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Application Of Environmental Chicken Feather Waste to Biodegradable Films for Potential Industrial Uses

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Abstract- One of the aims of the Sustainable Development Goals (SDG) is to proffer solutions to the environmental problems through the conversion of waste products to useful materials that are environmentally friendly, and that could bring a clean and safe environment. Poultry feathers have constituted significant environmental problems, being non-biodegradable, and scholars have been saddled with the aim of converting this waste into biodegradable products. This study was aimed at extracting keratin from chicken feathers and using it as a constituent in the production of bioplastic film. Keratin extraction was performed according to Elemile et al. (2022), and bioplastic film production was performed according to the procedure of Sharma et al. (2018). Characterization of synthesized bioplastics were done using various spectroscopic techniques such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), Fourier transform infrared spectroscopy (FTIR), and energy-dispersive X-ray spectroscopy (EDX), The SEM image of bioplastic films indicated presence of rough, porous, interconnected surface morphology with micro-void and layered structure indicating strong compatibility and strong intermolecular interactions between keratin and cellulose while that of keratin showed rough, porous and agglomerated morphology. The FTIR spectra of bioplastic films indicated characteristic amide I and II bands, while that of keratin showed functional groups, such as hydrogen bonding, typical of proteins. The EDX result for bioplastic films showed better qualities when compared to the keratin. From the analysis, it can be concluded that the bioplastic film showed better properties, which can be useful in industrial applications.

Keywords: Keratin, Biofilms, Spectroscopic Techniques.

I. INTRODUCTION

Chicken feathers are known as one of the common wastes that are generated from the poultry industry, which provides huge quantities of protein supplements that are required in the human diet. Other forms of waste obtained from chicken include bone residues, blood, and fats. These resources are currently converted into meat and bone meal, feather meal, blood meal, and fats/oils by the rendering process (Lasekan et al. 2013). Approximately five million tons of feathers are produced per year in the world (Poole et al. 2009; Tesfaye et al. 2017), but most of them are dumped in landfills, or a smaller amount is used in low-value animal feedstock (Bertsch and Coello 2005; Reddy and Yang 2007). As well, a large dumping area is required, and they produce a higher portion of heavy metals, chemicals, and pathogens, which have detrimental effects on groundwater and the environment (Cavello et al. 2012; Sharma and Gupta 2016). Conversely, exploitation of this waste fraction as feed or fertilizer is reported in recent studies, but some challenges of high energy consumption during disposal or conversion remain unsolved (Brandelli et al. 2015).

This necessitates the use of feather biomass to generate valuable products for environmental protection. Feathers primarily consist of about 90% keratin, an insoluble fibrous protein with characteristic structural strength. It is among the most abundant forms of hard protein present in nature (Onifade et al. 1998; Reddy and Yang 2007) and rich in cysteine, arginine, threonine, and hydrophobic amino acids, with high nutrient potential (Tiwary and Gupta 2012). Feather keratin has also been studied to develop various valuable bio-based materials (Barone 2009; Barone & Schmidt 2005; Poole and Church 2011; Reddy & Yang 2007; Yin et al. 2013).

It contains β-sheet crystallites and is highly cross-linked by cysteine 7 mol % (Alickovic et al, 2021). One of the interesting uses of feather keratin is in eco-composites and bioplastics (Pillai & Thomas, 2023). The formulation of effectual approaches to successfully extract keratin while reducing alterations to the protein's secondary structure lingers as a significant challenge. Various chemical methods like reduction or oxidation (Moritz & Latshaw 2001; Schrooyen et al. 2001b; Yin et al. 2013), enzymatic (Eslahi et al. 2013; Mokrejs et al. 2010; Onifade et al. 1998), and reactions in ionic liquids were reported to dissolve the hard keratin (Ji et al. 2014; Wang &Cao 2012).

