Research Article

Eco-Friendly Innovation: Fabrication and Characterization of Biodegradable Cups from Banana Trunk Fibres

Rajendran S.S [a*], Neelaveni Thangavel[a], Dhivith G[a], Baarath A K[a], Karthick saran P[a], Angalaparameswari S [b], Nandhini S[a], Anuyashika T[a]

[a]Department of Pharmaceutical Chemistry, RVS College of Pharmaceutical Sciences, Sulur, Coimbatore 641 402, Tamilnadu, India, Affiliated to The Tamil Nadu Dr MGR Medical University, Guindy, Chennai – 600032, Tamil Nadu, India.

[b]Department of Pharmaceutical Analysis, RVS College of Pharmaceutical Sciences, Sulur, Coimbatore 641 402, Tamilnadu, India, Affiliated to The Tamil Nadu Dr MGR Medical University, Guindy, Chennai – 600032, Tamil Nadu, India.

***Corresponding author's E-mail:** rajendran@rvsgroup.com

Received: 06-01-2026; **Revised:** 28-02-2026; **Accepted:** 05-03-2026; **Published online:** 20-03-2026.

ABSTRACT

Single-use plastics cause serious environmental pollution due to their non-biodegradable nature. Banana pseudostem, abundant agricultural waste rich in cellulose, offers a sustainable and biodegradable alternative for eco-friendly composite products. Banana pseudostem fibres collected from Sulur, Coimbatore, Tamil Nadu, India, were authenticated by the Botanical Survey of India. Fibres were mechanically extracted, retted (60–70°C), dried, and size-reduced. Cups were prepared using rice and potato starch binders (10% and 15% w/v) in a 1:1.5 ratio, molded, and evaluated for physical, mechanical, water absorption, leakage, and biodegradation properties. All formulations showed uniform thickness and mass, indicating consistent fabrication. Bowls with 15% starch (BRS2 and BPS2) demonstrated higher load-bearing capacity (150 g) than 10% formulations (100 g), confirming improved strength at higher binder concentration. Water absorption ranged from 72.6–86.1%, reflecting the hydrophilic nature of starch. BRS2 showed the best leakage resistance (7 seconds). Noticeable biodegradation occurred within 8 days, with significant breakdown by 15 days, indicating effective environmental degradability and the key role of binder concentration in performance. The biodegradable cups were successfully developed using banana pseudostem fibres and starch-based binders. BRS2 (15% rice starch) showed the best balance of strength, water resistance, and biodegradability. The study highlights the potential of converting agricultural waste into sustainable alternatives to Single-use plastic containers, thereby supporting environmental conservation and circular economy initiatives.

Keywords: Banana pseudostem; Biodegradable cups; Starch-based binder; Agricultural waste utilization; Mechanical strength; Sustainable packaging.

1. INTRODUCTION

The rapid increase in consumption of single-use plastic products has created a critical global environmental challenge. Conventional petroleum-based plastics are non-biodegradable, persist in ecosystems for decades, and contribute significantly to soil and water pollution. According to the United Nations Environment Programme, millions of tonnes of plastic waste enter the environment annually, posing severe threats to biodiversity, marine life, and human health. [1] The urgency to mitigate plastic pollution has intensified research efforts toward the development of sustainable, biodegradable, and eco-friendly alternatives derived from renewable resources.[2]

Agro-industrial residues have emerged as promising raw materials for green material innovation due to their abundance, renewability, low cost, and minimal environmental footprint. Among these, banana (*Musa paradisiaca*) cultivation generates substantial biomass waste in the form of pseudostem after fruit harvesting. India, being one of the largest banana-producing countries, produces enormous quantities of pseudostem waste annually, much of which remains underutilized. Recent studies have highlighted the valorization of banana pseudostem fibres for biodegradable composite applications due to their high cellulose content and favorable mechanical properties[3] Banana pseudostem fibres are rich in cellulose, hemicellulose, and lignin, imparting favorable strength and biodegradability, thereby making them suitable for molded eco-friendly product fabrication.[4]

