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Research

Durian albedo and eggshell-based smart edible film with infused butterfly pea flower extract as active agent

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Abstract

The aims of this research are to investigate the effects of different concentrations of butterfly pea flower extract infusion as an active agent on the properties of durian fruit albedo and eggshell-based smart edible films. The butterfly pea flower was extracted using water with the ratios of 1:50 (T1), 1:100 (T2), 1:150 (T3), 1:200 (T4), 1:250 (T5), and 1:300 (T6) (w/v). The film was formulated using durian albedo, eggshell, sorbitol, and cornstarch, which was mixed with butterfly pea flower extract and mold using the casting method. The analysis performed included anthocyanin and phenolic content, antioxidant activity, tensile strength, elongation, water vapor transmission rate, scanning electron microscopy, Fourier transform infrared spectroscopy, and smart indicator examination using fresh milk model system. Different concentrations of butterfly pea extract affect the physicochemical properties of smart edible film. The increase in extract concentration increased anthocyanin and phenolic contents, which align with the increase in antioxidant activity. Meanwhile, the presence of bioactive compounds in the formulation reduced the tensile strength of the film and increased its elongation, as confirmed by SEM and FTIR results. Smart edible film can act as an indicator in the fresh milk model by changing color according to the change in pH due to milk spoilage.

Keywords Durian albedo · Eggshell · Edible film · Packaging

1 Introduction

Durian (*Durio zibethinus*) is a notable tropical fruit native to Southeast Asia, often called the “king of fruits” due to its formidable size, thorn-covered husk, and strong aroma. Cultivated predominantly in Malaysia, Thailand, and Indonesia, durian plays a crucial role in local economies and cultures [1], featuring prominently in traditional dishes, desserts, and fried snacks [2]. The fruit’s smell of rotten onions, turpentine, and raw sewage leads to its prohibition in many public spaces [3]. Despite this, durian is highly valued for its rich, custard-like flesh. It offers a complex flavor profile ranging from sweet to savory, with notes reminiscent of almonds, garlic, and caramel [4]. It has been studied for its potential health benefits, including antioxidant properties that help reduce oxidative stress [5]. The fruit also contains high levels of sulfur-containing compounds, contributing to its characteristic odor, and may have antimicrobial effects [6].

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Durian waste, particularly the peel poses significant disposal challenges due to its bulk and tough, spiky exterior. The durian peel consists of outer shell and inner albedo. Durian peel has found various innovative applications beyond waste. It is utilized in agriculture as compost and animal feed due to its high fiber content, improving soil fertility and providing a nutrient source [7]. Environmentally, durian peel can be converted into biochar for soil enhancement, carbon sequestration, and activated carbon for water filtration [8]. Industrially, it serves as a raw material for bioenergy production, bioplastics, and paper, offering sustainable alternatives to conventional materials [9]. Additionally, the peel's fibers are used in textile manufacturing [10] and composite construction materials [11], while its antimicrobial properties are being researched for use in natural preservatives [12].

Meanwhile, the albedo of the durian, the white, spongy layer beneath the outer skin, constitutes a significant portion of the fruit's waste. This albedo is rich in dietary fiber and cellulose, presenting opportunities for various sustainable applications. The albedo of durian contains a substantial amount of dietary fiber, which can be beneficial in promoting digestive health when utilized in food products [13]. Additionally, the cellulose content makes it a potential raw material for industrial processes. Durian albedo can be processed into dietary fiber supplements or food products to enhance nutritional value [14].

The durian albedo is rich source of pectin. Pectin is composed of a primary structure featuring α -1,4-linked-galacturonic acid units. These units are partly methyl-esterified and incorporate a minor quantity of rhamnose in the principal chain, along with arabinose, galactose, and xylose in the branching chains. Pectin is known for its gelling, stabilizing, and emulsifying capabilities and highly regarded and safe hydrocolloid that finds extensive application across the food, pharmaceutical, and nutraceutical sectors [15]. The pectin-rich albedo can produce biodegradable plastics and packaging materials, offering a sustainable alternative to traditional plastics [16]. This film is made by extracting other polysaccharides from the durian albedo, which are then processed into a thin, biodegradable, and edible material. These films can be used for food packaging, providing a barrier to moisture and oxygen, thus extending shelf life [17]. Additionally, incorporating natural antioxidant or antimicrobial agents can enhance the film's preservative properties [18, 19].

Chicken eggshells, which effectively absorb carbon dioxide generated by respiration, decomposition, and bacterial activity, can also be utilized as a scavenger agent in edible film formulation [20]. These eggshells are rich in calcium oxide (CaO) and calcium hydroxide (Ca(OH)₂), substances that combine with carbon dioxide to produce calcium carbonate (CaCO₃).

This innovation reduces waste and adds value to durian by-products, contributing to environmental sustainability. Moreover, the infusion of active agents capable of reacting to changes in the surrounding environment can equip the edible material to indicate the quality changes of packaged products, known as smart or intelligent packaging.

Smart edible packaging, derived from natural and biodegradable materials, represents an innovative approach to sustainable food packaging. This type of packaging protects food and integrates smart features such as indicators for freshness, spoilage, and temperature changes. For example, incorporating natural dyes or pH-sensitive compounds can create color-changing indicators that signal food spoilage or contamination [21]. Additionally, these films can be enhanced with antioxidant or antimicrobial agents to prolong shelf life and ensure food safety.

