

Utilisation of Carboxymethyl Cellulose from Sugarcane Bagasse to Improve Physicochemical Properties of Fish Gelatine Based Films

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In this study, carboxymethyl cellulose was prepared from sugarcane bagasse (CMC SB) using alkalisation and etherification methods, and CMC SB was utilised to enhance the physicochemical properties of fish gelatine (FG) based films. Three volume ratios of FG:CMC SB blends, namely 90 FG:10 CMC SB, 70 FG:30 CMC SB and 50 FG:50 CMC SB were set to fabricate the biofilms. All components were mixed and degassed before casting and drying at 50 °C in an oven for 24 h. Incorporation of CMC SB into FG based films increased the elongation at break (EAB) and tensile strength (TS) values from 15.28 ± 1.02 MPa and $38.44 \pm 1.73\%$ (pure FG) to 16.79 ± 1.28 MPa and $43.36 \pm 2.17\%$ (50 FG:50 CMC SB), respectively. The interaction between the -OH groups of FG and the COO- groups of CMC SB was revealed by FTIR analysis. FESEM analysis showed that films with lower CMC SB concentrations exhibited a relatively homogeneous cross-sectional morphology, whereas higher CMC SB concentrations resulted in phase separation and heterogeneous structures. The films were degradable under simulated compost environmental conditions. In summary, FG:CMC SB films are potential candidate for environmental friendly food packaging materials.

Keywords: Biofilm, carboxymethyl cellulose, fish gelatine, food packaging, sugarcane bagasse

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Over the last few decades, the food industry's packaging utilisation has increased exponentially, driven by consumer demand for more durable, convenient products and safer. The food sector is estimated to consume more than 40% of all packaging materials used worldwide [1], demonstrating this element's significance in the food value chain. Millions of tonnes of synthetic plastic film derived from petroleum are used for a variety of purposes, particularly in the food packaging sector. Plastic packaging materials have been exploited and are accumulating in the environment at a very worrying rate. As an alternative to lessen environmental impact, environmentally friendly plastic food packaging has been proposed as a viable alternative to address this issue [2, 3]. Bio-based active packaging is a suitable candidate to replace synthetic plastics because it is non-toxic, versatility, low cost and environmental friendliness [4, 5].

Natural polymers such as proteins, lipids, and polysaccharides are significant constituents as raw materials for development of bioactive packaging

films [6, 7, 8]. Gelatine is a protein-derived biomaterial that is often used in the preparation of films as food packaging materials. This is due to its exceptional characteristics and film-forming ability, and versatility as well as low cost. Furthermore, gelatine is a renewable, edible, and biodegradable material that can be combined with bioactive substances to produce functional packaging films [9, 10, 11]. In general, gelatine film had substantial water absorption due to the presence of numerous hydrophilic groups, which may have weakened the film's mechanical characteristics and water vapour transfer. As a result, combining gelatine with other biopolymers including cellulose, chitosan and gum is a possible solution to eliminate the inadequacies of gelatine-based films [12, 13].

Carboxymethyl cellulose (CMC), a valuable cellulose derivative, is widely used in a variety of industries, including pharmaceutical, food exploration, paper, plastics, textile, paint, biomedical, construction, cosmetics, and oil, due to its superior film formability, high viscosity, good gas barrier

properties, biocompatibility, and stable internal network structure [9-16]. CMC is a water-soluble anionic derivative of cellulose, a linear polysaccharide composed of anhydro glucose units connected by β -1,4-glycosidic linkages. The primary molecular distinction between cellulose and CMC is that in the CMC structure, some anionic carboxymethyl groups (such as $-\text{CH}_2\text{COOH}$) replace the hydrogen atoms from some hydroxyl groups found in pure cellulose [17].

Sugarcane bagasse, a by-product of sugar production after extracting juice from sugarcane, is abundant throughout Asia and has the potential to be turned into value-added products. Sugarcane bagasse is a lignocellulosic substance that principally contains cellulose, hemicellulose, and lignin [18, 19]. As a result, it has the potential to be used as a raw material in the manufacture of a wide range of products via various conversion processes. Sugarcane bagasse can be converted into biopolymers or polymer derivatives. Kossalbayev et al. [20] emphasise the importance of research into a biodegradable composite made of cellulose and natural resins, which exhibits favourable mechanical properties and significant degradation under soil conditions, indicating its potential as a rigid packaging material with low environmental impact.

The creation of active packaging, which is thought to be one of the most effective methods for increasing the shelf life and enhancing the safety of packaged food items, is currently the subject of research. In order to produce active food packaging films, this study aims to explore unique alternative raw materials. Materials intended for food-packaging applications must exhibit adequate mechanical and thermal properties, effective barrier performance against gases, and sufficient optical transparency [21, 22, 23]. The current study aimed to assess the visibility of FG:CMC SB blend films as viable biodegradable materials for active food packaging applications.

EXPERIMENTAL

Chemicals and Materials

Fish gelatine (FG) with a bloom value of around 210 g and a mesh size of 20 was obtained from Malaysia's Halal Gelatine Hub. The method reported by Yaradoddi et al. [24] was used to produce carboxymethyl cellulose from sugarcane bagasse (CMC SB) with minor modifications. Glycerol with a purity of $\geq 99.0\%$ (Product No. G7757) was purchased from Sigma-Aldrich.

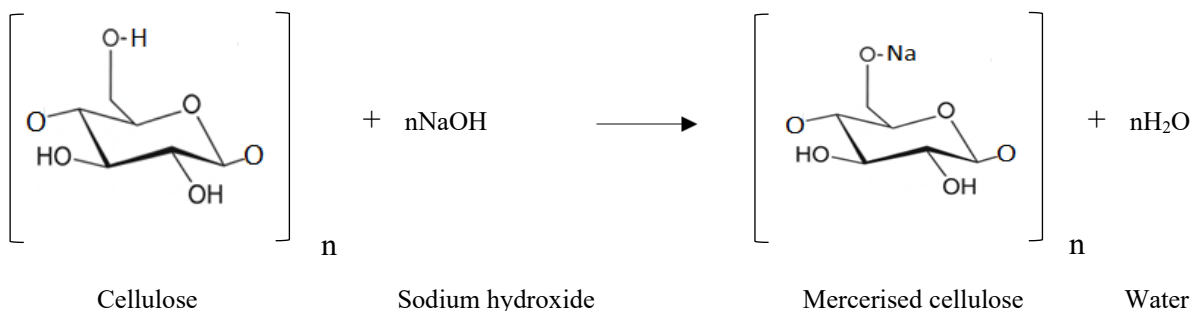
Preparation of Carboxymethyl Cellulose (CMC) from Sugarcane Bagasse (SB)

Cellulose Extraction from SB

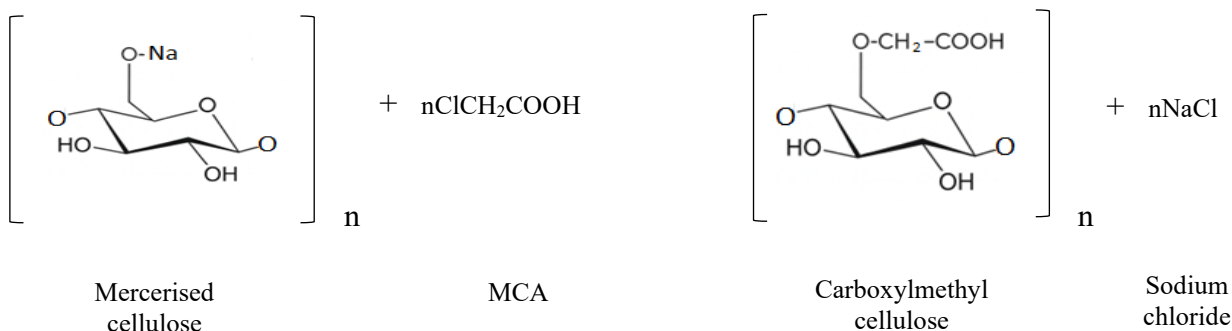
The overall procedure for cellulose extraction from sugarcane bagasse and its subsequent conversion into CMC is illustrated in Figures 1 and 2. Specifically, the schematic mechanism on producing CMC from cellulose is presented in Figure 1. Figure 2 illustrates schematic representation of the cellulose extraction from raw sugarcane bagasse. SB was cut into 1 to 2 cm little pieces. The SB pieces were weighed and dried at 80°C for 16 h. After the incubation period, the SB pieces were ground with a laboratory grinder. The 500 g SB was treated with 1000 mL of 0.5% (v/v) acetic acid and 1.0% (v/v) sodium chlorite for lignin removal and acid hydrolysis. Acid hydrolysis eliminates the imperfect crystalline structure and improves its purity. The mixture was heated in a water bath at 80°C for 2 h. At this stage, the appearance of SB changed from dark brown to light brown. The ground SB was filtered through a 0.5 mm diameter laboratory mesh. The cellulose pulp was rinsed with deionised water until a neutral pH was obtained. Then, the pulp was dried at 80°C to constant mass. The moisture content of SB was calculated as shown in Equation (1), and the moisture content of the pulp obtained was nearly 6.0% .

