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BIOFOAM FROM TAPIOCA STARCH AND SUGARCANE BAGASSE FIBRE WITH THE ADDITION OF GLYCEROL PLASTICISER

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ABSTRACT
This study focuses on producing biodegradable foam (biofoam) materials that are easily degradable and non-hazardous to human health. This research aims to develop environmentally friendly biofoam based on tapioca starch and sugarcane bagasse fibre, with the addition of glycerol as a plasticiser, using the thermopressing method. The variations in the composition of tapioca starch to sugarcane bagasse fibre used were (100:0)%, (70:30)%, and (60:40)%. The FTIR results revealed the presence of characteristic polysaccharide functional groups such as O–H, C–H, and C–O. Mechanical testing showed an increase in tensile strength and elastic modulus in samples with fiber addition, with the highest elastic modulus value obtained at the (70:30)% composition, reaching 13.258 MPa. The biofoam with a (70:30)% composition exhibited the most balanced mechanical and degradation properties, making this formulation potentially suitable as a replacement for styrofoam packaging. SEM images indicated that the biofoam without fiber had a relatively homogeneous surface, while the addition of 30% fiber resulted in the formation of macro pores that were still fairly well distributed. In contrast, the addition of 40% fiber showed agglomeration and large voids that reduced the interfacial bonding between fiber and starch, thereby weakening the mechanical properties. EDX analysis demonstrated the dominance of C and O elements, along with an increased presence of mineral elements (Si, Mg, Na) at higher fiber compositions.
Keywords: Biofoam, Tapioca Starch, Sugarcane Baggasse, Glycerol.
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INTRODUCTION

The increasingly efficient and productive lifestyle of contemporary society has led to a rapid and large-scale increase in plastic usage. Plastic is widely used because of its low cost, adequate strength, durability, and flexible characteristics.[1] As a result, human dependence on plastic packaging in daily life is considerable. Global plastic production is currently predicted to reach 100 million tons annually.[2] The high consumption of plastic has caused a serious problem- unmanaged plastic waste has become a major environmental threat. Most plastic waste ends up polluting terrestrial and aquatic ecosystems.[3,4] One type of plastic widely used as food packaging in daily activities is styrofoam, due to its light weight, moldability, water resistance, heat resistance, and affordability. Styrofoam consists of about 5% polystyrene and 95% air, making it extremely lightweight.[5] Although styrofoam has many advantages, it also has significant drawbacks. It is one of the food packaging materials with harmful long-term environmental effects, as styrofoam waste is difficult to degrade naturally.[6] Styrofoam waste is characterized by its chemical stability and resistance to decomposition. Over the past decade, large amounts of styrofoam waste-including cups, food containers, and electronic packaging- have accumulated in ecosystems due to massive disposal. This white solid waste is recognised as a global environmental hazard. The polystyrene and benzene components in styrofoam make it resistant to microbial degradation, while its combustion produces dioxins, which are carcinogenic compounds.[5] Polystyrene is a synthetic polymer derived from an aromatic hydrocarbon monomer called styrene. It contains a gas capable of expansion, pentane, dissolved within the polystyrene beads. When heated, the pentane expands, forming closed-cell structures of expanded polystyrene.[7] Researchers have sought to develop alternative materials to replace polystyrene-based styrofoam. One such alternative is biodegradable foam or biofoam.[5] Biofoam decomposes faster than styrofoam made from petroleum and is anticipated to reduce