Butterfly pea extract (*Clitoria ternatea*) can be a smart agent in edible packaging due to its natural pH-sensitive properties. The extract contains anthocyanins, which change color in response to pH variations, making it an excellent indicator of food freshness and spoilage. When incorporated into edible films, butterfly pea extract can visually signal changes in the food's condition. For instance, the extract is typically blue in a neutral pH environment. As the pH shifts to acidic, it turns red, and in basic conditions, it becomes greenish yellow [22]. In addition, butterfly pea extract is rich in phenolic compounds, contributing to its potent antioxidant activity. Studies have identified significant levels of phenolics such as anthocyanins, flavonoids, and phenolic acids in the extract. These compounds scavenge free radicals, preventing oxidative stress-related damage in biological systems. Research demonstrates that the high phenolic content in butterfly pea extract is closely linked to its strong antioxidant capacity, making it a valuable natural source of health-promoting antioxidants [23]. Research revealed that the infusion of butterfly pea extract into edible film formulation could function as an indicator and, at the same time, prolong the product's shelf life [18].

The number of studies on edible film is increasing rapidly. However, limited information is available on the utilization of durian albedo as edible film materials, and no published research has been found on the effects of the infusion of butterfly pea flower extract on the physicochemical characteristics of durian albedo-based edible film and its function as smart packaging. Therefore, this research aims to investigate the effects of different concentrations of butterfly pea flower extract infusion as an active agent on the properties of durian albedo-based edible film.

2 Materials and methods

2.1 Materials

The main ingredient for this research is durian albedo collected from the medium-scale durian-based food and beverage industry in Surabaya. Meanwhile, the eggshell was purchased from farmers in the Depok district, Banten Province, Indonesia. Cornstarch was commercially available from Egafood Co., Jakarta, Indonesia, and sorbitol (Sorbitol Liquid D Sorb; 0.133% reducing sugar; 6.82% total sugar) was purchased from Sorini Towa Berlian Corp. Moreover, CH_3COONa , KCl , Na_2CO_3 , HCl , and methanol were purchased from Merck, Germany. In addition, 2,2-diphenyl-1-picrylhydrazyl (DPPH), Folin Ciocalteu, and gallic acid were obtained from Sigma Chemical, Singapore. The freshly cut chicken breast was purchased from a traditional market in Surabaya, Indonesia.

2.2 Preparation of butterfly pea flower extract

The undesirable elements were removed from the butterfly pea flower by sorting and washing with tap water. Next, a tray with the flower was put in a cabinet drier set to 60 °C for 24 h. A grinder was used to powder the dried butterfly pea flower. The powder was put in an erlenmeyer flask and extracted with water at 80 °C for 1 h while the shaker was running at 125 rpm. The ratios used were 1:50, 1:100, 1:150, 1:200, 1:250, and 1:300 (w/v). Whatman filter paper No. 42 was utilized to filter the extracted substance. The collected supernatant was kept chilled until needed, and then it was put in a brown bottle and refrigerated.

2.3 Preparation of durian albedo

The durian albedo color was yellowish-white and had a fresh aroma. Then, the albedo was collected using a spoon and knife. The albedo was washed in tap water to remove the remaining durian flesh and other impurities. After that, 100 g of the albedo was weighed, and 500 mL of butterfly pea extract was added. Then, the mixture was crushed using a blender at 18,000 rpm for 3 min until fine puree was obtained.

2.4 Smart edible film production

A 100 g of durian albedo puree was placed in a glass container. Then, 2 g of sorbitol, 1.5 g of corn starch, and 0.5 g of eggshell powder was added. After that, the mixture was properly homogenized and heated to 80 °C for 3 min with constant stirring. Then, the mixture was left to cool until 40 °C. Immediately, 50 g of the mixture was placed into the aluminum sheet that functioned as a mold. Then, stainless steel tools were used to cast the solution. After spending 24 h in the storage room (23 °C, 60% relative humidity) until dry, the edible film was removed from the mold and kept for further analysis.

2.5 Extraction of edible film

The edible film was extracted using a previously published method [24]. In brief, a 1.5 g sample, 15 mL of methanol, and 30 mL of distilled water were stirred in the Erlenmeyer for 1 min and shaken constantly at 40 °C for 1 h using a water bath. Whatman filter paper no. 42 was used to filter the extract, and the supernatant was collected.

2.6 Anthocyanin content

The pH differential method [25] was applied to determine the anthocyanin content. In brief, two tubes containing 10 mL of buffer pH 1 and buffer pH 4 in each tube were prepared. Then, 1 mL of extract was added to each tube,

vortexed for 1 min, and immediately stored for 8 min. The absorbance was measured at 530 and 700 nm using a spectrophotometer. The total anthocyanin was determined using Eq. (1)

$$\begin{aligned} & \text{Total anthocyanin content (mg cy-3-glu equivalent/100 g sample)} \\ &= \frac{A \times MW \times DF \times 1000}{(\epsilon \times l)} \times \frac{\text{total extract's supernatant (mL)}}{\text{sample (g)}} \times 100 \text{ g sample} \end{aligned} \quad (1)$$

5 A is the absorbance ($A_{530\text{nm}} - A_{700\text{nm}}$)_{pH 1.0} - ($A_{530\text{nm}} - A_{700\text{nm}}$)_{pH 4.5}. MW is the molecular weight of cyanidin-3-glucoside = 449.2 g/mol. DF is the dilution factor. ϵ is the molar absorptivity of cyanidin-3-glucoside = 26,900 L/(mol cm). L is the length of the cuvette = 1 cm.