$$\text{Moisture content (\%)} = \frac{\text{Wet weight (g)} - \text{dry weight (g)}}{\text{Dry weight (g)}} \times 100 \quad (1)$$

Step 1: Alkalisiation



Step 2: Etherification



Side Reaction:



Figure 1. Schematic mechanism for the production of CMC from cellulose.

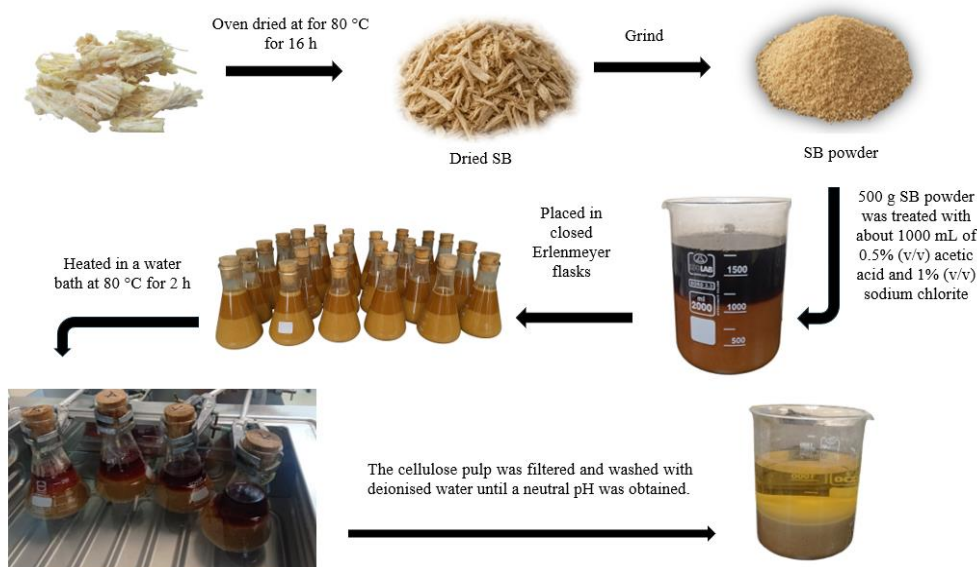


Figure 2. Schematic representation of the cellulose extraction from raw sugarcane bagasse.

Conversion of Cellulose from SB to CMCs

The conversion of cellulose from SB into CMC involves two primary steps, namely alkalisation and etherification, as illustrated in Figure 3. Maceration improves cellulose integrity and gives it a more radiant appearance. 400 mL of isopropanol and 100 mL of 30% (w/v) sodium hydroxide solution were used to soak the sugarcane cellulose pulp. To alkalisate the cellulose, the sample combination was incubated for approximately 1 h at 60 °C in a water bath. The fat body and exterior matter were removed using a high concentration of NaOH, giving SB a softer texture

without causing any damage. The production of CMC involves conversion of hydroxyl (-OH) group into ether (-CH₂COO-) group, and this process is known as etherification. Monochloroacetic acid (MCC) was added concurrently with the etherification process, and the reaction was maintained at 60 °C for over 3 h to create the dual phases. The lower solid phase was transferred to 70% (v/v) methanol and neutralised with acetic acid. To desalinate it from the side reaction, 70% (v/v) ethanol was used. After another methanol wash, it was let to dry overnight at 60 °C. Equation (2) was used to calculate CMC yield after weighing the samples.

$$\text{Yield of CMC (\%)} = \frac{\text{Weight of CMC (g)}}{\text{Weight of cellulose (g)}} \times 100 \quad (2)$$

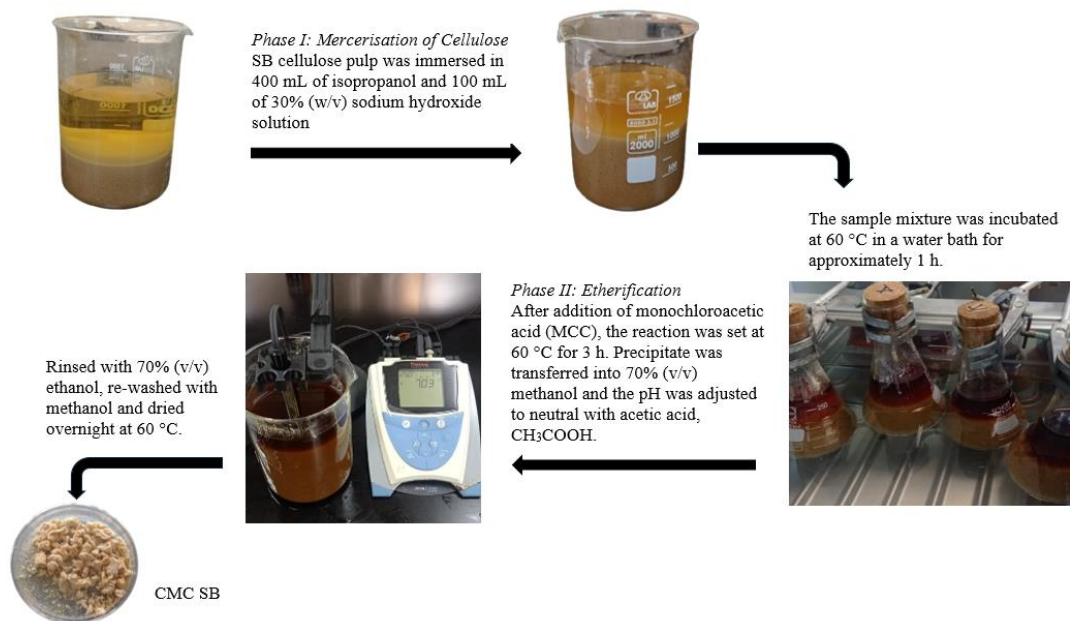


Figure 3. Schematic representation of the conversion of cellulose from SB to CMCs.

Preparation of Films

The film production procedure employed in this investigation was based on the methods of Khodaei et al. [25] with certain adjustments to improve film uniformity, structural integrity, and nanoparticle dispersion. Fish gelatine (FG) and carboxymethyl cellulose made from sugarcane bagasse were combined to create a binary composite that substituted the original process's combination of gelatine, gum tragacanth, and pectin polymer. FG:CMC SB ratios of 90:10, 70:30, and 50:50 (v/v) were used to create film-forming solutions (FFS). Before mixing, the CMC SB was centrifuged at 4,000 rpm for 10 mins at 25 °C to ensure complete homogeneity and the removal of insoluble residues. To remove any trapped air bubbles, the resultant mixtures were vacuum degassed for 20 mins after being homogenised for 10 mins using an ultrasonic processor (500 W, 20 kHz, pulse mode: 11 s on/2 s off). The films were cast into petri dishes and dried for 24 h at 50 °C to encourage uniform solvent evaporation and improve film uniformity, as reported by Khodaei et al. [25].

Preparation of FG:CMC SB Blended Films

FG Solution Preparation

IKA C-MAG HS 7 magnetic stirrer was used to suspend precisely 3.0 g of FG in 100 mL of deionised water and agitate it for 1 h at 750 rpm. After that, the suspension was magnetically whirled for a further hour while maintaining a constant temperature of 50 °C.

