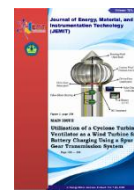




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Influence of Cassava Starch Content on the Physical, Mechanical, and Structural Properties of Silica Aerogel-Containing Biofoam

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Abstract

Cassava-starch-based biofoam is a promising biodegradable alternative to petroleum-based packaging materials. This study investigated the effect of cassava starch content on the physical, mechanical, and structural properties of biofoam containing corn cob fiber, polyvinyl alcohol (PVA), and silica aerogel. Four formulations were prepared by varying the cassava starch content from 48.75 to 56.25 g, while the amounts of corn cob fiber, PVA, and silica aerogel were kept constant. The samples were characterized in terms of density, water absorption, compressive strength, Fourier-transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD). The density remained approximately 0.6 g/cm^3 for samples A–C and increased to 0.7 g/cm^3 for sample D. Water absorption increased from 1.3% to 3.2% with increasing cassava starch content, indicating a higher hydrophilic character. Compressive strength varied considerably, with sample A showing the highest measured value of 6.09 MPa, whereas samples B–D exhibited values of 0.10–0.15 MPa. This substantial difference suggests that compressive strength was influenced by factors beyond starch content, including pore structure, fiber distribution, matrix formation, and sample homogeneity. The anomalously high value for sample A therefore requires verification through repeated testing. FTIR analysis confirmed functional groups associated with starch, PVA, corn cob fiber, and silica aerogel, while XRD indicated both crystalline and amorphous contributions. Overall, sample A exhibited the most favorable measured properties, although further verification is required before confirming it as the optimum formulation. The developed biofoam shows potential for biodegradable packaging applications, but further characterization is necessary to establish its suitability as a direct replacement for commercial styrofoam.

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Abstrak

Biofoam berbasis pati singkong merupakan salah satu alternatif bahan kemasan biodegradable yang berpotensi menggantikan material kemasan berbasis minyak bumi. Penelitian ini bertujuan untuk mengetahui pengaruh kandungan pati singkong terhadap sifat fisik, mekanik, dan struktur biofoam yang mengandung serat tongkol jagung, polivinil alkohol (PVA), dan silika aerogel. Biofoam dibuat dalam empat formulasi dengan variasi massa pati singkong sebesar 48,75–56,25 g, sedangkan massa serat tongkol jagung, PVA, dan silika aerogel dibuat tetap. Karakterisasi dilakukan terhadap densitas, penyerapan air, kuat tekan, spektroskopi inframerah transformasi Fourier (FTIR), dan difraksi sinar-X (XRD). Densitas sampel A–C berada pada kisaran $0,6 \text{ g/cm}^3$ dan meningkat menjadi $0,7 \text{ g/cm}^3$ pada sampel D. Penyerapan air meningkat dari 1,3% menjadi 3,2% seiring peningkatan kandungan pati singkong, yang menunjukkan meningkatnya sifat hidrofilik biofoam. Kuat tekan menunjukkan variasi yang cukup besar, dengan nilai tertinggi sebesar 6,09 MPa pada sampel A, sedangkan sampel B–D memiliki nilai sebesar 0,10–0,15 MPa. Perbedaan tersebut menunjukkan bahwa kuat tekan tidak hanya dipengaruhi oleh kandungan pati, tetapi juga oleh struktur pori, distribusi serat, pembentukan matriks, dan homogenitas sampel. Nilai kuat tekan sampel A yang jauh lebih

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tinggi perlu dikonfirmasi melalui pengujian berulang. Analisis FTIR menunjukkan keberadaan gugus fungsi yang berkaitan dengan pati, PVA, serat tongkol jagung, dan silika aerogel, sedangkan pola XRD menunjukkan kontribusi struktur kristalin dan amorf. Secara keseluruhan, sampel A memiliki kombinasi sifat terukur yang paling baik, meskipun diperlukan verifikasi lebih lanjut sebelum ditetapkan sebagai formulasi optimum. Biofoam yang dihasilkan berpotensi digunakan sebagai bahan kemasan biodegradable, tetapi karakterisasi tambahan masih diperlukan untuk memastikan kesesuaiannya sebagai pengganti langsung styrofoam komersial.

1. Introduction

The extensive use of conventional plastic-based food packaging, particularly polystyrene foam or styrofoam, has generated considerable environmental concerns because of its persistence after disposal and limited biodegradability. Although styrofoam is widely used because of its low density, low cost, and insulating properties, its accumulation as single-use packaging waste creates a significant challenge for sustainable waste management. Consequently, the development of biodegradable packaging materials from renewable resources has received increasing attention as a potential strategy for reducing dependence on petroleum-based packaging materials.

