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FABRICATION OF pH-RESPONSIVE BIODEGRADABLE SMART PACKAGING INCORPORATING ANTHOCYANINS

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Abstract

Objectives: Humans require food to survive. Consequently, the food business is constantly growing and reaching its zenith. The food sector places a lot of importance on food packaging, as it is an art, science, and technology for the safe and cost-effective delivery of goods to final customers. Food is packaged to protect it from microbes, dust, physical damage, odour, and other hazards. Recent advancements in food packaging include smart packaging that is designed to improve food safety, quality, and shelf life. **Methods:** In this study, anthocyanin was extracted from red cabbage and incorporated into a chitosan and polyvinyl alcohol mixture to form a pH sensitive biodegradable smart packaging material. **Findings:** The smart packaging material shows significant structural, barrier, and functional properties. The FTIR results exhibit the presence of medium intensity C-N, C-H, and O-H bonding's. The material also showed 23% water solubility and water transmission rate of 0.07 g/m2, which is needed for good packaging material. Further, the biodegradability test of the smart packaging material proves to have a high degradation capacity of 82%. Thus, the developed pH sensitive biodegradable smart packaging material is safe, non-toxic, biodegradable, and it can monitor the freshness and deterioration of food in real time without opening the package and preserve food for a longer time. **Novelty:** This study explores a biodegradable, pH-sensitive smart packaging material formulated with red cabbage anthocyanins, chitosan, and polyvinyl alcohol. Unlike traditional packaging, this innovative material can visually indicate food freshness in real time while being environmentally friendly and highly degradable. Its enhanced barrier properties and structural stability offer a promising sustainable alternative to synthetic food packaging.

Keywords: Anthocyanins, Smart Packaging, Biodegradable, Chitosan and Polyvinyl Alcohol.

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1. INTRODUCTION

In the food industry, packaging is essential for ensuring food safety, maintaining quality, and preserving freshness. It protects food from various contaminations from physical, chemical, and biological sources. The demands for food packaging have increased to provide consumers with high-quality food to meet strict requirements of material performance and longer shelf life.

Metals are frequently used in food packaging as closures for composite cans and glass bottles, as well as in a range of packing arrangements due to their strong barrier properties. In metal packaging, health and safety concerns involve the migration of substances like bisphenol A, lead, cadmium, mercury, aluminium, iron, and nickel. Issues such as can bulging, tin dissolution, blackening, and corrosion also arise. To mitigate these risks, metals are coated with protective lacquers to prevent direct contact with food and to reduce the migration of metal components, as metals can react with food products. Metal packing materials have a reduced global warming potential and improved recyclability as segregation is made easier due to their magnetic properties [16].

Glass packing materials are thermally stable and inert to food. But the labour-intensive and expensive nature of glass manufacture is its main drawback. Due to their unique eco-friendliness, paper and paperboard are widely used packaging materials for various food products, such as milk and milk-based items, beverages, dry powders, confections, and baked goods. However, it contains a number of hazardous chemicals, including phthalates, surfactants, bleaching agents, printing inks, and hydrocarbons, are added [17]. These chemicals can cause health problems, and the paper is easily dampened, which encourages the growth of fungi. The most popular materials for packaging are synthetic polymers due to their low density, affordability, and ease of processing. Unfortunately, a lot of these materials pose challenges for the environment because they are hard to recycle and take a long time to fully decompose in the natural world [44].

Smart packaging films extend the shelf life of food items, aid in evaluating food quality and safety, and provide information to customers about freshness and degradation without the requirement to open the package [15]. Smart packaging involves both intelligent and active packaging. Active packaging works to preserve food products, whereas intelligent packaging keeps an eye on the product's quality. Anthocyanin-based biodegradable polymer-based color indicator smart packaging material is suitable for use in environmentally friendly, human, and animal health and safety applications. Proteins, lipids, and polysaccharides are the typical biodegradable biopolymers used to make smart packaging material [69].

Anthocyanins are natural, non-toxic water-soluble pigments widely present in plants, flowers, fruits and vegetables and give them their characteristic red, orange, purple, pink, and blue colors. Chemically, anthocyanins are secondary metabolites found in plants that are part of the large group known as polyphenols, which is comprised of a subgroup of flavonoids. There are around 640 distinct types of anthocyanins found in nature. Cyanidin,

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pelargonidin, delphinidin, petunidin, peonidin, and malvidin are the six most prevalent anthocyanidins (aglycone form) [69, 55, 29, 36].

The anthocyanins have a natural pH-indicating property that can be employed as a color-based pH indicator that can be used to track the freshness and deterioration of food in real time, which is the basis for intelligent packaging. The color-based pH indicator functions as a gauge for microbial metabolites because microbes produce metabolites that can alter pH and cause a color shift. Additionally, anthocyanins have a number of positive health effects, including anti-inflammatory, anti-oxidant, retinoprotective effect, antimicrobial, anti-obesity, anti-cancer, and anti-diabetic properties [69]. Since oxidation and microbial contamination are the primary causes of food spoilage, the anti-oxidant and antimicrobial properties can be exploited to extend the shelf life of food, which is the basis of active packaging. Natural polymers can be used as the material for food packaging. Natural polymers such as chitosan, cellulose, starch, alginate, etc. can all be employed. Chitosan is a natural cationic polysaccharide with high molecular weight, and it’s the second most abundant polysaccharide on earth [69, 51]. It's produced by removing acetyl groups from chitin. It is frequently used as a food packaging material because of its unique properties, which include being biodegradable, biocompatible, non-toxic, having antimicrobial activity, and having film-forming abilities [69]. Furthermore, it possesses the ability to obstruct gas, flavor, and moisture passage [65], which forms one of the foundations of active packaging. Chitosan has certain drawbacks, such as brittle texture and poor mechanical qualities, but these can be worked around by combining it with other polymers or biopolymers. Polyvinyl alcohol is a biodegradable polymer that dissolves in water and is highly biocompatible. Due to the presence of high-density hydroxyl group on its side chain, it can be formed by connecting only carbon-carbon linkages. The mixing of chitosan and polyvinyl alcohol will improve the mechanical strength, elasticity, water resistance, etc. of the smart packaging material. These anthocyanin-based biodegradable smart packaging materials can be used to pack variety of foods, including fruits, vegetables, meat, pork, fish, shrimp, milk and cheese. This study aims to produce pH-sensitive biodegradable smart packaging material with anthocyanin, chitosan, and polyvinyl alcohol that could monitor real-time freshness and deterioration while also extending its shelf life. The resulting packaging material aims to prevent oxidation reactions and microbial contamination of food due to its antioxidant and antimicrobial properties, and it is also safe, non-toxic, biodegradable and eco-friendly.