Carboxymethyl Cellulose Sugarcane Bagasse (CMC SB) Solution Preparation

A 3.0 g quantity of CMC SB was distributed in 100 mL of deionized water. To ensure full disintegration, the resultant suspension was stirred above at ambient temperature for 1 h. The mixture was then centrifuged for 10 mins at 4,000 rpm using a Hettich Rotofix 32A centrifuge.

FG:CMC SB FFS Preparation

Different FG:CMC SB volume ratios, namely 90 FG:10 CMC SB, 70 FG:30 CMC SB, and 50 FG:50 CMC SB, were combined to make FFS. After that, 1.5 mL of glycerol solution was added into the mixtures to act as a plasticiser. The FFS was agitated on a hot plate for another hour to ensure uniformity. A Smart Ultrasonic Processor (Nanjing Genchen Scientific Instrument Co., Ltd.) with a titanium probe running at 500 W and 20 kHz in pulse mode was then used to homogenise it. In order to prevent overheating and ensure even dispersion of the nanofillers, the mode was programmed to be active for 11 s, interspersed with a 2 s pause every 10 mins. The FFS samples were vacuum desiccated for 20 mins at reduced pressure in order to remove dissolved gases. Additionally, pure gelatine films were created as a control.

Casting

Each 20 mL aliquot of FFS was gently pipetted into a 150 mL petri dish. The FFS solution was placed in a forced convection oven for 24 h at 50 °C for isothermal treatment. The resulting clear coatings were manually

removed after drying [25]. The films were then stored in a desiccator to retain their hygroscopic stability until further analysis.

Characterisation of Films

This study examined the physicochemical properties of all biopolymer films. The samples were analysed in triplicate, and the results are displayed as mean $\pm$ standard deviation (SD).

Thickness

Film specimens with a flat surface, uniform texture and consistent nominal thickness were selected. The film was divided into strips measuring 15 mm wide and 80 mm long. The thickness of each resulting strip was measured using an INSIZE 1108-150 Digital Calliper. Three discrete measurements were made at randomly selected positions along each strip to obtain a statistically robust average.

Elongation at break (EAB) and Tensile Strength (TS) Analyses

The average cross-sectional area was calculated by cutting the biopolymer film into 50 mm $\times$ 10 mm strips and measuring their thickness at three different places. The films' elongation at break (EAB) and tensile strength (TS) were measured using an Instron 5967 Universal Testing Machine with a 1 kN load cell, flat pneumatic grips set at a distance of 30 mm, and a preload of 0.1 N, in accordance with ASTM D822 Standard Test. EAB was estimated as the percentage increase in gauge length from 30 mm to the length at which the film failed. TS was computed by dividing the peak force at break by the beginning cross-sectional area.

Water Vapour Permeability (WVP) and Oxygen Permeability (OP) Analyses

The barrier viability of the biopolymer films for packaging applications was demonstrated through water vapour permeability (WVP) and oxygen permeability (OP) measurements. WVP was determined in accordance with ASTM E96-2016 standards using Equation (3):

$$WVP = \frac{WVTR}{\Delta p} \times \ell \quad (3)$$

where Δp is partial water vapour pressure difference across the film, ℓ is the film thickness, and WVTR is the water vapour transmission rate, calculated via Equation (4):

$$WVTR = \frac{\Delta m}{t \cdot A} \quad (4)$$

In Equation (4), Δm represents the mass change over time t , and A is the exposed film

surface area. Oxygen permeability (OP) was evaluated according to ASTM D3985 using a coulometric sensor-based Oxygen Permeability Analyzer (Systech Illinois 8501). OP was computed using Equation (5):

$$OP = \frac{OTR \times \ell}{\Delta p} \quad (5)$$

where OTR represents the oxygen transmission rate, expressed in $\text{cm}^3 \text{m}^{-2} \text{day}^{-1} \text{atm}^{-1}$. The expression comprises ℓ (film thickness), Δp (oxygen partial pressure in kPa across the film), and OTR (oxygen transmission rate).

Transparency Properties

The transparency of the samples was determined by collecting opacity data at 600 nm with an Agilent Cary 60 UV-Visible Spectrophotometer. The films were assessed at wavelengths ranging from 200 to 800 nm. Equation (6) formulated by Han and Floros [26] was used to calculate the opacity values:

$$\text{Transparency} = \frac{A_{600}}{x} \quad (6)$$

Where A indicates the absorbance at 600 nm and x denotes the film samples' thickness (mm).

Morphology and Microstructures

Field emission scanning electron microscopy (FESEM) was used to characterise the surface morphology of the produced biopolymer films, with special emphasis on porosity and structural uniformity. Before imaging, a small layer of gold was applied to the samples to improve conductivity. Microscopic observations were made with a Hitachi SU8020 FESEM at 2.0 kV. The morphologies of FG and CMC SB films were assessed at a magnification of 25,000 $\times$.

Fourier Transform Infrared (FTIR) Spectroscopy

The chemical composition, intermolecular interactions, and functional features of the films were all determined using a Thermo Nicolet 6700 Fourier Transform Infrared Spectrometer. Infrared spectra were acquired between 4000-400 cm^{-1} , with a spectral resolution of 4 cm^{-1} and 32 scans each measurement.

Biodegradation by Soil Burial Testing

The physical degradation and weight loss of the FG:CMC SB films were assessed using a modified laboratory soil burial method based on previously described protocols [27, 28]. Because this screening test focused exclusively on gravimetric mass loss, a standardised respirometric method (e.g., ISO 17556) was not utilised. The soil burial test was carried out over 30 days at an ambient laboratory temperature averaging

28 ± 2 °C. The burial medium consisted of a commercial universal gardening and potting soil. Biopolymer film samples (approximately 38 mg) were buried at a depth of 5 cm in plastic pots containing 500 g of soil. To maintain uniform environmental conditions and minimise evaporation, the pots were kept in a climate-monitored, dark laboratory environment. Triplicate samples were retrieved on days 10, 20, and 30 for cleaning, desiccating, and subsequent weight measurement. The weight loss percentage was calculated using Equation (7).

$$\text{Weight loss (\%)} = \frac{\text{Initial weight (g)} - \text{Final weight (g)}}{\text{Initial weight (g)}} \times 100 \quad (7)$$

RESULTS AND DISCUSSION

Cellulose Extraction from Sugarcane Bagasse

In this work, the cellulose recovery from sugarcane bagasse reached 65.8%, indicating that the extraction technique was effective in isolating the polysaccharide fraction from the lignocellulosic matrix. Al-Rajabi et al. [29] reported that alkaline treatment reduced hemicellulose content from 28.0% to 8.0%, demonstrating its efficiency in disrupting the

lignocellulosic structure. Non-cellulosic components and contaminants such as hemicellulose, lignin, pectin, and wax are also removed during decolourisation [30, -32]. Sugarcane bagasse becomes shrunken and softened after being treated with alkali. The bleaching procedure for fibre tries to boost its whiteness by eliminating hemicellulose and lignin. The yield of a cellulose content of 65.8% from the raw SB, indicates that the pre-treatment and derivatisation methods used are effective in isolating cellulose and converting it to CMC. Compared to previous studies, the cellulose obtained is lower than the natural cellulose content of raw bagasse, which is usually reported as only 40–50% [33-35].

Converting Cellulose from SB to CMCs

The yield of carboxymethyl cellulose (CMC) was obtained as 108% of the cellulose mass extracted after etherification. Although values exceeding 100% may seem counterintuitive, they are frequently reported in CMC synthesis. This phenomenon arises because the incorporation of carboxymethyl substituents during etherification increases the molecular weight of the polymer, thus contributing additional mass to the final product [36-38].