2.7 Phenolic content

The Folin Ciocalteu was used to determine the phenolic content [26]. Phenolic compounds measured by the Folin–Ciocalteu (FC) method are defined as aromatic compounds containing one or more hydroxyl groups (–OH) directly attached to an aromatic ring structure (phenol group). These compounds exhibit reducing properties, enabling them to react with the Folin–Ciocalteu reagent under alkaline conditions. In brief, 1 mL of extract was placed in a tube. Then, 9 mL of distilled water was added, homogenized, and diluted ten times. After that, 1 mL of diluted extract was pipetted, and 0.5 mL of Folin Ciocalteu was added. The reaction tube was then stored in a dark room for 8 min, and 4.5 mL Na₂CO₃ 2% was added. The tube was then stored for 1 h. The spectrophotometer was used to measure the absorbance at 765 nm. Gallic acid was used as standard. Therefore, the phenolic content was expressed as mg Gallic Acid Equivalent/100 g sample and calculated using Eq. (2)

$$\text{TPC (mg GAE/100 g sample)} = \frac{\text{total phenolic (ppm)}}{1000 \text{ mL}} \times \frac{\text{sample (mL)}}{\text{sample (g)}} \times 100 \text{ g sample} \times \text{Dilution Factor} \quad (2)$$

2.8 DPPH radical scavenging capacity

The DPPH method was performed using an established procedure [25]. Briefly, 0.25 mL, 0.5 mL, and 4 mL of extract, 0.1 mM DPPH solution, and methanol were added to a reaction tube. Then, the tube was vortexed and stored in a dark container for 30 min. The absorbance was measured spectrophotometrically at 517 nm. Meanwhile, water was used as a control. The DPPH radical scavenging activity (RSA) define as the ability of an antioxidant to neutralize free radicals by donating an electron or hydrogen atom, thereby preventing oxidative damage in biological systems. This activity is expressed as a percentage and calculated based on the reduction in free radical concentration after treatment with the antioxidant. Therefore the RSA was determined using Eq. (3).

$$\text{RSA} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100\% \quad (3)$$

2.9 Tensile strength and elongation

The ASTM D 882-18 method using a Universal Testing Machine (Zwick I Model Z0.5, UK) investigated both tensile strength and elongation. The edible film was cut into 145 mm length and 10 mm width. Meanwhile, the machine was set to the established setting (preload value of 2 N, test speed of 50 mm/min, and initial grip distance of 100 mm). The test was performed in triplicate.

2.10 Water vapor transmission rate (WVTR)

The Water Vapor Transmission Rate was examined using the gravimetric method [27]. Briefly, 10 g of dry silica gel was added in a shot glass. Then, 20 cm² of edible film was used to tightly seal the tip of the glass, stored in a desiccator containing saturated NaCl (RH 75%) at 26 °C. The absorption of water through the film was measured from the weight difference of the container each day of storage (g/m² per day).

2.11 Scanning electron microscopy

The smart edible film morphological analysis was conducted using a scanning electron microscope (FEI Inspect S50, Hillsboro, OR, USA) with a magnification of 1000x. The samples were coated with a thin layer of gold using an SPI Supplies/D2 Diode Sputtering System [28].

2.12 Fourier transform infra-red (FTIR) analysis

FTIR spectroscopy is measured within the 4000–400/cm range using Nicolet iS 10 FT-IR Spectrometer, Thermo Fisher Scientific, Waltham, Massachusetts, US. The optical setup was based on transmittance for the translucent edible packaging with an optical length path of 1 mm. Spectroscopy measurement was done on intact film, and the data was recorded as percent transmittance (%T), which translates to the amount of light that passed through the sample and was not absorbed or reflected. The Lambert–Beer Law transformed the data to absorption ($-\log T$) for chemical component evaluation [28].

2.13 Application of smart edible film as packaging indicator in fresh milk model

Briefly, 25 mL of fresh milk was stored in an opaque plastic jar ($d = 7.5$ cm; $h = 5$ cm), and the top of the jar was sealed using edible films. The container was stored at room temperature for 3 days (72 h). The color and pH of the edible films and the milk were determined every 24 h. The color was determined using Konica Minolta color reader cr-20. The equipment uses the *CIE Lab color space** and other derived color metrics, such as hue and chroma, to quantify and describe colors. The *Lab** color model is a three-dimensional representation of color, designed to be perceptually uniform and device independent. L^* is the Lightness, a^* is the red-green axis and b^* is the yellow-blue axis. Meanwhile, Hue is the color's "shade" or "type" and is derived from the a^* and b^* values. It is calculated as an angular position in the color wheel (0° to 360°). The chroma and hue can be calculated using formula 4 and 5.

