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Effect of Jackfruit Seed Starch Bioplastic Coating on the Properties of Acetylated Sorghum Starch-Based Biofoam

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Abstract

Expanded polystyrene packaging is widely used because of its low cost and light weight, but its poor biodegradability has encouraged further development through incorporation of renewable materials. This study aimed to evaluate the effect of jackfruit seed starch bioplastic coating on the properties of acetylated sorghum starch-based biofoam. Biofoam was prepared using acetylated sorghum starch as the main matrix and both its surfaces were coated with jackfruit seed starch bioplastic at different starch masses of 5, 7.5, 10, and 12.5 g. The samples were produced by thermopressing and characterized for their density, water absorption capacity, biodegradability, compressive strength, functional groups and microstructure. The results showed that the coating improves the structural compactness and compressive strength, but reduces water absorption capacity of the biofoam. The optimum biofoam coating formulation was using 7.5 g jackfruit seed starch, which resulted in the highest density and compressive strength, with the lowest water absorption capacity, while maintaining good biodegradability. FTIR results indicated physical interactions and hydrogen bonding between the coating and biofoam matrix, while SEM confirmed a denser and smoother surface morphology of the biofoam. These findings demonstrate that jackfruit seed starch bioplastic coating is a promising renewable strategy for improving biodegradable foam packaging performance.

Keywords: *Acetylated sorghum starch; biofoam; bioplastic coating; jackfruit seed starch; thermopressing*

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INTRODUCTION

Plastic waste has been a major global environmental problem for a long time. As a part of the global community, Indonesia generates millions of tons of plastic waste annually, much of which remains poorly managed (Shamsuddin et al., 2025). Among plastic-based packaging materials, expanded polystyrene (EPS), commonly known as syrofoam, is

widely used for food packaging because of its low cost, light weight, and excellent thermal insulation properties (Ghoshal et al., 2023). However, because EPS is derived from petroleum resources, it is less biodegradable, idifficult to recycle, and potentially releases hazardous compounds during use or disposal (Zhang et al., 2020). These environmental, health and safety global concerns have driven the development of biodegradable packaging materials derived from renewable biopolymers.

Starch-based biodegradable foam, commonly referred to as biofoam, has been widely studied as a potential alternative to EPS. This is because starch is abundantly available, renewable, inexpensive, biodegradable, and suitable for thermoplastic processing (Tapia-Blácido et al., 2022). Sorghum starch is particularly promising as a raw material for biofoam production because sorghum grains contain approximately 65–85% starch on a dry-weight basis, providing a high polysaccharide content for foam matrix formation (Zhang et al., 2025). Furthermore, sorghum is a highly versatile crop that can be cultivated under a wide range of agroclimatic conditions, making it a potentially sustainable and locally available starch source for biodegradable packaging applications (Hossain et al., 2022).

Despite these advantages, biofoam produced from native starch generally exhibits poor water resistance and limited mechanical strength due to the hydrophilic nature of starch and the brittleness of the resulting matrix (Pachori et al., 2019). The abundance of hydroxyl groups in starch facilitates water absorption, while weak intermolecular interactions can result in brittle foams due to their low structural stability. Chemical modification, such as acetylation, has been reported as an effective approach to mitigate these drawbacks by partially substituting hydroxyl groups with acetyl groups. This modification can improve the thermoplastic behavior, swelling properties, solubility, and processing performance of starch-based materials (Chakraborty et al., 2022; Subroto et al., 2023).

Several studies have attempted to improve starch-based biofoam by modifying the starch source, adding blowing agents, incorporating synthetic or natural polymers, and applying coating layers. Hendrawati et al., (2020) produced biofoam from acetylated sago starch using $NaHCO_3$ as a blowing agent and reported improved mechanical properties and biodegradability; however, water resistance remained a major limitation. Darni et al., (2026) developed biofoam based on acetylated sorghum starch and polyvinyl alcohol using $NaHCO_3$ as a blowing agent, with the best formulation obtained at 15% blowing agent addition. Nevertheless, the resulting water absorption was still relatively high for packaging applications. Meanwhile, Sutiarno et al., (2022) showed that the incorporation of functional biopolymer components or coating layers can reduce water absorption in biofoam, indicating that surface modification is an important strategy for improving the quality of starch-based foam materials.

Various approaches can be applied to improve biofoam performance, including starch acetylation, the addition of matrix-reinforcing polymers such as PVA or chitosan, the use of blowing agents to form cellular structures, filler incorporation, and surface coating. Acetylation improves the thermoplastic characteristics of starch, PVA and chitosan enhance matrix cohesion, and blowing agents promote pore formation during foaming (Darni et al., 2025). However, these internal modifications do not completely prevent surface water absorption because water can still penetrate through open pores and microvoids in the foam structure. In this context, bioplastic coating offers a complementary strategy by forming a thin barrier layer on the foam surface, filling surface pores, increasing structural compactness, and reducing direct contact between the hydrophilic matrix and water (Jahangiri et al., 2024). Jackfruit seed starch is a suitable coating material because jackfruit seeds contain a high starch fraction, while their amylose and amylopectin components contribute to film formation and flexibility (Brahma & Ray, 2023; Patel et al., 2025). However, studies on the use of jackfruit seed starch-based bioplastic as a coating layer for acetylated sorghum starch-based biofoam remain limited. Therefore, jackfruit seed starch-based bioplastic coating offers a promising and renewable strategy to improve the water resistance and mechanical performance of acetylated sorghum starch-based biofoam.