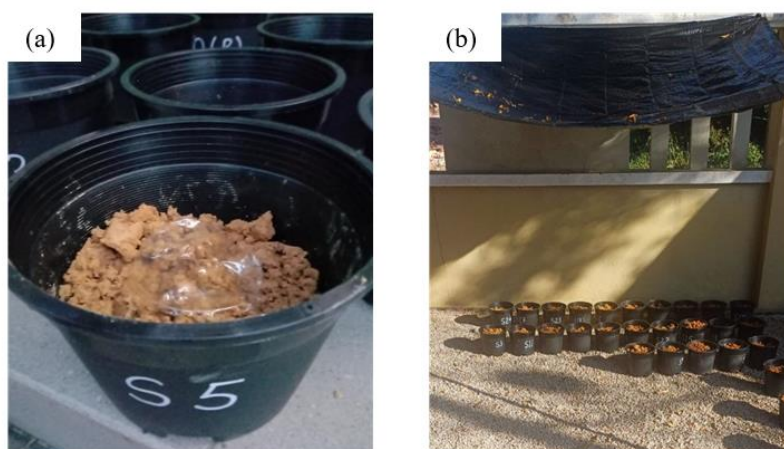


Figure 4. (a) FG:CMC SB biopolymer sheets were buried 5 cm below damp soil surface. (b) The pots containing the biopolymer films were placed under the shade to minimise direct sunlight exposure.

Table 1. Biocomposite films' mechanical characteristics.

Films	Thickness (mm)	Tensile Strength (MPa)	Elongation at Break (%)
Pure FG	0.12 ± 0.0102	15.28 ± 1.02	38.44 ± 1.73
(90 FG:10 CMC SB)	0.13 ± 0.0102	15.47 ± 1.19	38.93 ± 2.66
(70 FG:30 CMC SB)	0.14 ± 0.0063	16.05 ± 1.90	42.50 ± 2.95
(50 FG:50 CMC SB)	0.14 ± 0.0049	16.79 ± 1.28	43.36 ± 2.17

Characterisation of Films

Mechanical Properties

Before mechanical testing, the film thickness was measured and the results are shown in Table 1. Blending with CMC SB has increased the average thickness of the FG film to 0.13 ± 0.0102 mm, 0.14 ± 0.0063 mm, and 0.14 ± 0.0049 mm at the ratios of 90:10, 70:30, and 50:50, respectively. The film thickness was found to increase steadily with increasing CMC SB concentration. This indicated a consistent casting and good uniformity. When gelatine was incorporated into the CMC matrix, the resulting film became thicker, this change being due to the higher solids content. Méndez et al. [39] emphasised that high levels of CMC SB increased the uniformity and strengthened the film structure. The addition of FG, in turn, contributed to the thickness and thus increased the overall mass. This increase in thickness was not only explained by the higher solids content, but also by the stronger molecular interactions formed between FG and CMC SB [39]. Finally, the production of thicker films is associated with better water retention and greater solid deposition [40].

The inclusion of CMC SB considerably enhanced mechanical performance of FG-based films, as shown by the increase in TS and EAB values according to the addition of CMC SB composition. Pure FG films exhibited a TS of 15.28 ± 1.02 MPa and EAB of $38.44 \pm 1.73\%$, whereas the 50:50 FG:CMC SB combination had 16.79 ± 1.28 MPa and $43.36 \pm 2.17\%$, respectively. This increasing trend indicates that CMC SB contributes to a more cohesive and flexible matrix. This is most likely due to increased hydrogen bonding and increased polymer chain attachment. Tabari [41] reported a similar finding, of which gelatine films reinforced with CMC had higher mechanical integrity. This was due to greater intermolecular connectivity. Said and Sarbon [42] confirmed that polysaccharide-protein blends, especially those containing CMC, increased ductility and tensile strength. These properties are essential for packaging applications. Furthermore, Méndez et al. [39] demonstrated that the increment of CMC concentration not only increased the film strength but also promoted uniformity and water retention. This behavior suggests a potential plasticising effect during film formation. These findings highlight the synergistic interaction between FG and CMC

SB, resulting in biopolymer films with enhanced stretchability and mechanical strength.

Water Vapour Permeability (WVP) and Oxygen Permeability (OP) Analysis

The integration of CMC SB into FG-based films resulted in a considerable reduction in water vapour and oxygen permeability. As CMC SB content grew, WVP fell from 1.56 to $1.26 \text{ g m}^{-1} \text{ day}^{-1} \text{ atm}^{-1}$, and OP reduced from 1.28 to $1.01 \times 10^{-4} \text{ cm}^3 \text{ m}^{-2} \text{ day}^{-1} \text{ atm}^{-1}$. This improvement is attributed to the formation of a denser film matrix driven by hydrogen bonding and chain entanglement, which effectively reduces the free volume and creates tortuous diffusion pathways within the polymer matrix [10, 43]. Similar trends of enhanced barrier performance due to increased structural compactness and moisture retention in hydrocolloid-modified gelatine-CMC films have also been reported by Tran et al. [40] and Du et al. [43], further confirming the potential of this composite for food packaging and preservation applications.

Transparency Properties

Transparency and light transmission are two important aspects that have to be taken into account when preparing films for food packaging. Transparency studies of FG films showed a significant concentration-dependent drop in light transmission (Table 3), with pure FG having a value of 0.66 and falling to 0.61, 0.54, and 0.51 when 10, 30, and 50% CMC SB were added, respectively. CMC SB was found to have a significant impact on the optical properties of FG-based films. As the amount of CMC SB grew, light transmission in the UV and visible areas reduced, with transparency values dropping from 0.66 to 0.51. This trend indicates that CMC SB increased the UV resistance of the films although the optical clarity was found to decrease. Tran et al. [40] observed similar effects in gelatine/CMC films, including increased UV protection and decreased light penetration. Xu et al. [10] attributed these changes to higher matrix density and polymer interactions, while Du et al. [43] showed that such a blend is suitable for packaging relatively light-sensitive foods. These findings suggest the use of FG:CMC SB films as multifunctional packaging materials combining mechanical strength, optical protection and barrier performance.

Table 2. Water Vapour Permeability (WVP) and Oxygen Permeability (OP) values of biocomposite films.

Films	WVP (g m ⁻¹ day ⁻¹ atm ⁻¹)	OP × 10 ⁻⁴ (cm ³ m ⁻² day ⁻¹ atm ⁻¹)
Pure FG	1.56 ± 0.64	1.28 ± 0.30
(90 FG:10 CMC SB)	1.49 ± 0.26	1.22 ± 0.77
(70 FG:30 CMC SB)	1.35 ± 0.80	1.10 ± 0.54
(50 FG:50 CMC SB)	1.26 ± 0.32	1.01 ± 0.75

Table 3. Transparency and light transmission of biocomposite films.

Films	Transparency	Light transmission (%) at different wavelength (nm)						
		200	280	350	400	500	600	800
Pure FG	0.66	0.71	0.72	14.52	36.74	68.92	79.40	87.60
90 FG:10 CMC SB	0.61	1.32	2.84	18.42	44.26	69.20	79.32	88.50
70 FG:30 CMC SB	0.54	0.80	0.18	17.53	38.78	64.92	75.40	84.30
50 FG:50 CMC SB	0.51	0.72	1.48	14.92	34.66	58.20	71.68	78.96

Morphology and Microstructures

FESEM analysis demonstrated how the addition of CMC SB affected the microstructure of the FG films. Representative micrographs of biocomposite films at 25,000× are displayed in Figure 4. Consistent with previous reports by Ratna et al. [44], the pure FG films exhibited a relatively smooth, compact, and continuous surface structure with minimal visible defects, indicating the formation of a homogeneous gelatine matrix. The incorporation of CMC SB progressively altered the surface morphology of the FG films. The 90 FG:10 CMC SB film exhibited slight surface roughness accompanied by the presence of small microvoids, suggesting initial interactions between the gelatine matrix and CMC SB components. At a higher CMC SB ratio (70 FG:30 CMC SB), the film displayed microfibrillar features and more defined structural boundaries, indicating the development of a more complex polymer network due to the incorporation of cellulose-based components. Further increasing the CMC SB content to 50% resulted in

more pronounced phase separation, characterised by heterogeneous regions within the film matrix. This observation suggests reduced compatibility between FG and CMC SB at higher cellulose concentrations, leading to increased microstructural heterogeneity. Similar morphological changes have been reported in gelatine-CMC based films, where increasing CMC content contributed to enhanced surface roughness and structural irregularities due to differences in polymer chain organisation and intermolecular interactions [40]. Furthermore, Zafar et al. [45] and Méndez et al. [39] confirmed that the incorporation of CMC promoted the formation of microvoids and fibrillar structures. Therefore, while CMC SB contributes to the reinforcement of the FG matrix by improving mechanical properties, excessive CMC SB incorporation may reduce matrix uniformity and affect film homogeneity. Achieving an appropriate FG:CMC SB ratio is therefore essential to balance structural reinforcement and microstructural compatibility for optimal biocomposite film performance.

