

Research Article

Development of Biodegradable Plant Pots from Chitosan Reinforced with Natural Fibers for Agricultural Applications

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ABSTRACT

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This study aimed to develop biodegradable composite materials based on chitosan reinforced with natural fibers, including pineapple leaf fiber (PL), rice straw (RI), and sugarcane bagasse (BG), for use as biodegradable plant pots. The fibers were incorporated into a chitosan matrix at fiber-to-chitosan ratios of 1:0.08, 1:0.12, 1:0.16, 1:0.20, and 1:0.24 by weight, with glycerol used as a plasticizer. The composites were then fabricated using a molding and drying process. The effects of fiber type and composition on density, water absorption, thickness swelling, and biodegradation behavior were investigated. The results showed that fiber type significantly influenced the composite properties. PL-reinforced composites exhibited the highest density, water absorption, thickness swelling, and biodegradation rate, attributed to their high cellulose content and fibrillated structure. PL-reinforced composites exhibited the highest density (0.907 g/cm³) and biodegradation (97%), attributed to their high cellulose content and fibrillated structure. In contrast, RI composites showed the lowest density and biodegradation, while BG composites demonstrated intermediate behavior. Increasing chitosan content improved dimensional stability by reducing thickness swelling. Soil burial tests confirmed that all composites were biodegradable, with degradation increasing over time. Among the formulations investigated, the fiber-to-chitosan ratio of 1:0.16 was selected as the most suitable formulation for pot fabrication and plant cultivation tests due to its balanced dimensional stability and biodegradation performance. Furthermore, the developed composites were successfully fabricated into hollow pot structures using a two-part mold system. A plant cultivation test demonstrated that all biodegradable pots supported plant growth without visible toxicity and exhibited performance comparable to conventional plastic nursery bags.

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1. Introduction

The increasing use of plastic materials in agricultural applications, particularly nursery bags and plant pots, has led to significant environmental concerns due to their persistence and resistance to degradation. Over time, these materials fragment into microplastics (particles smaller than 5 mm), which are increasingly recognized as a critical environmental pollutant (Ghosh *et al.*, 2025). These microplastics accumulate in agricultural soils and can alter soil physicochemical properties, disrupt microbial communities, and impair plant growth, ultimately posing risks to food security and human health. In

agricultural systems, microplastics originate from various sources, including plastic mulching, irrigation systems, and the application of contaminated organic amendments, leading to their continuous accumulation in soil environments. Therefore, the development of biodegradable alternatives derived from renewable and natural resources has gained increasing attention as a sustainable approach to mitigate plastic pollution, particularly for short-term agricultural applications such as plant cultivation (Srisunont *et al.*, 2024; Ghosh *et al.*, 2025).

Numerous studies have investigated the development of biodegradable pots using a variety of natural and waste-derived

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materials. Agricultural residues such as water hyacinth, rice straw, sawdust, and coconut coir have been widely used due to their availability and biodegradability, often combined with cassava starch or other natural binders to enhance structural integrity (Tanpaiboonkul, 2022; Chaichan, 2019; Iriany, 2022; Manafi-Dastjerdi, 2022). These materials have been evaluated in terms of physico-chemical and mechanical properties, biodegradation behavior, and their suitability for plant nursery applications. More complex formulations incorporating multiple biomass sources, such as coffee grounds and rubber wood sawdust, as well as alternative wastes including coconut bagasse, tobacco dust, compost, and cow manure, have also been explored to improve performance and degradability (Chaichan, 2017; Somakul, 2020; Juming, 2022). In addition, lignocellulosic residues such as straw and palm-based wastes have been applied in bio-containers with additives like cellulose or molasses to enhance structural stability (Piyang, 2018; Tibalia, 2023). Overall, while biodegradable pots can be produced from a wide range of materials, their performance strongly depends on material selection and processing conditions, and achieving a balance between mechanical strength during use and effective biodegradation after disposal remains a key challenge.

