Journal of Academia Vol. 12, Issue 2 (2024) 172 – 185

DEVELOPMENT OF BIOCOMPOSITE FILM FROM BANANA PEEL AND CORN STARCH INCORPORATED WITH CINNAMON ESSENTIAL OIL

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Abstract

Utilization of the agricultural waste such as banana peel can help in reduce the rising environmental issues such as food waste and greenhouse gas emission. The purpose of this study is to develop biocomposite films from banana peel and corn starch incorporated with cinnamon essential oil (EO). The effect of the incorporation of cinnamon EO at different concentrations (1%, 3% and 5%) into banana peel and corn starch film on antimicrobial activity, mechanical properties and barrier properties were investigated and characterized. The properties of the developed films were tested using antimicrobial activity, thickness, colour analysis, mechanical properties, water vapour permeability (WVP) and water solubility test. It was found that the antimicrobial activity of the film significantly increased ($p<0.05$) with the increase of cinnamon EO concentration. The cinnamon EO had greater effect on Gram-positive bacteria (*Staphylococcus aureus* and *Bacillus cereus*) compared to Gram-negative bacteria (*Salmonella* and *Escherichia coli*). The L-value (lightness) of the film decreased with the increase of cinnamon EO. The thickness of the biodegradable films increased ($p<0.05$) with the addition of cinnamon EO; however, it also weakens the mechanical properties of the biocomposite films. This may due to the modification of structural positioning of the film matrix occurred with the addition of cinnamon EO, hence, resulted in brittleness and reduction strength of the biocomposite film. The WVP value of the film was not affected ($p>0.05$) with the addition of cinnamon EO. The water solubility of the film decreased ($p<0.05$) with the increased of cinnamon EO concentrations. This may due to the hydrophobic nature of cinnamon EO. Overall, incorporation of cinnamon EO into the banana peel and corn starch biocomposite film improved its antimicrobial activity and barrier properties, but weaken its mechanical properties.

Keywords: agricultural waste, antimicrobial activity, banana peel, biocomposite films, cinnamon essential oil

Article History:- Received: 26 Jun 2024; Revised: 3 July 2024; Accepted: 10 July 2024; Published: 31 October 2024

Introduction

Biocomposite are an environmental friendly alternative to traditional plastic packaging as they effectively reduce pollution. A biocomposite is a material composed of two or more distinct constituent materials that are combined to produce a new material with improved performance over individual constituent materials (Sun, 2013). Biocomposite film polymers can be produced from renewable and eco-friendly sources such as agriculture waste or food by-products. The biopolymers include polysaccharides (starch and cellulose), proteins (casein and gluten) and lipid (Kuddus, 2021).

Utilization of the waste product can help reduce the rising environmental issues such as greenhouse gas emission and animal chocking. The development of biocomposite film from agricultural waste has been identified as a critical aspect in addressing the issue of food waste and the strain on raw material resources, as well as contributing to waste management (Ahmad et al., 2022). Besides, utilization of the

waste product is able to reduce the economic concern as the source of bio-based materials is cheaper than the petrochemical-based materials. Besides, biopolymer from food industry by-product are known as an outstanding source for developing the films (Ahmad et al., 2022).

Banana peel are rich in total dietary fibre (40–50 %), protein, and amino acids (8–11%), lipids and fatty acids (2.2 % to 10.9 %) (Padam et al., 2014). Banana peel also contains high sources of starch which is about 18.5% (Fatimah et al., 2017). Banana peel generally consists of a high amount of total phenolic content ranging from 4.95 to 47 mg gallic acid equivalent/g dry matter (mg GAE/g DM), which is 1.5-3 times higher than that recorded in the flesh. Phenolic compounds can be classified into four groups such as hydroxycinnamic acids, flavanols, flavan-3-ol and catecholamines. Within hydroxycinnamic acids, ferulic acid dominates over other compounds, while rutin and its conjugates such as flavonoid glycosides are the most dominant component among the identified flavanols. Flavan-3-ols are the most abundant group of phenolics found in banana peel such as tannin (Vu et al., 2018). Phenolic compounds are one of phytochemicals that possess antioxidant and antimicrobial activity (Jafarzadeh et al., 2020)
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Starch is a component of biopolymer that is renewable, inexpensive and environmentally friendly. Starch has the highest biodegradation rate, followed by cellulose and chitosan. Starch biopolymer is optical, organoleptic and its barrier properties are ideal for film formation. However, their mechanical strength and properties are very poor. The use of starch alone limits its usage as a food packaging material because it is highly prone to breaking and fragile. The addition of co-biopolymer and additives to the starch film has been investigated to improve the mechanical and tensile properties of the film (Thakur et al., 2019).