$$\text{Chroma} = \sqrt{a^{*2}b^{*2}} \quad (4)$$

$$\text{Hue} = \arctan(b^*/a^*) \quad (5)$$

2.14 Statistical analysis

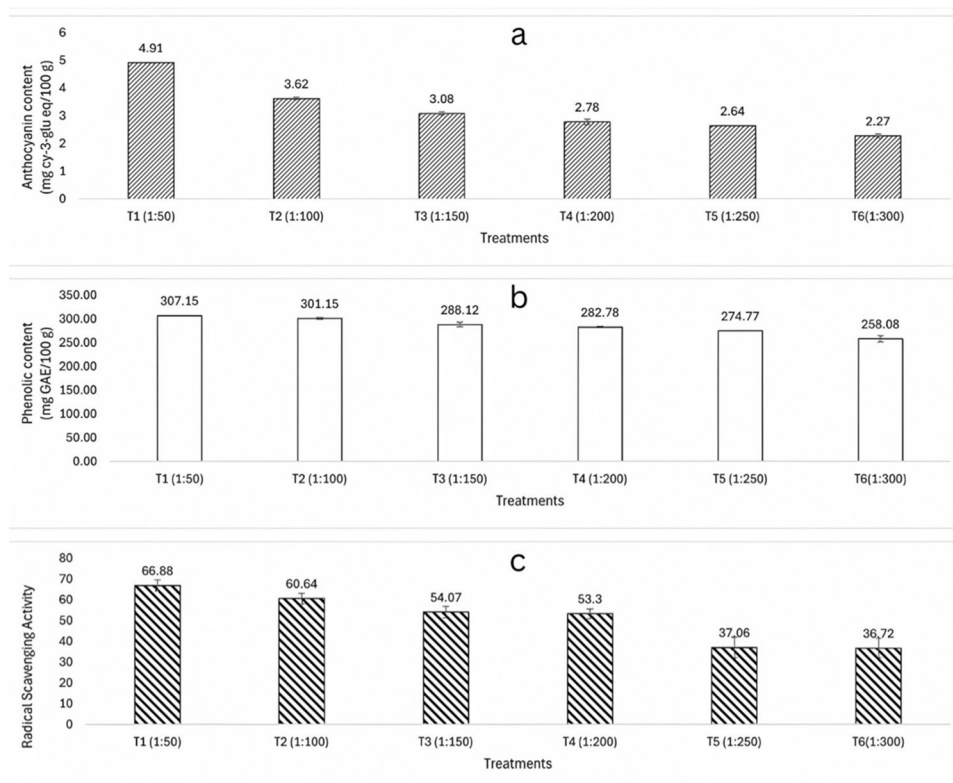
A single factor Randomized Block Design (RBD) was used for the experiment with the concentration of extract was the variable used. All analysis was performed in four replications. The data obtained were analyzed by ANOVA at $\alpha = 5\%$, followed by Duncan's Multiple Range Test (DMRT) using SPSS version 23.

3 Result and discussion

3.1 Anthocyanin content

The results showed that the highest anthocyanin value was in the T1 treatment, and the lowest was in the T6 treatment (Fig. 1a). The results show that the lower the butterfly pea flower extract concentration, the lower the total anthocyanins produced in smart edible film packaging. Anthocyanins are included in the group of flavonoid compounds, which are part of polyphenolic compounds, so the total anthocyanin results in smart edible film packaging will be aligned with the total phenol. The total anthocyanin content will generally be directly proportional to the phenol produced. This is in accordance with the same trend between the total phenol and anthocyanin results in the smart edible film packaging. The result aligns with a previously published study [29], which used anthocyanin as a freshness indicator in intelligent food packaging application at different concentrations and revealed that a higher extract concentration would provide a higher anthocyanin content in the film. Similar research suggested increased butterfly pea flower extract will increase

Fig. 1 **a** Anthocyanin, **b** phenolic content, and **c** antioxidant activity of smart edible film



the anthocyanin content. Moreover, anthocyanin from butterfly pea extract is suitable for pH indicators applied in gelatin-based film due to its sensitivity [30]. Other ingredients to produce edible film such as durian albedo and eggshell powder did not contribute to the total anthocyanin content.

3.2 Phenolic content

The total phenolic obtained in this study ranged from 258.08–307.15 mg GAE/100 g sample. Figure 1b. showed that the highest total phenolic content was in the T1 treatment, and the lowest phenol content was in the T6 treatment. Based on the results, the higher the concentration of butterfly pea flower extract added to smart edible film packaging, the higher the total phenolic content observed. The results follow previously published work, which states that high concentrations of butterfly pea flower extract have high levels of total phenol [22]. Previously published research revealed that the lower ratio of butterfly pea flower to water used in the extraction resulted in the low phenolic content determined [31]. Moreover, using butterfly pea extract on double-layer film revealed that the higher concentration contributes to increased phenolic compound in the film [18]. The phenolic compound of butterfly pea extract can be used as a dye in film due to their bioactive properties [32]. In addition to the butterfly pea extract, durian albedo also contributes to the phenolic content of edible film. The albedo of durian contains significant amounts of phenolic compounds and flavonoid [33, 34] that can supply the phenolic compound in the edible film.