Starch-based biofoam is a promising alternative to conventional polystyrene foam because starch is renewable, relatively inexpensive, widely available, and capable of forming a polymeric matrix. Starch-based foams are also considered suitable for single-use packaging applications because they can be processed using heating, molding, and other thermoplastic-processing techniques. Cassava starch is particularly attractive as a raw material because cassava contains a high starch content, approximately 81.60%, making it suitable for the production of biodegradable materials (Akmala & Supriyo, 2020). However, starch-based materials generally have several limitations, including brittleness, poor dimensional stability, and high sensitivity to moisture. The hydrophilic nature of starch is mainly associated with its hydroxyl groups, which can interact with water and lead to increased water absorption. Excessive water absorption can consequently reduce the mechanical strength and dimensional stability of starch-based packaging materials.

Several approaches have been investigated to improve the properties of starch-based foams, including blending starch with other polymers, incorporating natural fibers, adding inorganic fillers, modifying starch chemically, and applying hydrophobic coatings. Polyvinyl alcohol (PVA) is commonly used in starch-based materials because of its film-forming ability, flexibility, and compatibility with starch. The hydroxyl groups of starch and PVA can form hydrogen-bonding interactions, which may improve the structural integrity of the resulting composite. Previous research has demonstrated that the incorporation of PVA can improve the mechanical properties and reduce the moisture adsorption of starch-based aerogels.

Natural fibers can also be incorporated into starch-based biofoam to improve the structural properties of the material and utilize agricultural residues. In the present study, corn cob fiber was selected because corn cobs are an abundant agricultural by-product containing lignocellulosic components. The utilization of corn cob fiber can provide an additional value to agricultural waste while reducing the consumption of non-renewable packaging materials. The fiber can act as a reinforcing phase within the starch-based matrix, although its effectiveness depends on fiber distribution, interfacial interaction, moisture content, and the relative proportions of the composite components. The use of starch, natural fiber, and PVA in biodegradable foam has previously been reported to influence foam expansion, water adsorption, and mechanical properties.

In addition to starch, natural fiber, and PVA, silica aerogel was incorporated into the biofoam formulation. Silica aerogel is a highly porous material with low density, high specific surface area, low thermal conductivity, and tunable hydrophobicity. Its porous structure and surface characteristics make silica aerogel a potential inorganic filler for modifying the physical properties of polymer-based composites. Silica aerogel has also been investigated for applications related to insulation, adsorption, separation, and packaging materials. Nevertheless, the incorporation of silica aerogel into a starch-based biofoam system must be considered carefully because the filler may affect matrix formation, pore structure, interfacial interactions, density, and mechanical performance.

In this study, silica aerogel was incorporated at a constant amount to investigate the influence of cassava starch content on the properties of the resulting biofoam. The use of a constant silica aerogel content is important because it allows the effect of starch content to be evaluated without introducing an additional variable associated with the amount of silica aerogel. Therefore, the present study does not directly evaluate the effect of varying silica aerogel concentration, but rather examines the properties of cassava-starch-based biofoam containing a fixed amount of silica aerogel.

Previous studies have reported the development of biodegradable foams using starch, natural fibers, PVA, and other additives. However, the relationship between cassava starch content and the physical, mechanical, and structural properties of biofoam containing silica aerogel has not been sufficiently clarified. In particular, the effects of starch content on density, water absorption, compressive strength, functional groups, and crystal structure require further investigation. Changes in starch content may influence the formation of the polymeric matrix, the distribution of fiber and silica aerogel, the internal pore structure, and the interaction between the constituent materials. These changes may subsequently affect the overall performance of the biofoam.

The research gap addressed in this study is therefore the limited understanding of how cassava starch content affects the balance between the physical, mechanical, and structural properties of a corn-cob-fiber-reinforced biofoam containing silica aerogel and PVA. To address this gap, cassava starch content was varied at 48.75, 51.25, 53.75, and 56.25 g, while the amounts of corn cob fiber, PVA, and silica aerogel were maintained at 18.75, 25, and 11.25 g, respectively. The formulation details are consistent with the experimental composition reported in the manuscript.

The resulting biofoam samples were characterized in terms of density, water absorption, compressive strength, functional groups using Fourier-transform infrared spectroscopy (FTIR), and crystal structure using X-ray diffraction (XRD). The objective of this study was to determine the effect of cassava starch content on the physical, mechanical, and structural properties of silica-aerogel-containing biofoam. The results are expected to provide a better

understanding of the role of starch content in determining biofoam performance and to support the development of biodegradable packaging materials derived from cassava starch and agricultural waste.

2. Research Methods

2.1 Materials and Equipment

The materials used in this study were cassava starch, corn cob fiber, polyvinyl alcohol (PVA), silica aerogel, sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2), and distilled water. Corn cobs were used as the source of lignocellulosic fiber, while cassava starch was used as the main polymeric matrix. PVA was incorporated as a binder and flexibility-enhancing agent, whereas silica aerogel was added as an inorganic filler.