Cinnamon essential oil (EO) is derived from the bark or leaves of trees such as the Cinnamomum verum tree and Cinnamomum cassia tree. Cinnamon EO is an essential oil that contains natural preservative properties which include bioactive components (Vahedikia et al., 2019). Cinnamon contains a well-known agent due to its antimicrobial activities known as cinnamaldehyde. The cinnamon essential oil contains approximately 65-80% of cinnamaldehyde and lower levels of trans-cinnamic acid, eugenol, limonene, cinnamyl alcohol, and acetate (Jafarzadeh et al., 2020). These bioactive components play essential roles as antibacterial properties that make safe, effective and non-chemical additive alternatives used to preserve products and increase their shelf life. Study by Mahdi et al. (2010) showed that incorporation of cinnamon EO into chitosan films improved the water barrier properties and increased tensile strength. Hence, the purpose of this study was to add additives such as cinnamon EO into starch-based films. The use of cinnamon EO may increase the mechanical and barrier properties of the manufactured film, as well as its antimicrobial activity for potential use as an active packaging.

Methods

Preparation of banana peel powder

The banana peel was cut to small pieces and immersed in 0.5% (w/v) anhydrous citric acid solution to reduce enzymatic browning. After that, the banana peel was dried in an oven at 55°C for 24 hours. The dried peel was cooled at room temperature and grinded into flour using hammer mill. The grinded banana peel powder was sieved using sieve shaker. The powdered banana peel was stored in airtight container and stored in desiccator (Castillo-Israel et al., 2015).

Preparation of film

The films were produced by casting technique. Four types of banana peel and corn starch film were prepared in triplicate following (Souza et al., 2013;Medeiros Silva et al., 2020) with modifications: 1) standard banana peel and corn starch film (SBPCSF); 2) with the addition of 1% (w/w, relative to the filmogenic suspension) of cinnamon essential oil (BPCF1); 3) with the addition 3% (w/w) of cinnamon essential oil (BPCF3); and 4) with the addition 5% (w/w) of cinnamon essential oil (BPCF5).

Filmogenic suspension was prepared by mixing 8g banana peel flour, 2.8g of corn starch, 1.4g pectin and 200mL distilled water. The suspensions were heated in a water bath at 90°C with constant stirring for 30 minutes and homogenized in an ultra-homogenizer at 18000 rpm for 5 minutes. After that, 1.52g

glycerol was added and the solution was maintained at this temperature for 30 minutes with constant stirring. After that, cinnamon essential oil (1%, 3% and 5%) was emulsified with Tween 80 using a magnetic stirrer. Both mixtures prepared were added together and homogenized at constant stirring at 90°C for 30 minutes. Standard banana peel and corn starch film without essential oil was also prepared and considered as control. The solution was filtered using a muslin cloth to remove the remaining particles. Then, 25mL of the mixture was poured into glass petri dish 10cm in diameter and was dehydrated in an oven at 40°C for 24 hours. The films were placed in desiccators containing saturated solutions of silica gel to keep the relative humidity (RH) at 25°C for 48h, before being characterized.