Although various biodegradable materials have been developed for plant pot applications, most studies have primarily focused on starch-based, latex-based, or lignocellulosic binder systems, while limited attention has been given to chitosan-based composites. Chitosan is a natural biopolymer with excellent biodegradability, biocompatibility, and film-forming properties; it was selected in this study because it can act as a biodegradable binder while providing sufficient cohesion between natural fiber particles. However, its application in structural products such as plant pots remains limited due to its hydrophilic nature, which results in high water absorption and dimensional instability under moist conditions. In addition, chitosan-based materials generally exhibit relatively low mechanical strength, particularly when exposed to water, making it difficult to maintain structural integrity during use. These limitations highlight the need for material modification strategies, such as reinforcement with natural fibers, to improve the performance of chitosan-based systems. Recent studies have demonstrated the potential of chitosan-based composites in agricultural applications, including biodegradable mulch films, controlled-release fertilizer systems, and plant growth substrates, owing to their biodegradability and environmental compatibility. However, information regarding chitosan composites reinforced with different agricultural fibers for biodegradable pot applications remains limited. Furthermore, the influence of different agricultural fibers on the physical properties, water-related behavior, biodegradation, and practical plant cultivation performance of chitosan composites has not been systematically investigated. The novelty of this work lies

in the comparative evaluation of pineapple leaf fiber, rice straw, and sugarcane bagasse as reinforcements in chitosan-based biodegradable pots, with emphasis on their effects on dimensional stability, biodegradation behavior, and plant growth performance. Therefore, this study aims to develop biodegradable plant pots from chitosan reinforced with pineapple leaf fiber, rice straw, and sugarcane bagasse, and to evaluate their density, water absorption, thickness swelling, biodegradation behavior, and plant growth performance.

2. Materials and Methods

2.1 Materials

Chitosan (derived from shrimp shells) and acetic acid (food grade, 99.85%) were commercially obtained and used without further purification. Commercial glycerol was used as a plasticizer. Rice straw (RI), sugarcane bagasse (BG), and pineapple leaf fiber (PL) were used as natural fiber reinforcements.

2.2 Preparation of natural fibers

Rice straw, sugarcane bagasse, and pineapple leaf fiber were selected as natural fibers. The materials were sun-dried for 5-10 days until completely dried. The dried fibers were then mechanically ground using a grinder to obtain the desired particle size. The ground fibers were subsequently sieved through a 40-mesh sieve to obtain a more uniform particle size prior to composite preparation.

2.3 Preparation of fiber/chitosan composites

A 3% (w/v) chitosan solution was prepared in 2% (v/v) acetic acid under continuous stirring. Rice straw, sugarcane bagasse, and pineapple leaf fiber were then added at fiber-to-chitosan ratios of 1:0.08, 1:0.12, 1:0.16, 1:0.20, and 1:0.24 (by weight). Glycerol was incorporated as a plasticizer at a fiber-to-glycerol ratio of 1:1.5 (by weight). The mixture was stirred until homogeneous, poured into a rectangular mold, and dried at 100 °C for 7 h. The samples were then cooled to room temperature and removed for further characterization.

2.4 Preparation of fiber/chitosan composite pots

The prepared fiber/chitosan composite mixture was stirred until a homogeneous consistency was obtained. The mixture was then poured into a two-part mold equipped with an inner core to form a hollow pot structure, while the outer mold maintained the external shape and wall thickness. The assembled mold was placed in a drying oven at 100 °C for 7 h. After drying, the samples were allowed to cool to room temperature and then removed from the mold to obtain the final biodegradable pots. The preparation process is illustrated in Figure 1.



Figure 1 Preparation of fiber/chitosan composite pots:

(a) mixing of the composite mixture, (b) molding and drying in an oven, and (c) final biodegradable pots.

2.5 Testing and characterization

All measurements were performed in triplicate, and the average values are reported.

The density of the samples was measured using an electronic densimeter (MD-200S, Alfa Mirage, Japan) according to the instrument's standard procedure.

Water absorption was determined by immersing the dried samples in water at room temperature for 24 h. After immersion, the samples were removed, surface water was gently wiped off, and the samples were weighed. The water absorption was calculated using the following equation:

$$\text{Water Absorption (\%)} = \frac{Ww - Wd}{Wd} \times 100 \quad (1)$$

where Wd is the initial dry weight and Ww is the weight after immersion.