Based on this background, this study aims to produce acetylated sorghum starch-based biofoam using the thermopressing method and to apply jackfruit seed starch-based bioplastic as a coating layer on both foam surfaces. The specific objectives are to produce coated sorghum starch-based biofoam and to evaluate the effect of jackfruit seed starch bioplastic coating on the physical, mechanical, biodegradable, functional, and morphological properties of the resulting biofoam. The results of this study are expected to support the development of renewable biodegradable foam packaging with improved water resistance, structural compactness, and mechanical stability for potential food packaging applications.

MATERIALS AND METHODS

Materials

Sorghum starch was obtained from Bantul Regency, Special Region of Yogyakarta, Indonesia, and jackfruit seeds (JSS) were obtained from Mataram Baru, East Lampung Regency, Lampung, Indonesia. Glacial acetic acid (99% purity, Smartlab) and NaOH (Merck, Germany) were used for starch acetylation. Polyvinyl alcohol (PVA, 88% purity, Denka, Japan), sodium bicarbonate ($NaHCO_3$, 98.5% purity, ROFA, Indonesia), magnesium stearate (99% purity, JZRchem, China), glycerol (99.7% purity, ROFA, Indonesia), chitosan (85% purity, CV. Bio

Chitosan Indonesia), soy protein isolate (90.08% purity, Shandong Kawah Oils Co., China), carboxymethyl cellulose (CMC), and sorbitol (70% purity, PT Sorini Indonesia) were used in biofoam preparation. Distilled water was used as the solvent in all preparation steps.

Preparation of Acetylated Sorghum Starch

Acetylated sorghum starch was prepared according to Darni et al., (2026). A total of 300 g of sorghum starch was dispersed in 900 mL of distilled water. The pH of the suspension was adjusted to 8 using 0.5 M NaOH under continuous stirring for 20 minutes. Glacial acetic acid was then added until the pH reached 5. The mixture was heated in a water bath at 45°C for 90 minutes. After the reaction, the suspension was filtered using filter paper and a vacuum filtration system. The remaining slurry was washed four times with distilled water. The starch precipitate was then dried at 40°C, sieved through a 200-mesh sieve, and stored in a zip-lock bag until further use.

Preparation of Jackfruit Seed Starch

Jackfruit seed starch (JSS) was prepared according to (Indriani et al., 2023). One kilogram of jackfruit seeds was cut, soaked in water, and cleaned. The seeds were blended until a slurry was obtained. The slurry was filtered using filter paper, and the residue was washed three times with distilled water. The suspension was allowed to settle for 12 hours. The precipitate was dried under sunlight for two days and then sieved through a 200-mesh sieve. The resulting dry starch was used as the raw material for bioplastic coating preparation.

Preparation of Jackfruit Seed Starch Bioplastic Coating

The jackfruit seed starch bioplastic coating was prepared using different starch masses of 5, 7.5, 10, and 12.5 g. CMC and sorbitol were added at 15% and 30% of the jackfruit seed starch mass, respectively. The CMC and sorbitol were first dissolved in 100 mL of distilled water and stirred at 450 rpm for 50 minutes using a magnetic stirrer. Jackfruit seed starch was then added according to each formulation, and the mixture was heated to 80°C while stirring for another 40 minutes. The resulting solution was poured into a tray lined with aluminum foil and dried in an oven at 55°C for 6 hours.

Table 1. Formulation of jackfruit seed starch bioplastic coating.

Run	Jackfruit Seed Starch (JSS) (g)	Sorbitol (% weight of JSS)	CMC (% weight of JSS)	Distilled Water (mL)
1	0	0	0	0
2	5	30	15	100
3	7.5	30	15	100
4	10	30	15	100
5	12.5	30	15	100

The bioplastic sheet was separated from the aluminum foil and stored in a zip-lock bag until further use (Darni et al., 2026).

Synthesis of Coated Biofoam

A total of 2.5 g of acetylated sorghum starch was weighed for biofoam preparation. A chitosan solution was prepared by mixing 0.03 g of chitosan with 1.17 mL of acetic acid until a homogeneous solution was obtained. The biofoam mixture was prepared by adding 1.2 mL of chitosan solution, 0.2 g of magnesium stearate, 1.13 mL of glycerol, 2.5 g of PVA, 0.31 g of soy protein isolate, and $NaHCO_3$ as the blowing agent to the acetylated sorghum starch. The mixture was stirred until homogeneous and then placed into a mold lined with bioplastic sheets on both sides. The molded mixture was processed using thermopressing at 125°C for 15 minutes. The biofoam was removed from the mold, conditioned for 30 min at room temperature, and stored in a zip-lock bag for further analysis.