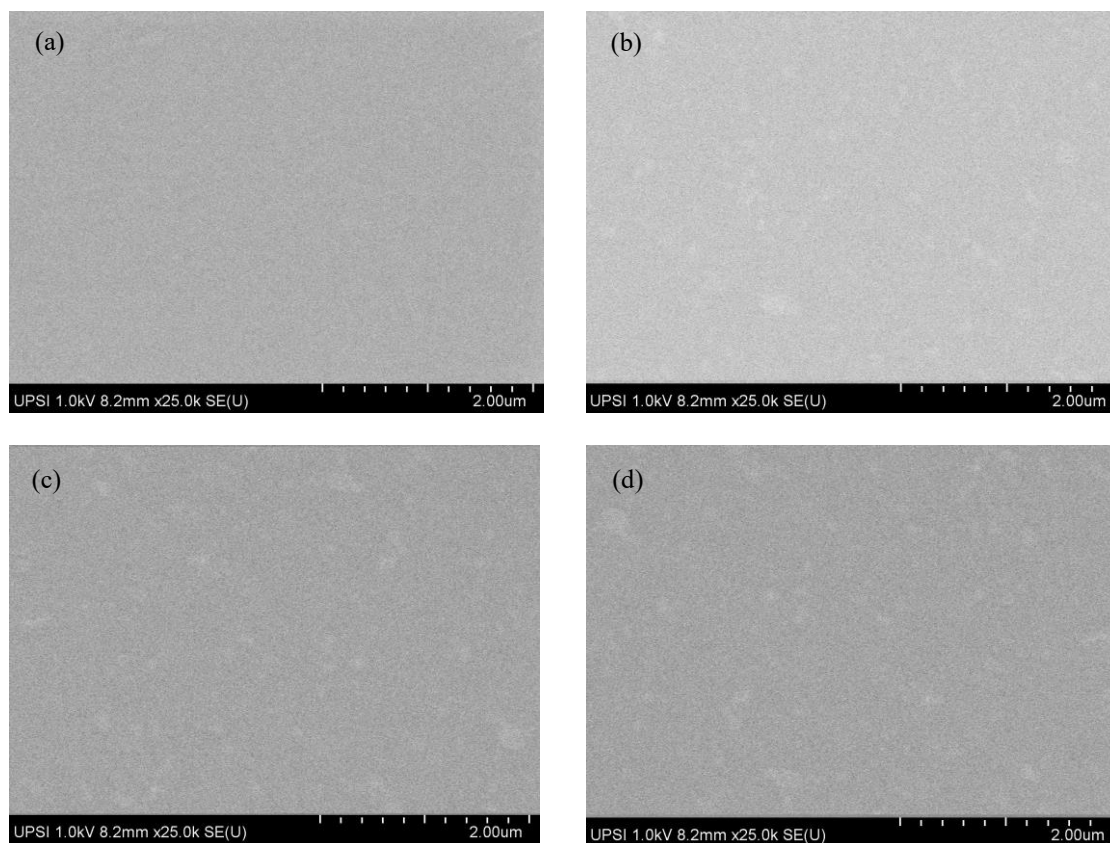


Figure 5. FESEM images of (a) Pure FG, (b) 90 FG:10 CMC SB, (c) 70 FG:30 CMC SB and (d) 50 FG:50 CMC SB at 25,000× magnification.

FTIR Analysis

FTIR spectroscopy was utilised to investigate the interactions of FG and CMC SB in biofilms. Figure 6 shows spectra obtained in the 4000–400 cm^{-1} region. All samples exhibited different absorption bands that corresponded to the functional groups found in the constituent biopolymers. The FTIR spectra of FG-CMC SB blended biofilms demonstrate molecular compatibility and progressive structural alteration as CMC SB content increases. The spectrum development over samples (a), (b), (c) and (d) revealed how hydrogen bonding, electrostatic interactions, and conformational rearrangements to construct a coherent biopolymer network.

The broad band at 3282 cm^{-1} , assigned to O–H and N–H stretching, is most intense in pure gelatine, reflecting abundant free hydroxyl and amine groups. With more incorporation of CMC, this band narrows and changes. This indicates stronger hydrogen bonding between the amino groups of gelatine and the hydroxyl/carboxyl functions of CMC. Such spectral behaviour has been observed in gelatine-CMC edible films modified with hydrocolloids,

where the hydrogen bonding increases. This addition increases the stability of the film while reducing water solubility.

It was found that, in higher addition of CMC SB blend, the 2937 cm^{-1} band (C–H stretching) showed lower intensity. This indicated limited chain mobility due to higher crosslink density. This result is in line with the conclusions of Zafar et al. [45], who reported similar attenuation in CMC-gelatine hydrogels loaded. This can be attributed to the denser polymer network. The amide I band at 1635 cm^{-1} broadened and shifted in the blend film. This revealed an electrostatic contact between gelatine's carbonyl group and the carboxyl group of CMC. Such structural alterations were also discovered, agreeing with the findings of Ratna et al. [44], who found similar FTIR shifts in antioxidant gelatine-CMC films containing plant extracts.

The 1404 cm^{-1} band, which corresponds to the COO^- symmetric stretching, strengthens with a larger CMC SB ratio. This indicates the effective integration of carboxymethyl groups. Similarly, the 1035 cm^{-1} peak, which is associated with C–O–C and C–O stretching, becomes more pronounced in the CMC

SB-rich film, indicating the role of the polysaccharide backbone. This spectral pattern correlates with the improved barrier and mechanical performance. Tran et al. [40] showed that such spectral features in gelatine-CMC edible films are associated with increased water resistance and film stability. This confirms the role of COO^- and C-O-C in network cohesion. Ratna et al. [44] further stated that the growth of COO^- and C-O stretching bands in gelatine-CMC films incorporated with plant extracts was associated with increased antioxidant and structural strengthening. Collectively, these studies confirm that the spectral evolution at 1404 and 1035 cm^{-1} is a reliable indicator of successful CMC incorporation. This composite has led to improved functionality in blended biopolymer films.

Among the ratios studied, the 50 FG:CMC SB blend (Figure 5d)) was found to have the most pronounced spectral shifts, indicating excellent molecular integration and synergistic interactions. This balanced composition promotes the formation of an interpenetrating polymer network, which balances the protein and polysaccharide domains. The FTIR results also support the idea that increasing the CMC concentration improves film uniformity, barrier properties and mechanical strength. Consequently, this blend emerges as a promising candidate for biodegradable food packaging. Overall, FTIR analysis confirmed that FG and CMC interact via hydrogen bonding and electrostatic forces, with matrix composition shifts directly influencing the structural integrity of the films.