There are several effective methods for the conversion of different biomass, like human hair, wool, and the production of value-added biomaterial for application in different sectors like tissue engineering (Lee et al. 2015). In some previous studies, keratin from different sources was used to manipulate the properties of different products, such as the fabrication of chitosan membranes to increase the wettability and tensile strength for biomedical applications (Mai et al 2017). Similarly, hydrolyzed keratin was used to modify the soy protein film with improved physicochemical properties (Garrido et al. 2018). Furthermore, in a recent study, blend modification of feather keratin-based films using sodium alginate was investigated, which expands the application in biomedical industries (He et al. 2017).

Due to the reported loss of one-third of the total plastic packaging into the environment. Researchers have been seeking a suitable alternative to petroleum-based plastics. In addition, the critical environmental problem of daily food loss and food waste, as estimated by the Food and Agriculture Organization (FAO), corresponds to 1.3 billion tons per year (Reddy & Yang, 2007). Scientists have considered combining food loss and food waste with the necessity to find a suitable alternative to petroleum-based plastics. Thus, giving rise to the development of bioplastics as a means of tackling both petroleum-based plastics and food waste/loss (Akinnawo 2024, and Reddy & Yang 2007). The huge volSume of chicken waste obtained as wastes from the poultry industry is an environmental nuisance to the general public; whereas Petroleum-based plastics are non-biodegradable and constituent nuisance to the environment; the environmental factors breakdown petroleum-based plastics to micro plastics which have been detected in human body, thus constituting life-threatening danger to humans as well as other living organisms; with this it is justifiable to convert chicken feathers (animal waste) to biodegradable plastics for diverse applications.

This study focused on the preparation and characterization of a bioplastic film derived from a blend of chicken feather-based keratin and cellulose. The physical and chemical properties of the extracted keratin and bioplastic film were investigated using instrumental methods of analysis.

II. MATERIALS AND METHODS

Production of chicken feather keratin

Raw chicken feathers (CFs) were obtained from a chicken processing plant in Ikere-Ekiti, Ekiti State, Nigeria. Before use, the feathers were washed with detergent to remove dirt and rinsed several times in running tap water to remove any trace of detergent, before further rinsing with deionized water. The clean feathers were then left to dry at room temperature for 7 days.

Hydrolysis of CFS and precipitation were carried out following the procedure as reported by Elemile et al. (2022). Chicken feather was hydrolyzed using a 1M NaOH solution. For hydrolysis, 1000 g of the clean dry CFs was weighed into a plastic bucket, and 2 L of the NaOH solution was added and allowed to react for 24 h, with intermittent stirring to mix every 1 h. The hydrolyzed feather fraction was separated from the unhydrolyzed fraction by sieving through a 1 mm plastic sieve (Elemile et al, 2022)

To precipitate the feather keratin from the hydrolyzed fraction, 10 % (w/w) of 35% HCl solution was added to the hydrolyzed CFs and gently stirred to allow for homogeneous mixing. The slurry was then left for 30 min for activation to take place and washed multiple times to remove the excess hydrochloric acid. The mixture was filtered using a Muslin cloth, and the filtrate (referred to as keratin) was dried in an air-dry at room temperature until constant weight (Elemile et al., 2022).

Production of keratin-cellulose biolistic film

Keratin-cellulose bioplastic film according to the procedure described by Sharma and Gupta (2016).

For production, 250 mg of the extracted dried keratin was dissolved in 5 mL of 2 M NaOH under vigorous agitation (300 rpm) at a temperature of 45 °C. After agitation, the mixture was poured into a 10 cm petri plate that had been greased with a greasing agent (3.5% glycerol and 0.2% microcrystalline cellulose in NaOH, and then the prepared bioplastic film was dried in an oven at 60 °C for a duration of 48 h. The thickness of the biofilm was measured using a micrometer, but the thickness of the biofilm can be varied using different quantities of keratin. The obtained biofilm was separated from the petri plate and stored. (Sharma et al., 2018).

Characterization of keratin and keratin-cellulose bioplastic film

Scanning Electron Microscopy and TEM

The surface and internal morphology of dried keratin and bioplastic film obtained was analyzed by Ziess EVO 50 scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

Fourier transform infrared (FTIR) spectroscopy

Chemical characterization of the keratin and bioplastic film extracted was done by using Fourier transform infrared (FTIR) spectroscopy with a Thermo Scientific Nicolet iS50.