Properties Testing of Biofoam

Density Test

For the density measurement, the biofoam sample was cut into a size of 2.5 cm × 2 cm and weighed. The volume was determined by multiplying the length, width, and thickness of the sample, which were measured using a caliper. The density of the biofoam was calculated using Eq. (1):

$$\rho = m/V \quad (1)$$

where ρ is the density of the sample (g/cm³), m is the sample mass (g), and V is the sample volume (cm³).

Water Absorption Test

The biofoam sample was cut into a size of 2.5 cm × 5 cm and weighed to obtain the initial weight. The sample was then immersed in water for 1 min to determine its water absorption capacity. Excess surface water was removed using tissue paper, and the final weight was recorded. The test was conducted according to the ISO 535: Determination of Water Absorptiveness. Water absorption was calculated using Eq. (2):

$$\text{Water Absorption (\%)} = ((W_1-W_0)/W_0) \times 100\% \quad (2)$$

where W_0 is the initial weight of the sample before immersion and W_1 is the final weight after immersion.

Biodegradabilitas Test

The biofoam sample was cut into a size of 3 cm × 3 cm and immersed in water for 1 minute. The sample was then weighed to obtain the initial weight. Subsequently, the sample was buried in soil at a depth of 10 cm for 14 days. After the burial period, the sample was removed, cleaned from attached soil particles, and weighed to obtain the final weight.

Biodegradability was determined based on the percentage of weight loss using Eq. (3):

$$\text{Weight Loss (\%)} = ((W_1-W_0)/W_0) \times 100\% \quad (3)$$

where W_0 is the initial weight of the sample before burial and W_1 is the final weight after burial.

Compressive Strength Test

The compressive strength of the biofoam was calculated using Eq. (4):

$$\sigma = F_{maks}/A \quad (4)$$

where σ is the compressive strength (MPa), Fmax is the maximum applied force (N), and A is the cross-sectional area of the sample (mm²).

Instrumental Characterization

Fourier-transform infrared spectroscopy (FTIR) analysis was conducted using an Agilent Cary 630 ATR-FTIR spectrometer (Agilent Technologies, USA) to identify the functional groups of native sorghum starch, acetylated sorghum starch, uncoated biofoam, and coated biofoam. Scanning electron microscopy (SEM) analysis was performed using FE-SEM EDS (ThermoScientific Quattro S) to observe the surface morphology and microstructural characteristics of the biofoam samples.

RESULTS AND DISCUSSION

The visual appearance of the biofoam and jackfruit seed starch bioplastic samples prepared using different coating formulations is presented in Figure 1.

Figure 1. Visual appearance of biofoam and jackfruit seed starch bioplastic samples with different formulations (a) uncoated biofoam; (b) biofoam coated with 12.5 g JSS; (c) biofoam coated with 10 g JSS; (d) biofoam coated with 7.5 g JSS; (e) biofoam coated with 5 g JSS; (f) bioplastic sheet with 12.5 g JSS; (g) bioplastic sheet with 10 g JSS; (h) bioplastic sheet with 7.5 g JSS; and (i) bioplastic sheet with 5 g JSS.

Figure 1 shows that the uncoated biofoam had a lighter and more uniform appearance, whereas the biofoam coated with jackfruit seed starch bioplastic appeared darker and less homogeneous. This difference indicates that the bioplastic coating layer was successfully attached to the surface of the acetylated sorghum starch-based biofoam. The darker color of the coated biofoam is mainly related to the natural color of the jackfruit seed starch bioplastic sheet, which tends to become brownish after being heated and dried as is the case with the manufacture of Starch-Based Bioplastic from Jackfruit Seed (Nguyen et al., 2022).

The color change in the jackfruit seed starch bioplastic may be attributed to starch gelatinization and thermal reactions during processing caramelization, and phenolic oxidation (He & Kong, 2025; Nguyen et al., 2022). These reactions can occur during heating, particularly in starch-based materials containing carbohydrates, residual proteins, and other minor organic compounds (Nath et al., 2022). Although color is not the main functional parameter of biofoam, the visual appearance provides preliminary information on coating distribution, surface coverage, and possible non-uniformity in the coated samples.

The coating formulation also influences the surface appearance of the biofoam. Samples with higher jackfruit seed starch content tended to show a darker and less uniform coating surface, which may indicate uneven film formation, local accumulation of coating material, or differences in drying behavior. Therefore, the visual characteristics shown in Figure 1 suggest that jackfruit seed starch bioplastic can modify the surface of acetylated sorghum starch-based biofoam, but an optimum coating amount is required to obtain more uniform surface coverage and improved material performance.

Physical Properties of Biofoam

Density

The effect of jackfruit seed starch bioplastic coating on the density of acetylated sorghum starch-based biofoam is presented in Figure 2.