Thickness swelling was evaluated by measuring the sample thickness before and after immersion in water at room temperature for 24 h. The swelling percentage was calculated using the following equation:

$$\text{Thickness Swelling (\%)} = \frac{T2 - T1}{T1} \times 100 \quad (2)$$

where $T1$ is the initial thickness and $T2$ is the thickness after immersion.

Biodegradation was evaluated using a soil burial test. The samples were buried at a depth of 10 cm below the soil surface. To simulate practical environmental conditions, the soil was watered every two days throughout the burial period. The samples were buried in soil for 15 and 30 days. After the specified period, the samples were removed, cleaned, dried, and weighed. The weight loss was calculated using the following equation:

$$\text{Weight Loss (\%)} = \frac{Wi - Wt}{Wi} \times 100 \quad (3)$$

where Wi is the initial weight and Wt is the weight after burial.

3. Results and Discussion

3.1 Fiber characteristics and density

Natural fibers are mainly composed of cellulose, hemicellulose, and lignin, with additional components such as

silica and ash depending on the plant source. Pineapple leaf fibers contain high cellulose content and exhibit porous lumen structures, which contribute to their high hydrophilicity (Asim *et al.*, 2015; Sufian *et al.*, 2020). Rice straw fibers are characterized by the presence of significant silica content, which influences their rigidity and water interaction behavior (Rosado *et al.*, 2021; Sharma *et al.*, 2023). In contrast, bagasse fibers contain relatively higher lignin content, resulting in lower hydrophilicity and improved dimensional stability (Hajiha and Sain, 2015; Niju and Swathika, 2019). The typical chemical compositions of these fibers are summarized in Table 1.



Figure 2 Macroscopic appearance of natural fibers used in this study: PL, RI, and BG.

The density of the fiber/chitosan composites, as shown in Figure 3, was significantly influenced by the type of natural fiber used. Among the three fiber types, the composites reinforced with PL showed the highest density, followed by BG, while those reinforced with RI showed the lowest density across all fiber. This trend can be explained based on the macroscopic structure of the fibers observed in Figure 2. PL fibers display a fine and fibrillated structure with high aspect ratio and large specific surface area. Such morphology promotes efficient packing and strong interfacial contact within the composite matrix, resulting in a more compact structure with reduced void content. In contrast, RI fibers exhibit an irregular, particle-like morphology, which limits packing efficiency and increases internal void formation. BG fibers show intermediate characteristics, consisting of short and relatively coarse fibers, leading to moderate packing behavior and density values. The observed results are consistent with previously reported density values of natural fibers. PL fiber is generally considered a relatively high-density lignocellulosic fiber, with reported values in the range of approximately 0.80-1.60 g/cm³ (Chokshi *et al.*, 2022; Chaves *et al.*, 2024). In contrast, rice straw is categorized as a low-density agricultural residue, particularly when processed into particleboard or bulk form, where densities are typically much lower due to its loose structure, generally ranging from approximately 0.30-0.50 g/cm³ depending on processing conditions and compaction level (Yang *et al.*, 2003; Zhang *et al.*, 2012, Chaves *et al.*, 2024). Similarly, sugarcane bagasse is also considered a low-density biomass material, although its density can vary depending on fiber processing and structural refinement, generally ranging from approximately 0.50-0.90

g/cm³ for bulk or fiber-based forms (Yogeshwaran and Priya 2020; Mahmud *et al.*, 2025).

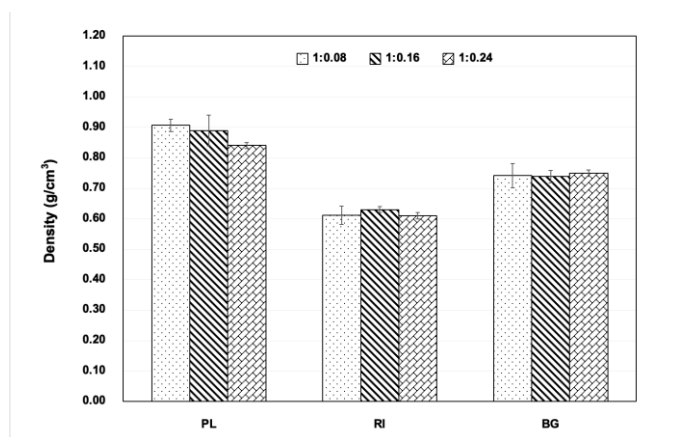


Figure 3 Density of fiber/chitosan composites reinforced with PL, RI, and BG at different fiber-to-chitosan ratios.