3.3 Radical scavenging activity

The antioxidant analysis aims to determine the effect of butterfly pea flower extract concentration on the antioxidant activity of smart edible film packaging. The test results show that the antioxidant activity of smart edible film packaging ranges from 36.72%–66.88%. The antioxidant activity of butterfly pea flower extract is contributed by anthocyanin and other phenolic compounds. The bioactive compound in the extract will donate its electron to stabilize free radicals. The DPPH method is a model used to examine the capability of components in the extract to donate their hydrogen atom to a DPPH radical, creating new bonds and transforming the DPPH radical into the stabilized compound, as shown in the yellow color of the solution [35].

The results of this study (Fig. 1c) show that the trend value decreases along with the decreasing concentration of butterfly pea flowers added to the smart edible film. The results can be caused by the butterfly pea flower extract concentration used. The higher the concentration added, the more antioxidants will be extracted. The results support previously published findings suggesting that butterfly pea extract is rich in bioactive compounds such as phenolic, flavonoids, and anthocyanin. Such compounds play a key role in the ability of the extract to act as antioxidants, with the higher concentration of extract contributing to the alleviation of antioxidant activity [22, 36, 37]. Moreover, butterfly pea extract was reported contribute 28% of the radical scavenging activity of gelatin-based film [38]. Similar result was obtained previously in the use of butterfly pea extract infusion on carboxymethyl cellulose/agar-based intelligent packaging increase their antioxidant activity [39]. In addition, the antioxidant activity of durian albedo-based smart edible film was also affected by the bioactive compound in the durian albedo, as reported [40] that durian albedo are rich sources of bioactive compounds such as phenolic and flavonoids.

3.4 Tensile strength

The results showed that the tensile strength of smart edible film packaging ranged from 3581–4876 N/mm², as presented in Table 1. The trend of tensile strength results increased as the concentration of butterfly pea flowers decreased. The higher tensile strength value indicates resistance to damage due to stretching and pressure. The lower concentration of butterfly pea extract indicates the limited availability of bioactive compounds in the smart edible film formulation. The bioactive compounds in the smart edible film will disturb the film's network formation. Therefore, instead of a rigid structure provided by the combination of durian albedo and corn starch, space or pores were formed due to the presence of bioactive compounds in the film. This result aligns with a previous report that the hydrogen bonds within polymer chains increase molecular mobility and, consequently, disrupt the integrity network that causes the high anthocyanin-incorporated gelatin/pectin film's tensile strength to be low [41]. The reduction in tensile strength could result from the presence of bioactive compounds creating an unbalanced microstructure of film [42]. Furthermore, compared to the edible film made of isolated material, the tensile strength of durian albedo-based film shown to be slightly lower. This could be due to the albedo that consisted of various compounds which could inhibit the formation of strong bond [43].

3.5 Elongation

The elongation results for smart edible film packaging ranged from 6.65%–9.04% (Table 1). The trend shows that the higher the butterfly pea flower extract concentration, the higher the elongation percentage. The smart edible film packaging of the T1 treatment had the most elastic characteristics compared to other treatments. The elasticity of the smart edible film packaging can be influenced by the OH groups in anthocyanins of butterfly pea extract, causing disruption of polymer bonds and resulting in inter-molecular spacing. Meanwhile, previous studies have suggested that the butterfly pea extract anthocyanin has a plasticizing effect due to its molecular interaction with hydrocolloids [30]. Furthermore, increased anthocyanin molecule infiltration could increase the free mobility of the chain of molecules, enhancing the flexibility of the film [44]. Similar trend with tensile strength result was observed that the percentage of elongation is slightly lower compared to isolated substances due to the complexity of materials which therefore influence the formation of film network [43].

Table 1 Tensile strength, elongation, and WVTR of smart edible film

Treatment	Tensile strength (N/mm ²)	Elongation (%)	WVTR (g/m ² . 24 h)
T1 (1:50)	3.58 ± 0.53 ^a	9.04 ± 0.7 ^f	156.71 ± 1.87 ^f
T2 (1:100)	3.59 ± 0.12 ^b	8.97 ± 0.32 ^e	140.83 ± 0.71 ^e
T3 (1:150)	3.80 ± 1.01 ^c	8.05 ± 1.32 ^d	136.95 ± 0.36 ^d
T4 (1:200)	3.93 ± 0.53 ^d	7.76 ± 0.63 ^c	133.19 ± 0.88 ^c
T5 (1:250)	4.03 ± 0.56 ^e	7.21 ± 1.74 ^b	127.05 ± 1.83 ^b
T6(1:300)	4.87 ± 0.11 ^f	6.65 ± 1.64 ^a	122.67 ± 0.33 ^a

Mean values in the same column with different letters are significantly different (p<0.05)

3.6 Water vapor transmission rate (WVTR)

The results showed that the WVTR on smart edible film packaging ranged from 122.67–156.7180 g/m². 24 h. The lowest WVTR value was obtained in the T6 treatment, and the highest was T1 with 156.7180 g/m². 24 h. It shows that the WVTR increases with the increasing concentration of the added butterfly pea flower extract. In the T1 treatment, the WVTR value was high because of the large butterfly pea flower extract used. The use of high butterfly pea flower extract will disrupt the stability of the polymer in smart edible film packaging because space forms in the microstructure, causing water molecules to pass through the pores of the film easily and increasing the water vapor transmission [45]. Adding active ingredients containing phenolic compounds can cause interactions among ingredients of edible film. Hydrogen and covalent bonds between phenolic compounds can interact with the film components' materials, disrupting protein interactions and weakening the film network [31]. The WVTR result is significantly lower compared to edible film made of carboxymethyl cellulose with 1008.61 g/m².24 h [27], but higher compared to the edible film made of multi-shaded gelatin and starch [46].