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environmental pollution resulting from styrofoam waste.[8] Biofoam is non-carcinogenic, safe for public health, biodegradable by microorganisms, and environmentally friendly.[9] Flexible, lightweight, water-resistant, thermally stable, and economically viable, biofoam can act as a substitute for polystyrene-based materials. Tapioca starch, considered a biopolymer, holds great potential as a base material for producing naturally degradable materials. Tapioca starch-based foams, similar to those made from other starches, exhibit less desirable properties such as high water absorption, lower strength, and reduced elasticity, which limit their application, particularly in food packaging.[10] In addition to starch, biodegradable packaging materials derived from sugarcane fiber can also be developed to minimise styrofoam usage. Sugarcane bagasse is often discarded carelessly, leading to environmental pollution and aesthetic degradation of surrounding areas. The Camming sugar factory produces more than 24,614 tons of sugar annually and generates waste reaching up to 90% of the processed sugarcane. The utilisation of sugarcane waste remains suboptimal, with only small amounts used as animal feed or energy sources. Sugarcane bagasse can function as the main raw material for producing biofoam since it contains up to 47% cellulose. The abundant cellulose content makes it a promising alternative in biofoam production. However, biofoam made from sugarcane bagasse has some limitations, such as low solubility in water.[11] Another issue is its limited flexibility. Therefore, additives are needed to modify and enhance water resistance and to improve mechanical properties.[12] The addition of glycerol increases flexibility, acting as a plasticiser that enhances elasticity by reducing internal hydrogen bonding and increasing intermolecular spacing. The production of biofoam has been investigated by many researchers using various materials and methods. One study by Rismawati explored the synthesis of biofoam from sugarcane bagasse by extracting cellulose through delignification and bleaching processes, followed by biofoam synthesis and characterisation using sugarcane bagasse cellulose with chitosan variations of 2, 3.5, 5, and 6.5 grams.[11] The isolated cellulose exhibited characteristic functional groups O–H, C–H, and C–O, confirming the presence of cellulose. XRD analysis showed a crystallinity index of 70.74%. The biofoam made with 2 g of chitosan exhibited the best characteristics, with a density of 1.23 g/mL, water absorption of 46.03% after 24 hours of immersion, and biodegradability of 20.68% within 28 days. Nugroho also conducted a study on biofoam to examine the effects of different Polyvinyl Alcohol (PVA) concentrations on biofoam quality and production. Four levels of PVA (0, 1, 2, and 3% w/w) were tested in mixtures of cassava starch dough and 15% WHF.[13] Biofoam was produced using a thermal pressing machine at 190°C for 3 minutes. The study revealed that increasing PVA concentration resulted in smoother dough and stronger mechanical properties. The biofoam containing 2% PVA showed compressibility of 32 N/mm², water absorption of 10%, moisture content of 12%, and good biodegradability, with 87% of the material decomposing after 30 days in soil.

EXPERIMENTAL

Material and Methods

The materials used in this study were sugarcane bagasse, tapioca starch, glycerol, and distilled water, along with 3.5% HNO_3, $NaNO_2$, 2% NaOH, 2% $Na_2S_2O_3$, and 1.75% NaOCl for the cellulose extraction process from sugarcane bagasse. The sugarcane bagasse was first rinsed with clean water to eliminate impurities and then cut into small pieces, and dried in the sunlight until completely dry. Subsequently, the dried bagasse was ground using a grinder into powder form and sieved through a 100 mesh sieve to obtain fine fiber powder. The cellulose extraction process was carried out by mixing 75 grams of bagasse powder with 1 liter of 3.5% HNO_3 solution containing 10 mg of $NaNO_2$, followed by heating at 90°C for 2 hours. The mixture was then filtered, and the resulting residue was rinsed with distilled water until a neutral pH was reached. The residue was subsequently dissolved in 750 mL of 2% NaOH solution mixed with 2% $Na_2S_2O_3$ and heated at 50°C for 1 hour. Afterwards, the mixture was filtered and washed again until it reached a neutral pH. The process was continued with a bleaching step using 250 mL of 1.75% NaOCl solution at 70°C for 30 minutes. After final filtration and washing to neutral pH, cellulose was successfully obtained.

The biofoam preparation was conducted using the thermopressing method through two main stages: mixing and molding. In the mixing stage, tapioca starch, extracted sugarcane bagasse cellulose, glycerol, and distilled water were weighed according to the composition variations, then mixed using a mixer for two minutes until homogeneous, with gradual addition of distilled water to achieve the desired dough

texture. The molding stage was performed by preheating the aluminium mould to 100°C, pouring the prepared dough into the mould, and levelling the surface. The mixture was then pressed at 170°C for 10 minutes using a thermopress machine. The formed biofoam was taken out of the mold and allowed to cool at room temperature. The resulting product was subsequently characterised through tensile testing, FTIR, and SEM-EDX analyses.