3.2 Water absorption and thickness swelling

The water absorption and thickness swelling of the fiber/chitosan composites are presented in Figure 4(a) and (b), respectively. The results indicate that both properties were influenced by fiber type and content of chitosan. PL composites exhibited the highest water absorption and thickness swelling, while BG showed the lowest water absorption but slightly higher thickness swelling than RI. PL composites showed the highest values due to their high cellulose content and highly fibrillated structure, which increase hydrophilicity and provide a larger specific surface area for water interaction (Asim *et al.* 2015, Sethupathi *et al.* 2024). These characteristics facilitate water penetration into the composite matrix, leading to both higher water uptake and greater structural expansion. BG composites exhibited the lowest water absorption, which can be attributed to their relatively higher lignin content that reduces water affinity (Kamande *et al.*, 2026). However, BG showed slightly higher thickness swelling than RI, indicating that although less water is absorbed, the composite structure can still undergo expansion once water penetrates. This behavior suggests that the fibrous structure of BG allows more flexibility or rearrangement in the thickness direction. RI composites showed moderate water absorption but lower thickness swelling. This behavior is likely related to the presence of silica and the more rigid, particle-like structure of rice straw fibers, which restrict dimensional expansion even when water is absorbed.

In addition, the effect of chitosan content on thickness swelling was clearly observed. Increasing the chitosan ratio resulted in a decrease in thickness swelling for all fiber types. This behavior can be attributed to the formation of a more compact and stable matrix, which restricts water penetration and limits structural expansion during immersion. As a result, higher

chitosan content enhances the dimensional stability of the composites. Although the composites showed relatively high water absorption, this property may be beneficial for biodegradable plant pot applications. The absorbed water can help retain moisture in the growing medium and support plant growth during cultivation. In addition, water uptake may promote degradation of the pots after disposal. However, excessive water absorption may reduce dimensional stability during use. Therefore, an appropriate fiber-to-chitosan ratio is important to achieve a balance between usability and biodegradability.

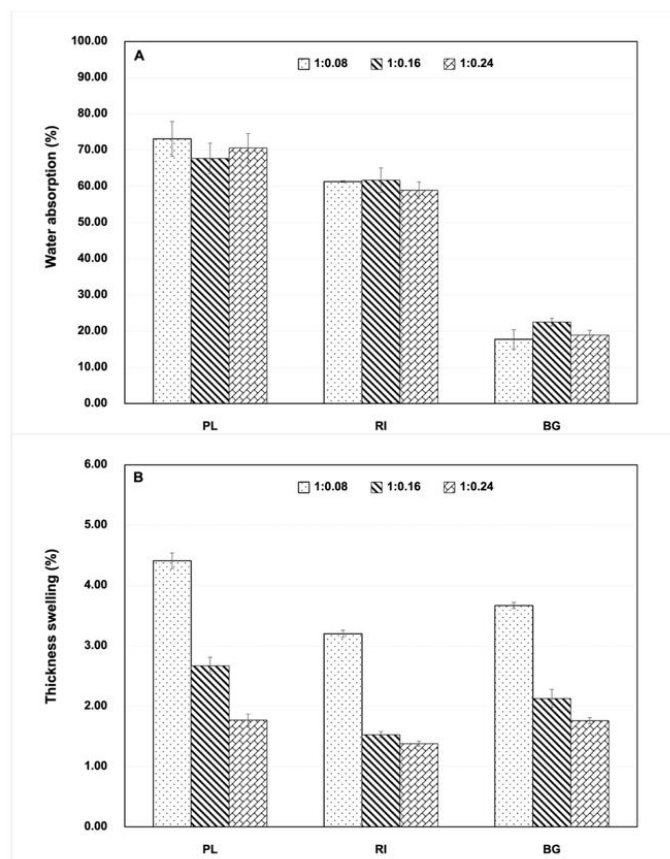


Figure 4 Water absorption (A) and Thickness swelling (B) of fiber/chitosan composites reinforced with PL, RI, and BG at different fiber-to-chitosan ratios.