The equipment used in this study included a digital balance, pH paper, beakers, spatulas, an oven, a mortar and pestle, a mixer, filter cloth, Petri dishes, a mold, and a hot-pressing machine. The characterization instruments included a Nicolet iS10 Fourier-transform infrared (FTIR) spectrometer, an X'Pert Powder PW30/40 X-ray diffractometer, and a texture analyzer.

2.2 Bleaching of Corn Cob Fiber

Corn cob fiber was treated to reduce the content of lignin and other non-cellulosic components. A total of 50 g of finely ground corn cob powder was immersed in 500 mL of 10% NaOH solution, corresponding to a solid-to-liquid ratio of 1:10. The mixture was stirred using a mixer and maintained for 24 h.

After the alkaline treatment, the mixture was filtered using a filter cloth. The resulting residue was subsequently immersed in 100 mL of 10% H_2O_2 solution for 24 h. The mixture was then filtered, and the residue was washed repeatedly with distilled water until the odor of H_2O_2 was no longer detected.

The washed residue was transferred to a Petri dish and dried in an oven at 50°C for 16 h. The dried material was then used as the corn cob fiber component in the biofoam preparation.

2.3 Biofoam Preparation

The biofoam was prepared using a hot-pressing method. The composition of the biofoam was varied by changing the amount of cassava starch, while the amounts of corn cob fiber, PVA, and silica aerogel were maintained constant.

First, the dried and finely ground corn cob fiber was placed in a mixing container. PVA was then added, and the mixture was stirred until the fiber and PVA were evenly distributed. Cassava starch and silica aerogel were subsequently added to the mixture. The resulting mixture was stirred until a relatively homogeneous and sufficiently thick mixture was obtained.

The mixture was then transferred into a mold and subjected to hot pressing at a pressure of 100 MPa and a temperature of 70°C for 10 min. After the pressing process, the formed biofoam was removed from the mold and prepared for further characterization.

The composition of each biofoam formulation is presented in Table 1.

Table 1. Variations in ingredient composition

Sample Code	A	B	C	D
Starch (g)	48.75	51.25	53.75	56.25
Fiber (g)	18.75	18.75	18.75	18.75
PVA (g)	25	25	25	25
Silica (g)	11.25	11.25	11.25	11.25

The variation in cassava starch content was based on a formulation reported by Sumardiono et al. (2021). In the present study, the amounts of corn cob fiber, PVA, and silica aerogel were kept constant to specifically evaluate the effect of cassava starch content on the properties of the biofoam.

2.4 Sample Characterization

The prepared biofoam samples were characterized in terms of functional groups, crystal structure, water absorption, density, and compressive strength.

1. Fourier-Transform Infrared Spectroscopy. Functional group analysis was performed using a Nicolet iS10 FTIR spectrometer over the wavenumber range of 4000–400 cm^{-1} . The FTIR spectra were analyzed by identifying the characteristic absorption bands associated with the functional groups of starch, PVA, corn cob fiber, and silica aerogel. The absorption bands were interpreted by comparing the measured spectra with established FTIR references and previously reported results. Particular attention was given to the O–H, C–H, C=O, Si–O–Si, and Si–OH groups because these groups are related to hydrogen bonding, the lignocellulosic structure, and the presence of silica aerogel in the biofoam matrix.

2. X-Ray Diffraction Analysis. The crystal structure of the biofoam samples was analyzed using an X'Pert Powder PW30/40 X-ray diffractometer. The instrument was operated at 40 kV and 30 mA. The measurements were conducted over a 2θ range of 10°–100° with a step size of 0.02°. The diffraction data were analyzed qualitatively using QualX software version 2.24. Quantitative analysis was performed using Rietica software. The XRD patterns were used to

evaluate the structural characteristics of the biofoam and to identify changes in the crystalline and amorphous regions associated with variations in cassava starch content.

3. Water Absorption Test. The water absorption test was performed to evaluate the resistance of the biofoam samples to water uptake. Each sample was cut into a square specimen measuring 2 cm × 2 cm and weighed to obtain its initial mass. The specimen was then immersed in water for 1 min. After immersion, the sample was removed from the water, and excess water on the surface was gently removed using tissue paper. The sample was then weighed again to obtain its final mass. The water absorption capacity was calculated using Equation (1):

$$\text{Water Absorption Capacity (\%)} = \frac{(\text{sample weight after dipping} - \text{initial sample weight})}{\text{initial sample weight}} \times 100\% \quad (1)$$

4. Density Measurement. The density of the biofoam samples was determined by measuring their mass and volume. Each sample was cut into a specimen measuring approximately 3 cm × 3 cm. The mass of the specimen was measured using a digital balance. The length, width, and thickness of the specimen were measured using a caliper. The volume was calculated by multiplying the length, width, and thickness of the sample. The density was then calculated using Equation (2):

$$\rho = \frac{m}{v} \quad (2)$$

with, ρ = density (g/cm³), m = mass (g), v = volume (cm³).