RESULTS AND DISCUSSION

The tensile test results of the synthesised biofoam based on ASTM D-638 type I standards are shown in Fig.-1.

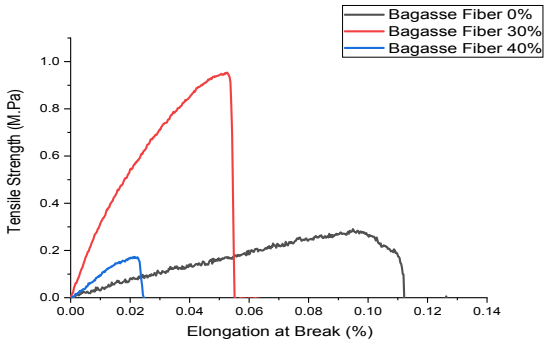


Fig.-1: Tensile Test Graph

Figure-1 shows the stress–strain relationship graph. The composition without fiber (0%) exhibits the highest elongation, indicating that the material is flexible but lacks strength due to the absence of cellulose reinforcement. The presence of glycerol as a plasticiser provides a softening effect by disrupting hydrogen bonds between chains, allowing tapioca starch molecules to become more flexible and stretch further.[14] The addition of 30% fiber produces the maximum stress with good elongation. This composition represents the optimum point, where the addition of cellulose nanofibril fibers from bagasse enhances the tensile strength and elastic modulus of the biofoam until a certain composition, at which the fibers effectively act as reinforcement within the material structure.[15] At 40% fiber content, both stress and strain values decrease due to excessive fiber aggregation and poor dispersion. This condition weakens the interfacial bonding between fiber and matrix, making cracks more likely to form when a load is applied, thereby reducing mechanical performance.[16] Thus, the addition of fiber in an optimal amount improves the mechanical properties of the biofoam, whereas excessive fiber content reduces them. This aligns with the principle of natural composites, where material strength is determined by the interaction between reinforcement and matrix. The tensile test results of tapioca starch-based biofoam with the addition of bagasse fiber at various compositions (0%, 30%, and 40%) are shown in Fig.-2.

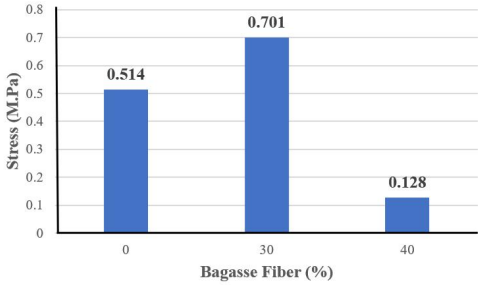


Fig.-2: Stress of Tapioca Starch-Sugarcane Bagasse Fiber Biofoam

Tensile strength is the primary indicator of a material's ability to withstand force before breaking. As shown in Fig.-2, the highest tensile strength value of 0.701 MPa was obtained at the composition of 30% bagasse fiber and 70% starch, indicating optimal interaction between the fiber and the matrix. In contrast, the lowest value of 0.128 MPa was observed at 40% fiber and 60% starch composition, due to fiber agglomeration, poor mixing, and the formation of voids that initiate cracks. This finding emphasises the importance of maintaining a balance between fiber and matrix to achieve optimal mechanical properties.

This result shows an improvement compared to a previous study, which used bagasse fiber with avocado seed starch, yielding a maximum tensile strength of 0.382 MPa.[2] The improvement is attributed to the enhanced interaction of starch with fiber, which strengthens the mechanical properties of the biofoam. Moreover, the decomposition of cellulose fibers produced longer strands capable of interlinking, thus yielding higher tensile strength. This indicates that tapioca starch as a matrix can produce biofoam with greater tensile strength, particularly at the 30% composition. Therefore, it can be concluded that the formulation with 30% bagasse fiber and 70% tapioca starch is the most optimal. Figure-3 shows the relationship between elongation at break and variations in bagasse fiber composition in tapioca starch-based biofoam.

