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Valorization of *Eichhornia crassipes* for Biodegradable Food Packaging

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Abstract*— Water hyacinth (*Eichhornia crassipes*) is an invasive aquatic plant widely distributed in freshwater bodies in Sri Lanka. Its rapid proliferation obstructs waterways and adversely affects aquatic ecosystems. This biomass is often removed during management activities, but its productive use is limited, presenting an opportunity to turn this resource into a value-added material. This study investigated the valorization of *E. crassipes* biomass for the development of biodegradable starch-based sheets intended for food-packaging applications. The collected biomass was subjected to sodium bicarbonate ($NaHCO_3$)-assisted alkaline boiling, pulped, and incorporated into a cassava-starch matrix. Three water hyacinth fibre/starch formulations, 40:60 (S1), 50:50 (S2), and 60:40 (S3), were fabricated by wet forming and evaluated for tensile strength, density, water absorption, and thickness. The fibre/starch ratio considerably influenced the measured properties. S2 achieved the highest tensile strength of 63.73 MPa, whereas S1 and S3 recorded 54.80 and 58.00 MPa, respectively. S1 exhibited the lowest density (0.83 g/cm³), water absorption (141.66%), and thickness (2.0 mm), compared with 1.08 g/cm³, 170.00%, and 2.6 mm, respectively, for S3. The 40:60 fibre/starch formulation showed the best overall performance, though its high water absorption indicates a need for better moisture resistance. These findings suggest a method to transform invasive *E. crassipes* biomass into biodegradable packaging, connecting aquatic weed management with waste valorization material use in Sri Lanka.

Keywords: *Eichhornia crassipes*; water hyacinth; waste valorization; biodegradable food packaging; starch biocomposite; circular economy

I. Introduction

Water hyacinth (Eichhornia crassipes) is an invasive aquatic plant that has become problematic in freshwater environments, including those in Sri Lanka. Its rapid vegetative growth enables the formation of dense floating mats that can restrict water flow, reduce light penetration and dissolved oxygen, and interfere with irrigation, fisheries, and other uses of freshwater systems (Yan et al., 2017). Although removal can control excessive growth, the harvested biomass requires appropriate management. This creates an opportunity to consider E. crassipes not only as an invasive biomass requiring disposal, but also as a lignocellulosic feedstock for material development. Previous research has explored water hyacinth for several material applications because of its fibrous structure and cellulose content (Guna et al., 2017; Arivendan et al., 2022).

One potential route for utilizing this biomass is its conversion into fibre-based packaging materials. This approach is particularly relevant to food packaging, where conventional plastics remain widely used because of their functional performance but generate persistent waste after disposal (Harikrishnan et al., 2023). Natural fibres and starch-based matrices provide an alternative material platform because both can be derived from renewable biological resources. However, starch alone has limitations in mechanical performance and moisture sensitivity, while incorporation of lignocellulosic fibres can alter the strength and structural characteristics of the resulting composite (Mohanty et al., 2005; Behera et al., 2025). Water hyacinth has consequently been investigated in biodegradable boards and food-service products, demonstrating its potential for forming fibre-reinforced structures (Rahmawati et al., 2018). Nevertheless, material performance depends strongly on fibre content and fibre–matrix interaction; therefore, increasing the proportion of biomass does not necessarily produce better packaging performance (Behera et al., 2025).

Within the Sri Lankan context, research has already demonstrated the extraction and characterization of fibres from locally available water hyacinth (Rathnapriya et al., 2024), yet its conversion into starch-bound sheets for food-packaging applications remains comparatively underexplored. Accordingly, this study investigates the utilization of E. crassipes biomass as reinforcement in cassava-starch-based packaging sheets. Three fibre-to-starch ratios—40:60, 50:50, and 60:40—were evaluated for tensile strength, density, water absorption, and thickness. This study investigates the impact of different fibre/starch ratios on these properties to identify the best formulation.

II. Materials and Methods

A. Water Hyacinth Fibre Preparation

Fresh water hyacinth (Eichhornia crassipes) was collected from a freshwater source in Sri Lanka, thoroughly washed, and cut into 2–3 cm pieces before being sun-dried. This lignocellulosic biomass serves as a fiber source for material applications (Guna et al., 2017; Arivendan et al., 2022). The biomass underwent alkaline boiling with sodium bicarbonate ($NaHCO_3$) at 90–100 °C for 2–4 h to aid fiber separation and remove non-cellulosic constituents (Arivendan et al., 2022; Rathnapriya et al., 2024). After treatment, the material was washed to eliminate residual chemicals and blended with water to create a uniform pulp.