5. Compressive Strength Test. The compressive strength of the biofoam samples was measured using a texture analyzer equipped with a TA41 probe. The samples were compressed at a probe speed of 0.5 mm s⁻¹. The compressive strength was calculated as the maximum compressive force divided by the initial cross-sectional area of the specimen, as expressed in Equation (3):

$$\sigma_c = \frac{F_{max}}{A} \quad (3)$$

where σ_c = compressive strength (N mm⁻² or MPa); F_{max} = maximum compressive force (N); A = initial cross-sectional area of the specimen (mm²). Because 1 N mm⁻² = 1 MPa, the compressive strength values expressed in N mm⁻² are numerically equivalent to values expressed in MPa.

3. Results and Discussion

3.1 Density

The density values of the biofoam samples are presented in Figure 1. Samples A, B, and C exhibited similar density values of approximately 0.6 g/cm³, whereas sample D showed a slightly higher density of approximately 0.7 g/cm³.

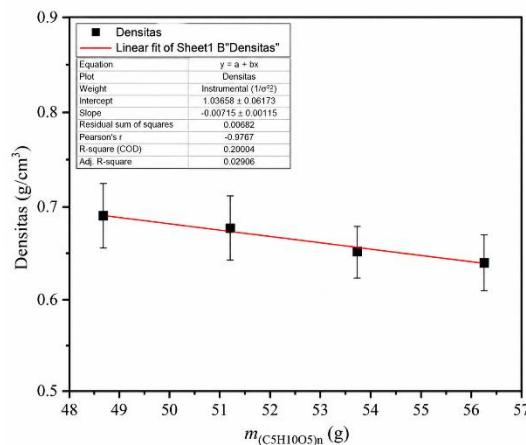


Figure 1. Effect of cassava starch content on the density of biofoam

The relatively small variation in density indicates that increasing the cassava starch content from 48.75 to 56.25 g did not substantially change the overall bulk density of the biofoam. This result may be associated with the constant amounts of corn cob fiber, PVA, and silica aerogel in all formulations. Consequently, the increase in starch content mainly changed the proportion of the starch matrix without producing a large change in the overall mass-to-volume ratio.

The slightly higher density of sample D may indicate a denser internal structure or reduced pore volume at the highest starch content. A higher starch content may produce a more compact matrix during molding, resulting in a

smaller volume of the final biofoam. However, this interpretation should be considered cautiously because the pore structure was not directly observed using microscopy.

The density values obtained in this study are higher than those generally reported for highly porous starch aerogels. Starch-based aerogels are usually characterized by very low density because of their highly porous structure, whereas molded starch composite foams may exhibit higher density depending on the processing method, formulation, and degree of compaction (Zhao et al., 2024).

The relatively high density observed in this study may provide better dimensional stability, although it can reduce the lightweight advantage commonly associated with conventional foam packaging. Previous research has shown that the density of starch-based foams is strongly influenced by the formulation, fiber content, and processing conditions (Mali et al., 2010).

3.2 Water Absorption

Figure 2 shows that water absorption increased progressively with increasing cassava starch content. The water absorption values were 1.3%, 1.9%, 2.6%, and 3.2% for samples A, B, C, and D, respectively.

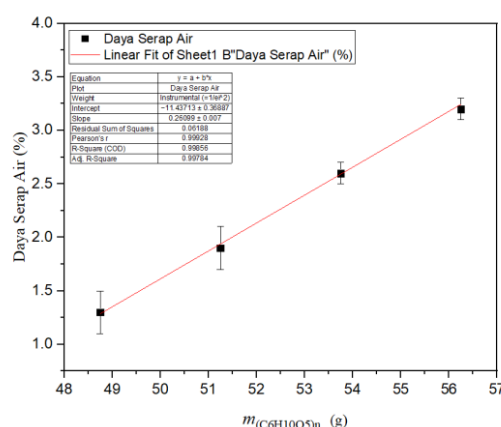


Figure 2. Effect of cassava starch content on the water absorption of biofoam

The lowest water absorption was observed for sample A, which contained the lowest amount of cassava starch. In contrast, sample D, containing the highest starch content, exhibited the highest water absorption. This trend indicates that the starch content strongly influenced the interaction between the biofoam and water.