Energy Dispersive X-Ray (EDX)

Analysis was carried out to determine the elemental composition of the extracted keratin and the developed keratin-based bioplastic film.

III. RESULTS

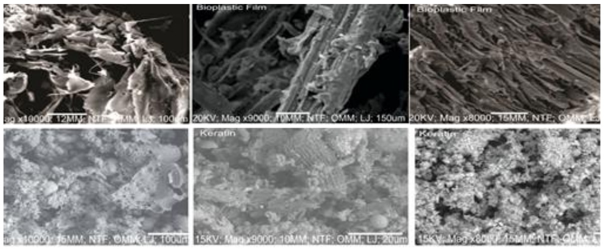

Fig. 1: Scanning electron microscope (SEM) image of the biofilm and keratin

The SEM micrographs of the keratin–cellulose bioplastic film revealed a heterogeneous but interconnected surface morphology. The micrographs showed a rough, interconnected surface with micro-voids and layered structures, indicating good compatibility and strong intermolecular interactions between keratin and cellulose. In addition, the image shows a continuous matrix with interlinked domains, indicating successful film formation, which is typical of hydrogen bonding interactions between keratin functional groups (–NH, –CO) and cellulose hydroxyl groups (–OH). The dark regions correspond to micro-voids or pores, likely formed during solvent evaporation and drying. However, no distinct or isolated phases of keratin or cellulose are observed, which is an indication of good compatibility and homogeneous dispersion of keratin within the cellulose matrix. (Fig 1).

For the keratin, the SEM micrograph showed rough, porous, and agglomerated morphology with granular domains, indicating possible disruption of the native feather structure and successful keratin extraction. The keratin surface is characterized by numerous micro-pores and voids, visible as darker regions distributed across the image. In addition, keratin appears as clustered, granular domains rather than a continuous film. Also, the keratin typography showed a non-uniform surface texture that reflects heterogeneous particle sizes and random aggregation. Compared to the extracted keratin, the bioplastic film exhibits a more compact, continuous, and homogeneous morphology, indicating improved structural integrity and stronger intermolecular interactions upon blending. Unlike the bioplastic film, no smooth or continuous matrix is observed, confirming that the pure keratin lacks inherent film-forming ability without blending or plasticization (Fig. 1). The TEM image of the biofilm showed a heterogeneous microstructure with irregular dark clusters embedded in a lighter, spongy matrix, consistent with keratin proteins cross-linked with cellulose in bioplastic films. The presence of pores and channels suggests good interconnectivity, which enhances properties like flexibility and water permeability in such materials. The observed granularity matches reports of well-dispersed keratin in cellulose matrices, confirming successful blending without phase separation. This morphology supports applications in packaging or biomedical films, where nanoscale porosity aids biodegradability (Fig. 2).

The TEM image of the pure keratin revealed aggregated nanoparticles or fibrillar clusters with sizes ranging from 8 to 13 nm, as annotated. The granular, clustered appearance reflects the hierarchical structure of β-keratin, consisting of fine microfibrils (around 3 nm diameter) embedded in a protein matrix. The presence of dark, electron-dense regions indicates densely packed keratin domains or stained microfibrils, while the lighter areas are suggestive of amorphous matrix or voids between aggregates. The measured particle sizes (e.g., 8.5 nm, 10.5 nm) aligned with nano-scale keratin filaments or protofibrils, which are typical in feather keratin. Comparatively, unlike the more porous, network-like structure observed for the biofilm, the pure keratin showed tighter clustering and less interconnectivity, highlighting cellulose's role in expanding matrix voids during blending. (Fig. 2).