3.7 SEM analysis

SEM analysis offers a more comprehensive understanding of the biodegradable film's microstructure, including evaluating its uniformity, structural integrity, surface smoothness, and any voids or fractures within the film. The findings from the SEM analysis are depicted in Fig. 2. All the films showed structure with some heterogeneity and roughness. As confirmed by the other parameters, the T1 showed heterogeneity with some pores exhibited. The presence of a high concentration of extract disturbs the formation of pectin and starch networks, thus leaving some pores in the structure of the edible film. Meanwhile, in T6, a more homogenous structure was observed. All the samples have a rough upper surface that indicates surface heterogeneity. It is caused by the durian albedo fiber and some eggshell powder, which cannot dissolve completely in the solution. Compared to previously published research using various starch and hydrocolloids, the microstructure of durian albedo-based edible film has the rougher surface and less uniform network. Nevertheless, the structural integrity is similar to other works [47, 48].

3.8 FTIR analysis

The film's appearance remains clear, with a noticeable purple hue due to the inclusion of anthocyanin pigment. The physical and chemical properties of the films were assessed using FTIR spectroscopy analysis. Figure 3. presents the spectra for the three selected treatments. The findings indicate that incorporating varying concentrations of the extract decreases the film's transmittance. A reduction in transmittance typically occurs when light is reflected and absorbed, indicating

Fig. 2 SEM result of smart edible film **a** the upper side and **b** the lower side

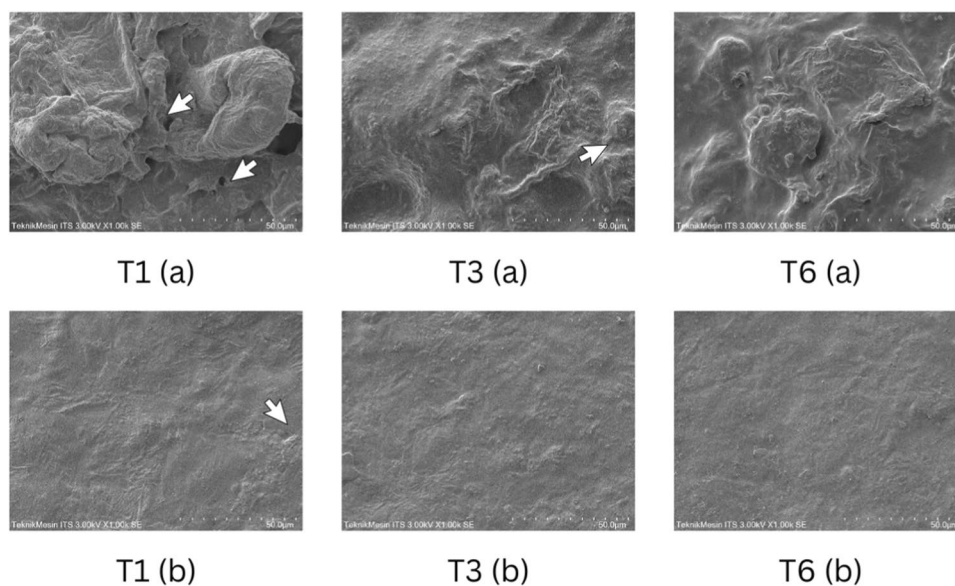
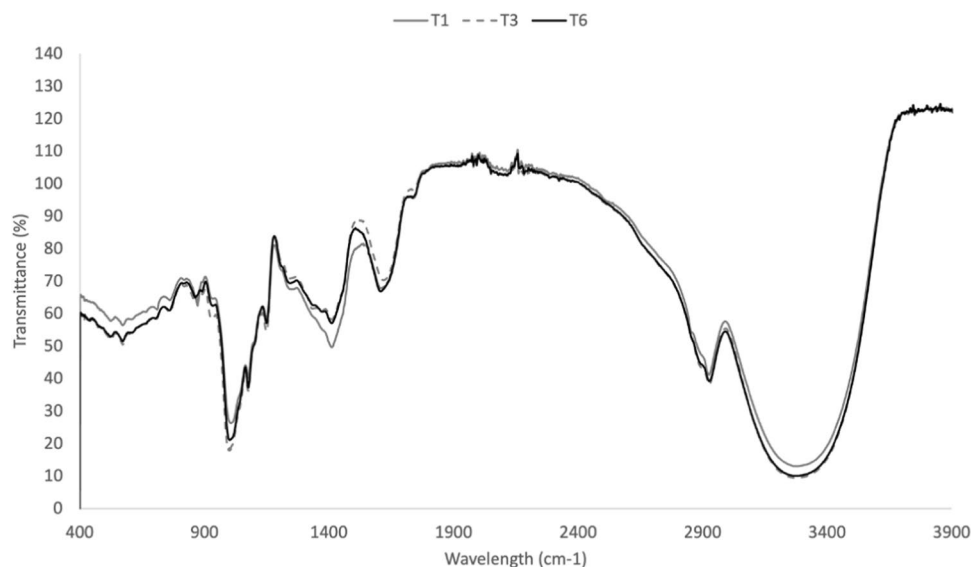