The increase in water absorption can be associated with the greater proportion of starch in the composite matrix. The hydroxyl groups present in starch and PVA can interact with water, allowing the material to absorb moisture. Therefore, increasing the amount of starch may increase the number of hydrophilic sites available for water interaction. The water sensitivity of starch-based materials is widely reported as one of their main limitations in packaging applications (Zheng et al., 2019; Zhao et al., 2024).

The increase in water absorption observed in this study is consistent with the general behavior of starch-based foams. Starch-based materials tend to absorb moisture because of the presence of polar groups, particularly hydroxyl groups, in the polymeric structure (Zheng et al., 2019).

The result also indicates that the constant silica aerogel content was not sufficient to prevent the increase in water absorption caused by the higher starch content. Although silica aerogel may contribute to modifying the pore structure and moisture response of the composite, its effect in this study cannot be separated from the effect of the starch matrix because the silica aerogel content was kept constant.

The relatively low water absorption values obtained in the short-duration test suggest that the samples had limited water uptake under the tested conditions. However, these results should not be interpreted as evidence of long-term water resistance. Further testing involving longer immersion times, repeated wetting and drying, and water contact-angle measurements would be required to evaluate the moisture resistance of the biofoam more comprehensively.

Previous research on cassava starch, sugarcane bagasse fiber, and PVA foams showed that water absorption was affected by the relative proportions of the composite components. The addition of PVA and fiber could modify the water resistance of the starch-based foam, although the effect depended on the formulation and fiber content (Mali et al., 2010).

3.3 Compressive Strength

The compressive strength results are shown in Figure 3. The compressive strength values of samples A, B, C, and D were 6.09, 0.12, 0.15, and 0.10 MPa, respectively.

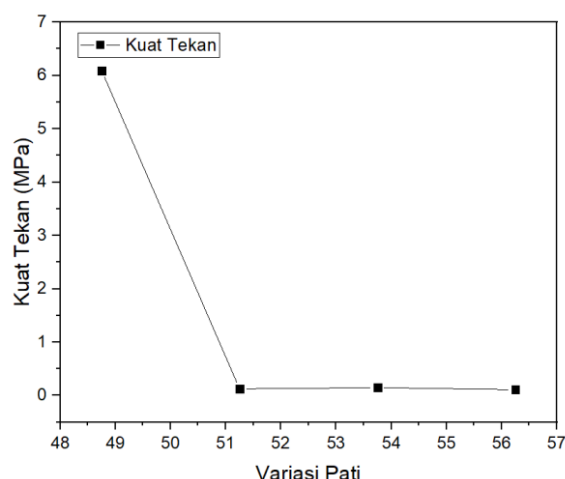


Figure 3. Effect of cassava starch content on the compressive strength of biofoam

Sample A exhibited a substantially higher compressive strength than samples B, C, and D. The value of 6.09 MPa is approximately one order of magnitude higher than the values obtained for the other formulations. In contrast, samples B–D showed relatively low compressive strength values, ranging from 0.10 to 0.15 MPa.

The strength did not show a progressive increase or decrease with increasing starch content. Therefore, the compressive strength cannot be explained solely by the amount of starch in the formulation. The mechanical response may also have been affected by differences in matrix formation, pore distribution, fiber dispersion, interfacial bonding, and the homogeneity of the molded samples.

The unusually high value obtained for sample A should be interpreted carefully. This result may represent a real improvement in structural integrity, but it may also be influenced by specimen preparation or testing factors. Possible factors include differences in specimen dimensions, cross-sectional area, sample thickness, local defects, density distribution, loading orientation, or the calculation of compressive stress from the measured force.

Because the compressive strength of sample A differs considerably from the other samples, the result should be verified using the original force–displacement data and repeated measurements. The specimen dimensions, calculated cross-sectional area, number of replicates, and standard deviation should also be reported. If the value of 6.09 MPa is confirmed by repeated testing, sample A may possess a substantially different internal structure from the other formulations. If the value cannot be reproduced, it should be treated as an anomalous measurement.

The relatively low compressive strength of samples B–D suggests that increasing the starch content did not necessarily improve the load-bearing capability of the biofoam. This finding indicates that a higher starch fraction may increase the amount of hydrophilic matrix without necessarily improving the structural reinforcement of the composite.

Previous research has shown that the mechanical properties of starch-based foams depend not only on starch content but also on the presence of PVA, natural fibers, moisture content, and foam microstructure. In particular, the strength of starch-based foams may decrease at high relative humidity because water acts as a plasticizer in the starch-rich matrix (Mali et al., 2010).

The use of PVA can improve the structural integrity of starch-based materials through interactions between the polymeric components. However, the mechanical effect of PVA depends on its concentration and the structure formed during processing (Joshi et al., 2023).