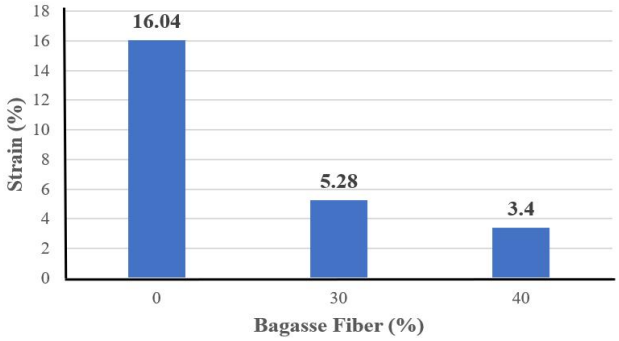


Fig.-3: Strain of Tapioca Starch–Sugarcane Bagasse Fiber Biofoam

Elongation at break indicates the material's ability to undergo plastic deformation before fracturing. Based on Fig.-3, the biofoam without fiber (0%) exhibits the highest elongation of 16.04%, while the addition of 30% and 40% fiber results in a decrease to 5.28%. This reduction is due to the crystalline cellulose nature of bagasse fiber, which increases stiffness and limits polymer chain mobility, as well as fiber agglomeration at high concentrations, which introduces weak points and cracks. According to previous findings, increasing bagasse fiber concentration in the starch biopolymer matrix enhances tensile strength and elastic modulus but decreases elongation at break.[17] This occurs because the rigid nature of bagasse fiber increases matrix stiffness and limits polymer chain flexibility.

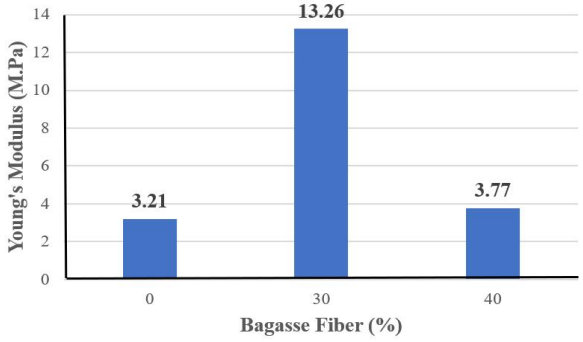


Fig.-4: Young's Modulus of Tapioca Starch–Bagasse Fiber Biofoam

Figure-4 shows the effect of varying bagasse fiber concentrations on the Young's Modulus of tapioca starch-based biofoam. The highest value, 13.26 MPa, was obtained at 30% fiber composition, which is significantly higher than 0% (3.21 MPa) and 40% fiber (3.77 MPa). This increase indicates that fiber–matrix distribution at 30% is optimal, resulting in higher stiffness and resistance to deformation. Bagasse fiber acts as reinforcement through its rigid microfibril network, consistent with fiber composite principles. However, at 40% fiber, agglomeration leads to non-homogeneity and weak points, reducing stress transfer effectiveness. Excessive fiber also disrupts intermolecular starch bonding, decreases cohesion, makes the biofoam brittle, and reduces compatibility. Thus, there is an optimal fiber usage limit at the 30% composition, where fiber-matrix interaction is most efficient in enhancing Young's Modulus. Increasing fiber content beyond this point decreases mechanical performance due to imbalance in composition and internal structure.

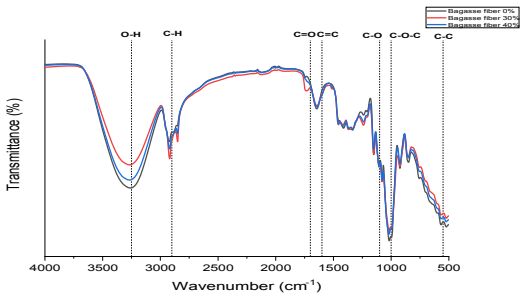
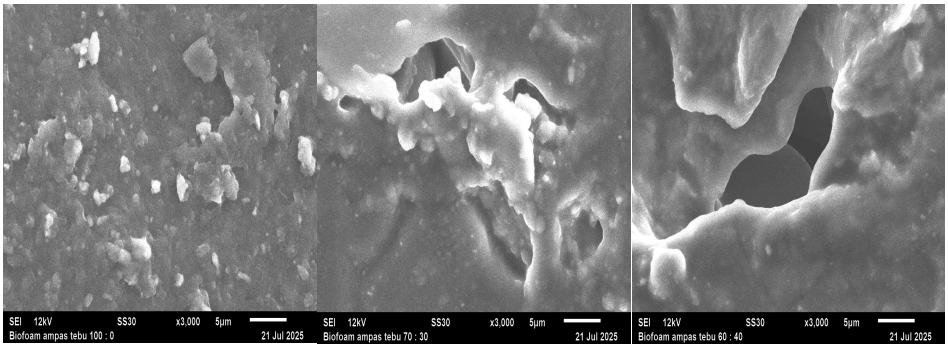