2. MATERIALS AND METHODS

2.1 Anthocyanin extraction

2.1.1 Extraction from red cabbage [57,3]

The red cabbage (*Brassica oleracea var. capitata f. rubra*) was procured from a nearby supermarket SPAR and the extraction was done by the solvent extraction method. The flask was filled with 10 g of sample (red cabbage) and 100 mL of solvent (ethanol). It was kept in the dark at 4°C for 72 hours. After the scheduled maceration, the contents of the

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flask were filtered through Whatman paper No. 1, and the filtrate was evaporated using a steam distillation unit at 40°C for one hour. Afterward, it was kept in the dark at 4°C until it was needed.

2.1.2 Confirmatory test for anthocyanin [56]

The presence of anthocyanin was confirmed by sulphuric acid test and sodium hydroxide test.

Sulphuric acid test:

A few drops of concentrated H_2SO_4 were added to 1 mL of the extract in a test tube. The presence of anthocyanin was confirmed by a color change from pink to red.

Sodium hydroxide test:

A few drops of 1N NaOH were added to 1 mL of the extract in a test tube. The presence of anthocyanin was confirmed by the color changing from pink to yellow.

2.1.3 Characterization for anthocyanin [52]

The extracted anthocyanin was characterized by Gas Chromatography – Mass Spectrometry to confirm the presence of anthocyanin component. The extracted sample was injected directly into GCMS and the resulted peaks were analysed to identify anthocyanin.

2.2 Production of pH sensitive biodegradable smart packaging material [3]

To prepare the chitosan solution, 1 gram of chitosan powder was dissolved in 100 milliliters of 1% acetic acid, with continuous magnetic stirring at room temperature until fully dissolved. For the PVA solution, 3 grams of PVA powder were dissolved in 100 milliliters of distilled water, with constant magnetic stirring at 70°C until completely dissolved. The film-forming solution was prepared by mixing CS and PVA solution at a ratio 7:3 (v/v), and the anthocyanin extract was added at 25% concentrations. To promote cross linking of the film, 1.5 mL of 0.1% (w/v) sodium tripolyphosphate (Na5P3O10) solution was added to the film-forming solution.

The air was removed from the film-forming solution before it was poured onto flat surface trays. After few days the films were peeled from the trays.

2.3 Characterization of produced smart packaging material

2.3.1 Colour and pH of the film

The colour of the film was visually determined. The film was taken and mixed with distilled water in a beaker. The pH of the plastic was measured after being soaked for one day.

2.3.2 Fourier Transform Infrared Spectroscopy (FTIR) Analysis [6]

The chemical bond and functional group of the film were obtained using a Fourier transform infrared (FTIR) spectrometer (Thermo Fisher Scientific) at the range of 4000-400 cm−1.

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2.3.3 Elongation at break [67]

A rectangular film strip (12 cm x 10 cm) was cut out and elongated by applying uniform pressure at all the ends until its rupture. The initial length and the elongated length were noted, and elongation at break was calculated using the formula,

$$\text{Elongation at break (\%)} = \frac{Elongated\ length}{Original\ initial\ length} \times 100$$

2.3.4 Water vapor transmission rate [2]

The film, 7 cm in diameter, was cut out and placed above the mouth of the beaker containing 25 mL of phosphate- buffered saline. The initial weight of the beaker was measured before incubation and was incubated at 35°C for 24 hours.

Then the final weight of the beaker was measured after incubation. The water vapor transmission rate was determined by using a specific formula,

$$\text{Water Vapor Transmission Rate (g/m2)} = \frac{(Initial\ weight - Final\ weight)}{Exposed\ area}$$

2.3.5 Swelling index [2]

The film was cut into a 4 cm x 4 cm square, and its dry weight was recorded. Then the dry film was incubated in phosphate-buffered saline solution with pH 7 at 37°C. The film's wet weight was recorded after 24 hours.

The swelling index of the film was determined using the formula,

$$\text{Swelling index} = \frac{(Wet\ weight - Dry\ weight)}{Dry\ weight}$$

2.3.6 Water solubility [6]

The film was cut into a 4 cm x 4 cm piece and dried in an oven at 50°C overnight. Then the initial dry weight of the film was measured and placed in 25 mL of distilled water for 24 hours at room temperature with gentle shaking.

The wet film was dried again in an oven at 50°C overnight, and the dry weight of the film was measured. The water solubility was determined using the formula,

$$\text{Water solubility (\%)} = \frac{(Initial\ dry\ weight - Final\ Dry\ weight)}{Initial\ Dry\ weight}$$

2.3.7 Moisture content [6]

The film of a certain size was cut, and its initial weight was measured. Then the film was placed in an oven at 50°C for 24 hours, and the final weight was measured.

The moisture content in the film was determined using the formula,

$$\text{Moisture content (\%)} = \frac{(Initial\ weight - Final\ weight)}{Initial\ weight} \times 100$$

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2.3.8 Thermal stability [6]

About 10 mg of the film was heated at a rate of 10 °C/min from 20 to 100 °C on a hot plate, and the thermal property was studied.