3.4 FTIR Analysis

The FTIR spectra of the biofoam samples are presented in Figure 4 and Table 2. The spectra show absorption bands associated with the main constituents of the composite, including cassava starch, PVA, corn cob fiber, and silica aerogel.

The broad absorption band in the hydroxyl region is associated with O–H stretching vibrations from starch, PVA, cellulose, and surface hydroxyl groups of silica-containing components. The presence of this band is consistent with the hydrophilic nature of the starch-based matrix and may explain the increase in water absorption observed with increasing starch content.

The absorption bands associated with C–H stretching are related to the carbohydrate and polymeric components of the biofoam. Signals in the carbonyl region may be associated with oxygen-containing groups present in the lignocellulosic fiber or other constituents of the composite. The Si–O–Si and Si–OH-related bands indicate the presence of the silica aerogel component in the biofoam structure.

The general similarity of the FTIR spectra among samples A–D suggests that changing the cassava starch content did not produce a new dominant functional group. Instead, the main chemical constituents remained similar, while their relative contributions to the composite may have changed.

The FTIR results support the water absorption data. The presence of hydroxyl-containing components in all samples explains why the biofoam remained capable of interacting with water. Furthermore, the increase in water absorption with increasing starch content is consistent with the greater contribution of starch-related hydrophilic groups in samples containing higher starch amounts.

Similar FTIR characteristics have been reported for starch–PVA-based aerogels, in which the spectra indicate the presence of hydroxyl groups and interactions between starch and PVA without necessarily forming completely new functional groups (Joshi et al., 2023).

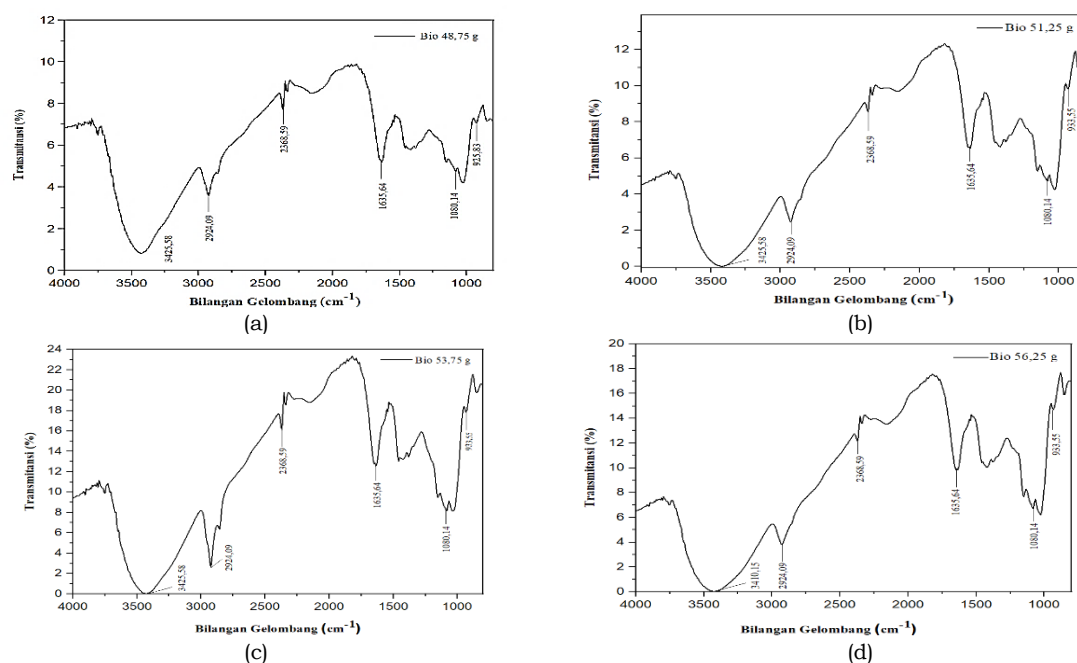


Figure 4. FTIR spectra of biofoam containing different cassava starch contents

Table 2. Functional group analysis results

Sample A	Sample B	Sample C	Sample D	Group Function	Vibration	Reference
3425.58	3425.58	3425.58	3410.15	OH	stretching	Flanagan et al., 2016
2924.09	2924.09	2924.09	2924.09	CH	stretching	Flanagan et al., 2016
1635.64	1635.64	1635.64	1635.64	C=O	stretching	Radhiyatullah et al. (2015), Amin et al., 2019
1080.14	1080.14	1080.14	1080.14	Si-O-Si	stretching	Chen et al., 2017
925.83	933.55	933.55	933.55	Si-OH	stretching	Liao et al., 2018

However, the FTIR spectra alone cannot establish the formation of a new chemical bond between starch, PVA, fiber, and silica aerogel. A more definitive interpretation would require comparison of peak positions, peak intensities, and possible peak shifts relative to the spectra of the individual raw materials.

