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DEVELOPMENT OF A BIODEGRADABLE CUP USING GROUNDNUT SHELL WASTE

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ABSTRACT—

Utilizing agricultural residues for sustainable product development offers a promising pathway to convert low-value waste into functional eco-friendly materials. This study presents the design and development framework for a biodegradable cup fabricated from groundnut shell waste. Groundnut shells, rich in lignocellulosic components, serve as a natural filler combined with a starch-based binder and glycerol to form a mouldable biocomposite. The proposed manufacturing route encompasses shell collection, cleaning, drying, grinding, sieving, binder preparation, composite mixing, compression moulding, and final conditioning. A cup geometry with a nominal capacity of 120 mL is designed alongside a matched male–female aluminium mould using CAD tools. Furthermore, a preliminary finite-element modelling (FEM) and static structural analysis of the cup design are conducted. Because this work represents a Stage-1 development study, experimental fabrication and physical testing results are reserved for future work; thus, claims regarding long-term liquid-holding capacity or certified biodegradability require future empirical validation.

Keywords: *Groundnut shell waste; biodegradable cup; agricultural waste; starch binder; biocomposite; compression moulding; finite-element analysis.*

1. Introduction

1.1 Background

Single-use disposable cups are ubiquitous across institutions, corporate offices, food-service sectors, and public events. However, their short operational lifespan combined with poor end-of-life management creates severe environmental challenges. To address this, researchers are actively exploring agricultural residues as viable feedstocks for value-added materials. These residues help minimize waste accumulation while partially offsetting reliance on conventional petrochemical polymers. Groundnut shells are an abundant fibrous agricultural by-product packed with lignocellulosic constituents—namely cellulose, hemicellulose, and lignin—making them ideal candidate fillers for sustainable composite applications.

1.2 Need for the Study

This project directly targets the underutilization of groundnut shell waste and mitigates the ecological burdens tied to traditional disposable plastics. Designing an effective disposable cup requires more than a simple mouldable shape: the container walls must retain dimensional stability, resist cracking, and prevent structural softening or leakage throughout its intended use window. Consequently, this study establishes an integrated approach combining material selection, cup geometry design, mould engineering, manufacturing planning, and preliminary structural simulation.

1.3 Aim and Objectives

The primary aim of this work is to conceptualize, design, and plan the fabrication and evaluation of a biodegradable cup utilizing groundnut shell waste and a bio-based binder. The core objectives are:

- To prepare and characterize groundnut shell powder as a viable composite filler.
- To develop optimal shell–starch binder formulations.
- To design a functional cup geometry and a corresponding compression mould.
- To identify key processing parameters for compression moulding.
- To outline a rigorous evaluation framework covering density, water absorption, leakage resistance, dimensional stability, mechanical strength, and soil degradation.

1.4 Scope and Limitations

This study documents a laboratory-scale Stage-1 design and development initiative. It covers material conceptualization, proposed manufacturing methods, CAD modelling, and initial finite-element simulations. Physical fabrication and experimental testing are outside the immediate scope of this paper. Consequently, food-contact safety, commercial scalability, and certified compostability remain subjects for subsequent empirical verification.

2. Literature Review

Prior research demonstrates that agro-residues can be successfully integrated into eco-friendly packaging materials. Groundnut shell powder has frequently served as an organic filler in various polymer matrices. However, findings from polymer composites cannot be directly extrapolated to starch-bound, 100% bio-based tableware. Key challenges cited in literature include moisture sensitivity, barrier performance limitations, scaling difficulties, and strict food-contact compliance. Addressing these parameters requires meticulous formulation adjustments and standardized testing.



Figure 1. Groundnut shells, the agricultural waste feedstock used in the proposed study.



Figure 2. Groundnut shells and processed shell powder as shown in the project report.