Antimicrobial activity – Disk diffusion method

The antimicrobial activity of the film was determined following method by Souza et al. (2013) and Azlin-Hasim et al. (2015). This analysis was carried out using Gram positive and Gram-negative bacteria which were *Bacillus cereus (B. cereus), Staphylococcus aureus (S. aureus)* and *Escherichia coli (E. coli), Salmonella enteric*a respectively. All tests were performed in triplicate and the average was calculated. Firstly, the bacteria were grown in Mueller-Hinton Broth (MHB) under constant agitation on orbital shaker (New Brunswick Innova® 40/40R - Benchtop Orbital Shaker) at 170 rpm for 18h at 30°C *(B. cereus*) and 37°C *(S. aureus, E. coli and Salmonella enterica)* (~10^8 CFU/ml). Then the bacteria were undergoing serial dilution for 2 times until achieved ~10^6 CFU/ml. For the agar diffusion method, Mueller-Hinton Agar (MHA) plates were swabbed with the target microorganisms. Before use, the film was cut to circular shape (6mm) and decontaminated by exposing it to UV light for 15 minutes in laminar flow. The films were placed in the middle of the inoculated agar plates and incubated for 24 hours at 30°C and 37°C. The positive control was also prepared for this analysis using 1%, 3% and 5% of cinnamon EO. Then, 10µl of cinnamon EO was pipetted onto Whatman Antibiotic Assay Discs (6mm) and the disc was decontaminated by exposing to UV light for 15 minutes in laminar flow. The disc was placed in the middle of the inoculated agar plates and incubated for 24 hours at 30°C and 37°C. The antimicrobial activity was evaluated by the formation of an inhibition zone around the disk samples, which was characterized by surrounding clear areas. The inhibition zone was determined by measuring its diameter.

Thickness

The thickness measurements were measured at 5 random positions on the film, in triplicate. The thickness was measured using a digital micrometre (The Mitutoyo digital QuantuMike) with a scale of 0–25 mm and a precision of 0.001 mm, and the average was calculated (Medeiros Silva et al., 2020).

Tensile strength

The determination of the tensile strength of the films were carried out using a texture analyser TA.XT. Plus Texture Analyzer (Stable Micro System Ltd. UK). The tensile strength was determined using 3 replicates with a 5kg load cell, probe A/TG Tensile Grips, distance between the claws of 50mm and the test speed of 1mm/s. The films were cut to form test specimens of 100 × 15 mm. The results were obtained from the force (N) versus distance (mm) curve and calculated according to the Equation 1:

$$\sigma = \frac{F_{max}}{A} \qquad \text{(Equation 1)}$$

Where σ correspond to the tensile strength (MPa), F_{max} is at the maximum force (N) applied and A is the cross-sectional area (mm^2) (Arquelau et al. 2019).

Colour

Colour values of the films were measured at 3 random positions on the film, in triplicate and the average was calculated. The colour of the films was measured using a colourimeter (Chroma meter CR-400 Konika Minolta Sensing, Inc, Japan). The colourimeter was first calibrated on a white standard plate and the colour was expressed in CIELAB system where L* (+meaning lightness, - meaning darkness), a* (+meaning redness, - meaning greenness), and b* (+meaning yellowness, - meaning blueness).

Fourier-transform Infrared spectroscopy

Fourier-transform Infrared spectroscopy (FTIR) analysis was used to examine the presence of certain chemical groups and crosslinking in the films. A small piece of the film was cut and placed onto the germanium plate. The spectra were taken in 32 scans between 4000 and 400cm^{-1} using Thermo Scientific Nicolet iS10 FTIR Spectrometer (Fatimah et al., 2017).

Water Vapour Permeability

The water vapour permeability (WVP) of the films was measured according to the modified ASTM E96 (ASTM, 2013). The films were sealed onto glass permeation bottle containing 1.5g of silica gel (0% RH). The permeation bottle was weighed together with film to calculate the initial weight before placed in a desiccator contained with distilled water at room temperature. The permeation bottle was then weighed at 1 h interval over 7 h of period. The water vapour permeability (WVP) was calculated as in Equation 2:

$$WVP\ (g/msPa) = w \times \frac{x}{At} \times (P_2 - P_1) \qquad \text{(Equation 2)}$$

Where w is the weight gained by the cup (g), x is the average film thickness (m), A is the permeation area (m2), t is the time gained (s) and $P_2 - P_1$ is the difference of partial pressure (Pa).

Water solubility

The water solubility of the film was determined as reported by Zhou et al. (2021) with modifications. The films were cut into 2 cm × 2 cm samples, and then the film was dried in an oven at 105 °C until the weight remains unchanged. The film was then weighed, and its weight was recorded as W_i. Then the dried film sample was immersed in 50 mL deionized water at room temperature for 1 hour. Finally, the undissolved film was taken out and dried in an oven at 105 °C until the weight remains unchanged, was recorded as W_f. The measurement was repeated three times and the average value was taken. The water solubility was calculated according to the Equation 3:

$$S = \frac{W_i - W_f}{W_i} \times 100 \qquad \text{(Equation 3)}$$

Where S refers to water solubility (%), W_i refers to the initial dry weight of the film and W_f refers to the final dry weight of the film.