2.4 Application study of produced smart packaging material

2.4.1 Colour response analysis [41]

The film was cut into small strips and placed in different pH solutions to visualize the colour change of the strips in different pH mediums. This property was also analysed on food material by wrapping the food material with the film and allowed it to get spoiled to observe the colour changes.

2.4.2 Freshness indicator analysis

A piece of film was cut out and placed at room temperature in a clean, dry place. The film was observed for its colour change, which indicates the degree of freshness.

This property was also analysed on food material by wrapping the food material with the film and observing the colour changes.

2.4.3 Shelf-life analysis [6]

The film was wrapped and sealed with a food material. This was then left in a clean, dry place. After that, at regular intervals, the stored food condition was observed, and the duration of the food getting spoiled was noted.

The produced material was also compared with the polyethylene plastic material.

2.5 Biodegradability test

2.5.1 Soil burial method [60]

The film of 5 cm x 5 cm was cut out, and the initial weight was measured. The film was buried in the soil at a depth of 5 cm for 30 days. Every 5 days, the film was examined, and the final weight was measured. The degradation percentage of the film was calculated using the formula,

$$\text{Degradation \%} = \frac{(Initial\ weight - Final\ weight)}{Initial\ weight} \times 100$$

2.5.2 ASTM G21 method [60]

Potato dextrose agar plates were prepared, and a square piece of film was placed on the surface of the media.

The pure culture of Aspergillus niger was spread on the film and incubated at 30°C for 1 or 2 weeks.

Duplicates were made for this process. The growth of fungi on the film was used to examine the degradability. A higher amount of fungal growth on the film indicates greater degradability.

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3. RESULTS AND DISCUSSION

3.1 Anthocyanin extraction

3.1.1 Extraction from red cabbage

The red cabbage extract was collected using the solvent extraction method. The red cabbage was macerated in ethanol for 72 hours, as shown in Fig. 1(a). After maceration, the extract was filtered, and the filtrate was concentrated using stream distillation to obtain anthocyanin extract, as shown in Fig. 1(b). The extracted substance was then utilized for additional processing steps.

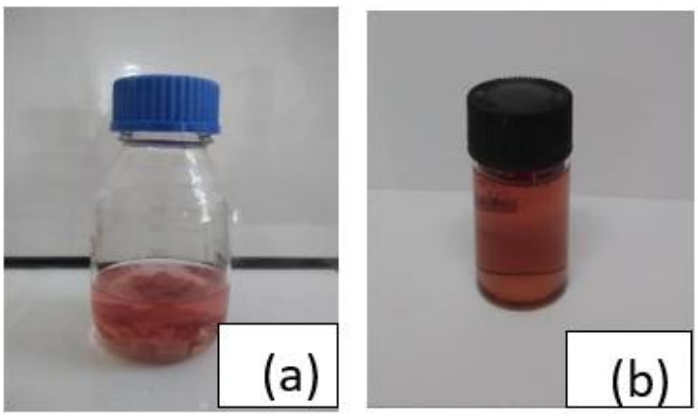

Figure 1: Extraction from red cabbage (a) Maceration; (b) Anthocyanin extract

3.1.2 Conformation for anthocyanin

The sulphuric acid test and the sodium hydroxide test were performed on the extract. The sulphuric acid test resulted in red colour formation, as shown in Fig. 2(a), and the sodium hydroxide test resulted in yellow colour formation, as shown in Fig. 2(b). Therefore, the presence of anthocyanin was confirmed in the extract.

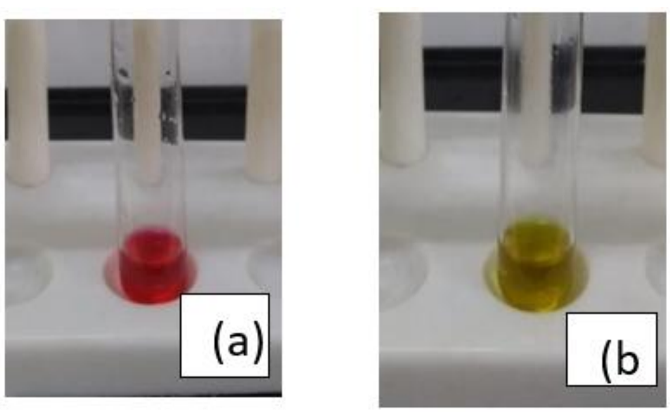

Figure 2: Confirmation for anthocyanin (a) Sulphuric test; (b) Sodium hydroxide test

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3.1.3 Characterization for anthocyanin

The obtained extract was analysed for the presence of anthocyanin through GCMS, and a chromatogram was generated as shown in Fig. 3. The results from GC-MS confirm the presence of anthocyanin in the extract in the form of cyanidin-3,5-O-diglucoside, with a retention time of 15.3994 and an area percentage of 2.21.