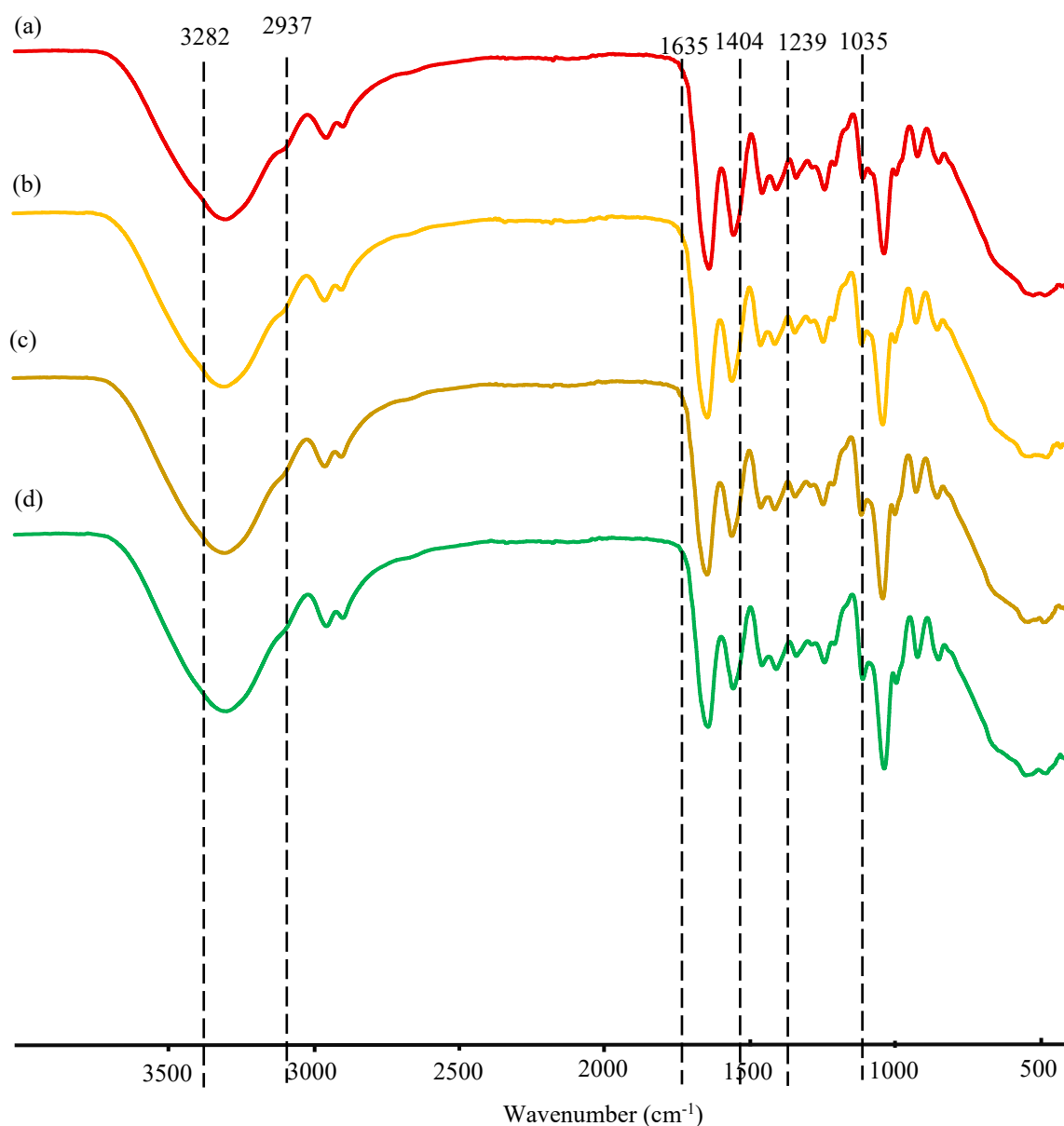


Figure 6. FTIR spectra of (a) pure FG, (b) 90 FG:10 CMC SB, (c) 70 FG:30 CMC SB, and (d) 50 FG:50 CMC SB.

Biodegradation by Soil Burial Testing

Table 4 shows how biofilms degraded during a 30-day period. The biodegradation properties of the films were evaluated after they had been left in the soil in order to evaluate film breakdown in soil. The percentage of biodegradation was estimated using Equation (7), and the results are displayed in Figure 7.

From the experiments, the pure FG film is the most degraded with a total of 98% biodegradation by day 30, while the 50 FG:50 CMC SB mixture showed the least degradation of 70%. Soil biodegradation study clearly showed that the biodegradation of FG films was severely impaired when combined with CMC SB. By day 30, the pure FG film was almost completely degraded, retaining only 0.0123 ± 0.006 g of the initial mass of 0.6137 ± 0.014 g. This rapid degradation reflects the inherent susceptibility of gelatine to microbial enzymatic hydrolysis. Proteases and soil microorganisms readily attack the peptide bonds, leading to the fragmentation and dissolution of the film matrix, as reported in a previous study [41]. Similar rapid degradation of gelatine-based films has also been reported, with protein films typically losing structural integrity within weeks due to microbial colonization and enzymatic activity [42]. In studies of gelatine/CMC films containing antioxidant extracts, biodegradation was reported to be high, with >80% degraded within 14 days [46]. Pure gelatine films were found to degrade more rapidly than gelatine mixed with CMC or other polymers, as the mixtures tended to form a denser structure [42].

The incorporation of CMC was found to slow down the degradation process. The 90 FG:10 CMC SB mixture retained ~12% of its mass after 30 days, while 70 FG:30 CMC SB and 50 FG:50 CMC SB retained ~25% and ~30% of the original film mass,

respectively. The concentration of CMC SB was inversely proportional to the biodegradation rate. This is consistent with previous findings that the incorporation of polysaccharides increases the water resistance and compactness of the film [40, 41]. According to He et al. [47] CMC interacts with gelatine through hydrogen bonding, forming a denser polymer network that reduces solubility and microbial accessibility. As a result, higher CMC SB content provides greater durability but slows down the biodegradation process. This trend was also found in previous studies involving biopolymer blends for packaging and biomedical applications [48].

The standard deviation values (± 0.013 to ± 0.072) were found to highlight the natural variability in the soil burial tests. The larger deviations observed at day 20 for pure FG and 90 FG:10 CMC SB may reflect uneven microbial activity. Such variability is common in biodegradation studies. This is because soil composition, moisture and microbial density are naturally non-uniform [41]. Despite this, the overall trend remains robust: increasing CMC content consistently slows degradation. Mechanistically, gelatine films degrade rapidly because proteins are hydrophilic and readily hydrolysed while CMC, a cellulose derivative, is more resistant due to its polysaccharide backbone and lower solubility [49]. Regardless of the variability observed in the soil burial test, the overall trend remained consistent: increasing CMC SB content progressively slowed the biodegradation of the films. Mechanistically, pure gelatine films degraded rapidly due to gelatine's high hydrophilicity and susceptibility to hydrolysis by soil microorganisms. In contrast, a denser polymer network that formed through incorporation of CMC SB reduced solubility and restricted microbial accessibility, thereby enhancing resistance to biodegradation [40-47].

Table 4. Biodegradation of biopolymer films in soils.

Biopolymer Film	Mass (g) of biopolymer films according to biodegradation time (days)			
	0	10	20	30
Pure FG	0.6137 ± 0.014	0.1841 ± 0.037	0.0985 ± 0.064	0.0123 ± 0.006
90 FG:10 CMC SB	0.6205 ± 0.029	0.1986 ± 0.054	0.1364 ± 0.072	0.0745 ± 0.051
70 FG:30 CMC SB	0.6136 ± 0.013	0.2025 ± 0.038	0.1780 ± 0.038	0.1534 ± 0.047
50 FG:50 CMC SB	0.6202 ± 0.023	0.2481 ± 0.048	0.2171 ± 0.064	0.1861 ± 0.058

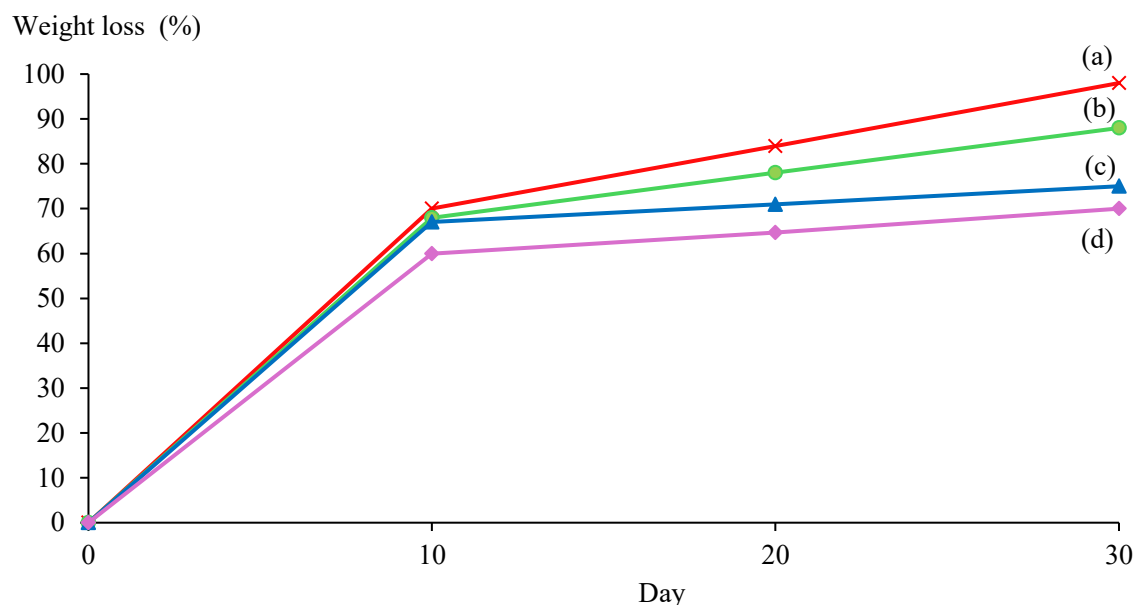


Figure 7. Percentage biodegradability of (a) pure FG, (b) 90 FG:10 CMC SB, (c) 70 FG:30 CMC SB, and (d) 50 FG:50 CMC SB in the soil.