Natural fibre–reinforced biodegradable composites have gained attention as potential substitutes for synthetic polymers in packaging and disposable food containers. Starch, a biodegradable and biocompatible polysaccharide, is widely explored as a natural binder due to its film-forming capacity, renewability, and ease of processing. Rice and potato starches are readily available, cost-effective, and environmentally benign. However, starch-based materials exhibit inherent hydrophilicity, influencing their mechanical stability and water resistance. Optimization of starch concentration has been reported to significantly improve structural integrity and functional performance of biodegradable composites.[5]

In this context, the present study focuses on the fabrication and characterization of biodegradable cups using banana pseudostem fibres as reinforcement and rice and potato starch as natural binders. The research emphasizes converting agricultural waste into value-added eco-friendly products, thereby promoting sustainable material development and circular economy principles. Physical, mechanical, water absorption, leakage resistance, and biodegradation properties were systematically evaluated to

determine the influence of binder concentration on product performance. This reserach aims to provide a practical and scalable alternative to single-use plastic containers while contributing to environmental conservation and sustainable resource utilization.

2. MATERIALS AND METHODS

2.1. Materials

All chemicals used in the study were of analytical grade.

2.2. Methods

PREPARATION OF BIODEGRADABLE CUPS FROM BANANA PSEUDOSTEM FIBRES:

2.2.1. Raw Material Collection and Authentication

Fresh banana pseudostem (*Musa paradisiaca*) was collected from local agricultural fields. Banana pseudostem is widely reported as an abundant agricultural waste rich in cellulose and suitable for fibre extraction and biodegradable product development. The plant material was authenticated by the Department of Botany of the institution. The pseudostem was washed thoroughly to remove soil and debris.[6]

2.2.2. Fiber Extraction

The pseudostem sheath was separated manually and cut into small strips. Fibres were extracted using a mechanical scraping method, which removes the parenchymal tissues while retaining long fibres. A mild alkali-free hot-water retting (60–70°C, 1 hr) was used to loosen fibre bundles an approach similar to retting techniques reported in fibre extraction research.[7]

2.2.3. Drying of Fibers

Extracted fibres were washed thoroughly and dried at 50–60°C in a hot-air oven for 6–8 hours until constant weight was obtained. Controlled oven drying at moderate temperatures is recommended to prevent thermal degradation of natural fibres.[8]

2.2.4. Size Reduction

Dried fibres were ground using a milling machine to obtain uniform short fibres (1–3 mm). They were sieved through a 60–80 mesh sieve to achieve consistent particle size suitable for composite formation and improved mechanical properties.[9]

2.2.5. Binder Preparation

A natural binder was prepared using rice starch + water (10% w/v)- **RS1**, rice starch + water (15% w/v)- **RS2**, Potato starch + water (10% w/v)- **PS1** and Potato starch + water (15% w/v)- **PS2**. Starch slurry was heated to 70–80°C to allow gelation and chain entanglement, forming a viscous adhesive matrix.[10]

2.2.6. Mixing of Fibers with Binder

Short banana fibres were slowly incorporated into the hot binder in a 1:1 to 1:1.5 ratio (w/w). Banana fibres + RS1- **BRS1**, banana fibres + RS2- **BRS2**, banana fibres + PS1- **BPS1** and banana fibres + PS2- **BPS2**.The mixture was stirred continuously to ensure homogeneous distribution. The composite dough was kept at 50–60°C to maintain workability.[11]

2.2.7. Molding into cup Shape

The warm composite dough was placed into a circular plate mold (upper and lower die). The mold was compressed using a hot press. After pressing, plates were cooled under ambient air. Compression moulding is widely used for manufacturing natural fibre-based biodegradable products.[12]

2.2.8. Physical Characterization Studies

Thickness Measurement & Mass of Biodegradable cups

Thickness (mm): Measure at 3–5 points using a vernier caliper; record mean and SD.

Mass (g): Weigh each cup on an analytical balance.