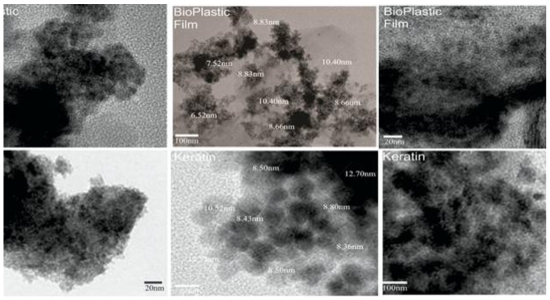

Fig. 2: Transmission electron microscope (TEM) image of the biofilm and keratin

Energy dispersive X-ray spectrums

The EDX spectrum showed carbon (50.75 wt %) as the major component of the biofilm, with oxygen (14.9 wt %), which supports the carbonyl, hydroxyl, and amide groups essential for hydrogen bonding in the film. Other elemental compositions include magnesium (1.67 wt%), calcium (2.05 wt%), sodium (3.68 wt%), aluminum, potassium (2.13 wt.%), iron (3.68 wt.%), and sulfur (3.60 wt%). For the pure keratin, the EDX spectrum revealed the presence of silicon (60.23 wt. %), oxygen (10.85 wt %), and aluminum (8.10 wt. %) as the most dominant elements. Other elements, such as magnesium, carbon, calcium, iron, sulphur, sodium, and potassium were present as 4.52, 3.85, 2.68, 3.92, 1.69, 1.06, and 1.12 wt.%, respectively (Fig. 3)

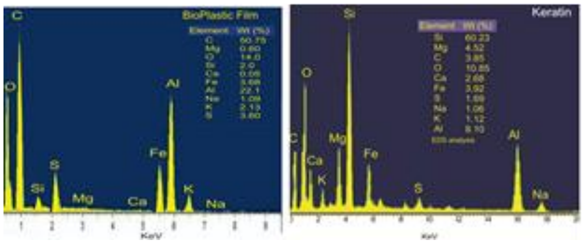

Fig. 3: EDX spectrum of the biofilm and keratin

The FTIR analysis of the keratin and bioplastic revealed the presence of amide bands (1650 and 1540 cm⁻¹), indicating protein content in both samples. In the keratin, stronger amide and N–H/O–H signals, consistent with its protein-rich nature, while the bioplastic film revealed broader O–H and C–O bands, suggesting a polysaccharide or glycerol-based structure, typical of starch-based bioplastics. The FTIR analysis of the keratin and bioplastic revealed the presence of amide bands (1650 and 1540 cm⁻¹), indicating protein content in both samples. In the keratin, stronger amide and N–H/O–H signals, consistent with its protein-rich nature, while the bioplastic film revealed broader O–H and C–O bands, suggesting a polysaccharide or glycerol-based structure, typical of starch-based bioplastics (Table 1).

Table 1: FTIR functional groups of the keratin and bioplastic film Keratin

Wavenumber (cm⁻¹)	Functional Group / Vibration	Interpretation
Keratin		
3292.54	N–H or O–H stretching	Hydrogen bonding is typical of proteins
2959.34 – 2877.60	C–H stretching	Aliphatic chains (CH_3, CH_2)
1744.91	C=O stretching	Carbonyl group (possibly from amide or ester)
1635.43	Amide I (C=O stretch)	Protein backbone (α-helix or β-sheet)
1541.23	Amide II (N–H bend, C–N stretch)	Confirms protein structure

1231.41	Amide III	Complex protein vibrations
772.84 – 355.47	Fingerprint region	Unique to keratin structure(Zhang *et al.*, 2021)
Bioplastic		
3292.54	N–H or O–H stretching	Hydrogen bonding is typical of proteins
2959.34 – 2877.60	C–H stretching	Aliphatic chains (CH_3, CH_2)
1744.91	C=O stretching	Carbonyl group (possibly from amide or ester)
1635.43	Amide I (C=O stretch)	Protein backbone (α-helix or β-sheet)
1541.23	Amide II (N–H bend, C–N stretch)	Confirms protein structure
1231.41	Amide III	Complex protein vibrations
772.84 – 355.47	Fingerprint region	Unique to keratin structure (Shavandi *et al.*, 2017).