Statistical analysis

All treatments were prepared in triplicate (n=3). Statistical analysis was done using Minitab 21 Statistical Software. One-way ANOVA at 95% level of significance at α= 0.05 together with Tukey's multiple comparison was used to determine significant differences between samples for all analysis study. Data was presented as mean ± standard deviation with significant letter.

Result and Discussion

Antimicrobial activity

The antimicrobial activity of cinnamon EO as positive control was evaluated by measuring the diameter of inhibition zone around the Whatman antibiotic assay discs, which was characterized by surrounding clear areas. The inhibition zone of different concentration of cinnamon essential oil tested against different types of microorganism (*B. cereus S. aureus, Salmonella* and *E. coli*) is shown in Table 1. An example of inhibition zone of around the discs is shown in Figure 1. In general, there was a significant ($p<0.05$) increased of antimicrobial activity against all microorganism tested with the increased of cinnamon EO. In addition, cinnamon EO had greater effect on Gram-positive bacteria (*S. aureus* and *B. cereus*) compared to Gram-negative bacteria (*Salmonella* and *E. coli*). This finding was supported by a study conducted by Raeisi et al. (2015) that cinnamon EO showed higher antimicrobial activity against *S. aureus* than *E. coli*. This may due to the difference of membrane structure of these bacteria. Gram negative bacteria such as *Salmonella* and *E. coli* have peptidoglycan cell wall which restrict the destruction of bacteria cells by lipophilic cinnamon EO (Hasheminya et al., 2019). Due to the absence of an outside phospholipid membrane in Gram-positive bacteria, hydrophobic components and the

phospholipid layer of the cell membrane come into direct contact. This resulted in increased of ion permeability, enzyme deterioration and excretion of intercellular constituent (Raeisi et al., 2015).

Table 1. Inhibition zone of different concentration of cinnamon essential oil tested against different types of microorganisms*

	Diameter inhibition zone (cm)			
CEO	***B. cereus***	***S. aureus***	***Salmonella***	***E. coli***
1%	1.15±0.21^{c}	0.90±0.14^{b}	0.0±0.0^{c}	1.05±0.071^{b}
3%	2.27±0.12^{b}	1.57±0.21^{a}	1.6±0.173^{b}	1.867±0.153^{a}
5%	3.05±0.21^{a}	1.87±0.15^{a}	2.9±0.141^{a}	2.367±0.351^{a}

*Means that do not share a letter are significantly different.

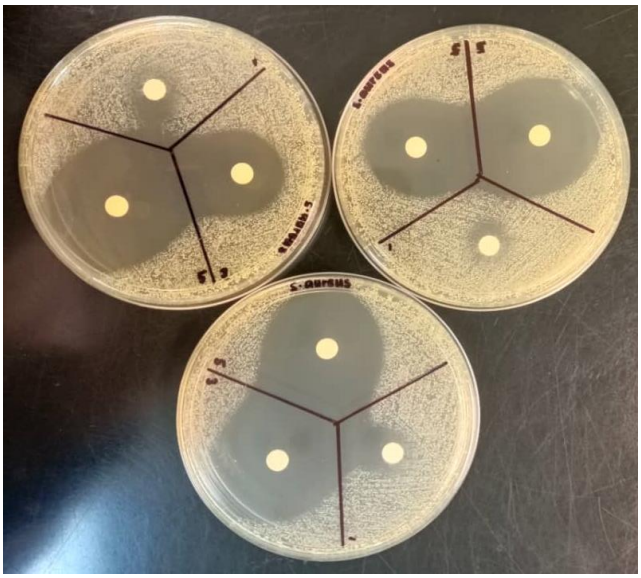

Figure 1. Example of inhibition zone of different concentration of cinnamon essential oil tested against *S. aureus*