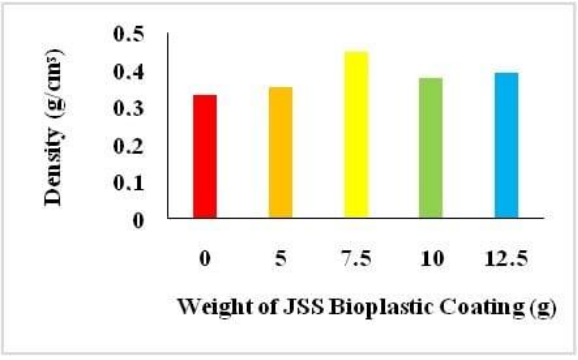

Figure 2. Effect of jackfruit seed starch bioplastic coating on biofoam density.

The density of the biofoam increased from 0.333 g/cm³ in the uncoated sample to 0.450 g/cm³ in the sample coated with 7.5 g of jackfruit seed starch. This increase indicates that the bioplastic coating filled void spaces and partially covered the open

pores within the biofoam structure, resulting in a more compact matrix. The improvement in density also suggests better layer and the acetylated sorghum starch-based foam surface. A similar mechanism was reported by Maamoun & Mahmoud, (2022), who stated that the incorporation of polymeric components can improve structural compactness by filling cavities and reinforcing the foam matrix.

However, the density did not increase continuously with further addition of jackfruit seed starch. At 10 g of coating, the density decreased to 0.379 g/cm³, while at 12.5 g it slightly increased to 0.394 g/cm³. This fluctuation indicates that excessive coating material may reduce coating uniformity and cause agglomeration or uneven particle distribution. Such irregularities can generate new pores, microvoids, or structural defects in the biofoam matrix. This finding is consistent with Azizati et al., (2024), who reported that excessive filler or solid content in starch-based biofoam can lead to agglomeration and irregular pore formation, thereby affecting the density and structural stability of the material.

Overall, the density values of the biofoam ranged from 0.333 to 0.450 g/cm³, which was higher than the density of commercial expanded polystyrene (EPS). This result indicates that the coated biofoam has a more compact structure, but it also shows that the material is heavier than conventional EPS packaging. Therefore, higher density is not always the most desirable characteristic in biofoam development. An optimum density is required because biofoam should maintain sufficient compactness and mechanical strength while remaining lightweight for packaging applications. In this study, the 7.5 g coating formulation provided the highest density and indicated the most effective pore-filling effect. However, further optimization of coating thickness, drying conditions, and formulation uniformity is still needed to reduce excessive weight while maintaining good water resistance and mechanical performance.

Water Absorption

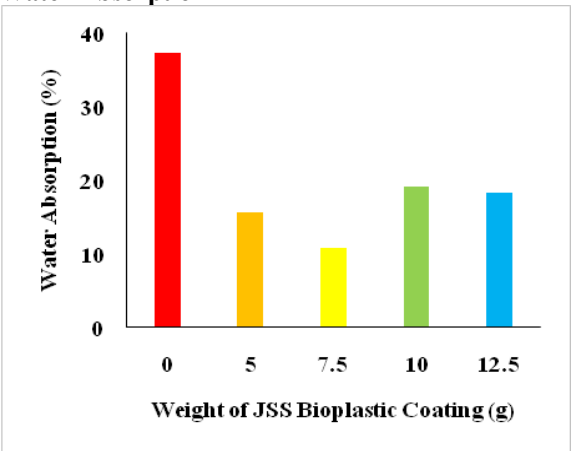

Figure 3. Effect of jackfruit seed starch bioplastic coating on the water absorption of biofoam.

The effect of jackfruit seed starch bioplastic coating on the water absorption of acetylated sorghum starch-based biofoam is presented in Figure interaction between the coating
3.Figure 3 shows that the uncoated biofoam had the highest water absorption value, reaching 37.30%, while the lowest water absorption value was obtained in the biofoam coated with 7.5 g of jackfruit seed starch, at 10.83%. This result indicates that the jackfruit seed starch bioplastic coating effectively reduces water uptake by covering surface pores and forming a barrier layer on the biofoam surface. With the 7.5 g coating, the bioplastic layer likely filled the open pores more uniformly, resulting in a denser and more compact structure. This finding is consistent with the density result, where the 7.5 g coated sample showed the highest density, indicating reduced porosity and improved structural compactness.

However, increasing the coating concentration to 10 and 12.5 g caused the water absorption value to increase again. This suggests that excessive coating material did not further improve the water resistance of the biofoam. Instead, a higher starch concentration may have caused agglomeration, uneven coating distribution, and microcrack formation during drying or thermopressing. These structural defects can create additional pathways for water penetration into the foam matrix. A similar phenomenon was reported by Amaraweera et al., (2022), who explained that poor structural uniformity, pore defects, and microcracks can increase water uptake in starch-based biodegradable foam materials.