3. Materials and Proposed Design

3.1 Materials

- **Filler:** Groundnut shell powder (waste-derived lignocellulosic reinforcement).
- **Binder:** Corn or tapioca starch (biodegradable matrix).
- **Plasticizer:** Glycerol (to enhance flexibility and processability).
- **Medium:** Distilled or processed water.
- **Optional Additives:** Cellulose pulp, bagasse fibre, citric acid (crosslinking aid), or natural wax barrier coatings (subject to safety verification).

3.2 Proposed Cup Geometry

Parameter	Proposed Value
Nominal capacity	120 mL
Top internal diameter	65 mm
Bottom internal diameter	45 mm
Internal height	70 mm
Target wall thickness	2.0–3.0 mm
Bottom thickness	3.0–4.0 mm
Draft angle	5–7°
Rim design	Rolled or thickened
Internal corner radius	≥ 3 mm

3.3 Mould Design

The proposed compression mould comprises a female cavity and a matching male core. Aluminium or mild steel is recommended due to favorable machinability and thermal conductivity. Design criteria emphasize uniform wall-clearance gaps, appropriate draft angles, edge smoothing, alignment pins, pressure-loading surfaces, and designated vents for steam release.

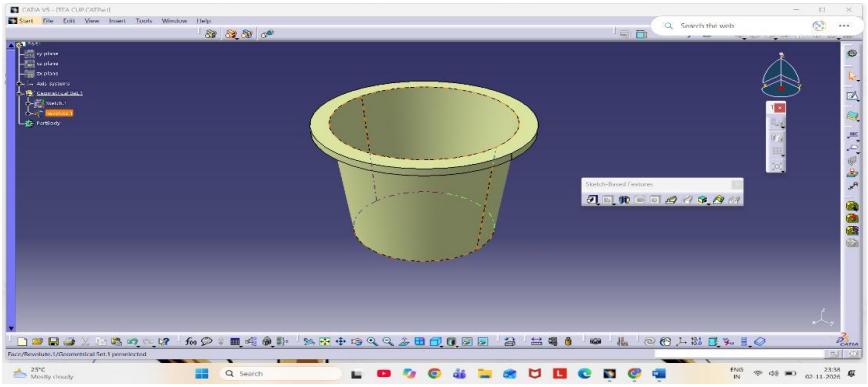


Figure 3. CAD view of the proposed cup model.

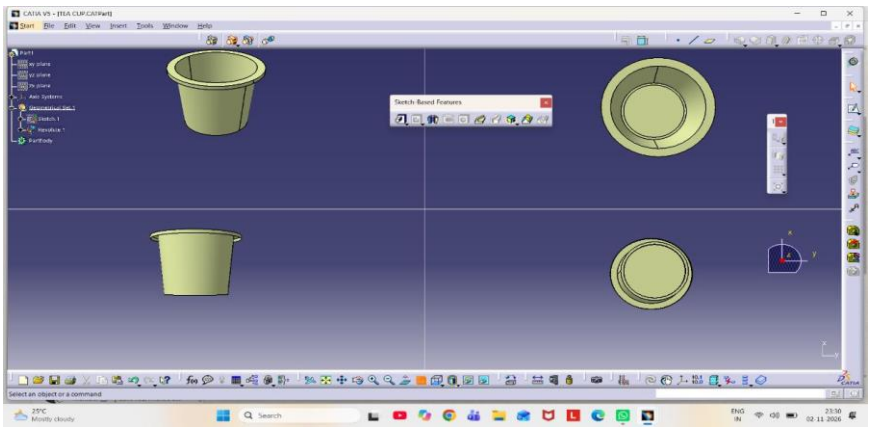


Figure 4. CAD model views of the cup geometry.