The inhibition zone of biocomposite based film containing different concentration of cinnamon EO tested against different types of microorganism is shown in Table 2. An example of inhibition zone of around the biocomposite based film is shown in Figure 2. The diameter of inhibition zone of biocomposite based film containing cinnamon EO had similar result with was using cinnamon EO alone (see Table 1), which the antimicrobial activity of biocomposite film increased as the concentration of the cinnamon EO increased. The biocomposite film incorporated with cinnamon EO had a greater effect against *B. cereus* and *S. aureus* as compared to *Salmonella* and *E. coli*. This is in agreement with what was reported by Syafiq et al. (2021) that incorporation of essential oil increased antimicrobial activity of film against *S. aureus* and *E. coli*. This may due to hydrophobic property of essential oil which enables them to penetrate into bacterial cell membrane and attack the phospholipid bilayer of the cell membrane as well as interfere with the enzyme system and compromise the genetic material of bacteria (Song et al., 2018). This will eventually result in the cell death.

However, it was noted that lower antimicrobial activities were observed for cinnamon EO added onto the biocomposite films. This may due to the limited effectiveness of since cinnamon EO had lower exposure doses to the bacteria and furthermore, the antimicrobial effects become highly mass transport limited (Kumar et al., 2005).

Table 2. Inhibition zone of biocomposite based film containing different concentration of cinnamon EO tested against different types of microorganism*

	Diameter inhibition zone (cm)			
Sample	***B. cereus***	***S. aureus***	***Salmonella***	***E. coli***
SBPCSF	-	-	-	-
BPCSF1	-	-	0.75±0.071^{c}	0.75±0.07^{b}
BPCSF3	2.45±0.07^{b}	2.13±0.23^{b}	1.45±0.21^{b}	1.00±0.14^{b}
BPCSF5	2.90±0.17^{a}	3.17±0.25^{a}	2.77±0.06^{a}	2.13±0.06^{a}

SBPCSF (control film without cinnamon EO), BPCSF1 (banana peel and corn starch film with 1% cinnamon EO), BPCSF3 (banana peel and corn starch film with 3% cinnamon EO, BPCSF5 (banana peel and corn starch film with 5% cinnamon EO)

*Means that do not share a letter are significantly different.

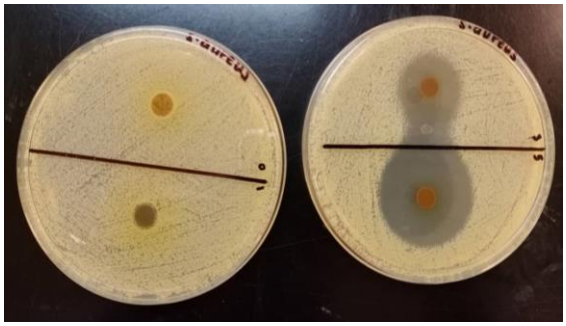

Figure 2. Example of inhibition zone of biocomposite based film containing different concentration of cinnamon EO tested against *S. aureus*

Thickness

The thickness of biocomposite based film incorporated with cinnamon EO is shown in Table 3. There was a significantly ($p<0.05$) increased on the film thickness with the increased of cinnamon EO concentration. Fatin et al. (2022) reported curry leaf EO incorporated into chitosan-based film significantly increased the mean thickness. Other than that, Cai et al. (2020) reported that the incorporation of thyme EO microcapsule significantly increased thickness of starch films. The difference in film thickness may be influenced by variability in nature, composition, and solid content present in the film structure (Zahedi, 2019). Besides, this may be due to the addition of EO that disrupts and restrict intermolecular interaction between polymers which can increase free volumes and mobility of polymers (Haghighi et al., 2019). The constituent of EO may also increase the spatial distance of the film matrix which results in thicker film (Khezrian & Shahbazi, 2018).

Table 3. Thickness of biocomposite based film incorporated with different concentration of cinnamon EO.

Sample	**Thickness (mm)**
SBPCSF	0.1232±0.0198^{b}
BPCSF1	0.1405±0.0211^{ab}
BPCSF3	0.1575±0.0072^{ab}
BPCSF5	0.1820±0.0153^{a}

SBPCSF (control film without cinnamon EO), BPCSF1 (banana peel and corn starch film with 1% cinnamon EO), BPCSF3 (banana peel and corn starch film with 3% cinnamon EO, BPCSF5 (banana peel and corn starch film with 5% cinnamon EO)

*Means that do not share a letter are significantly different.