3.3 Biodegradation behavior under soil burial

The biodegradation behavior of the fiber/chitosan composites under soil burial conditions is presented in Figure 5(a) and (b), corresponding to 15 and 30 days of burial, respectively. The results show that weight loss increased with burial time for all composites, indicating progressive biodegradation in the soil environment. Among the different fiber types, PL composites exhibited the highest weight loss, followed by BG, while RI showed the lowest weight loss at both time intervals.

Table 1 Chemical composition and structural characteristics of natural fibers used in this study.

Fiber type	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Other components	Reference
PL	70-82	5-12	5-13	Wax, Ash	(Asim <i>et al.</i> , 2015; Sufian <i>et al.</i> , 2020)
RI	32-47	19-27	5-24	Silica 10-15%	(Rosado <i>et al.</i> , 2021; Sharma <i>et al.</i> , 2023)
BG	40-50	25-35	18-24	Ash	(Hajiha and Sain, 2015; Niju and Swathika, 2019)

At 15 days (Figure 5(a)), all samples showed moderate weight loss, with PL composites demonstrating slightly higher degradation compared to BG and RI. After 30 days (Figure 5(b)), the differences became more pronounced, where PL composites exhibited a significant increase in weight loss, while BG showed intermediate degradation and RI remained the most resistant. This trend indicates that the degradation process becomes more evident with prolonged exposure to soil conditions. The higher biodegradation of PL composites can be attributed to their high cellulose content and highly fibrillated structure, as discussed in Section 3.1. These characteristics enhance water absorption (Figure 4) and increase the accessibility of microorganisms to the composite matrix. As reported by (Ibrahim *et al.*, 2025), water uptake can induce structural swelling in cellulose, thereby opening the matrix and allowing microbial enzymes to penetrate more easily. This improved accessibility promotes microbial activity and enzymatic degradation, resulting in a higher weight loss. BG composites exhibited moderate biodegradation behavior. Although BG showed the lowest water absorption, its fibrous structure and relatively higher lignin content provide a balance between resistance and degradability. As observed in Section 3.2, BG composites exhibited slightly higher thickness swelling than RI, suggesting that some structural expansion occurs after water penetration. This expansion may allow partial accessibility of microorganisms into the composite structure, contributing to moderate degradation. In contrast, RI composites exhibited the lowest biodegradation. This behavior can be attributed to the presence of silica and the more rigid, particle-like structure of rice straw fibers. As discussed previously, RI composites showed lower thickness swelling, indicating limited structural expansion. This restricts microbial penetration and reduces the accessibility of degradable components, resulting in lower weight loss during soil burial.

The visual appearance of the fiber/chitosan composites before and after 30 days of soil burial is presented in Table 2. Clear physical changes can be observed for all samples after burial, confirming the biodegradation behavior discussed in Figure 5. PL composites exhibited the most severe structural deterioration after soil burial. The samples lost their original shape, showing fragmentation, surface erosion, and

disintegration into smaller pieces, particularly at lower chitosan content (1:0.08 and 1:0.16).