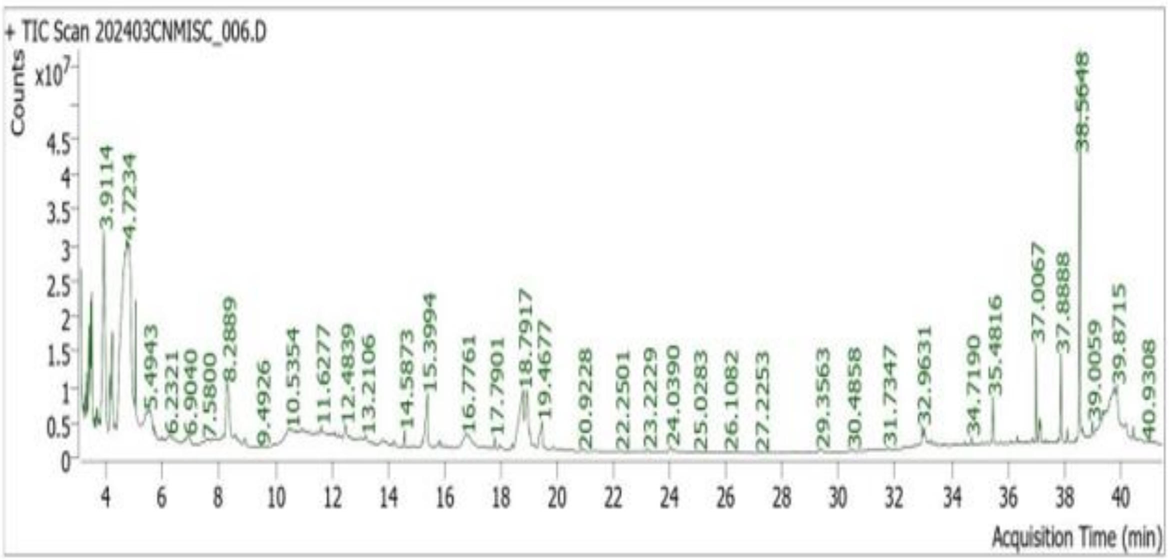

Figure 3: Chromatogram obtained from the GC-MS of anthocyanin extract

3.2 Production of pH sensitive biodegradable smart packaging material

After casting the film-forming solution onto the trays, within 3–4 days the film was formed and peeled off (Fig. 4).

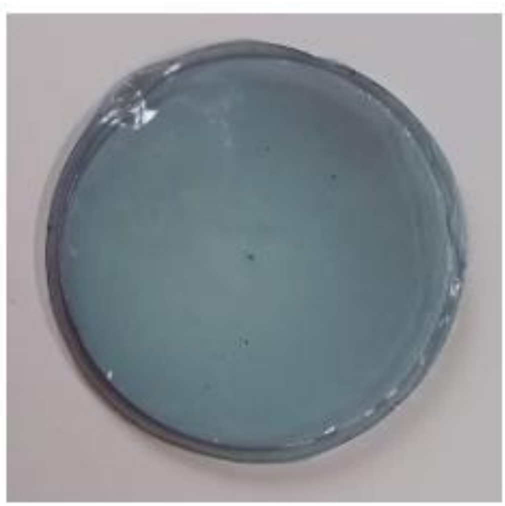

Figure 4: Smart packing film

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3.3 Characterization of produced smart packaging material

3.3.1 Colour and pH of the film

Table 1: Colour and pH of the film

Colour	Bluish green (Fig.9)
pH	7.5 – 8

3.3.2 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

The FT-IR spectrum of the film was analyzed in the region 400 cm^{-1} - 4000 cm^{-1} which exhibited complex vibrational modes. The frequency ranges that were observed were 817.66 cm^{-1}, 1020.91 cm^{-1}, 1408.66 cm^{-1}, 1555.58 cm^{-1}, 2919.77 cm^{-1} and 3256.26 cm^{-1}. The FTIR spectrum of the film is represented in Fig. 5.

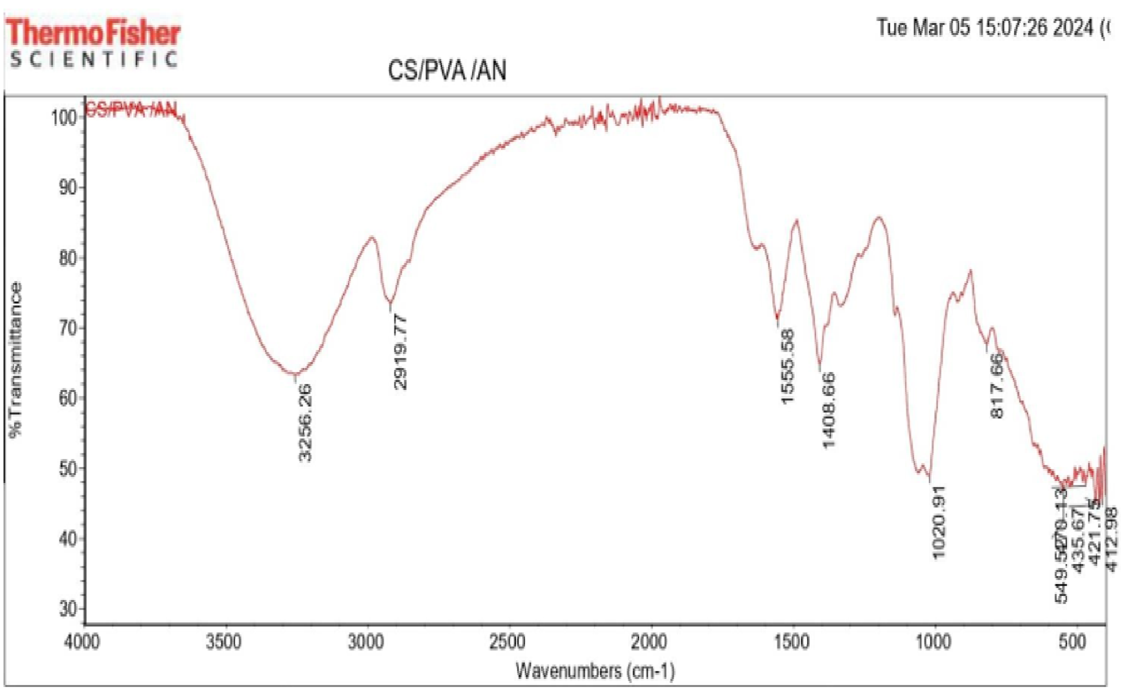

Figure 5: FTIR analysis of the film

The structural characteristics are crucial to a film's overall quality. The structures are formed due to molecular interactions between different groups in CS, PVA, and anthocyanin.

3.3.3 Elongation at break

Elongation at break (EAB) is one of the mechanical attributes of the film, which gives strength and flexibility to the film. It also maintains the integrity and sustainability of the food material. The EAB was performed, and the result tabulated is shown in table 3. The synthesized smart packaging film shows a poor EBA of 12.5% EAB.