B. Starch Binder and Composite Formulation

Cassava starch was chosen as the matrix for producing biodegradable biocomposites with lignocellulosic reinforcement (Mohanty et al., 2005; Behera et al., 2025). The binder was made by mixing 100 g cassava starch, 500 mL distilled water, 10 g glycerol, and 5 mL vinegar, then heating the mixture at 75–80 °C for 10–15 min until it gelatinized. After cooling to 40–50 °C, it was mixed with water hyacinth pulp. Three formulations were prepared to study the effect of fiber content on sheet properties: S1 (40% fiber:60% starch), S2 (50%:50%), and S3 (60%:40%). This allowed for a progressive increase in the fiber fraction while decreasing the starch matrix.

Table 1 fibre-to-starch formulations used for sheet fabrication.

Sample	Fiber (%)	Starch (%)	Average Tensile Strength (MPa)
S1	40	60	54.80
S2	50	50	63.73
S3	60	40	58.00

C. Sheet Fabrication

The fibre pulp and starch binder were combined and sheets were fabricated by wet forming, similar to methods used for water hyacinth-based materials (Rahmawati et al., 2018). The slurry was spread over a wooden mesh frame, drained, and leveled with a roller for thickness uniformity. The sheets were sun-dried for 1–3 days and then oven-dried at 60 °C for 24 hours to remove moisture.

D. Material Characterization

The developed sheets were characterized in terms of tensile strength, density, water absorption, and thickness. Tensile strength was measured using a Universal Testing Machine following ASTM D638-14, while density was determined from the measured mass and specimen volume, with the thesis referring to ASTM D792-20. Water absorption was evaluated according to ASTM D570-22 by immersing pre-dried specimens in distilled water at 23 ± 1 °C for 24 h.

III. Results and Discussions

The fibre-to-starch ratio influenced both the mechanical and physical characteristics of the developed *Eichhornia crassipes*–starch sheets. As summarized in Table 2, tensile strength reached a maximum at 50% fibre content, whereas density, water absorption, and thickness increased progressively as the fibre fraction increased.

Table 2 Mechanical and physical properties of E. crassipes–starch sheets

Sample	Fibre: Starch (%)	Tensile strength (MPa)	Density (g/cm³)	Water absorption (%)	Thickness (mm)
S1	40:60	54.80	0.83	141.66	2.0
S2	50:50	63.73	0.94	155.00	2.3
S3	60:40	58.00	1.08	170.00	2.6

A. Tensile Strength

Tensile strength increased from 54.80 MPa for S1 (40:60 fibre/starch) to 63.73 MPa for S2 (50:50), corresponding to an increase of approximately 16.3%. However, when the fibre content was increased further to 60%, the tensile strength decreased to 58.00 MPa. Thus, the highest tensile strength was obtained at the intermediate fibre/starch ratio rather than at the highest fibre loading.

The increase from S1 to S2 suggests that increasing the fibre fraction initially contributed to the load-bearing capacity of the sheet. Water hyacinth is a lignocellulosic material, and its fibrous structure can contribute to reinforcement when incorporated into a polymer matrix (Guna et al., 2017; Behera et al., 2025). Similar interest in water-hyacinth reinforcement has been reported for thermoplastic starch composites, supporting its potential role as a fibrous component in starch-based materials (Behera et al., 2025).

The reduction observed for S3 is equally important. At higher fibre loading, the amount of starch available relative to the fibre fraction was reduced. This may have affected fibre wetting, bonding, and stress transfer through the matrix. Natural-fibre composite behaviour is strongly influenced by fibre–matrix interactions, and increasing reinforcement beyond a suitable level does not necessarily result in a corresponding increase in strength (Mohanty et al., 2005). The present results are consistent with this general behaviour. Nevertheless, fibre dispersion and interfacial morphology were not examined in this study; therefore, the mechanism responsible for the

reduction in S3 cannot be confirmed from the tensile results alone.

From a formulation perspective, these findings show that maximizing the water-hyacinth content is not sufficient to maximize mechanical performance. S2 provided the highest tensile strength despite containing less fibre than S3. Further investigation of fibre distribution, interfacial bonding, and fracture morphology would help explain this response more clearly.