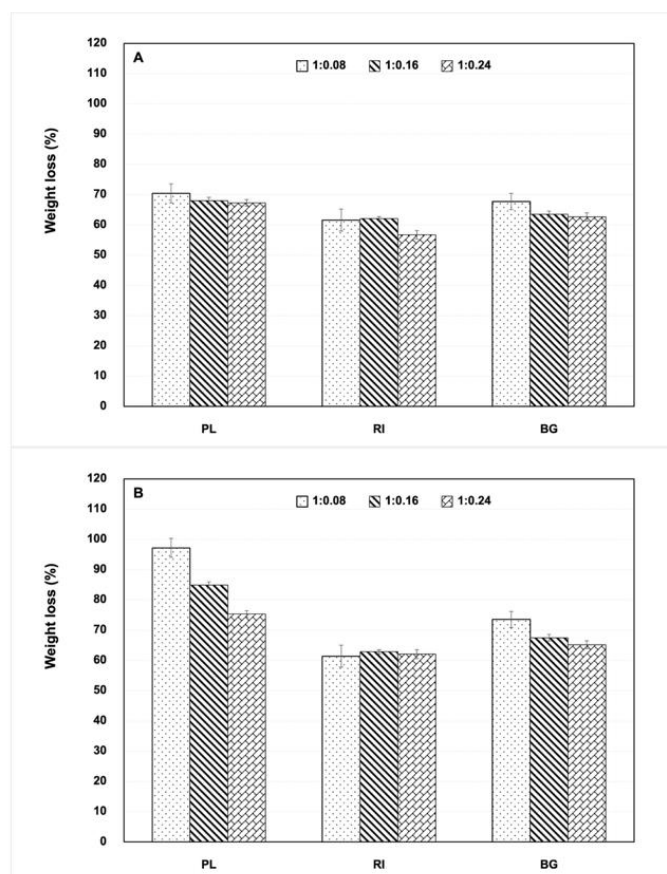


Figure 5 Weight loss (%) of fiber/chitosan composites reinforced with PL, RI, and BG during soil burial test after (a) 15 days and (b) 30 days.

This observation is consistent with the highest weight loss values obtained in Figure 5, indicating extensive biodegradation. The pronounced degradation of PL composites can be attributed to their high cellulose content and fibrillated structure, which facilitate water absorption and microbial penetration, accelerating the breakdown of the material. BG and RI composites exhibited relatively less pronounced visual changes after soil burial compared to PL. Most samples generally retained their overall shape, with observable surface roughness, localized cracking, and partial fragmentation after burial. These changes indicate that degradation occurred, although the structural integrity of the composites was still partially

maintained. The visual observations are consistent with the weight loss results in Figure 5, where BG and RI showed lower to moderate biodegradation compared to PL.

In addition, the effect of chitosan content on visual degradation can also be observed. Composites with higher chitosan ratios (1:0.24) generally retained their structural integrity better than those with lower ratios, showing less fragmentation and surface damage. This supports the previous findings (Section 3.2), where higher chitosan content contributed to a more compact and stable matrix, thereby slowing down the degradation process.

Table 2 Appearance of fiber/chitosan composites before and after 30 days of soil burial.

Sample	Before soil burial	After soil burial 30 days
PL 1:0.08		
PL 1:0.16		
PL 1:0.24		
RI 1:0.08		
RI 1:0.16		

Table 2 Appearance of fiber/chitosan composites before and after 30 days of soil burial. (Continuous).

Sample	Before soil burial	After soil burial 30 days
RI 1:0.24		
BG 1:0.08		
BG 1:0.16		
BG 1:0.24		

3.4 Application test for plant cultivation

The application performance of the fiber/chitosan composites as biodegradable plant pots was evaluated through a plant growth test, as shown in Figure 6. All samples were able to support plant growth over a period of one month, indicating that the developed materials are suitable for agricultural use. No visible signs of plant toxicity, such as leaf discoloration, growth inhibition, or plant death, were observed in any of the samples. This suggests that the presence of chitosan and glycerol in the composite matrix did not adversely affect plant development. The growth performance of plants cultivated in the biodegradable pots was comparable to that of the conventional plastic nursery bag. The quantitative plant growth data are summarized in Table 3. Plants grown in all biodegradable pots exhibited comparable growth to those cultivated in the conventional plastic nursery bag, with plant heights ranging from 12.5 to 14.5 cm and leaf numbers ranging from 8 to 10 after 30 days of cultivation. The highest plant height was observed for PL:CS (14.5 cm), whereas the highest number of leaves was recorded for RI:CS (10 leaves). These results indicate that the

developed composites provide a suitable environment for plant growth without causing harmful effects. The results demonstrate that the fiber/chitosan composites are not only biodegradable but also functionally viable as plant-growing containers, supporting their potential application as eco-friendly alternatives to conventional plastic pots.