3.5 XRD Analysis

The XRD patterns of the biofoam samples are shown in Figure 5. The diffractograms indicate that the biofoam contains both crystalline and amorphous structural contributions.

The crystalline contribution is associated with the ordered regions of the starch, cellulose-containing fiber, PVA, and silica-containing phase, whereas the broad diffraction features are related to the amorphous regions of the composite matrix. The combination of crystalline and amorphous phases is expected for a biofoam prepared from starch, natural fiber, PVA, and silica aerogel.

The differences in cassava starch content may influence the relative intensity and broadness of the diffraction peaks. However, the XRD patterns should be interpreted primarily in terms of changes in peak intensity, peak position, and degree of crystallinity.

The XRD results can be related to the mechanical and water absorption properties. A more ordered structure may contribute to improved mechanical resistance, whereas a more amorphous structure may provide greater accessibility of hydrophilic groups and consequently increase water absorption. Nevertheless, the compressive strength data do not show a direct relationship with starch content. Therefore, the mechanical behavior was likely influenced not only by crystallinity but also by pore structure, density distribution, fiber dispersion, and interfacial interactions.

Previous studies on starch-based materials have reported that the final crystalline structure is affected by starch composition, polymer blending, water content, and processing conditions. Consequently, changes in XRD patterns should be interpreted together with the formulation and processing history of the material (Zheng et al., 2019).

The available results do not provide sufficient evidence to assign specific crystal systems, such as triclinic silica or hexagonal starch, unless the diffraction peaks have been matched with an appropriate crystallographic database. Therefore, phase identification should be based on comparison with standard reference patterns rather than on the general appearance of the diffractogram.

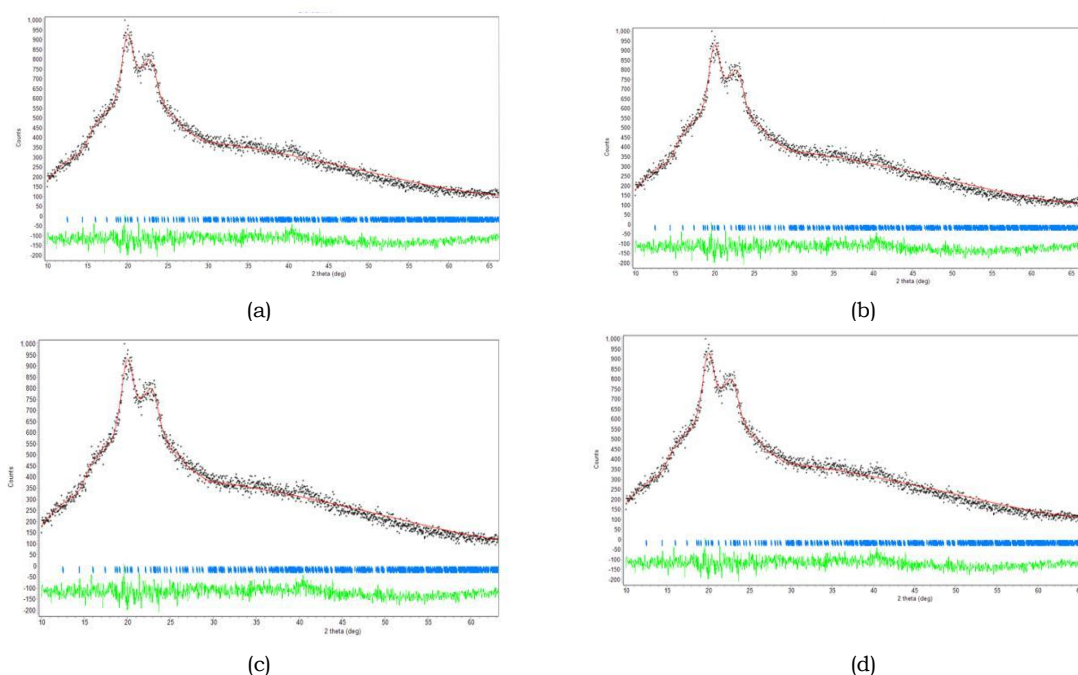


Figure 5. XRD patterns of biofoam containing different cassava starch contents

A more complete discussion would require calculation of the relative crystallinity or crystallinity index for each sample. Such analysis would allow the structural changes observed by XRD to be quantitatively compared with density, water absorption, and compressive strength.

3.6 Relationship between Physical, Mechanical, and Structural Properties

The results show that increasing cassava starch content produced a clear increase in water absorption, while the density changed only slightly. Water absorption increased from 1.3% in sample A to 3.2% in sample D, whereas density increased from approximately 0.6 to 0.7 g/cm³.