Table 3 Tensile Strength Test Results

Sample	*E. crassipes* fibre (%)	Cassava starch (%)
S1	40	60
S2	50	50
S3	60	40

B. Density and Thickness

Density increased progressively from 0.83 g/cm³ for S1 to 0.94 g/cm³ for S2 and 1.08 g/cm³ for S3. A similar trend was observed for thickness, which increased from 2.0 mm to 2.3 mm and 2.6 mm, respectively. Therefore, increasing the fibre fraction from 40% to 60% produced both denser and thicker sheets.

These changes are relevant when considering the structure of the wet-formed material. A greater proportion of water-hyacinth pulp increases the amount of lignocellulosic material present within the sheet, while simultaneously reducing the relative starch content. The resulting changes in solids content, fibre packing, and sheet consolidation may contribute to the observed increase in density and thickness. Previous work has demonstrated the suitability of water hyacinth as a feedstock for fibre-based materials, although the final structure depends strongly on processing and formulation conditions (Guna et al., 2017; Rahmawati et al., 2018).

The progressive increase in thickness also needs to be considered when interpreting tensile performance. Because formulation changes altered the physical structure of the sheets, the differences between S1, S2, and S3 cannot be attributed to fibre content alone without further structural characterization. Future work should therefore control sheet grammage and forming pressure more closely to separate the effect of composition from variations introduced during wet forming and drying.

Table 4 Density Test Results

Sample	Fiber (%)	Starch (%)	Average Density (g/cm³)
S1	40	60	0.83
S2	50	50	0.94
S3	60	40	1.08

C. Water Absorption

Water absorption increased with fibre loading, rising from 141.66% for S1 to 170.00% for S3, indicating that S3 absorbed about 20.0% more water than S1 after 24 hours (Table 5). This trend relates to the hydrophilic nature of lignocellulosic fibres and starch, which interact well with water. While water hyacinth has been studied for biodegradable products, its high water uptake highlights moisture sensitivity as a key limitation for using these sheets in applications involving direct contact with moist foods. Barrier modification is necessary to address this issue.

Table 5 Water Absorption Test Results

Sample	Fiber (%)	Starch (%)	Water Absorption (%)
S1	40	60	141.66
S2	50	50	155.00
S3	60	40	170.00

Considering the four measured properties together provides a clearer interpretation than examining each result independently. S2 exhibited the highest tensile strength (63.73 MPa), but its water absorption (155.00%), density (0.94 g/cm³), and thickness (2.3 mm) were higher than those of S1. Conversely, S1 had a lower tensile strength of 54.80 MPa but recorded the lowest density, thickness, and water absorption. S3 contained the greatest proportion of water-hyacinth fibre but did not provide the highest tensile strength and showed the greatest density, thickness, and water absorption.

These differences indicate that there is no single formulation that performs best for every measured property. S2 is preferable when tensile strength alone is considered, whereas S1 provides a more balanced combination of the properties evaluated in this study. Importantly, this interpretation should not be taken to mean that S1 is an optimized food-packaging formulation. Packaging performance also depends on properties that were not investigated here, including water-vapour and oxygen barrier behaviour, dimensional stability, food-contact safety, thermal response, biodegradation under controlled conditions, and performance during storage.

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IV. Discussion & Conclusion

This study demonstrated the feasibility of valorizing invasive *Eichhornia crassipes* biomass as reinforcement for starch-based packaging sheets. Among the three formulations, S2 (50:50 fibre/starch) achieved the highest tensile strength of 63.73 MPa, representing a 16.3% increase over S1 (54.80 MPa); however, further increasing the fibre content to 60% reduced the tensile strength to 58.00 MPa. In contrast, S1 (40:60) recorded the lowest density (0.83 g/cm³), water absorption (141.66%), and thickness (2.0 mm), compared with 1.08 g/cm³, 170.00%, and 2.6 mm, respectively, for S3. Based on the measured properties, S1 provided the most balanced overall performance, while S2 was preferable where tensile strength was prioritized. The high water absorption in all formulations limits their use in food packaging, indicating a need for better moisture-barrier performance. The findings propose a lab-scale method to convert water hyacinth biomass into a valuable material, supporting a circular waste-utilization approach.

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