Tensile strength

The tensile strength of biocomposite based film incorporated with cinnamon EO have been assessed. However, data is not provided because the films ruptured (Figure 3) before attached to the probe of texture analyzer due to the films were too brittle. Arezoo et al. (2020) reported that the increasing amount of cinnamon EO to film structure significantly reduced the tensile strength. However, the finding is contradicted with a study by Syafiq et al. (2021) which mentioned that the addition of cinnamon EO in sugar palm based nanocellulose/ starch biocomposite films significantly increased the tensile strength. This may due to cinnamon EO can easily penetrate into biopolymer network and eventually reduced the intra and inter-molecular interactions.

Figure 3. Ruptured banana peel and corn starch film incorporated with cinnamon EO

This damaged the continuous film matrix, which allowed the weaker polymer-oil interactions in the film matrix to partially replace the stronger intermolecular polymer interactions (Zhou et al., 2021). Other than that, the decrease in tensile strength may due to the hydrophobicity of cinnamon EO and discontinuity of the film caused by the rearrangement of biopolymer (Zhou et al., 2022). Besides, EO probably affected the interaction between the polymer and glycerol which result in brittle film (Medeiros Silva et al., 2020). The presence of sugars and protein in banana peel powder may act as plasticizer and made the film become less resistant (Martelli et al., 2013).

Colour

The colour parameter (L*, a* and b*) of biocomposite films incorporated with cinnamon EO is shown in Table 4. The L* value of biocomposite based film significantly ($p<0.05$) decreased with the increased of cinnamon EO, which means the addition of cinnamon EO reduced the lightness of the films significantly. This is supported by Yi et al. (2022) which reported that the addition of papaya seed EO decreased the L* value of the chitosan/polyvinyl alcohol film. This may due to the scattering of light through the polymer matrix in the presence of cinnamon EO droplets (Fasihi et al., 2023).

In general, the addition of cinnamon EO significantly ($p<0.05$) increased the a* and b* value, which indicated that the redness and yellowness of the biocomposite films compared to control films. This is in line with Sharma et al. (2023), who prepared polylactic acid (PLA) and polybutylene adipate-co-terephthalate (PBAT) composite blend films incorporated with titanium dioxide (TiO_2) and cinnamon EO, and found that the b* value increased with the concentration of cinnamon EO. This may due to the

phenolic composition as well as the natural yellow colour of cinnamon essential oil (Hasheminya & Dehghannya, 2021).

Table 4. Colour of biocomposite based film incorporated with different concentration of cinnamon EO

Sample	L*	a*	b*
SBPCSF	45.70±1.31[a]	11.50±1.33[c]	6.53±0.48[c]
BPCSF1	37.47±1.46[b]	18.60±0.34[a]	19.75±2.20[a]
BPCSF3	36.40±1.38[b]	13.11±1.64[c]	12.83±2.06[b]
BPCSF5	35.38±1.21[b]	16.17±0.88[b]	16.92±0.75[ab]

SBPCSF (control film without cinnamon EO), BPCSF1 (banana peel and corn starch film with 1% cinnamon EO), BPCSF3 (banana peel and corn starch film with 3% cinnamon EO, BPCSF5 (banana peel and corn starch film with 5% cinnamon EO)

*Means that do not share a letter are significantly different

FTIR

Fourier transform infrared (FTIR) spectra of biocomposite films incorporated with different concentration of cinnamon EO, as well as cinnamon EO alone is shown in Figure 4. It can be seen from the Figure 4(a) that presented the FTIR spectrum of cinnamon EO. The peak displayed at 3028 cm^{-1} was assigned to C-H stretching. The cinnamon EO exhibited characteristic peak at 1680 and 1620 cm^{-1} indicating aldehyde carbonyl C==O stretching vibration. The peak at 1580 cm^{-1} was caused by the vibration of the benzene ring skeleton of cinnamon EO (Han et al., 2018). The band at 1126 cm^{-1} corresponded to the C-O-H stretching of other phenolic compounds (Wen et al., 2016). The cinnamon EO had some distinctive peaks at 690, 748, 1450 cm^{-1}, which corresponded to the phenyl group of cinnamaldehyde (Chen et al., 2023).