2.2.9. Impact Test (Load Bearing Capacity):

Place standard load (e.g., 1 kg) on cup placed on flat surface; observe deflection/crack. Record pass/fail for single-use suitability.[13]

2.2.10. Water Absorption Test: (Water Uptake (Swelling) Study)

Cut 2 × 2 cm specimen (or use whole cup if desired). Dry in oven at 105 °C for 24 h and weight (W_o). Immerse specimen in distilled water at 25 °C for 24 h. Remove, blot surface, weight (W_1).

$$\text{Water uptake (\%)} = ((W_1 - W_o) / W_o) \times 100.$$

This method aligns with water absorption studies on banana fibre-based composites.[14]

2.2.11. Water Leakage Test:

Oven-dry sample at 105 °C until constant weight; then pour water in it and calculate the time, which it holds.

2.2.12. Biodegradation Test

Bury samples in garden soil at appropriate conditions. Maintain moisture (moisten soil weekly). At intervals (15, 30, 60, 90 days) retrieve replicate samples, gently clean soil, dry at 60 °C. Document visual changes (disintegration, colour change).[15]

3. RESULT AND DISCUSSION

3.1.1. Raw Material Collection and Authentication:

Fresh banana pseudostem were collected from the local agricultural fields of sulur, Coimbatore Tamilnadu, India. The plant was identified by local farmers and authenticated (**BSI/SRC/5/ 23/2025-26/Tech./781**) by Dr. M. Palanisamy, Scientist 'E' and Head of office (I/C), Botanical Survey of India, Southern Regional Centre, Coimbatore, Tamilnadu, India.

3.1.2. Fiber extraction:

The pseudostem sheath was manually separated, cleaned, and cut into small strips. Fibers were extracted by mechanical scraping to remove parenchymal tissues while retaining long fibers. A mild alkali-free hot-water retting at 60–70°C for 1 hour was applied to loosen fire bundles, followed by washing and air-drying before further analysis.

3.1.3. Drying of fibers:

The extracted fibers were thoroughly washed to remove residual impurities and then dried in a hot-air oven at 50–60°C for 6–8 hours until a constant weight was achieved. Controlled oven drying at moderate temperatures was adopted to prevent thermal degradation and preserve the structural integrity of the natural fibers.

3.1.4. Size reduction:

Approximately 150 g of dried fibers were obtained and ground using a milling machine to produce uniform short fibers (1–3 mm), which were further size-reduced into a coarse powder. The ground material was sieved through a 60–80 mesh sieve to achieve consistent particle size distribution, ensuring suitability for composite fabrication and improved mechanical performance.

3.1.5. Binder preparation:

A natural binder was prepared using rice starch + water (10% w/v)- **RS1**, rice starch + water (15% w/v)- **RS2**, Potato starch + water (10% w/v)- **PS1** and Potato starch + water (15% w/v)- **PS2**. Starch slurry was heated to 70–80°C to allow gelation and chain entanglement, forming a viscous adhesive matrix. Starch-based binders are commonly employed in biodegradable composite systems due to their renewability and binding efficiency.

3.1.6. Mixing of fibers with binder:

The size reduced pseudostem fibers were incorporated in a 1:1.5 ratio to the binder mixture. Banana fibers + RS1- **BRS1**, banana fibers + RS2- **BRS2**, banana fibers + PS1- **BPS1** and banana fibers + PS2- **BPS2**.The mixture was stirred continuously to ensure homogeneous distribution. The composite dough was kept at 50–60°C to maintain workability

3.1.7. Molding:

The composite dough is molded in the stainless steel and dried.