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Table 3: Elongation at break

Original initial length	12 cm
Elongated length	1.5 cm
Elongation at break (%)	12.5 %

3.3.4 Water vapor transmission rate

The water vapor transmission rate (WVTR) establishes the film's permeability. This is one of the important properties to extend the shelf life of the food by maintaining a suitable moist environment and reducing moisture transfer between the food and the surrounding environment. WVTR was performed for the film and the result tabulated is shown in Table 4.

Table 4: Water vapour transmission rate

Initial weight	78.45 g
Final weight	76.70 g
Exposed area	19.62 m^2
WVTR	0.07 g/m^2

3.3.5 Swelling index

The swelling index is another essential barrier property of food packaging material. This describes the material's ability to absorb moisture and swell. It also influences the colour response efficiency of the film. The swelling index was performed on the film, and the result tabulated is shown in Table 5.

Table 5: Swelling index

Dry weight	0.11 g
Wet weight	0.37 g
Swelling index	0.70

The swelling index of food packaging material should be low. But the film shows a 70% swelling index, which is poor.

3.3.6 Water solubility

Water solubility deals with the water sensitivity of the film. A good packaging material should contain high water resistance property as to protect and preserve the food. The result is shown in Table 6.

The water solubility percentage of the produced film is 23%, which is found to be of good significance.

Table 6: Water solubility

Initial dry weight	0.11 g
Final dry weight	0.08 g
Water solubility (%)	23.36%

3.3.7 Moisture content

Moisture content measures the amount of moisture present in the film. The low moisture content of the food packaging material has the ability to preserve and protect food for a longer time. Table 7 presents the results for the film's moisture content. The film was found to have less moisture content of 23%.

Table 7: Moisture content

Initial weight	0.12 g
Final weight	0.11 g
Moisture content (%)	23.36%

3.3.8 Thermal stability

Thermal stability is about the thermal degradation of the material. The film's thermal stability was performed as shown in Fig. 9.

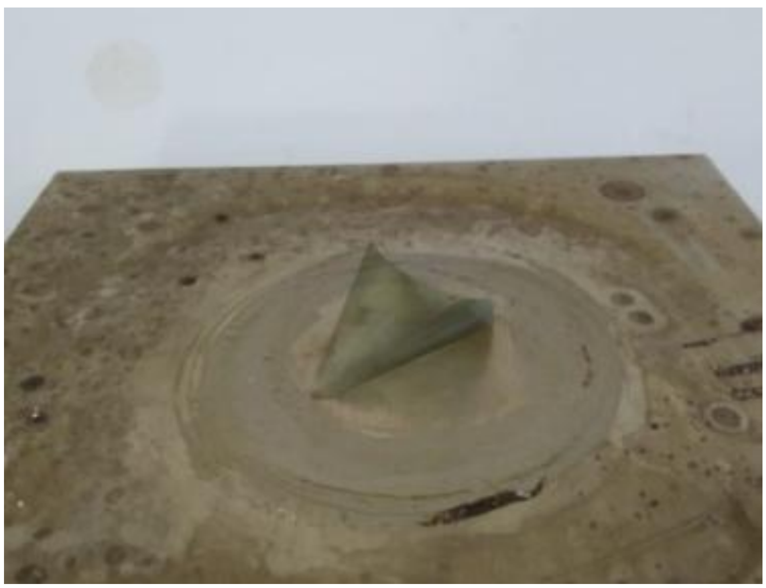

Figure 6: Thermal stability

Up to 50°C, the film retained its colour and beyond that point, it began to form dark colouration. Above 50°C, the film began to degrade thermally, losing properties. The film exhibits low thermal stability.

3.4 Application of produced smart packaging material

3.4.1 Colour response analysis

The films were submerged in concentrated sulphuric acid and 1N sodium hydroxide. The colour change of the film was observed where the film changed to a red colour in concentrated sulphuric acid (pH - 2), as shown in Fig. 10(a) and a yellow colour in 1N sodium hydroxide (pH - 14) as shown in Fig. 15(b).

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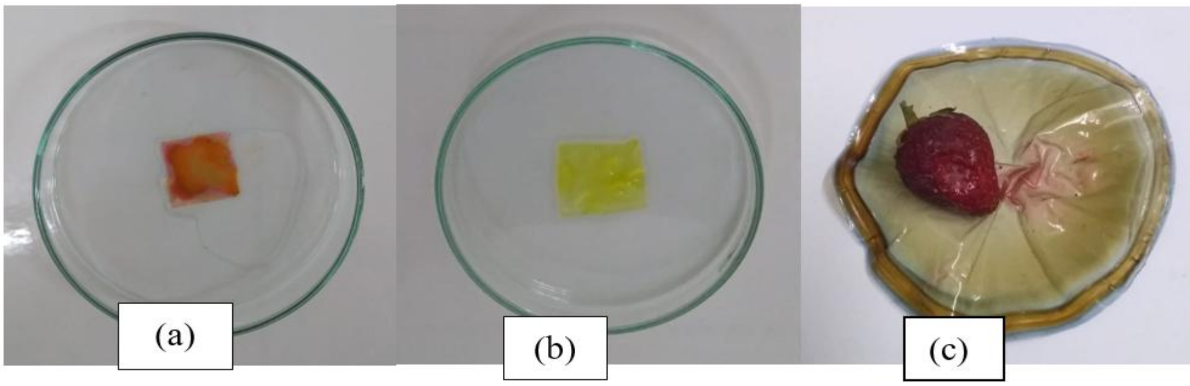

Figure 10: Colour response analysis (a) In conc. sulphuric acid; (c) In 1N sodium hydroxide

When a strawberry was wrapped in film and allowed to spoil, the film became exposed to liquid that leaked out of the rotten strawberry, causing it to turn pink due to the acidic condition of the liquid from the strawberry, as shown in Fig. 11. Hence, the smart packaging material produced is highly sensitive to pH and acts as a visual indicator that detects food deterioration in real time.