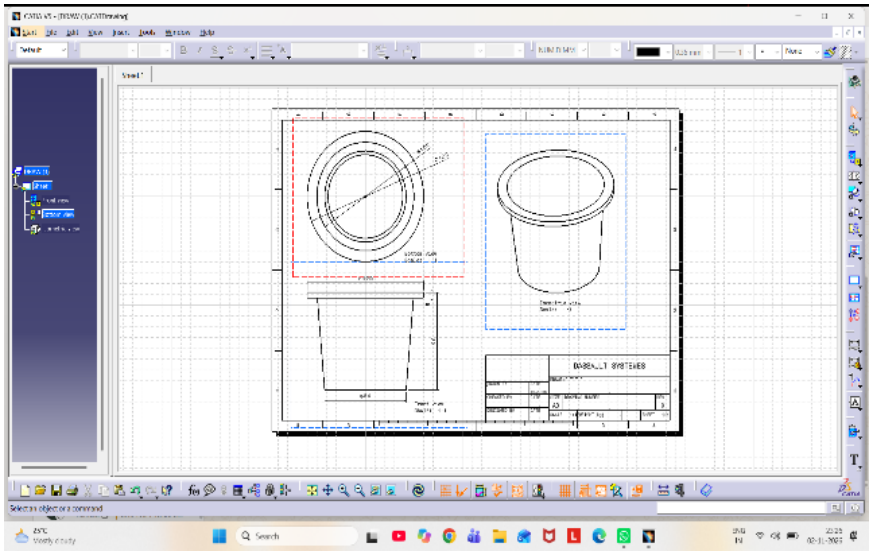


Figure 5. Cup 2D engineering drawing shown in the project report.

4. Proposed Methodology

4.1 Groundnut Shell Preparation

Raw groundnut shells are collected, manually sorted to remove foreign debris (stones, metal, kernels, and dirt), thoroughly washed, and oven-dried at 70–80 °C until constant weight is achieved. The dried shells are mechanically ground and sieved into controlled particle-size fractions (e.g., < 250 µm and 250–500 µm) and stored in airtight, labelled containers.

4.2 Binder Preparation and Composite Mixing

The starch binder is prepared by dispersing measured quantities of starch in water, adding glycerol as a plasticizer, and heating the mixture under continuous stirring to 70–85 °C to induce gelatinization. Prepared groundnut shell powder is then gradually blended into the matrix until uniform particle coating is attained.

4.3 Compression Moulding and Conditioning

The proposed manufacturing sequence involves preheating the compression mould, placing a controlled charge of the composite blend into the cavity, closing the tool gradually to purge trapped air and moisture, applying target pressure for a set dwell time, demoulding, flash trimming, and post-drying.

4.4 Proposed Evaluation Plan

Future empirical testing will evaluate visual uniformity, dimensional accuracy, density, water absorption rate, leakage resistance, axial/rim compression strength, and soil-burial biodegradation using standard testing procedures.

5. Cup Modelling and Preliminary Structural Analysis

A 3D CAD model of the cup was developed and imported into ANSYS Mechanical for static structural evaluation. The material properties assigned to the groundnut-shell composite model include a density of 1200 kg/m³, a Young's modulus of 5×10^8 Pa, and a Poisson's ratio of 0.3.

Applying fixed boundary constraints alongside simulated static pressure loads (340 Pa and 680 Pa), the preliminary model yielded a maximum total deformation of 8.162×10^{-10} m and a maximum von Mises stress of 5.788 Pa. While these preliminary computational outputs confirm model stability under low loads, they serve as a baseline theoretical exercise. Future iterations will incorporate experimentally verified material properties and dynamic load conditions.

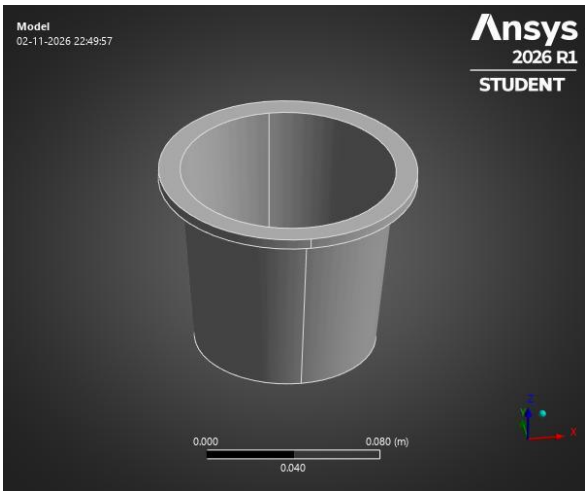


Figure 6. Cup geometry used for the preliminary ANSYS structural model.