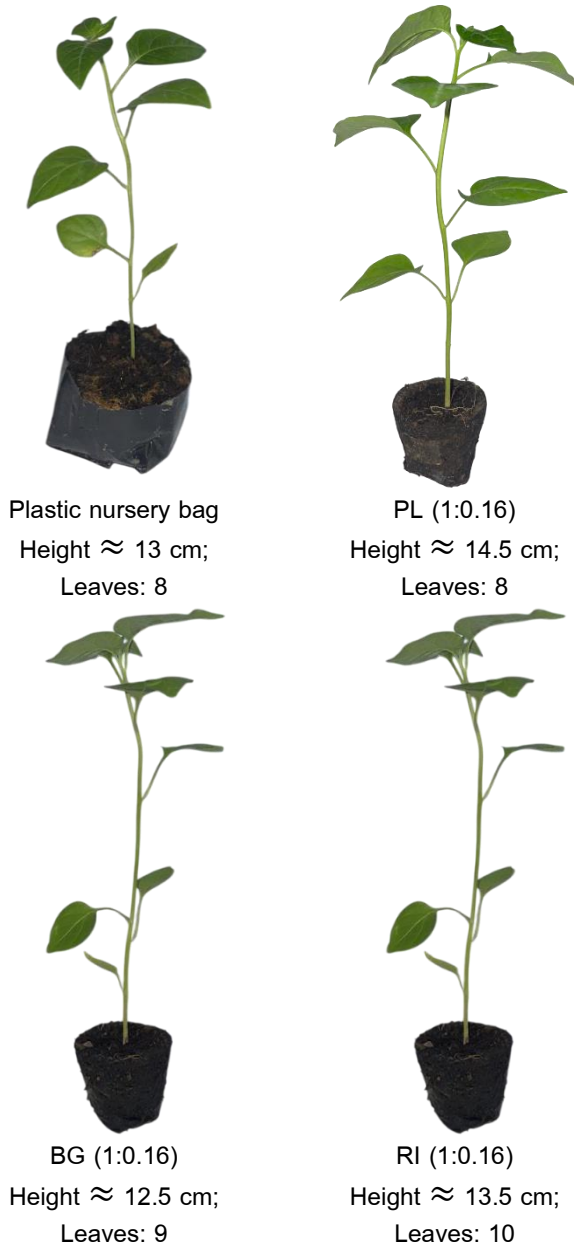


Figure 6 Chili plant growth in biodegradable pots (PL, RI, BG) and plastic nursery bag after 1 month of cultivation.

Table 3 Plant growth performance after 30 days of cultivation in different pot types.

Pot type	Plant height (cm)	Number of leaves
Plastic nursery bag	13.0	8
PL (1:0.16)	14.5	8
BG (1:0.16)	12.5	9
RI (1:0.16)	13.5	10

4. Conclusion

This study successfully developed biodegradable fiber-reinforced chitosan composites using pineapple leaf fiber (PL), rice straw (RI), and sugarcane bagasse (BG). The results showed that fiber type significantly influenced density, water absorption, thickness swelling, and biodegradation behavior. PL composites exhibited the highest density, water uptake, and biodegradation due to their high cellulose content and fibrillated structure, while RI showed the lowest values and BG demonstrated intermediate behavior. Increasing chitosan content improved dimensional stability by reducing thickness swelling. All composites were biodegradable under soil burial conditions and could be fabricated into hollow pot structures. The plant cultivation test confirmed that the developed pots supported plant growth without visible toxicity and showed comparable performance to conventional plastic nursery bags. These findings highlight the potential of fiber/chitosan composites as eco-friendly and biodegradable alternatives for agricultural applications. The 1 : 0.16 fiber-to-chitosan ratio showed a balanced combination of dimensional stability and biodegradation performance, making it the most suitable formulation for biodegradable pot production. The developed materials show potential for use as sustainable nursery pots in agricultural applications. However, this study focused primarily on physical properties and biodegradation behavior. Future work should include mechanical characterization and advanced material analyses to further evaluate their practical performance and long-term applicability.

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6. Declaration of Generative AI Use

ChatGPT was used only for English grammar correction and language refinement. All AI-assisted text was reviewed and edited by the authors, who take full responsibility for the final content of the manuscript.

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