FTIR spectra of banana peel and corn starch film with different concentrations (0%, 1%, 3% and 5%) were shown in Figure 4 (b), (c), (d) and (e), respectively. For SBPCSF, BPCSF1, BPCSF3 and BPCSF5, there was broad absorption band at 3020 – 3600 cm^{-1} due to stretching of the O-H groups form by the bonding of O-H at the end of polymer chain of starch and plasticizers (Sanyang et al., 2016). The peak also corresponds to stretching of hydroxyl group (-OH) caused by the vibrational stretching occur in carbohydrate structure (Kiran et al., 2022). The intensity of the C-H peak at about 2920 cm^{-1} increased significantly with the increased concentration of cinnamon EO incorporated into biocomposite based film. This indicating that the content of ester groups increased may due to the C-H bond in the cinnamon EO molecule (Shen & Kamdem, 2015). This is supported by Zhou et al. (2021) that the intensity of C-H peak increased significantly with the addition of cinnamon EO. Other than that, the peak at about 1730 cm^{-1} for SBPCSF, BPCSF1, BPCSF3 and BPCSF5 were considered to be the C=O stretching vibration.

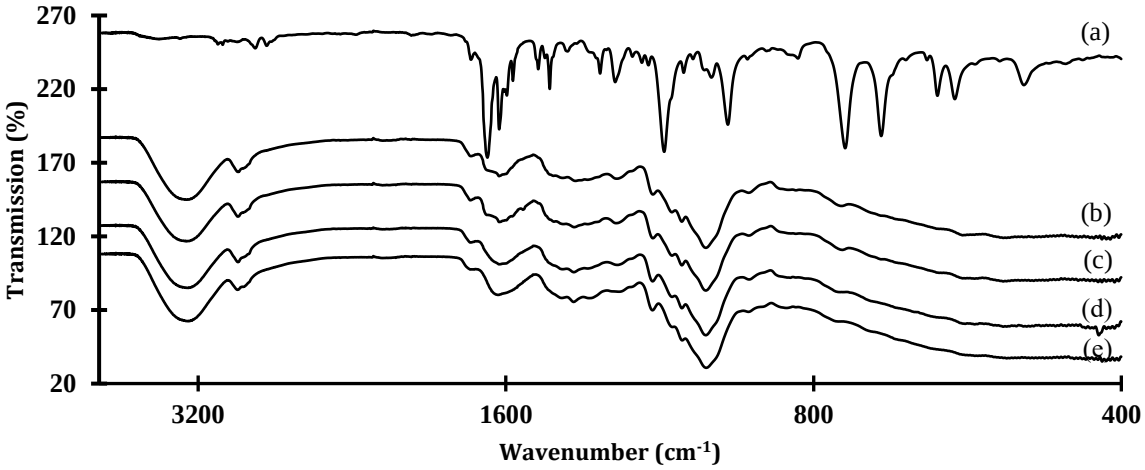

Figure 4. Fourier transform infrared (FTIR) spectra of (a) cinnamon EO (b) SBPCSF (c) BPCSF1 (d) BPCSF3 (e) BPCSF5

Water vapour permeability

The WVP of biocomposite based film incorporated with cinnamon EO is shown in Table 5. There was no significant difference of the film WVP between all sample tested regardless the concentration of cinnamon EO used. Similar occurrence was noticed in a study conducted by Ardjoum et al. (2023) that found the addition of thyme EO has no significant difference in WVP of composite film. This may be due to the presence of pores and holes on the film surface as showed in Figure 5. The pores formation was influenced by the rough, coarse and granulated banana peel powder. This may be due to the present of fibre derived from the outer peel. The pores formation increased the WVP of the film. Other than that, the increased in WVP may be due to the hydrophobic structure of the cinnamon EO that help in restraining or prolonging the penetrating of water vapour molecules through the films (Zhou et al., 2021). Other than that, microstructure of film determines the amount of WVP, and addition of EO can weaken intermolecular interaction of polymers and trap air bubbles in the film- increase water vapour transfer through the film (Maryam et al., 2023).

