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Research Article

Duck Eggshell as Bioploymer Film

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Abstract: *The increasing demand for eco-friendly radiation shielding materials has prompted exploration of sustainable biopolymers reinforced with natural waste-derived fillers. This study investigates the utilization of duck eggshell waste, an abundant agricultural byproduct, as a functional additive in biopolymer films for radiation protection applications. Duck eggshells, primarily composed of calcium carbonate, were processed into fine powder and incorporated into biodegradable polymer matrices to enhance mechanical strength and attenuate ionizing radiation. The resulting biopolymer films were characterized for their structural and radiation-shielding properties using fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), ultraviolet-visible spectroscopy (UV-Vis.) and gamma-ray attenuation measurements. Results demonstrated that the inclusion of eggshell powder improved film density and radiation absorption capacity while maintaining biodegradability and flexibility. This approach not only valorizes eggshell waste but also offers a sustainable alternative to conventional synthetic shielding materials, contributing to environmentally responsible solutions in medical, industrial, and nuclear applications. The study highlights the potential of waste-derived biopolymers in advanced functional materials.*

1. INTRODUCTION

In recent years, waste management and environmental sustainability have grown to be significant worldwide issues . Massive amounts of food and agricultural waste are produced, which if improperly managed, can cause major environmental problems. Duck eggshells are one of the most common wastes from the food and poultry sectors. Duck eggshells, which are usually thrown away as waste, are mostly made of calcium carbonate ($CaCO_3$), a mineral with exceptional qualities including great thermal stability, superior mechanical strength, and the capacity to absorb radiation. Therefore, using leftover duck eggshells as a raw material offers a low-cost and environmentally beneficial way to create luxurious products.

The United States Department of Agriculture (USDA) projects the consumption statistics to reach up to 8917 million dozen by 2028 . Some of the countries with the highest annual egg consumption statistics are Japan, Paraguay and China where individuals consume 320, 309 and 300 eggs respectively. This rise in egg consumption has triggered the corresponding surge in egg production globally e.g. continuing the example of United States, egg production was recorded to be around 9334 million dozen in 2019 and is expected to reach around 9410 million dozen in 2020 (Waheed et al., 2020). The same scenario is seen globally with egg production expected to stay steady or progress modestly among the major markets around the world. In India, 30-year high production yield of around 83 billion eggs was reported in 2016. In Malaysia, the issue is particularly relevant given the significant volumes of eggshell waste generated annually. Estimates suggest that the country produces over 70,000 tons of eggshell waste each year (Zamri et al., 2025).

Biopolymer films made from natural polymers such starch, gelatin, chitosan, or polyvinyl alcohol (PVA) have gained attention as biodegradable materials that potentially replace of traditional synthetic polymers. However, pure biopolymer films frequently have limitations such as weak barrier properties and low mechanical strength (Homavand et al., 2025). These qualities and effectiveness can be further enhanced by adding inorganic fillers, such as calcium carbonate from eggshells. Furthermore, conventional materials like lead are useful in the field of radiation protection, but because of their toxicity and non-degradability, they present risks to the environment and human health (Tochaikul & Moonkum, 2024). Therefore, it is essential to create sustainable radiation shielding materials from biodegradable and renewable sources. A new type of green composite films that combine biopolymers and $CaCO_3$ generated from duck eggshells may be able to reduce harmful radiation while encouraging waste valorization and sustainability.

2. LITERATURE REVIEW

As the demand for sustainable materials continues to rise, biopolymer films have become a sustainable substitute for conventional petroleum-based polymers. However, the majority of biopolymers have worse durability and limited radiation resistance, which limits their use in industries that need sterilisation or radiation shielding. Therefore, it is necessary to improve biopolymer films' capacity to protect against radiation by adding appropriate chemicals or natural fillers. The calcium carbonate (CaCO3) found in duck eggshell waste, which is widely accessible and frequently thrown away, may enhance the mechanical strength and radiation shielding capacity of biopolymer composites. In addition to supporting waste valorisation and environmental sustainability, using this waste may enhance the biopolymer film's functioning.

Hence, the problems identified to be related to this study Nevertheless, despite being biodegradable and eco-friendly, biopolymer films still lack the mechanical and radiation- resistant properties of synthetic polymers, while radiation shielding materials currently in use are predominantly non-biodegradable and derived from petrochemical sources, leading to environmental disposal concerns. Furthermore, although duck eggshell waste presents a promising sustainable alternative, its effectiveness in enhancing radiation shielding performance remains to be fully confirmed, and the formulation as well as processing of duck eggshell-based biopolymer films must be optimised to achieve adequate mechanical strength, flexibility, and shielding performance comparable to industrial standards.

3. METHODOLOGY

The method begins wth the sample preparation process, which involved mixing, heating, moulding, and drying to produce the biopolymer film. This was followed by the radiation treatment stage, the sample were exposed to three radiation sources: Americium-241, Cesium-137, and Cobalt-60. Through this process, the properties of both irradiated and non-irradiated samples could be examined and compared to evaluate the impact of radiation on the developed biopolymer film. The sample that had undergo radiation treatment were sent for analysis the effectiveness of the biopolymer film as a radiation shielding material using duck eggshell as a natural filler. The samples were characterized using three different instruments: FTIR, UV-Vis and SEM, to investigate their structural and morphological characteristics.

4. FINDINGS

The samples were analysed by using Fourier Transform Infrared Spectroscopy (FTIR), SEM and UV-Vis in order to study their chemical structure, surface morphology and the functional group.