Figure 1: The cups of BRS1, BRS2

Figure 2: The cups of BPS1, BPS2

CHARACTERIZATION STUDIES FOR THE BIODEGRADABLE CUPS:

3.1.8. Physical Characterization Studies:

Thickness Measurement of Biodegradable cups

Table 1: Thickness Measurement of Biodegradable cups

S. No	Sample	Thickness (mm)
1	BRS1	1.0
2	BRS2	1.3
3	BPS1	1.1
4	BPS2	1.2

The thickness of the prepared biodegradable cups ranged from 1.0 mm to 1.3 mm. Among the formulations, BRS1 exhibited the lowest thickness (1.0 mm), while BRS2 showed the highest thickness (1.3 mm). BPS1 and BPS2 demonstrated intermediate thickness values of 1.1 mm and 1.2 mm, respectively. Overall, the variation in thickness among the samples was minimal (±0.15 mm), indicating relatively uniform fabrication and good reproducibility of the molding process. The narrow thickness range (1.0–1.3 mm) confirms consistency in preparation across all formulations. Thickness is a critical physical parameter in biodegradable cups, as it directly influences mechanical strength, flexibility, rigidity, degradation rate, and load-bearing capacity. The slightly greater thickness observed in BRS2 may contribute to enhanced mechanical strength and comparatively slower degradation due to increased material density, whereas the lower thickness of BRS1 may result in relatively faster degradation and slightly reduced mechanical resistance.

Mass of Biodegradable cups

Table 2: Mass of Biodegradable cups

S. No	Sample	Mass (g)
1	BRS1	19.819
2	BRS2	20.344
3	BPS1	19.325
4	BPS2	20.252

The mass of the biodegradable cups ranged from 19.325 g to 20.344 g, demonstrating minimal variation among the formulations. BRS2 exhibited the highest mass (20.344 g), followed closely by BPS2 (20.252 g), while BRS1 showed an intermediate value (19.819 g) and BPS1 recorded the lowest mass (19.325 g). The overall variation of approximately 1.02 g indicates only minor differences in material distribution or compression during fabrication. All formulations displayed mass values within a narrow range (~19–20 g), confirming acceptable uniformity in preparation and consistency in the quantity of polymer blend used for molding. Mass is an important physical parameter influencing mechanical strength, density, compactness, degradation behavior, and potential drug-loading capacity (if applicable). The slightly higher mass observed in BRS2 and BPS2 may be attributed to greater polymer concentration, higher compression

force during molding, or reduced porosity. In contrast, the lower mass of BPS1 may suggest relatively higher porosity, lower compaction, or minor variations in the polymer blend ratio. When correlated with thickness data, samples with higher thickness (such as BRS2 and BPS2) also demonstrated higher mass, indicating uniform density distribution. Such consistency is essential, particularly in biomedical applications, to ensure predictable mechanical support and controlled biodegradation. Overall, the small variation in mass among samples demonstrates good reproducibility of the fabrication process and acceptable uniformity of the biodegradable cup formulations.

3.1.9. Impact Test (Load Bearing Capacity):

Table 3: Weight Holding Capacity of Biodegradable Plates

S. No	Sample	Weight it Holds (g)
1	BRS1	100
2	BRS2	150
3	BPS1	100
4	BPS2	150

The impact/load-bearing test revealed two distinct performance groups among the biodegradable cup formulations. BRS2 and BPS2 withstood a maximum load of 150 g, whereas BRS1 and BPS1 tolerated up to 100 g, demonstrating comparatively lower mechanical strength. Thus, BRS2 and BPS2 exhibited superior load-bearing capacity and structural stability without failure under higher stress conditions. Load-bearing capacity is a critical parameter for biodegradable materials, particularly in biomedical applications such as bone fixation and tissue engineering, where adequate mechanical stability is required during the healing period. The enhanced performance of BRS2 and BPS2 may be attributed to improved polymer cross-linking, higher structural compactness, stronger internal bonding between polymer chains, and optimal polymer composition. Correlation with physical characterization data indicates that formulations with relatively higher thickness and mass (BRS2 and BPS2) also demonstrated superior load-bearing capacity, suggesting that increased density and compactness contributed to enhanced mechanical resistance. In contrast, BRS1 and BPS1, which exhibited lower thickness and mass values, showed reduced load-bearing capacity, possibly due to slight variations in compaction or internal structural integrity affecting impact resistance. Overall, the results confirm that BRS2 and BPS2 are mechanically more stable formulations and are therefore more suitable for applications requiring higher load resistance and durability during the biodegradation process.