3.4.2 Freshness indicator analysis

When used as a freshness indicator, the film progressively turns yellow over the course of several days, as shown in Fig. 12. When the film was wrapped around a strawberry, the same characteristic was also observed.

The strawberry's freshness was demonstrated by the slow colour shift. The film appeared bluish green with the fresh strawberry, and as the strawberry age and loose its freshness, the film began to turn yellowish brown as shown in Fig. 13.

Thus, the produced smart packaging material also serves as a visual freshness indicator that tracks the freshness of food products in real time.

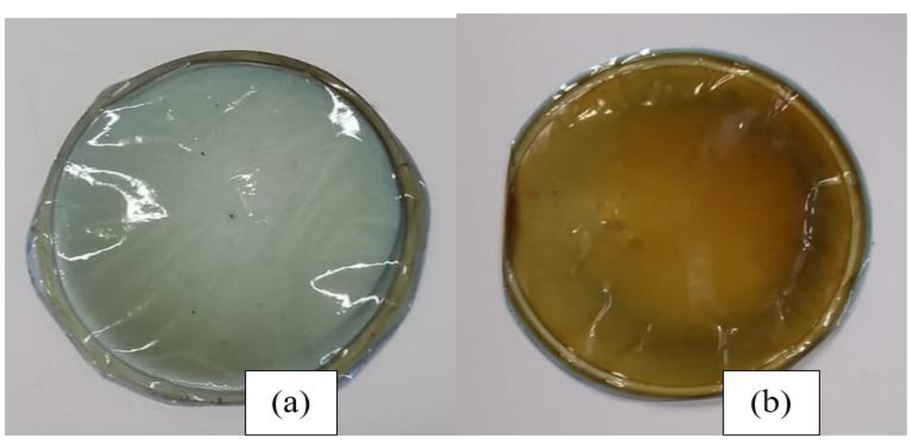

Figure 11: Freshness indicator analysis (a) New film; (b) Film after several days

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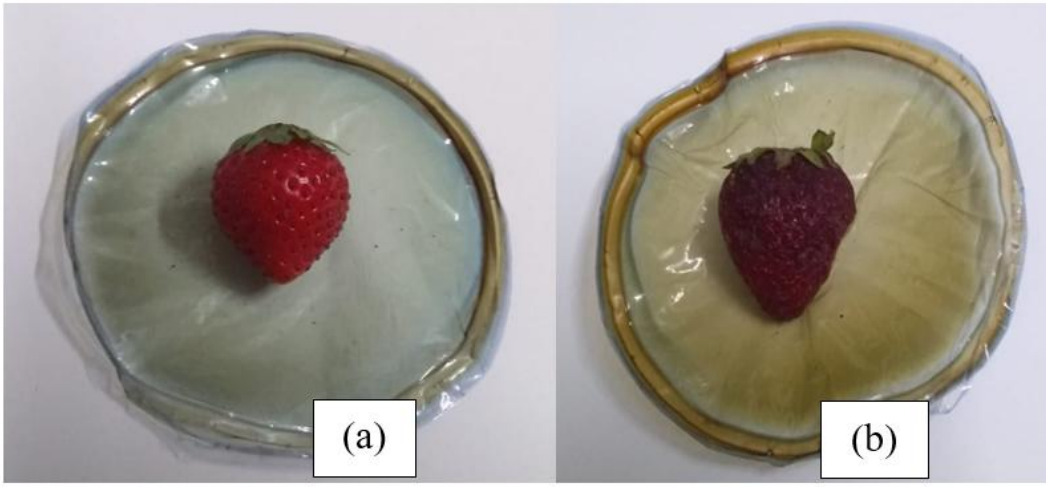

Figure 12: Freshness indicator analysis on food material (a) Fresh strawberry; (b) Strawberry after few days

3.4.3 Shelf-life analysis

Fresh strawberries were purchased, one wrapped in a polyethylene bag and the other with the produced smart packaging film. The strawberry in the polyethylene bag got spoiled with black colouration and fungal development on the 3rd day, as shown in Fig. 14(a). But the strawberry wrapped in smart packaging film started to show black colouration and mushiness on the 3rd day, as shown in Fig. 14(b) and on the 5th day, it got spoiled. As a result, the smart packaging film that was produced helps to extend the shelf life of food products.

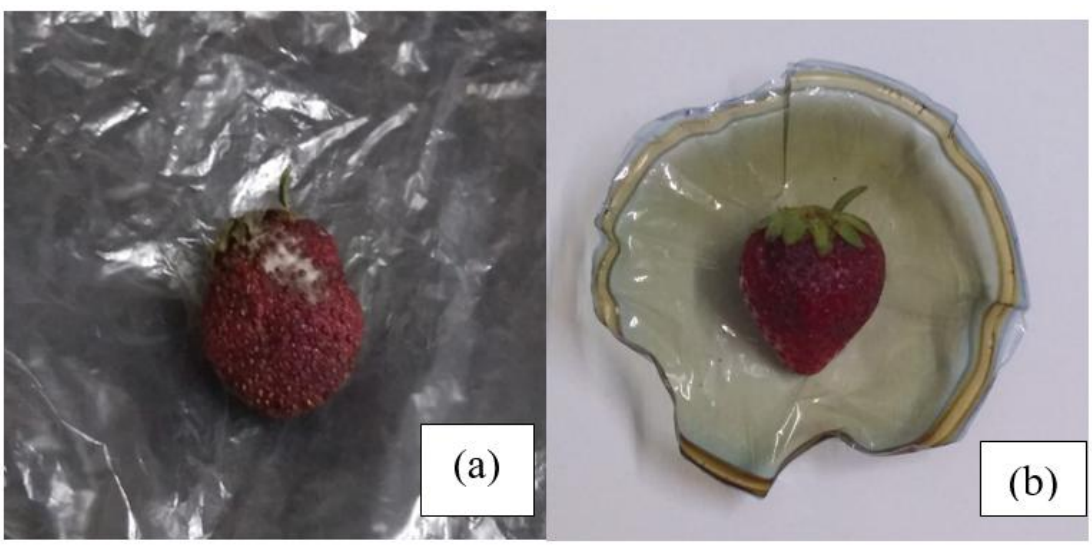

Figure 13: Shelf-life analysis (a) Strawberry stored in polyethylene bag; (b)Strawberry wrapped with the produced smart packaging film