Although the coating significantly reduced water absorption compared with the uncoated biofoam, the values obtained in this study were still higher than those of commercial foam standards, such as Synbra Technology (<2%) and EPS (<4%). This indicates that the hydrophilic nature of starch-based biofoam was not completely eliminated by the jackfruit seed starch bioplastic coating. The presence of hydroxyl groups in starch, CMC, and sorbitol may still promote water interaction, even when the surface is coated. Therefore, the coating improved water resistance but did not yet achieve the hydrophobic performance of synthetic polymer-based packaging materials.

These findings imply that jackfruit seed starch bioplastic coating is a promising surface modification strategy for reducing water absorption in acetylated sorghum starch-based biofoam. The 7.5 g coating formulation provides the most effective balance between pore coverage and coating uniformity. However, further improvement is needed to enhance the water barrier properties of the material.

Biodegradability Test

The effect of jackfruit seed starch bioplastic coating on the biodegradability of acetylated sorghum starch-based biofoam is presented in Figure 4.

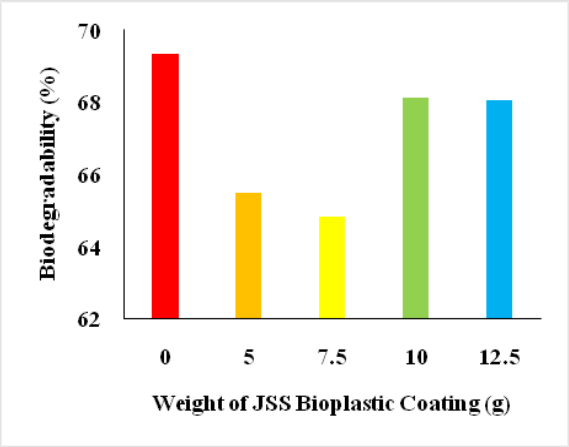

Figure 4. Effect of jackfruit seed starch bioplastic coating on biofoam biodegradability.

Figure 4 shows that the biodegradation of the biofoam after 14 days ranged from 64.83% to 69.34%. These results indicate that all biofoam samples exhibited high degradability, confirming that the use of jackfruit seed starch bioplastic coating did not prevent the decomposition of acetylated sorghum starch-based biofoam. The high degradation rate was attributed to the biodegradable nature of the main components, including sorghum starch, jackfruit seed starch, CMC, sorbitol, PVA, chitosan, and soy protein isolate (Elgharbawy et al., 2024; He & Kong, 2025). These biopolymer-based materials can absorb water and undergo hydrolysis, which facilitates microbial attack and accelerates material breakdown in soil (Mohammadian et al., 2024).

The lowest degradation value was observed in the biofoam coated with 7.5 g of jackfruit seed starch. This result was consistent with the density and water absorption results, where the 7.5 g coating produced the most compact structure and the lowest water uptake. A denser coating layer can reduce water diffusion and limit direct microbial contact with the starch-based matrix, thereby slowing the hydrolysis and biodegradation process. Gabriel et al., (2024) reported that biodegradation of starch-based materials is strongly influenced by water penetration, microbial activity, and the accessibility of polymer chains to hydrolytic degradation. Therefore, the lower degradation value at 7.5 g indicates that the coating effectively improved structural compactness and water resistance while still maintaining biodegradability.

In contrast, the highest degradation value was observed in the biofoam coated with 10 g of jackfruit seed starch. This increase may be related to less uniform coating formation, agglomeration, and microcrack development at higher coating concentrations. These structural defects can increase water penetration and provide more accessible pathways for microorganisms, thereby accelerating degradation. This interpretation is also consistent with the water absorption and SEM results, which indicate that excessive coating material may produce microstructural irregularities rather than a more effective barrier layer.

Although the coating layer acted as a partial barrier to water and microorganisms, the biofoam still degraded by more than 60% within 14 days. Compared with the EN 13432 standard, which requires 90% degradation within 6–9 months, the degradation performance obtained in this study indicates that the coated biofoam has promising biodegradability for short-term packaging applications. However, the relatively rapid degradation also suggests that the material may be more suitable for disposable or dry-food packaging rather than long-term packaging under humid conditions.

These findings imply that jackfruit seed starch bioplastic coating can improve the water resistance and structural compactness of biofoam without eliminating its biodegradable character. Nevertheless, further research is needed to evaluate biodegradation under different environmental conditions, such as controlled composting, high humidity, and real packaging disposal environments. Future studies should also examine the relationship between coating thickness, microbial activity, and degradation kinetics to ensure that the material maintains an appropriate balance between functional stability during use and biodegradability after disposal.

Compressive Strength of Biofoam

The effect of jackfruit seed starch bioplastic coating on the compressive strength of acetylated sorghum starch-based biofoam is presented in Figure 5.