Table 5. The water vapour permeability (WVP) value of biocomposite based film on different concentration of cinnamon essential oil.*

Sample	WVP (g/msPa)
SBPCSF	0.0151±0.0041[a]
BPCSF1	0.0144±0.0030[a]
BPCSF3	0.0167±0.0066[a]
BPCSF5	0.0196±0.0034[a]

SBPCSF (control film without cinnamon EO), BPCSF1 (banana peel and corn starch film with 1% cinnamon EO), BPCSF3 (banana peel and corn starch film with 3% cinnamon EO, BPCSF5 (banana peel and corn starch film with 5% cinnamon EO)

*Means that do not share a letter are significantly different.

Figure 5. Texture surface of banana peel and corn starch film incorporated with cinnamon EO

Water solubility

Figure 6 shows the water solubility of the biocomposite film based on different concentration of cinnamon EO. There was a significant difference ($p<0.05$) of water solubility between control film with other biocomposite films regardless any concentration of cinnamon EO used. This is in agreement with Fasihi et al. (2023) which obtained water solubility of film decreased with the addition of ginger EO. This could be attributed to the hydrophobic nature of cinnamon EO as well as the interaction between cinnamon EO and polymer matrix (Chen et al., 2023). Ghasemlou et al. (2013) also stated that increase addition of essential oil will eventually decrease the hydrophilicity of the film.

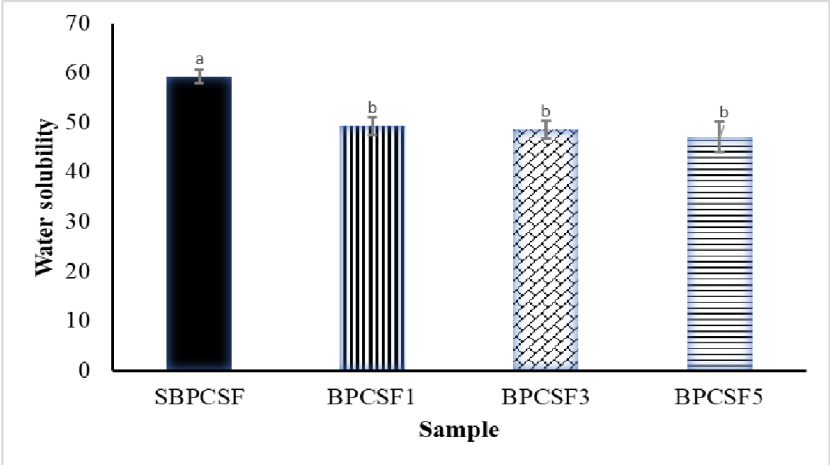

Figure 6. Water solubility of composite based film using different concentration of cinnamon essential oil

SBPCSF (control film without cinnamon EO), BPCSF1 (banana peel and corn starch film with 1% cinnamon EO), BPCSF3 (banana peel and corn starch film with 3% cinnamon EO, BPCSF5 (banana peel and corn starch film with 5% cinnamon EO)

*Means that do not share a letter are significantly different.

Conclusion

In conclusion, incorporation of cinnamon EO in biocomposite based film develop from banana peel and corn starch significantly increased the antimicrobial properties against *S. aureus, B. cereus, Salmonella* and *E. coli*. The thickness of biocomposite films significantly increased with addition of cinnamon EO. Besides, addition of cinnamon EO into biocomposite film significantly decreased the lightness and water solubility of the film, while the water vapour permeability of biocomposite films were not significantly affected with the addition of cinnamon EO. In addition, the incorporation of cinnamon EO

into biocomposite films reduced the tensile strength of the film. Overall, incorporation of cinnamon EO in banana peel and corn starch film improves its antimicrobial activity and barrier properties but weakens its tensile strength.

Acknowledgement/Funding

The author received no financial support for the research. The author would like to thank Faculty of Fisheries and Food Science, University Malaysia Terengganu for the facilities provided.

Author Contribution

FNNN Khairul Jamil - Conceptualization, data curation and writing draft; MK Zainol - writing- review and editing; AS Hasim - Supervision, writing- review and editing.

Conflict of Interest

The author declares no conflict of interest.

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