This result suggests that the starch content had a stronger effect on moisture uptake than on bulk density. The increase in water absorption may be associated with the greater proportion of hydrophilic starch in the matrix. In contrast, the relatively small density variation indicates that the overall volume and compactness of the molded biofoam remained relatively similar among the formulations.

The compressive strength did not follow the same trend as water absorption or density. Sample A exhibited a much higher strength than the other samples, whereas samples B–D showed values between 0.10 and 0.15 MPa. This indicates that the mechanical properties were not controlled by starch content alone.

The differences in compressive strength may be related to the internal structure of the samples. Factors such as pore size, pore connectivity, fiber distribution, matrix continuity, and the adhesion between starch, PVA, fiber, and silica aerogel may have a greater influence on mechanical performance than the total starch content. The importance of formulation and microstructure in determining the mechanical properties of starch-based foams has also been reported by Mali et al. (2010).

Overall, the results indicate that the formulation with the lowest starch content, sample A, exhibited the lowest water absorption and the highest measured compressive strength. However, the unusually high compressive strength of this sample requires verification before it can be used as the basis for selecting the optimum formulation.

3.7 Potential Application of the Biofoam

The results demonstrate that cassava-starch-based biofoam containing corn cob fiber, PVA, and silica aerogel can be produced with relatively low water absorption under the tested conditions. The use of cassava starch and corn cob fiber also provides an opportunity to utilize renewable agricultural resources in the development of biodegradable packaging materials.

Starch-based materials have been widely investigated as alternatives to petroleum-based packaging materials because of their renewability and biodegradability. However, their practical application is commonly limited by moisture sensitivity and insufficient mechanical performance (Zheng et al., 2019; Zhao et al., 2024).

Among the tested samples, sample A showed the lowest water absorption and the highest measured compressive strength. However, the mechanical result should be confirmed through repeated testing because of the substantial difference between sample A and the other formulations.

The present results suggest that the biofoam may be considered a potential material for lightweight packaging applications. Nevertheless, the available data are not yet sufficient to conclude that the material can directly replace commercial styrofoam. Such a claim would require additional comparison involving compressive strength, density, water resistance, thermal insulation, dimensional stability, biodegradability, and performance under actual packaging conditions.

Previous research has demonstrated that cassava-starch-based aerogels and foams have potential as biodegradable packaging materials, particularly when their mechanical properties and moisture sensitivity are improved through polymer blending or structural modification (Joshi et al., 2023).

Further studies should include microscopic analysis of the pore structure, repeated compressive-strength measurements, longer-term water absorption tests, contact-angle measurements, thermal analysis, and biodegradation testing. These analyses would provide a stronger basis for determining the suitability of the biofoam for practical packaging applications.

4. Conclusions

Cassava-starch-based biofoam containing corn cob fiber, PVA, and silica aerogel was successfully prepared using different cassava starch contents. The variation in starch content affected the physical properties of the resulting biofoam, particularly water absorption.

The density of the biofoam remained relatively constant at approximately 0.6 g/cm³ for samples A–C and increased slightly to 0.7 g/cm³ for sample D. In contrast, water absorption increased progressively from 1.3% to 3.2% as the cassava starch content increased from 48.75 to 56.25 g. This result indicates that a higher starch content increased the hydrophilic character of the biofoam.

The compressive strength did not show a consistent relationship with cassava starch content. Sample A exhibited the highest measured compressive strength of 6.09 MPa, whereas samples B–D showed considerably lower values ranging from 0.10 to 0.15 MPa. Therefore, the compressive strength was likely influenced not only by starch content but also by factors such as pore structure, matrix formation, fiber distribution, and sample homogeneity. The unusually high value of sample A should be confirmed through repeated measurements and verification of the original testing data.

The FTIR spectra indicated the presence of functional groups associated with starch, PVA, corn cob fiber, and silica aerogel. The similarity of the spectra suggests that changing the starch content did not produce a new dominant functional group. The XRD patterns indicated the presence of both crystalline and amorphous structural contributions, although quantitative crystallinity analysis and phase identification are required for a more detailed interpretation.

Based on the combined results, sample A showed the most favorable balance of the measured properties because it exhibited the lowest water absorption and the highest measured compressive strength. However, the compressive-strength result requires further verification before sample A can be confirmed as the optimum formulation.

Overall, the biofoam has potential as a biodegradable packaging material based on cassava starch and corn cob fiber. Nevertheless, the current results are not yet sufficient to confirm its direct replacement of commercial styrofoam. Further investigations involving pore-structure analysis, repeated mechanical testing, long-term water absorption, thermal properties, dimensional stability, biodegradability, and comparison with commercial packaging materials are required to establish its practical application.

5. References

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