CONCLUSION

This study successfully synthesised CMC from sugarcane bagasse and incorporated it into FG films to improve physicochemical performance and durability. By valorising agricultural waste, the work provides a cost-effective alternative to commercial CMC and advances sustainable packaging materials. The blended films demonstrated notable improvements in mechanical properties: tensile strength increased from 15.28 ± 1.02 MPa (pure FG) to 16.79 ± 1.28 MPa (50 FG:50 CMC SB), while elongation at break rose from $38.44 \pm 1.73\%$ to $43.36 \pm 2.17\%$, confirming enhanced flexibility and resilience. The transparency was found to decrease with the addition of the amount of CMC SB. FTIR analysis confirmed the strong intermolecular interactions between FG and CMC SB. FESEM observations indicated that films containing lower CMC SB concentrations exhibited a relatively homogeneous morphology, while higher CMC SB concentrations resulted in phase separation and heterogeneous structures, suggesting reduced compatibility at elevated CMC SB contents. Biodegradation tests found that the increase in CMC SB was inversely proportional to the degradation capacity. The pure FG film was almost completely degraded (98% by day 30), while the FG: CMC SB mixture showed a slower degradation, with the 50 FG:50 CMC SB formulation only reaching 70% degradation by day 30. This indicates that although the incorporation of CMC SB enhances the barrier properties and prolongs durability, it was also found to delay microbial attack. This is owing to the semi-crystalline structure and low water solubility. Overall, these findings highlight that tailoring the FG:CMC

SB ratio allows for a strategic balance between mechanical performance and environmental compatibility. In general, gelatine-rich films are suitable for short-cycle packaging requiring rapid biodegradation, while higher CMC SB mixtures offer longer shelf life with controlled disposal considerations. FG:CMC SB blended biopolymer films can be used as a promising biodegradable packaging solution derived from renewable agricultural resources.

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REFERENCES

1. Arfelli, F., Roguszevska, M., Torta, G., Iurlo, M., Cespi, D., Ciacci, L. and Passarini, F. (2024) Environmental impacts of food packaging: Is it all a matter of raw materials? *Sustainable Production and Consumption*, **49**, 318–328.
2. Khodaei, D., Álvarez, C. and Mullen, A. M. (2021) Biodegradable packaging materials from

- animal processing co-products and wastes: An overview. *Polymers*, **13(15)**, 2561.
3. Wang, S., Xia, P., Wang, S., Liang, J., Sun, Y., Yue, P. and Gao, X. (2019) Packaging films formulated with gelatin and anthocyanins nanocomplexes: Physical properties, antioxidant activity and its application for olive oil protection. *Food Hydrocolloids*, **96**, 617–624.
4. Hu, S., Han, L., Yu, C., Pan, L. and Tu, K. (2025) A review on replacing food packaging plastics with nature-inspired bio-based materials. *Foods*, **14(10)**, 1661.
5. Gautam, S., Verma, M. and Lakhanpal, T. S. (2025) Machine-learning driven design of bio-based active food packaging films with improved mechanical properties. *Sustainable Food Technology*, **3(6)**, 1705–1722.
6. Singh, S., Habib, M., Rao, E. S., Kumar, Y., Bashir, K., Jan, S. and Jan, K. (2025) A comprehensive overview of biodegradable packaging films: Part I—sources, additives, and preparation methods. *Discover Food*, **5(1)**, 41.
7. Zhao, M., Han, P., Mu, H., Sun, S., Dong, J., Sun, J., Lu, S., Wang, Q. and Ji, H. (2025) Food packaging films from natural polysaccharides and protein hydrogels: A comprehensive review. *Food Chemistry: X*, **25**, 102174.
8. Gupta, D., Lall, A., Kumar, S., Patil, T. D. and Gaikwad, K. K. (2024) Plant-based edible films and coatings for food-packaging applications: recent advances, applications, and trends. *Sustainable Food Technology*, **2(5)**, 1428–1455.
9. Azarifar, M., Ghanbarzadeh, B. and Abdulkhani, A. (2020) The effects of gelatin-CMC films incorporated with chitin nanofiber and *Trachyspermum ammi* essential oil on the shelf life characteristics of refrigerated raw beef. *International Journal of Food Microbiology*, **318**, 108493.
10. Xu, X., Xi, Y. and Weng, Y. (2025) Gelatin-based materials: fabrication, properties and applications in the food packaging system. *RSC Advances*, **15(37)**, 30605–30621.
11. Said, N. S., Howell, N. K. and Sarbon, N. M. (2023) A review on potential use of gelatin-based film as active and smart biodegradable films for food packaging application. *Food Reviews International*, **39(2)**, 1063–1085.
12. Duan, Q., Chen, Y., Long, Y. and Xie, F. (2022) Chitosan–gelatin films: plasticizers/nanofillers affect chain interactions and material properties in different ways. *Polymers*, **14(18)**, 3797.
13. Park, S., Oh, Y., Yun, J., Yoo, E., Jung, D., Park, K. S., Oh, K. K. and Lee, S. H. (2020) Characterization of blended cellulose/biopolymer films prepared using ionic liquid. *Cellulose*, **27(9)**, 5101–5119.
14. Yarahmadi, A., Dousti, B., Karami-Khorramabadi, M. and Afkhami, H. (2024) Materials based on biodegradable polymers chitosan/gelatin: a review of potential applications. *Frontiers in Bioengineering and Biotechnology*, **12**, 1397668.
15. Pormsila, W. and Udomphoch, P. (2025) Biodegradable Film of starch-based carboxymethyl cellulose from rice husk and straw for application in food preservation. *Processes*, **13(5)**, 1387.
16. Ștefănescu, B. E., Socaciu, C. and Vodnar, D. C. (2022) Recent progress in functional edible food packaging based on gelatin and chitosan. *Coatings*, **12(12)**, 1815.
17. Rahman, M. S., Hasan, M. S., Nitai, A. S., Nam, S., Karmakar, A. K., Ahsan, M. S., Shiddiky, M. J. and Ahmed, M. B. (2021) Recent developments of carboxymethyl cellulose. *Polymers*, **13(8)**, 1345.
18. Stroescu, M., Romina, A. and Mureșan, C. C. (2024) A comprehensive review on sugarcane bagasse in food packaging: properties, applications, and future prospects. *Hop and Medicinal Plants*, **32(1-2)**, 169–184.
19. Ramos Olortegui, G. D. and Barinotto, R. (2024) Use of the sugar cane bagasse (*Saccharum officinarum*) for the preparation of biodegradable food packages. In *9th North American Conference on Industrial Engineering and Operations Management, Washington D.C.*, 668–680.
20. Kossalbayev, B. D., Belkozhaev, A. M., Arman, A., Kadirshe, D. K., Tastambek, K. T., Akaidar, K. and Gaukhar, T. (2025) Biodegradable packaging from agricultural wastes: A comprehensive review of processing techniques, material properties, and future prospects. *Polymers*, **17(16)**, 2224.
21. Bamps, B., Guimaraes, R. M. M., Duijsters, G., Hermans, D., Vanminsel, J., Vervoort, E., Buntinx, M. and Peeters, R. (2022) Characterizing mechanical, heat seal, and gas barrier performance of biodegradable films to determine food packaging applications. *Polymers*, **14(13)**, 2569.
22. Sangroniz, A., Zhu, J. B., Tang, X., Etxeberria, A., Chen, E. Y. X. and Sardon, H. (2019) Packaging materials with desired mechanical and barrier properties and full chemical recyclability. *Nature Communications*, **10(1)**, 3559.
23. Ikedionu, C. A., Idoko, F. A. and Ojochogwu, O. J. (2024) Design and development of biodegradable