3.1.10. Water Absorption Test: (Water Uptake (Swelling) Study)

Table 4: Water Uptake Study of Biodegradable cups

S. No	Sample	Initial Weight (W_o) (g)	Final Weight (W_1) (g)	Water Uptake (%)
1	BRS1	19.819	34.224	72.6
2	BSR2	20.344	37.867	86.1
3	BPS1	19.325	34.834	80.2
4	BPS2	20.252	36.913	82.2

$$\text{Water uptake (\%)} = ((W_1 - W_o) / W_o) \times 100.$$

The percentage of water uptake among the biodegradable cup formulations ranged from 72.6% to 86.1%, indicating considerable swelling behavior across all samples. BSR2 exhibited the highest water uptake (86.1%), whereas BRS1 showed the lowest swelling percentage (72.6%). BPS1 and BPS2 demonstrated comparable water absorption values of 80.2% and 82.2% respectively. All formulations showed a significant increase in weight after immersion, reflecting the hydrophilic nature of the starch-based polymeric matrix. Water uptake, or swelling index, is a critical parameter in biodegradable materials, as it influences polymer hydrophilicity, matrix porosity, degradation rate, mechanical stability, and potential drug release behavior where applicable. The higher swelling observed in BSR2 suggests greater hydrophilic polymer content, increased porosity, and a relatively looser polymer network structure, which may facilitate faster biodegradation, enhanced fluid penetration, and reduced long-term mechanical strength. In contrast, the lower swelling exhibited by BRS1 may indicate higher cross-linking density, a more compact polymer arrangement, and reduced porosity, potentially resulting in slower degradation, improved mechanical stability, and sustained structural integrity. The moderate swelling behavior observed in BPS1 and BPS2 reflects a balanced hydrophilic–hydrophobic interaction within the polymer matrix, which is desirable for applications requiring controlled degradation along with adequate mechanical support. Furthermore, correlation with earlier impact test results suggests that formulations exhibiting moderate swelling and good structural compactness, such as BPS2, also demonstrated superior load-bearing capacity, indicating an inverse relationship between excessive swelling and mechanical strength.

3.1.11. Water Leakage Test:

This parameter is particularly important for biodegradable cups intended for biomedical or packaging applications, where short-term fluid resistance and structural stability are required before gradual degradation.

Table 5: Water Holding Capacity and Leakage Time

S. No	Sample	Amount of Water it Holds (mL)	Time Begins to Leakage (sec)
1	BRS1	55	4
2	BRS2	53	7
3	BPS1	51	3
4	BPS2	50	5

The water-holding and leakage study revealed noticeable differences among the biodegradable cup formulations. BRS1 held the highest volume of water (55 mL), followed by BRS2 (53 mL), while BPS1 and BPS2 retained comparatively lower volumes of 51 mL and 50 mL, respectively. Despite holding slightly less water than BRS1, BRS2 exhibited the longest leakage resistance time (7 seconds), indicating superior water resistance. In contrast, BPS1 began leaking earliest, within 3 seconds, demonstrating the lowest resistance to water penetration. These findings suggest that volume-holding capacity does not necessarily correlate with leakage resistance.