4.1 Fourier Transform Infrared Spectroscopy (FTIR)

The essential tool for chemical fingerprinting and analysing the intermolecular interactions in the composite system is FTIR spectroscopy. The presence of the duck eggshell filler and the corn starch polymer matrix will be confirmed by the expected spectrum of the composite film. Specifically, the characteristic chemical signature of the eggshell's primary component, calcite calcium carbonate ($CaCO_3$) will be validated by the appearance of three key, distinct absorption bands, confirming successful integration: a strong absorption band around $1400cm^{-1}$ which is indicative of the carbonate stretching vibration, along with two sharp deformation peaks near $872cm^{-1}$ and $712cm^{-1}$. According to (Vonnie et al., 2022), the observation of these specific $CaCO_3$ peaks is chemically valid and directly applicable to the duck eggshell used in this study, as the chemical structure of the $CaCO_3$ core remains identical across poultry species.

The most critical scientific evidence will be derived from analyzing the high-energy hydroxyl (O-H) stretching region (typically $3600 - 3000cm^{-1}$). When the pure corn starch film is compared to the composite film, the O–H peak is expected to shift slightly or become narrower. This change indicates that a chemical interaction has occurred between the starch and the added filler. This change in the spectrum clearly shows that new hydrogen bonds have formed between the hydroxyl groups in the starch polymer and the Ca^{2+} ions and carbonate groups from the duck eggshell filler. This phenomenon, as reported in the reference literature, shows that the materials are chemically compatible. It leads to a more ordered, compact, and tightly packed internal structure. This structural improvement is the key reason the film is expected to gain the stiffness and density needed for effective radiation shielding.

4.2 Scanning Electron Microscopy (SEM)

The Scanning Electron Microscopy (SEM) analysis is expected to reveal how the incorporation of duck eggshell powder influences the microstructure of the biopolymer film. Based on the previous article of (Qiao et al., 2021), it is expected to present the surface and cross- sectional SEM micrographs of the control biopolymer film and the duck eggshell powder reinforced films prepared at different filler loadings. The control film without duck eggshell powder is expected to exhibit a smooth, compact, and continuous surface morphology, indicating a uniform polymer matrix without structural defects. Similar surface characteristics were reported by Sun et al., (2014) for pure cornstarch films, where the absence of eggshell powder resulted in a homogeneous structure without pores or cracks. This morphology serves as a baseline for evaluating the effect of duck eggshell powder incorporation.

Previous studies show that when a small amount of eggshell powder (about 2–3 wt.%) is added to polymer films, the particles can mix well with the polymer. It was found that films with 2 wt.% eggshell powder had smooth, even surfaces, but when the amount was increased to 3 wt.%, the surface became uneven because the particles did not bond as well to the polymer. In this study, duck eggshell powder is added in much higher amounts, from 10 to 50 wt.%, because a higher calcium carbonate ($CaCO_3$) content is needed for radiation shielding.

At lower filler contents of 10 and 20 wt.% duck eggshell powder, the SEM images are expected to show relatively smooth and compact surfaces with well-dispersed particles embedded within the biopolymer matrix. At these concentrations, the polymer matrix is still able to effectively bind and encapsulate the eggshell particles. The increased $CaCO_3$ content is expected to enhance particle packing and interfacial contact, resulting in a denser internal structure compared to the control film , which is beneficial for improving radiation attenuation performance.

As the filler content increases further to 30–50 wt.%, noticeable changes in surface morphology are expected, including increased roughness, particle agglomeration, and surface irregularities. These features indicate that particle which particle interactions begin to dominate over particle matrix bonding, limiting the ability of the polymer to maintain a uniform structure. Despite this structural degradation, the formation of $CaCO_3$ rich regions and increased material density is expected to enhance radiation shielding effectiveness (Ranganathan et al., 2020). Overall, the observed morphological evolution is expected to follow the same fundamental trend reported in previous studies, while extending it to higher filler loadings suitable for sustainable radiation protection materials.

4.3 UV-Vis Spectrophotometry

Researchers Fecheyr et al., (2017), reported that thin films prepared from ground chicken eggshell particles exhibited very low UV transmittance, with values below 10% across the UV region, indicating that most ultraviolet radiation was effectively blocked by the eggshell layer. This result suggests that eggshell particles are capable of significantly reducing UV penetration when formed into a continuous film. In the UV-Vis analysis, the eggshell-based films showed consistently low UV transmittance throughout the measured UV range, implying that ultraviolet radiation does not easily pass through the eggshell structure. The strong UV attenuation was attributed to the combined effects of light scattering and reflection caused by the irregular size and morphology of the eggshell particles, rather than selective chemical absorption. This indicates that eggshell waste can function as an effective physical UV barrier, making it suitable for radiation protection applications.

Therefore, in this study, it is expected that biopolymer films incorporated with duck eggshell waste will exhibit a similar UV-Vis behavior, characterized by low UV transmittance and enhanced UV-blocking performance. Although duck eggshells are used instead of chicken eggshells, both types share similar chemical composition and mineral structure, predominantly composed of $CaCO_3$ (Ajayan et al., 2020). As a result, the duck eggshell-based biopolymer films are anticipated to demonstrate effective UV radiation shielding, supporting their potential use as a sustainable and environmentally friendly radiation protection material.

5. CONCLUSION

The radiation shielding performance of the cornstarch-based biopolymer films reinforced with duck eggshell powder (DESP) is expected to improve with increasing filler content. This enhancement is attributed to the presence of calcium carbonate ($CaCO_3$) in duck eggshells, which possesses a higher effective atomic number and density compared to the biopolymer matrix. Polymer composites reinforced with inorganic fillers have been widely reported to exhibit superior attenuation of ionizing radiation compared to neat polymers due to increased photon–matter interaction probability

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