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3.5 Biodegradability test

3.5.1 Soil burial method

A piece of the film was buried in the soil, as shown in Fig. 15 and after every 5 days, the weight of the film was measured. The degradation percentage was calculated using the formula, and the results tabulated are shown in Table 8 and graphed as seen in Fig. 16.

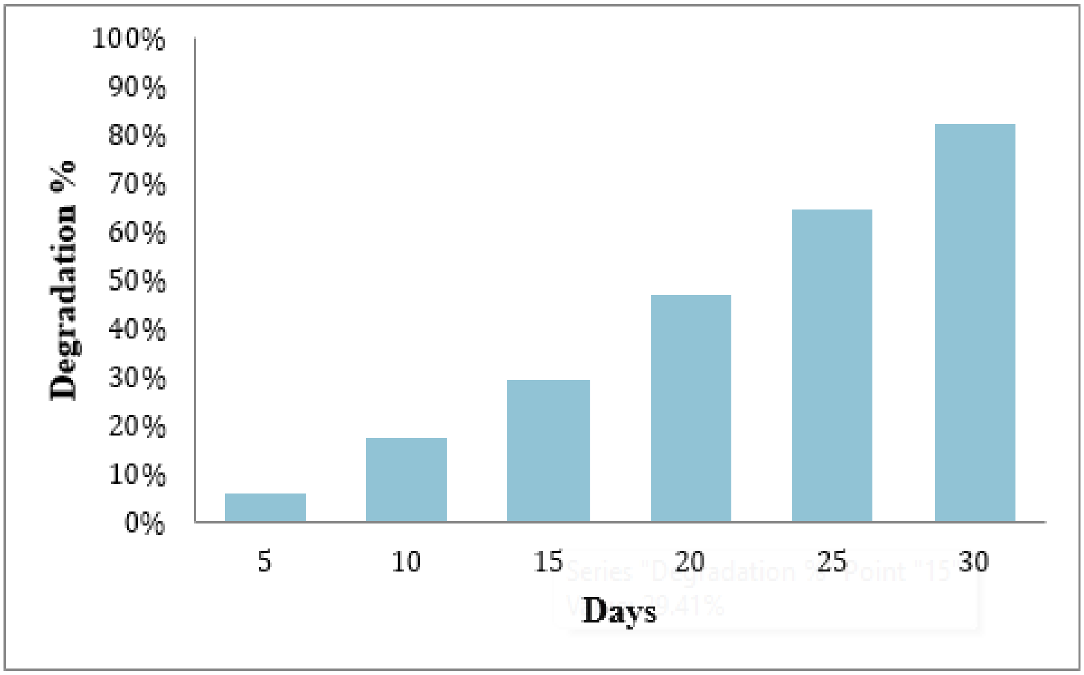

Figure 14: Degradation percentage of the film for 30 days

The results show that the produced smart packaging film has 82% degradation capability for 30 days. Therefore, the film is highly biodegradable.

3.5.2 ASTM G21 Method

The synthesized film was tested with *Aspergillus niger* on a PDA to evaluate the degradability of the film.

After 24 hours, fungal growth was observed with a cottony white appearance, as shown in Fig. 17(a).

The spore formation started to appear on the 4th day. By the 10th day, maximum *Aspergillus niger* growth was, in Fig. 17(b). The high fugal growth on the film suggests that it has a higher biodegradable capacity.

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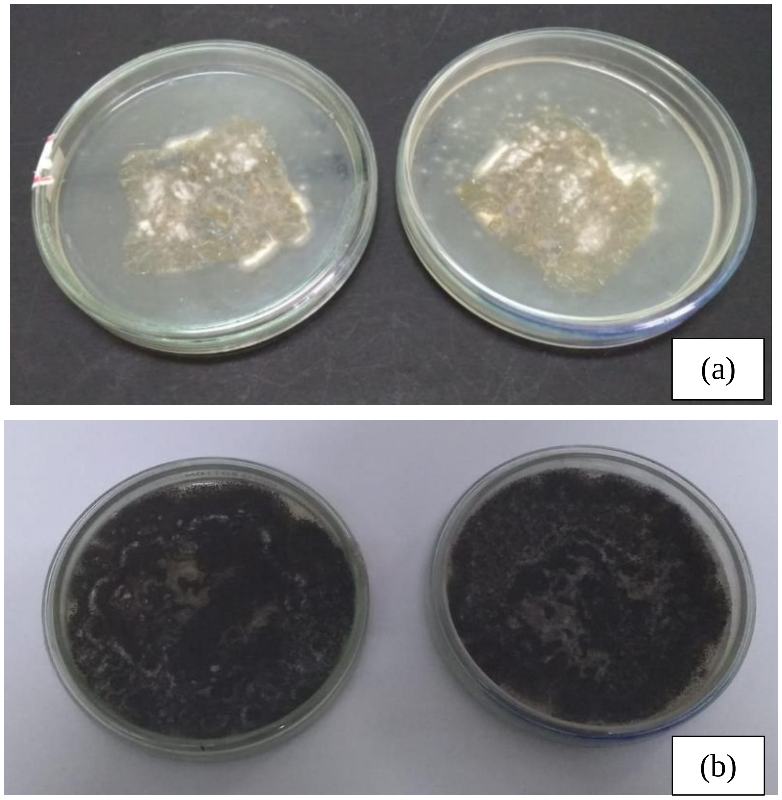

Figure 15: ASTM G21 biodegradability test (a) After 24 hours; (b) On the 10th day

Utilizing biodegradable polymers to produce packaging materials is one efficient method, and the food packaging industry is already using some of these biodegradable polymers. The addition of pH sensitive property to the biodegradable packaging material is a remarkable innovation in the food packaging industry and acts as a smart packaging material.