Fig.-5: Functional Group Spectrum of Biofoam

From Fig.-5, it can be observed that a very broad and strong absorption peak appears at the wavenumber range of approximately (3200–3600) cm^{-1}, corresponding to the stretching vibration of hydroxyl groups (–OH). These groups may originate from water molecules or alcohol groups within the cellulose and hemicellulose structures. This absorption is a characteristic feature of lignocellulosic materials, as –OH groups are extensively involved in hydrogen bonding among polysaccharide chains. The absorption peaks at around (2850–3000) cm^{-1} are associated with aliphatic C–H stretching vibrations, originating from methyl ($–CH_3$) and methylene ($–CH_2–$) groups. This indicates the presence of linear or branched aliphatic structures within cellulose. At wavenumbers of (1600–1760) cm^{-1}, absorption peaks appear, indicating the presence of carbonyl groups (C=O) derived from ester, aldehyde, or carboxylic acid compounds. These groups generally originate from hemicellulose or lignin degradation products, particularly from non-structural portions that undergo mild oxidation during processing. The strong peak at (1025–1300) cm^{-1} indicates the presence of C–O bonds, which are part of the lignin structure. Lignin is a complex aromatic polymer composed of phenylpropanol monomers. These peaks suggest that the lignin in sugarcane bagasse remains relatively intact and chemically active. The range of (1200–1000) cm^{-1} encompasses significant peaks attributed to the bond elongation of C–O–C (ether) and C–O (alcohol) bonds, which are commonly found in glycosidic linkages of cellulose and hemicellulose. The presence of these groups further confirms that sugarcane bagasse retains its main lignocellulosic structure, which has not been completely degraded. Peaks below 600 cm^{-1} are often associated with C–C or even C–X (halogen–carbon) bond vibrations. Although not dominant, these peaks indicate the presence of heavier components or the carbon backbone structure. The chemical bonding structure among starch, cellulose, and glycerol can also be identified through the presence of functional groups such as C–H (starch), C–O (alcohol), and O–H (starch–cellulose–glycerol).

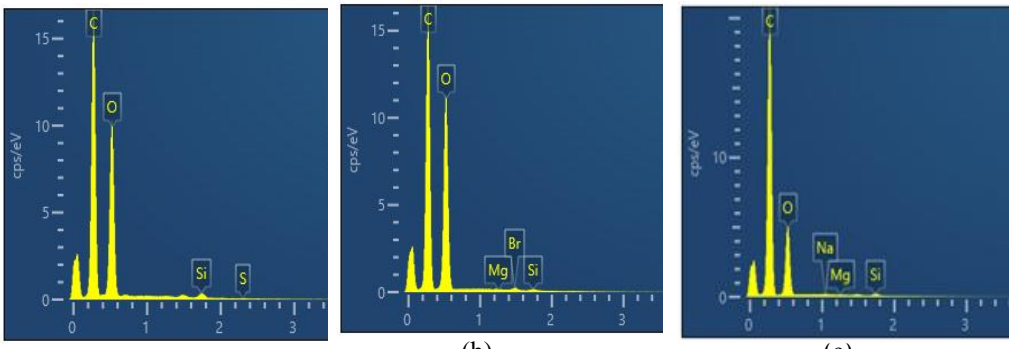


(a) (b) (c)

Fig.-6: SEM Micrographs of Tapioca Starch-Based Biofoam with Sugarcane Bagasse Fiber Addition at 3000X Magnification. (a) Without Fiber (0%); (b) 30% Sugarcane Bagasse Fiber; (c) 40% Sugarcane Bagasse Fiber

Figure-6 indicates the biofoam morphology, where at the 100:0 composition (pure starch), the surface appears relatively continuous with small micro-pores. At the 70:30 composition, irregular macro-pores are formed due to non-homogeneous fiber dispersion and reduced interfacial adhesion. At the 60:40

composition, large voids and fiber agglomerations become more evident, indicating poor mixing, resulting in suboptimal fiber–starch bonding and decreased mechanical strength of the biofoam.



