with 80% plastic waste and 20% jute fiber provides maximum tensile behavior. However, combination 2—80% plastic waste and 20% rice straw fiber—offers maximum flexural strength. This work will significantly contribute to this field, especially in preventing agricultural land pollution, promoting a sustainable and eco-friendly plastic waste recycling process, and developing low-cost composite materials.

4. Conclusion

WPC composite material plays a vital role in addressing Bangladesh's waste plastic crisis. To tackle this issue, we experimentally prepared various recipes and predicted their outcomes through comprehensive mechanical testing. We varied the composition, including jute fiber and rice straw proportions, and conducted tensile, bending, impact tests, water absorption, density measurements, and microscopic sectional analysis. Notably, the mix with 80% plastic waste and 20% jute fiber showed the highest tensile strength. Meanwhile, the combination of 80% plastic waste and 80% rice straw fiber provided the best flexural strength, which is considered optimal. This research will greatly advance the field of composite materials. Additionally, recycling waste plastics could contribute significantly to sustainability efforts in Bangladesh.

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Data Availability: The data datasets measured and analyzed in this investigation are accessible from the corresponding author upon reasonable request

Authors' Contributions: Md. Mukul Uddin: Conceptualization, Investigation, Formal analysis, Writing—Original draft. Md. Nurul Islam: Writing, review, and editing. Md. Arif Istiak Siam: Drafting, writing. Md. Shawon Ahmed: Investigation. Md. Abdul Monem: Review and editing. Md. Maruf Tahmid: Validation, Reviewing, and Editing. Md. Sejan Hossain: Validation, Reviewing, and Editing. Md. Almostasim Mahmud: Reviewing and Editing. Mohammad Nurul Islam: Reviewing and Editing.

Conflict of Interest: We declare that the authors have no competing interests as defined by Nature Research, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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