- polymers for green packaging solutions. *International Journal Healthcare Sciences*, **12(2)**, 84–110.
24. Yaradoddi, J. S., Banapurmath, N. R., Ganachari, S. V., Soudagar, M. E. M., Mubarak, N. M., Hallad, S., Hugar, S. and Fayaz, H. (2020) Biodegradable carboxymethyl cellulose based material for sustainable packaging application. *Scientific Reports*, **10(1)**, 21960.
 25. Khodaei, D., Oltrogge, K. and Hamidi-Esfahani, Z. (2020) Preparation and characterization of blended edible films manufactured using gelatin, tragacanth gum and Persian gum. *LWT*, **117**, 108617.
 26. Han, J. H. and Floros, J. D. (1997) Casting antimicrobial packaging films and measuring their physical properties and antimicrobial activity. *Journal of Plastic Film and Sheeting*, **13(4)**, 287–298.
 27. Pantelic, B., Ponjavic, M., Jankovic, V., Aleksic, I., Stevanovic, S., Murray, J., Fournet, M. B. and Nikodinovic-Runic, J. (2021) Upcycling biodegradable PVA/starch film to a bacterial biopigment and biopolymer. *Polymers*, **13(21)**, 3692.
 28. Malekzadeh, E., Tatari, A. and Dehghani Firouzabadi, M. (2024) Effects of biodegradation of starch-nanocellulose films incorporated with black tea extract on soil quality. *Scientific Reports*, **14(1)**, 18817.
 29. Al-Rajabi, M. M., En, K. J., Mahmud, S. S. and Abdullah, M. F. (2024) Impact of alkali concentration in delignification treatment for cellulose extraction from rice straw. *Jordanian Journal of Engineering and Chemical Industries*, **7(3)**, 94–102.
 30. Abolore, R. S., Jaiswal, S. and Jaiswal, A. K. (2024) Green and sustainable pretreatment methods for cellulose extraction from lignocellulosic biomass and its applications: A review. *Carbohydrate Polymer Technologies and Applications*, **7**, 100396.
 31. Bernal-Lugo, I., Jacinto-Hernandez, C., Gimeno, M., Montiel, C. C., Rivero-Cruz, F. and Velasco, O. (2019) Highly efficient single-step pretreatment to remove lignin and hemicellulose from softwood. *BioResources*, **14(2)**, 3567–3577.
 32. Vilaro, P., Li, K., Moyna, G., Jiang, H., Gurau, G. and Rogers, R. D. (2024) Use of ionic liquids for hemp fiber degumming. *ACS Sustainable Chemistry and Engineering*, **12(34)**, 12819–12826.
 33. Mubarak, A. A., Ilyas, R. A., Ngadi, N., Nordin, A. H. and Alkbir, M. F. M. (2025) Isolation and characterization of cellulose from sugarcane bagasse fiber (*Saccharum officinarum*) via delignification and mercerization treatment using response surface modeling (RSM). *Biomass Conversion and Biorefinery*, **15(19)**, 26485–26499.
 34. Sylvere, N., Omar, T., Youness, A., El Farissi, L. and Lina, G. (2025) Innovative applications of sugarcane bagasse in the global sugarcane industry. *Processes*, **13(12)**, 3796.
 35. Chougala, V., Gowda, A. C., Nagaraja, S. and Ammarullah, M. I. (2025) Effect of chemical treatments on mechanical properties of sugarcane bagasse (*Gramineae saccharum officinarum* L) fiber based biocomposites: a review. *Journal of Natural Fibers*, **22(1)**, 2445571.
 36. Ab Rasid, N. S., Zainol, M. M. and Amin, N. S. (2021) Synthesis and characterization of carboxymethyl cellulose derived from empty fruit bunch. *Sains Malaysiana*, **50(9)**, 2523–2535.
 37. Syukri, D., Suryanto, H., Faridah, A., Refdi, C. W., Diliarosta, S., Rahmi, I. D., Fiana, R. M., Saputra, A. and Rahmi, Z. J. A. (2025) Fabrication of carboxymethyl cellulose (CMC) derived from *Themeda gigantea* cellulose with various concentrations of sodium monochloroacetate. *OnLine Journal of Biological Sciences*, **25(1)**, 104–114.
 38. Churam, T., Usubharatana, P. and Phunggrassami, H. (2025) Sustainable synthesis and characterization of carboxymethyl cellulose from agricultural byproducts: corn leaf and rice straw. *Engineered Science*, **33**, 1374.
 39. Méndez, P. A., Cervera, G. and Reyes, L. M. (2025) Development and characterization of gelatin/CMC-based oral films incorporating *Crescentia cujete* L. extracts for bioactive delivery. *Food Biophysics*, **20(4)**, 165.
 40. Tran, T. T. V., Nguyen, N. N., Nguyen, Q. D., Nguyen, T. P. and Lien, T. N. (2023) Gelatin/carboxymethyl cellulose edible films: Modification of physical properties by different hydrocolloids and application in beef preservation in combination with shallot waste powder. *RSC Advances*, **13(15)**, 10005–10014.
 41. Tabari, M. (2017) Investigation of carboxymethyl cellulose (CMC) on mechanical properties of cold water fish gelatin biodegradable edible films. *Foods*, **6(6)**, 41.
 42. Said, N. S. and Sarbon, N. M. (2022) Physical and mechanical characteristics of gelatin-based

- films as a potential food packaging material: A review. *Membranes*, **12(5)**, 442.
43. Du, J., Zhu, Q., Guo, J., Gu, J., Guo, J., Wu, Y., Ren, L., Yang, S. and Jiang, J. (2025) Preparation and characterization of edible films from gelatin and hydroxypropyl methyl cellulose/sodium carboxymethyl cellulose. *Heliyon*, **11(1)**, e41613.
 44. Ratna, Aprilia, S., Arahman, N., Bilad, M. R., Suhaimi, H., Munawar, A. A. and Nasution, I. S. (2022) Bio-nanocomposite based on edible gelatin film as active packaging from *Clarias gariepinus* fish skin with the addition of cellulose nanocrystalline and nanopropolis. *Polymers*, **14(18)**, 3738.
 45. Zafar, A., Khosa, M. K., Noor, A., Qayyum, S. and Saif, M. J. (2022) Carboxymethyl cellulose/gelatin hydrogel films loaded with zinc oxide nanoparticles for sustainable food packaging applications. *Polymers*, **14(23)**, 5201.
 46. Ratanasongtham, P., Sukplee, P. and Wongnongwa, Y. (2024) Development of antioxidant film based on gelatin and carboxymethylcellulose incorporated with *Tecoma stans* (L.) Juss. ex Kunth Petals extract for biodegradable food packaging. *Journal of Metals, Materials and Minerals*, **34(2)**, 1781.
 47. He, K., Sheng, W., Yang, L., Yang, Y., Tang, T., Wang, C., Jiang, G. and Tian, Y. (2024) Novel carboxymethyl cellulose/gelatin-based film incorporated with zein-stabilized lemon essential oil pickering emulsion for the preservation of cherries. *Foods*, **13(16)**, 2602.
 48. Madej-Kiełbik, L., Gzyra-Jagięła, K., Jóźwik-Pruska, J., Dziuba, R. and Bednarowicz, A. (2022) Biopolymer composites with sensors for environmental and medical applications. *Materials*, **15(21)**, 7493.
 49. Zhang, L., Liu, H., Zheng, L., Zhang, J., Du, Y. and Feng, H. (1996) Biodegradability of regenerated cellulose films in soil. *Industrial and Engineering Chemistry Research*, **35(12)**, 4682–4685.