The anthocyanin was successfully extracted from red cabbage and confirmed the presence of anthocyanin using sulphuric acid test and sodium hydroxide test, where the extract changed its colour to red and yellow, respectively. The GC-MS analysis of the extract also confirmed the presence of anthocyanin in the form of cyanidin-3,5-O-diglucoside, with a retention time of 15.3994 and an area percentage of 2.21. Based on the research by Subramanian *et al.,* 2022 [56], cyanidin-3,5-O-diglucoside is the major anthocyanin component present in red cabbage. According to Sarpate *et al.,* 2010[52], peonidin-3-glucoside, an anthocyanin component, was identified at a retention time of 14.700, which is almost identical to the obtained retention value of cyanidin-3,5-O-diglucoside anthocyanin. The GC-MS technique was found to be effective technique by Murathan *et al.,* 2016[40], for the identification of a large number of bioactive compounds.

The pH sensitive biodegradable smart packaging material was produced using CS, PVA and anthocyanin from red cabbage. The colour of material was bluish green with the pH

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of 7.5 – 8. The structural analysis of the material was done using FTIR and was found to have various covalent bonds and hydrogen bonds. The structures in the material are due to molecular interactions such as strong intermolecular hydrogen bonding between the amino groups of CS and the hydroxyl groups of PVA, as well as hydrogen bond and electrostatic interactions between the film polymers and anthocyanin [63,61,67,64,20]. The developed film contains alkyl halides groups (C-Cl, medium stretch), aromatic groups (C-C, medium stretch), aliphatic amine group (C-N, medium stretch), alkanes (C-H, strong stretch), and carboxylic acid group (O-H, medium stretch) at the peak range 549.52 cm^{-1}, 817.66 cm^{-1}, 1020.91 cm^{-1}, 2919.77 cm^{-1}, and 3256.26 cm^{-1} respectively. The results obtained are nearly similar to FTIR analysis results of Subramanian *et al.,* 2022.

Mechanical properties help to study the food packaging material's behaviour and handling conditions [12]. One of the mechanical properties is elongation at break and the material has a poor elongation at break of 12.5%, this is due to the poor mechanical strength of CS and also use of less concentration of PVA. The film made by Prietto *et al.,*2017[48] using starch and anthocyanin from red cabbage showed elongation at break of 91% which is far higher percentage than the produced material.

Barrier properties are another essential property that food packaging must have in order to keep food isolated from the external environment. The barrier properties include water vapour transmission rate, swelling index, water solubility and moisture content. The film exhibits good amount of water vapour transmission rate and less percentage of water solubility and moisture content which is required for a good packaging material. The film developed by Prietto *et al.,* 2017 [12] showed solubility of 49% which is much higher than the produced smart packaging material. But the swelling index of material is 70% which is undesirable for a packaging material and this is due to the presence of hydrophilic groups in the material. According to Pereira *et al.,* 2015[45], the film made from CS, PVA and anthocyanin showed 38% swelling index which is less than the produced smart packaging.

In addition, the material also shows low thermal stability because of the presence of less stable anthocyanin and weak intermolecular interaction present among the components of the material. The produced smart packaging material had thermal degradation 40^{o}C which was nearly identical to the film produced by Pereira *et al.,* 2015[45].

The smart packaging material performs as visual pH and freshness indicator as well as was able to increase the shelf life of food products. The pH and freshness indication are due to the presence of anthocyanin. The anthocyanin exhibits change colour in different pH mediums because of the formation of different components. The red colour appears at pH 1–4 due to the production of the flavylium cation. The formation of carbinol pseudo base is the reason for the pink colour at pH 4–6. Quinoidal base development results in purple and blue coloration between pH 7–8, while above pH 8, chalcone occurrence causes a gradual change in colour from green to yellow [15]. The pH sensitivity of the developed smart packaging results was found to be nearly identical to the results of Alizadeh-Sani *et al.,* 2021[6] methylcellulose and chitosan film. The freshness is indicated

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by gradual colour change to yellowish brown. This characteristic results from anthocyanin's sensitivity to light, pH, temperature, and other factors, which causes colour change to yellowish brown or colourless product [15]. The shelf life of food products is increased due to the antimicrobial and antioxidant properties of anthocyanin as well as the antimicrobial properties of chitosan, which can prevent food-borne microorganisms and oxidation reaction, thereby preserving the food for a longer time [69, 24, 4, 15]. The biodegradability nature of the smart packaging material was assessed by soil burial and ASTM G21 methods. The degradation percentage in soil burial method was found to be 82% for 30 days because they are easily decomposed by the natural soil micro flora. Further, in ASTM G21 method degradation rate was high due to high fungal growth on the material within 10 days [60]. The outcomes of this current work demonstrates that the pH sensitive biodegradable smart packaging material produced serves as an effective food packaging material and fulfils its intended purpose. Future research is required to address the issues with elongation, swelling index and thermal stability of this material.

4. CONCLUSION

In conclusion, the developed pH sensitive biodegradable smart packaging material is sensitive to pH, monitors real time freshness, detects food spoilage and increases the food shelf life. It is also safe, non-toxic, biodegradable, and eco-friendly, so this material can be replaced with widely used plastic materials. This would be a cutting-edge development in the food packaging industry and also an effective strategic tool for marketing.

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