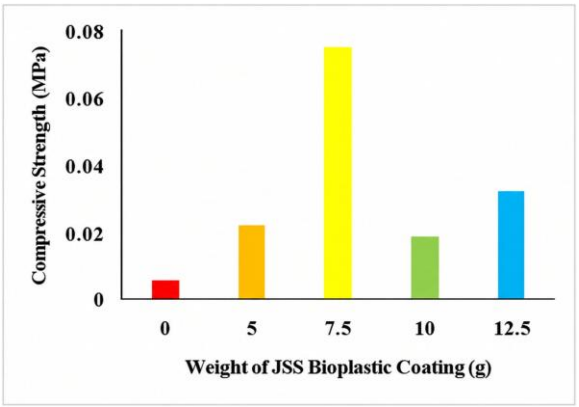

Figure 5. Effect of jackfruit seed starch bioplastic coating on the compressive strength of biofoam.

Figure 5 shows that the compressive strength of the biofoam increased after the application of jackfruit seed starch bioplastic coating. The uncoated biofoam exhibited the lowest compressive strength, indicating that the foam matrix without surface coating had weak structural resistance under compression. This low strength was likely related to the presence of open pores, poor surface compactness, and limited reinforcement within the starch-based matrix. The addition of the coating

improved the compressive strength, with the highest value observed in the biofoam coated with 7.5 g of jackfruit seed starch. This result indicates that an optimum amount of coating can reinforce the biofoam surface, fill microvoids, and improve load distribution during compression.

The improvement in compressive strength at 7.5 g was consistent with the density and water absorption results. In this formulation, the biofoam showed the highest density and the lowest water absorption, suggesting that the coating formed a more compact and homogeneous structure. The jackfruit seed starch bioplastic layer likely acted as a reinforcing surface layer that reduced pore defects and strengthened the interaction between the coating and the acetylated sorghum starch-based matrix. Therefore, the increase in compressive strength was not only caused by the additional mass of coating material, but also by better pore filling, surface coverage, and structural compactness.

However, the compressive strength decreased when the coating concentration was increased to 10 g and 12.5 g. This decrease indicates that excessive jackfruit seed starch did not further improve the mechanical properties of the biofoam. Instead, excess coating material may cause agglomeration, uneven coating distribution, irregular pore formation, and microcrack development during drying or thermopressing. These structural defects can weaken the foam matrix and reduce its ability to withstand compressive loads. This finding is in agreement with Azizati et al., (2024), who reported that excessive solid content or filler addition in starch-based biofoam can produce agglomeration and irregular pores, resulting in a more fragile structure.

Compared with the ASTM C578 Type I EPS standard of 0.068 MPa, the biofoam coated with 7.5 g of jackfruit seed starch met and exceeded the minimum compressive strength requirement. This indicates that the optimum coating formulation improves the mechanical feasibility of acetylated sorghum starch-based biofoam for packaging applications. However, the compressive strength remained lower than the Synbra Technology standard of 0.2 MPa, suggesting that further improvement is still required before the material can match the performance of commercial synthetic foam. These results imply that jackfruit seed starch bioplastic coating is a promising strategy to enhance the mechanical performance of biodegradable biofoam, but optimization of coating thickness, formulation homogeneity, and processing conditions is necessary to achieve stronger and more stable foam structures.

Foutier Transfrom Infrared Spectroscopy (FTIR) Analysis

FTIR analysis was performed to identify the functional groups of native sorghum starch, acetylated sorghum starch, uncoated biofoam, and biofoam coated with jackfruit seed starch bioplastic. The FTIR spectra of native sorghum starch and acetylated sorghum starch are presented in Figure 6.

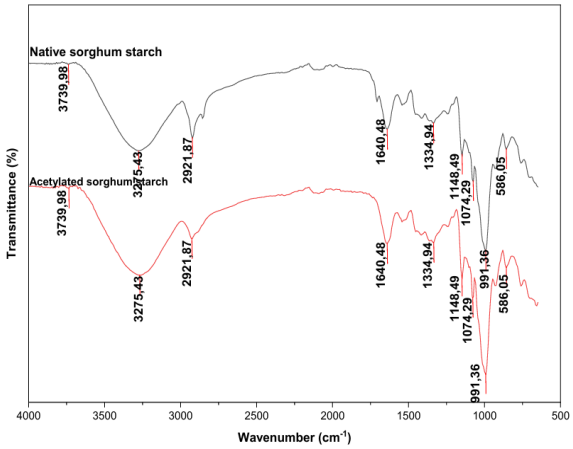

Figure 6. FTIR spectra of native sorghum starch and acetylated sorghum starch

Figure 6 shows that native sorghum starch and acetylated sorghum starch exhibited similar major absorption regions, indicating that the basic starch structure was still maintained after acetylation. A broad O–H absorption band was observed around 3272–3299 cm^{-1} in both samples (Piyapan & Aramwit, 2024). However, the intensity of this band decreased after acetylation, indicating a reduction in hydroxyl groups due to partial substitution by acetyl groups. This change suggests that the acetylation process modified the hydrophilic sites of sorghum starch, which can contribute to improved water resistance and better processing behavior in biofoam preparation.