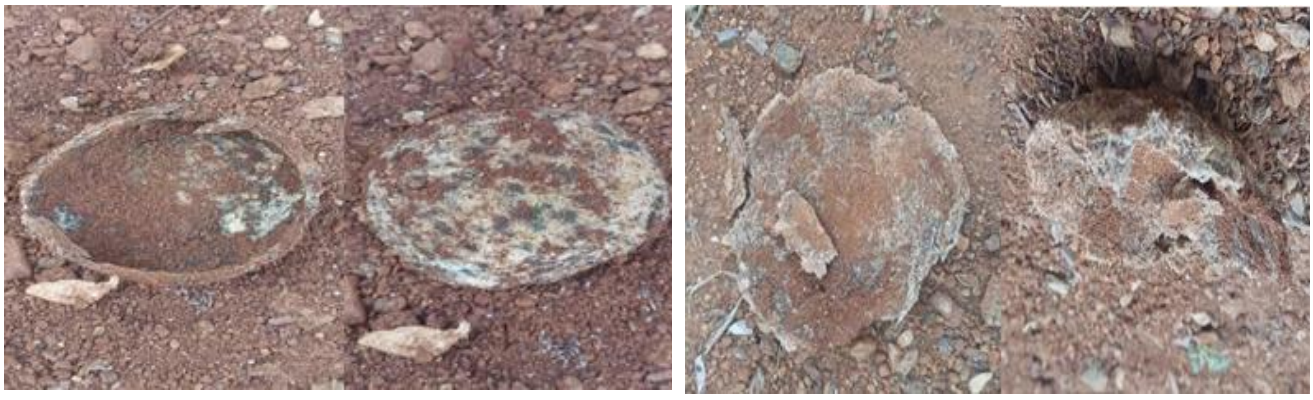
The water leakage test serves as an important evaluation of surface integrity, porosity, polymer matrix compactness, and overall water resistance capacity. The extended leakage time observed in BRS2 suggests better structural compactness, lower permeability, stronger intermolecular bonding, and reduced surface porosity. Although BRS1 retained a slightly higher water volume, its earlier leakage onset (4 seconds) indicates comparatively lower surface resistance. Similarly, BPS1 and BPS2, which showed leakage at 3 and 5 seconds respectively, may possess higher surface porosity and a less compact polymer network, resulting in reduced resistance to fluid penetration.

Correlation with previous mechanical studies further supports these observations. BRS2, which demonstrated superior impact strength (150 g), also showed the highest leakage resistance, confirming its enhanced mechanical integrity and compact structure. BPS2, despite exhibiting good impact strength (150 g), showed moderate leakage resistance (5 seconds), suggesting acceptable but slightly lower surface compactness compared to BRS2. Overall, formulations with better compactness and mechanical strength tended to demonstrate improved water resistance. The results indicate that BRS2 is the most water-resistant formulation, whereas BPS1 is comparatively less resistant to leakage. This parameter is particularly significant for biodegradable cups intended for biomedical or packaging applications, where short-term fluid resistance and structural stability are required prior to gradual biodegradation.

3.1.12. Biodegradation Test:

The biodegradation study demonstrated progressive structural deterioration of the prepared biodegradable cups under natural environmental conditions. After 8 days, visible surface changes were observed, including partial discoloration, surface roughening, and early signs of microbial growth and erosion. Although overall structural integrity was still maintained at this stage, minor cracks and slight softening had begun to appear, indicating the initiation of degradation. By 15 days, significant structural breakdown was evident, characterized by pronounced cracks, fragmentation, surface peeling, and noticeable deformation. The samples exhibited substantial loss of mechanical strength, increased microbial colonization, brittleness, and partial disintegration into smaller fragments.

These observations confirm that noticeable degradation begins within 8 days, with substantial structural breakdown occurring by 15 days, demonstrating effective biodegradability within a relatively short period. The results indicate that the polymer matrix is susceptible to environmental factors such as moisture, microbial activity, and soil enzymes, leading to gradual decomposition.



After 8 days: **After 15 days:**

Figure 3: The biodegradability of cups

The biodegradation process likely involves water penetration into the polymer matrix, followed by microbial colonization, enzymatic hydrolysis, polymer chain scission, and eventual loss of mechanical integrity. The early surface roughness observed at 8 days suggests initial hydrolytic degradation and microbial action, potentially accelerated by the hydrophilic nature of the starch-based matrix. By 15 days, extensive cracking and fragmentation indicate significant reduction in molecular weight, loss of cohesive strength, and advanced microbial decomposition.

The progressive degradation pattern suggests that the material maintains temporary structural stability during its functional period before undergoing accelerated breakdown. Such behavior is desirable for eco-friendly disposable products and sustainable packaging materials, where adequate mechanical strength is required for short-term use followed by safe environmental degradation without harmful residues. The observed degradation profile therefore supports the suitability of the prepared formulations for environmentally sustainable applications.