Fig. 3 FTIR result of smart edible film



that the anthocyanins' active absorption components lower the transmittance observed. As the concentration of the absorbing agent increases, the film becomes less transparent. The most prominent peak observed between 3000 and 3400/cm in most spectra is generally linked to the $-OH$ stretching of hydroxyl functional groups. Anthocyanin, being hydrophilic, participates in forming hydrogen bonds within the film. Comparing different treatments reveals that adding pigment causes stretching vibrations, indicating the presence of anthocyanin within the film's matrix. The anthocyanin pigment, largely trapped within the film matrix, is an effective agent for film formation. Similar pattern was observed from previous work indicated the peak around 3450/cm in anthocyanin enriched polyvinyl alcohol-based edible film [49].

3.9 Examination in fresh milk model

3.9.1 Color of smart edible film packaging

Smart edible film packaging with the addition of butterfly pea flower extract has a blue color with different intensities; the greater the ratio of butterfly pea flower extract used, the more intense the light blue color is produced. Based on the results (Table 2), there was a change in the color of the smart edible film packaging during storage, where there was a decrease in the intensity of the blue color in the smart edible film packaging, fading to a greenish color. The data shows that the L^* , a^* , b^* , and chroma values increase as the concentration of the extract used decreases. In contrast, the $^{\circ}h$ value decreases as the butterfly pea flower extract concentration decreases. This is because anthocyanins produce a dark color as the butterfly pea flower extract concentration increases [41]. In contrast, the interaction between the anthocyanin hydroxyl group and the ammonia group of the volatile amine compound can cause a decreasing $^{\circ}h$ value. Studies showed that the addition of anthocyanin extract will affect the $^{\circ}h$ value in the film, where the higher the anthocyanin extract added, the $^{\circ}h$ value will increase. In contrast, if the extract concentration is low, the $^{\circ}h$ value will decrease [50]. During the storage period of 3 days, smart edible film packaging experienced a color change towards greenish, which indicates that smart edible film packaging responded to basic pH. Data show that the pH of cow's milk tends to be acidic because of the spoilage bacteria presence. The longer the storage, the higher pH of the milk will become acidic. Spoilage bacteria will cause protein degradation during storage caused by proteolytic bacteria that produce ammonia gas [51, 52]. Ammonia gas produced by spoilage bacteria will be trapped, causing the edible color to turn yellowish green.

3.9.2 pH of fresh milk

Milk's pH changes were measured to determine the ability of smart edible film packaging to be an indicator of food deterioration, which is expected to indicate the freshness of packaged food products. In this research, milk was used as a model system of food spoilage. The results can be seen in Table 3. Milk on day 0 had a normal pH value for fresh milk, but the pH of milk in all treatments was decreased during storage. Treatment T1 showed a decrease in the inhibition of pH compared

Table 2 Changes in the color of smart edible film packaging used as an indicator of milk deterioration