The absorption bands in the C–H stretching region appeared around 2922–2929 cm^{-1}, while several bands were also observed in the fingerprint region (Thombare et al., 2023). After acetylation, the bands at approximately 2847 and 1148 cm^{-1} became less distinct or disappeared, indicating changes in the C–H and C–O vibration environments of the starch structure (Yusuf, 2023). The absorption region around 1640 cm^{-1} was still observed, while changes in the C–O and C–O–C regions between 1244 and 998 cm^{-1} indicated structural modification in the starch molecules after acetylation (Al-Harrasi et al., 2025). The persistence of absorption bands around 998–857 cm^{-1} suggests that the main polysaccharide backbone of starch remained stable. Overall, the decrease in O–H intensity and changes in the C–H and C–O absorption regions confirmed that acetylation successfully altered the functional group environment of sorghum starch without completely disrupting its basic structure.

The FTIR spectra of uncoated biofoam and biofoam coated with different weight of jackfruit seed starch bioplastic are presented in Figure 7.

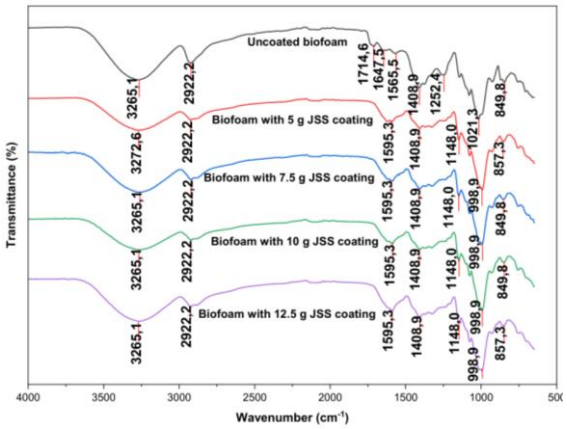

Figure 7. FTIR spectra of uncoated biofoam and biofoam coated with different weight of jackfruit seed starch bioplastic.

Figure 7 shows that the uncoated and coated biofoam samples had similar main absorption patterns, indicating that the coating process did not form new dominant chemical groups in the biofoam structure. A broad O–H absorption band appeared around 3265–3276 cm^{-1} (Ndruru et al., 2024) in all samples, representing hydroxyl groups from starch, PVA, CMC, sorbitol, and other biopolymer components. The coated biofoam samples showed slight changes in O–H intensity compared with the uncoated biofoam, which may indicate hydrogen bonding interactions between the jackfruit seed starch bioplastic coating and the acetylated sorghum starch-based biofoam matrix.

The C–H absorption band around 2922 cm^{-1} (Kusuma et al., 2026) was observed in all biofoam samples, suggesting that the basic hydrocarbon structure of the starch- and PVA-based matrix remained relatively stable after coating. The absorption bands around 1714–1647 cm^{-1}, which are associated with carbonyl and bound-water-related vibrations, appeared more prominent in the uncoated biofoam and became less intense in the coated samples. This decrease suggests that the jackfruit seed starch bioplastic layer may have covered part of the functional groups on the biofoam surface. In addition, the C–O and C–O–C absorption regions around 1252–998 cm^{-1} (Al-Harrasi et al., 2025) were observed in all samples and showed slight intensity differences after coating. These changes were related to the contribution of jackfruit seed starch, CMC, and sorbitol in the coating layer.

The similarity among the FTIR spectra of the coated biofoam samples indicates that increasing the jackfruit seed starch coating did not substantially change the chemical structure of the biofoam. Instead, the coating mainly modified the surface through physical interaction, pore coverage, and hydrogen bonding between compatible biopolymer components. This interpretation is consistent with the density, water absorption, and compressive strength results, where the 7.5 g coating produced the most compact structure and the best balance of properties. Therefore, the FTIR results confirm that jackfruit seed starch bioplastic coating improved the biofoam primarily through physical surface modification rather than chemical bond formation.

Although FTIR analysis confirmed the presence of functional group interactions between the coating and the biofoam surface, this method could not quantify the degree of acetylation or the strength of hydrogen bonding. Therefore, further studies should include additional analyses, such as degree of substitution, thermal analysis, contact angle measurement, and water vapor permeability testing, to better understand the relationship between chemical modification, coating interaction, and barrier performance of acetylated sorghum starch-based biofoam.

Scanning Electron Microscopy (SEM) Analysis

The surface morphology of the uncoated and coated acetylated sorghum starch-based biofoam was observed using SEM, as shown in Figure 8.