4. CONCLUSION

The study demonstrates the successful development of biodegradable cups from banana pseudostem fibers reinforced with starch-based natural binders. All formulations exhibited consistent physical properties, acceptable mechanical strength, and effective biodegradation. Among the tested formulations, BRS2 (15% rice starch) showed the most balanced performance, combining superior mechanical strength, improved water resistance, and controlled degradation. The findings highlight the potential of utilizing agricultural waste materials for the production of eco-friendly, sustainable alternatives to conventional plastic products, offering promising applications in biodegradable packaging and disposable materials.

Source of Support: The author(s) received no financial support for the research, authorship, and/or publication of this article

Conflict of Interest: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

1. United Nations Environment Programme. From pollution to solution: A global assessment of marine litter and plastic pollution. Nairobi: UNEP; 2021.
2. Shen M, Song B, Zeng G, Zhang Y, Huang W, Wen X, et al. Biodegradable plastics: A review of environmental impacts and prospects. Sci Total Environ. 2020;704:135285.
3. Kumar R, Ul Haq M, Raina A, Anand A. Industrial applications of banana fiber: A review. Mater Today Proc. 2021;44:543–8.
4. Saba N, Jawaid M, Asim M. Recent advances in banana fiber based composites and their applications. J Clean Prod. 2022;330:129938.
5. Gadhave RV, Das A, Mahanwar PA, Gadekar PT. Starch-based biodegradable films: Recent progress and applications. Carbohydr Polym. 2023;301:120290.Shivashankar S, Nachane RP, Kalpana S. Composition and properties of fibre extracted from pseudostem of banana (*Musa* sp.). *J Hortic Sci.* 2013;1(2):646.
6. Pillai GS, Morya S, Khalid W, Khalid MZ, Almalki RS, Siddeeg A. Banana pseudostem: an undiscovered fiber enriched sustainable functional food. Journal of Natural Fibers. 2024 Dec 31;21(1):2304004. Evaluation of banana pseudostem fibres for packaging material development. *Packag Technol Sci.* 2025;0:1–13.
7. Badanayak P, Jose S, Bose G. Banana pseudostem fiber: A critical review on fiber extraction, characterization, and surface modification. Journal of Natural Fibers. 2023 Apr 24;20(1):2168821.
8. Mudoi MP, Sinha S, Parthasarthy V. Polymer composite material with nettle fiber reinforcement: a review. Bioresource Technology Reports. 2021 Dec 1;16:100860.
9. Ruangnarong C, Khojitmate S, Srivorradatphisan S, Panyathikun N, Chonsakorn S. Evaluation of mechanically extracted banana fibers from pseudostem layers: a sustainable textile raw material. Heliyon. 2024 Nov 15;10(21).
10. Mohd NA, Amini MH, Masri MN. Properties and characterization of starch as a natural binder: A brief overview. Journal of Tropical Resources and Sustainable Science (JTRSS). 2016 Dec 30;4(2):117-21.
11. Othman S, Tarmiti NA, Shapi'i R, Zahiruddin S, Tawakkal IS, Basha R. Starch/banana pseudostem biocomposite films for potential food packaging applications. BioResources. 2020 May 1;15(2):3984.
12. Shuvo ZH, Rahman MZ, Saha B, Ador MS. Composite materials from synthetic and natural sources: Fabrication techniques and applications.
13. Fazita MN, Khalil HA, Izzati AN, Rizal S. Effects of strain rate on failure mechanisms and energy absorption in polymer composites. InFailure analysis in biocomposites, fibre-reinforced composites and hybrid composites 2019 Jan 1 (pp. 51-78). Woodhead Publishing.
14. Chauhan DS, Lal AB, Thakur D, Singh K, Vashisht P. Development and evaluation of biodegradable cutlery from sweet lime peel waste: A sustainable and efficient alternative to recycled plastics. Pharma Innov. J. 2024;13:262-8.
15. Pires JR, Souza VG, Fuciños P, Pastrana L, Fernando AL. Methodologies to assess the biodegradability of bio-based polymers—current knowledge and existing gaps. Polymers. 2022 Mar 27;14(7):1359.