(a) (b) (c)

Fig.-7: EDX Results of Tapioca Starch-Based Biofoam with Sugarcane Bagasse Fiber Addition. (a) without Fiber; (b) 30% Sugarcane Bagasse Fiber; (c) 40% Sugarcane Bagasse Fiber

Table-1: Elemental Composition of Biofoam with Different Tapioca Starch to Sugarcane Bagasse Fiber Ratios

Element	Weight without fiber % (a)	Weight of bagasse fiber 30 % (b)	Weight of bagasse fiber 40% (c)
C	63.68 ± 0.24	61.50 ± 0.21	79.77 ± 0.06
O	34.39 ± 0.23	36.88 ± 0.20	19.17 ± 0.06
Si	1.56 ± 0.10	0.40 ± 0.07	0.85 ± 0.03
S	0.26 ± 0.11	-	-
Mg	-	0.05 ± 0.05	0.07 ± 0.02
Br	-	1.16 ± 0.13	-
Na	-	-	0.14 ± 0.02

For the starch composition without fiber, the elements are dominated by carbon (C) and oxygen (O), consistent with the polysaccharide composition of starch and the presence of glycerol. The very low levels of silicon (Si) and sulfur (S) are likely derived from ash or inherent minerals in the starch, or minor contamination from equipment. This profile indicates that the matrix remains largely organic with minimal inorganic content. At the 70:30 composition of starch and bagasse fiber, the elements are still dominated by C and O; however, magnesium (Mg), silicon (Si), and bromine (Br) elements appear. The presence of Mg and Si reflects the ash content from sugarcane bagasse fibers, with the increase indicating the fiber's contribution to the inorganic phase of the biofoam. The trace amount of Br is likely adventitious (a minor contaminant from the environment or auxiliary materials) and not part of the main structure. At the 60: 40 composition, in addition to the dominant C and O peaks, sodium (Na), Mg, and Si are more prominently detected compared to the 70:30 composition. This indicates an increasing contribution of mineral components from the fibers at higher fiber fractions. Sodium may originate from residual salts in the synthesis process, while Mg and Si likely come from fine silica particles present in the fiber cell walls. Across all variations, C and O bonds dominate the starch-glycerol matrix. The addition of sugarcane bagasse fiber enhances the detection of inorganic minerals (particularly Si, Mg, and occasionally Na), which are characteristic of lignocellulosic fiber ash or mineral residues. As the fiber fraction increases, the composition becomes richer in minerals, and the local elemental distribution becomes more heterogeneous due to incomplete dispersion.

CONCLUSION

Biofoam based on tapioca starch with the addition of sugarcane bagasse fiber and glycerol using the thermopressing method was successfully produced. The tapioca starch-to-sugarcane bagasse fiber composition of (70:30)% was determined as the optimal formulation, exhibiting the highest tensile strength of 0.701 MPa and a Young's modulus of 13.26 MPa. FTIR analysis shows the presence of characteristic polysaccharide functional groups –OH, C–H, C=O, and C–O, indicating successful chemical interaction among starch, sugarcane bagasse cellulose, and glycerol in forming the biofoam

structure. SEM analysis showed that biofoam without fiber exhibited a homogeneous surface with micro-pores, while the addition of 30% fiber produced irregular macro-pores due to non-homogeneous fiber dispersion and reduced interfacial adhesion. In contrast, at 40% fiber, agglomeration and large voids were observed, leading to reduced homogeneity and mechanical strength of the biofoam. EDX analysis revealed that C and O elements were dominant, with increasing Mg, Si, S, and Br elements corresponding to higher fiber content.

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CONFLICT OF INTERESTS

The authors declare that they have no conflicts of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-12: Responsible Consumption and Production*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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