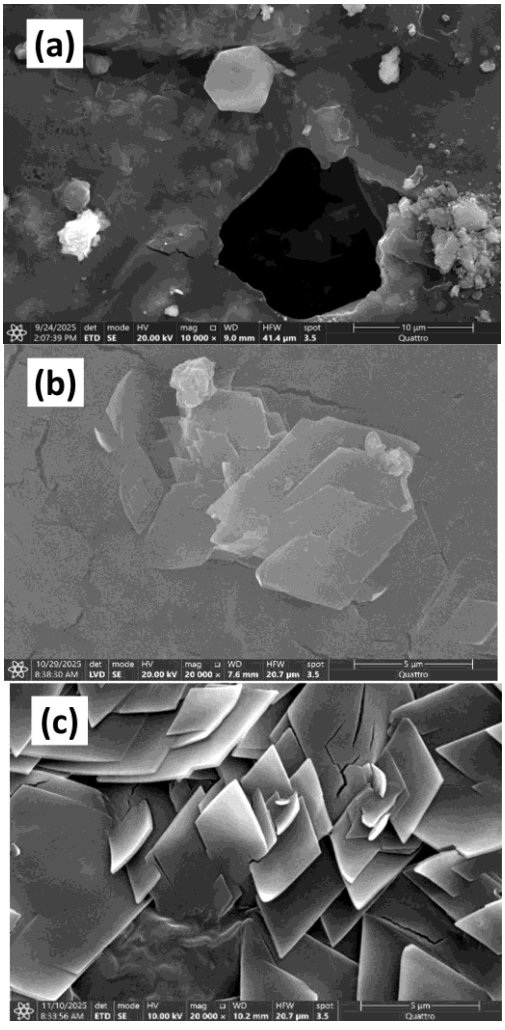

Figure 8. Surface morphology of biofoam: (a) uncoated biofoam at 10,000× magnification; (b) biofoam with 7.5 g JSS coating at 20,000×

magnification; and (c) biofoam with 10 g JSS coating at 20,000× magnification.

Figure 8 shows clear differences in the surface morphology of the uncoated and coated biofoam samples. The uncoated biofoam exhibits a rough and porous surface, with visible open gaps and cavities. This morphology indicates that the uncoated biofoam had a less compact structure, which allowed easier water penetration into the matrix. This observation is consistent with the water absorption results, where the uncoated biofoam showed the highest water uptake. The presence of open pores also explains the lower compressive strength of the uncoated sample, as a more porous structure generally provides weaker resistance to mechanical load.

The biofoam coated with 7.5 g of jackfruit seed starch showed a smoother and denser surface morphology. The pores appeared smaller, and several microcavities were partially covered by the bioplastic coating layer. This structure indicates that the coating effectively filled the surface voids and improved the compactness and homogeneity of the biofoam matrix. The denser morphology of this sample supports the results of density, water absorption, and compressive strength tests, where the 7.5 g coating produced the highest density, the lowest water absorption, and the highest compressive strength. These findings suggest that an optimum amount of jackfruit seed starch coating can improve surface integrity and enhance the functional performance of acetylated sorghum starch-based biofoam.

In contrast, the biofoam coated with 10 g of jackfruit seed starch showed a rougher surface with visible agglomerates and microcracks. This morphology indicates that excessive coating material may cause non-uniform film formation and irregular distribution on the biofoam surface. The higher solid weight may also promote starch retrogradation during drying or thermopressing, resulting in a less homogeneous structure. These agglomerates and microcracks can act as weak points in the material and create additional pathways for water penetration. Therefore, the increase in water absorption and the decrease in compressive strength at higher coating concentration can be attributed to these structural defects.

Overall, the SEM analysis confirms that the performance of coated biofoam is strongly influenced by coating uniformity and surface morphology. The 7.5 g jackfruit seed starch coating provides the most effective surface modification by reducing pore openness and improving matrix compactness. However, excessive coating caused agglomeration and microcrack formation, which reduced the effectiveness of the coating layer. Further studies should optimize the coating thickness, drying conditions, and film-forming composition to obtain a more uniform surface structure and improve the water resistance and mechanical stability of starch-based biofoam.

CONCLUSION

Jackfruit seed starch bioplastic coating improves the performance of acetylated sorghum starch-based biofoam by enhancing structural compactness, reducing water absorption, increasing compressive strength, and maintaining biodegradability. The 7.5 g jackfruit seed starch coating was identified as the optimum formulation because it produced the most balanced physical, mechanical, and morphological properties. FTIR analysis indicated that the coating process occurred mainly through physical interactions and hydrogen bonding without the formation of new dominant chemical groups, while SEM observations confirmed that the optimum coating produced a smoother and denser surface with fewer open pores. However, excessive coating content caused non-uniform surface coverage, agglomeration, and microcrack formation, which reduced the effectiveness of the coating. Overall, jackfruit seed starch bioplastic coating is a promising renewable surface modification strategy for developing biodegradable biofoam packaging with improved water resistance and mechanical stability, although further optimization is still required to approach the performance of commercial synthetic foam materials.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Yuli Darni: Writing - review & editing, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Septia Maharani**: Writing original draft, Visualization, Investigation. **Lia Lismeri**: Conceptualization, Investigation, Formal analysis. **Simparmin Br Ginting**: Conceptualization, Formal analysis. **Aris Setiawan**: Writing-review & editing, Visualization, Conceptualization, Investigation. **Sudibyo**: Methodology, Formal analysis. **Nindya Indah Kusumawardani:** Conceptualization, Investigation.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No funding related this study.

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