Treatments	Days	L	a*	b*	Chroma	°Hue
T1	0	40.6 ± 0.6 ^a	-5.7 ± 0.1 ^a	-4.5 ± 0.1 ^a	7.3 ± 0.2 ^a	218.4 ± 1.3 ^d
	1	44.9 ± 0.5 ^b	-6.9 ± 0.1 ^b	-3.6 ± 0.2 ^b	7.6 ± 0.1 ^b	207.7 ± 1.1 ^c
	2	48.7 ± 0.3 ^c	-9.4 ± 0.4 ^c	-2.6 ± 0.3 ^c	9.7 ± 0.4 ^c	195.3 ± 1.0 ^b
	3	50.3 ± 0.4 ^d	-11.5 ± 0.4 ^d	-2.0 ± 0.2 ^d	11.6 ± 0.4 ^d	189.7 ± 1.2 ^a
T2	0	43.4 ± 0.7 ^a	-6.4 ± 0.5 ^a	-1.0 ± 0.1 ^a	6.5 ± 0.5 ^a	188.3 ± 1.5 ^d
	1	47.0 ± 0.6 ^b	-7.8 ± 0.3 ^b	-0.7 ± 0.1 ^b	7.8 ± 0.3 ^b	184.7 ± 0.8 ^c
	2	48.4 ± 0.4 ^c	-9.4 ± 0.4 ^c	-0.4 ± 0.1 ^c	9.4 ± 0.4 ^c	182.1 ± 0.4 ^b
	3	50.2 ± 0.5 ^d	-11.2 ± 0.5 ^d	-0.2 ± 0.1 ^d	11.2 ± 0.5 ^d	180.9 ± 0.3 ^a
T3	0	51.2 ± 0.4 ^a	-8.7 ± 0.2 ^a	1.9 ± 0.1 ^d	8.9 ± 0.3 ^a	167.8 ± 0.6 ^d
	1	54.1 ± 0.4 ^b	-11.1 ± 0.3 ^b	3.1 ± 0.3 ^c	11.5 ± 0.4 ^b	165.0 ± 0.6 ^c
	2	56.2 ± 0.3 ^c	-12.4 ± 0.4 ^c	3.5 ± 0.3 ^b	12.9 ± 0.4 ^c	164.2 ± 0.9 ^b
	3	58.8 ± 0.4 ^d	-13.8 ± 0.5 ^d	4.3 ± 0.3 ^a	14.4 ± 0.5 ^d	162.8 ± 0.7 ^a
T4	0	55.3 ± 0.5 ^a	-10.0 ± 0.4 ^a	3.5 ± 0.3 ^a	10.8 ± 0.8 ^a	161.0 ± 1.3 ^d
	1	58.9 ± 0.5 ^b	-12.0 ± 0.6 ^b	4.5 ± 0.4 ^b	12.8 ± 0.6 ^b	159.4 ± 1.4 ^c
	2	63.1 ± 0.5 ^c	-13.0 ± 0.3 ^c	5.0 ± 0.2 ^c	13.7 ± 0.7 ^c	158.6 ± 0.6 ^b
	3	65.5 ± 0.4 ^d	-14.3 ± 0.3 ^d	5.9 ± 0.3 ^d	15.5 ± 0.4 ^d	157.7 ± 0.7 ^a
T5	0	56.7 ± 0.2 ^a	-11.6 ± 0.2 ^a	5.1 ± 0.2 ^a	12.6 ± 0.3 ^a	156.0 ± 0.8 ^d
	1	58.5 ± 0.4 ^b	-13.0 ± 0.3 ^b	6.1 ± 0.3 ^b	14.5 ± 0.4 ^b	154.2 ± 1.2 ^c
	2	63.2 ± 0.6 ^c	-14.8 ± 0.7 ^c	7.3 ± 0.4 ^c	16.6 ± 0.9 ^c	153.1 ± 0.4 ^b
	3	66.2 ± 0.6 ^d	-17.5 ± 0.5 ^d	8.8 ± 0.2 ^d	19.8 ± 0.7 ^d	152.0 ± 1.0 ^a
T6	0	58.6 ± 0.2 ^a	-10.9 ± 0.1 ^a	6.7 ± 0.2 ^a	12.8 ± 0.1 ^a	148.4 ± 0.8 ^d
	1	63.0 ± 0.8 ^b	-12.2 ± 0.4 ^b	8.0 ± 0.3 ^b	14.6 ± 0.4 ^b	146.6 ± 0.6 ^c
	2	67.0 ± 0.4 ^c	-14.1 ± 0.4 ^c	10.2 ± 0.6 ^c	17.4 ± 0.7 ^c	144.1 ± 1.1 ^b
	3	68.9 ± 0.3 ^d	-15.7 ± 0.3 ^d	12.3 ± 0.4 ^d	19.9 ± 0.4 ^d	141.8 ± 0.9 ^a

Mean values in the same column with different letters are significantly different (p<0.05)

Table 3 Changes in the pH of milk

Treatment	Days of storage			
	0	1	2	3
T1	6.71 ± 0.01 ^d	5.70 ± 0.36 ^c	4.85 ± 0.18 ^b	4.71 ± 0.16 ^a
T2	6.71 ± 0.01 ^d	5.31 ± 0.40 ^c	4.56 ± 0.08 ^b	4.40 ± 0.12 ^a
T3	6.70 ± 0.01 ^d	4.97 ± 0.25 ^c	4.58 ± 0.10 ^b	4.45 ± 0.03 ^a
T4	6.70 ± 0.01 ^d	5.01 ± 0.29 ^c	4.52 ± 0.09 ^b	4.42 ± 0.06 ^a
T5	6.71 ± 0.01 ^d	5.02 ± 0.30 ^c	4.51 ± 0.07 ^b	4.38 ± 0.06 ^a
T6	6.71 ± 0.01 ^d	5.01 ± 0.30 ^c	4.58 ± 0.06 ^b	4.35 ± 0.05 ^a

Mean values in the same column with different letters are significantly different (p<0.05)

to other treatments because treatment T1 has the highest phenolic and anthocyanin content. The presence of these two bioactive components can act as antioxidants and antimicrobial agents. The decrease in pH during the storage process can occur because the milk has undergone deterioration by bacteria [51]. The presence of bioactive components can inhibit milk damage as indicated by pH value [53]. Previous finding in support of this result which suggests that the presence of bioactive compounds in salep mucilage-based edible film could inhibit the rise of pH due to fish deterioration [21].

4 Conclusion

Food waste such as durian albedo and eggshell can be used as edible film ingredients. Further development of edible film is creating a smart edible film by infusing active agents such as anthocyanin extract from butterfly pea flower. Different concentrations of butterfly pea extract affect the physicochemical properties of smart edible film. The extract

concentration increased anthocyanin and phenolic contents, which aligned with the increase in antioxidant activity. Meanwhile, bioactive compounds in the formulation reduce the film's tensile strength and increase the elongation, as confirmed by SEM and FTIR results. Smart edible film can act as an indicator in the fresh milk model by changing the color according to the pH change due to milk spoilage. Durian albedo and eggshells as food waste have promising results that can be used as ingredients for smart edible film packaging.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The collection of the plants used in the study complies with local or national guidelines with no need for further affirmation.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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