IV. DISCUSSION

This study reveals keratin extraction from chicken feathers and its utilization in the production of keratin–cellulose bioplastic films. Results from keratin extraction efficiency and composition showed an extraction yield of 80% under alkaline hydrolysis. This is an indication that alkaline hydrolysis was effective in the disruption of the highly cross-linked β-keratin structure. The presence of high cysteine and extensive disulfide bonding is reported to confer mechanical rigidity and resistance to degradation in feather keratin (Shavandi et al., 2017; Wang et al., 2022). The observed sulfur content (2.7%) in the extracted keratin in this study confirmed the likely presence of cysteine-rich domains, which are known to characterize hard keratins. Aluigi et al. (2018) have reported similar sulfur ranges in feather-derived keratin.

The surface morphology revealed by the SEM micrographs showed the presence of distinct morphological transformation from the granular, porous structure of extracted keratin to the compact, continuous morphology of the keratin–cellulose bioplastic film. In the pure keratin, agglomerated particles with micro-voids, reflecting disruption of native feather architecture, were observed. The morphology of the pure keratin is consistent with earlier studies that have reported fragmented, irregular keratin particles following alkaline hydrolysis (Shavandi et al., 2017). However, the keratin–cellulose film showed a more homogeneous and interconnected structure that was devoid of clear phase separation. This is an indication of the presence of strong intermolecular interactions, mostly hydrogen bonding between keratin amide groups and cellulose hydroxyl groups. Zhang et al. (2021) have reported observation of similar morphological compatibility in protein–polysaccharide blends, where hydrogen bonding enhances structural integrity and mechanical cohesion in related studies. In the case of the TEM analysis, a nanoscale dispersion of keratin particles was revealed within the cellulose matrix. The revealed 8–13 nm keratin aggregates correspond to protofibrillar dimensions reported for β-keratin microfibrils. The higher porosity in the blended film could suggest that cellulose can serve as a structural scaffold that improves interconnectivity and potentially enhances flexibility and biodegradability (Zhang et al., 2021).

The EDX spectrum of the blended film showed that carbon and oxygen are present as dominant elements, which is consistent with materials that are protein and polysaccharide-based. The detection of sulfur showed the presence of keratin-derived cysteine residues, while the presence of minor elements (Ca, Mg, K, and Na) could be due to processing chemicals or residual mineral content.

The FTIR analysis and chemical interactions showed the preservation of characteristic protein amide bands, which is an indication of retention of secondary structure after extraction of the keratin. The observed broad peak of O–H/N–H stretching band near 3292 cm^{-1} in both keratin and the bioplastic film is an indication of extensive hydrogen bonding. As observed in the bioplastic film, the broadening and intensity changes in O–H and C–O stretching regions may be possible interactions between keratin and cellulose, which are commonly reported in protein–polysaccharide composites and are indicative of intermolecular bonding rather than simple physical mixing (Zhang et al., 2021; Shavandi et al., 2017).

V. CONCLUSION

Overall, the results confirm that alkaline hydrolysis effectively extracts high-yield keratin while preserving functional groups. The extracted keratin alone exhibits poor film-forming ability but blends successfully with cellulose. Also, hydrogen bonding is the dominant interaction mechanism in the composite film, while thermal stability and structural homogeneity improve upon blending. The produced keratin–cellulose bioplastic shows promising characteristics for sustainable packaging applications. The findings highlight the potential of chicken feather-derived keratin as a sustainable raw material for biodegradable bioplastic production. The produced biofilm presents a promising eco-friendly alternative to conventional petroleum-based plastics, thus contributing to waste valorization and circular bioeconomy initiatives.

Author contributions statement

The main author conceptualized the study, carried out a literature review, was involved in laboratory analysis, analyzed the data, and wrote the manuscript's first draft. Co-authors: 'EA' supervised the study, analyzed the data, and contributed to the manuscript first draft; ‘OTO’ co-supervised the study, carried out data analysis, and contributed to the manuscript first. All authors approved the final draft of the manuscript before submission.

Competing interests

The authors have no competing interest(s).

Data Availability Statement

All data were obtained from the results of characterization and are available upon request

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