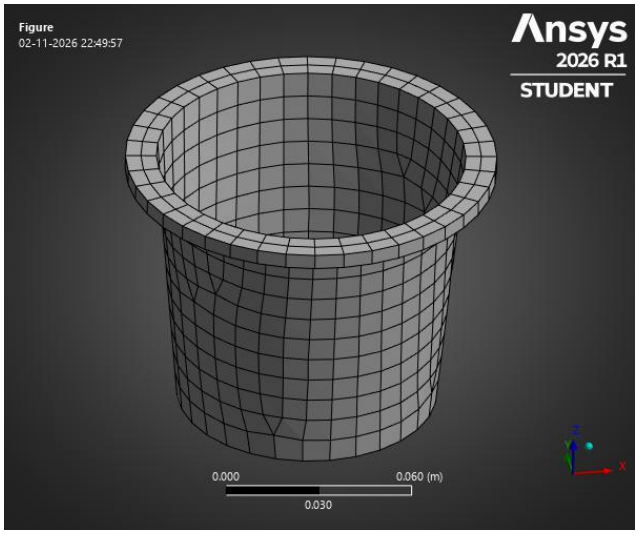


Figure 7. Finite-element mesh of the cup model.

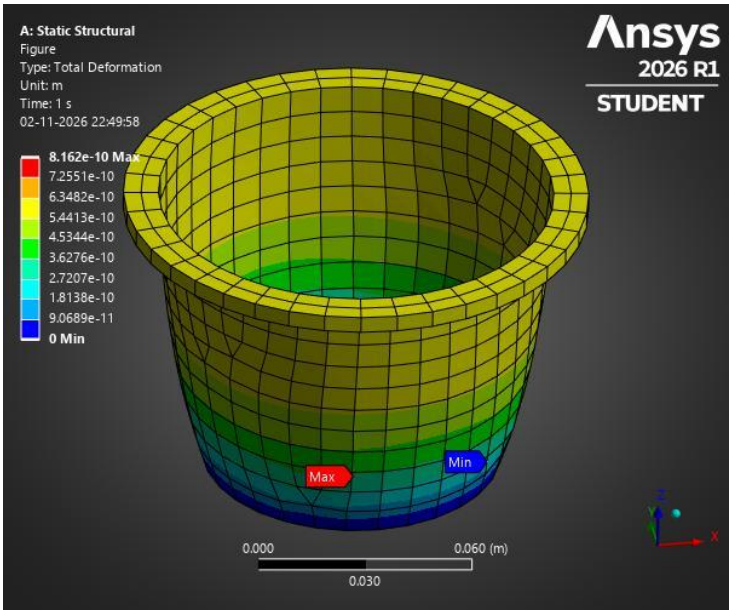


Figure 8. ANSYS static structural total deformation contour.

6. Discussion

This paper establishes a comprehensive developmental roadmap for producing sustainable tableware from agricultural waste. By combining waste management with mechanical design and finite element simulation, the study outlines a structured methodology to overcome common challenges in biocomposite manufacturing. Because this report represents a Stage-1 design study, the primary contribution lies in laying down the groundwork for future physical prototyping and optimization.

7. Conclusion

This study presents the comprehensive design framework for a biodegradable cup manufactured from groundnut shell waste, starch, and glycerol. Utilizing CAD modelling and preliminary ANSYS structural analysis, the physical parameters and mechanical feasibility of a 120 mL cup design were established. As this work represents a Stage-1 framework, subsequent experimental validation, prototype fabrication, and safety assessments are required before commercial deployment.

8. Future Work

- Fabrication of physical cup prototypes across varied material formulations.
- Optimization of moulding temperature, pressure, and dwell cycles.
- Execution of standardized mechanical, moisture absorption, and degradation assays.
- Food-contact migration safety evaluations to ensure consumer safety compliance.

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