https://doi.org/10.17221/81/2025-CJFS

Preparation and characterisation of antioxidative edible films based on cocoa pods extract incorporating black or green tea extract

Triana Lindriati, Siti Mutimmah, Maryam Husnul Istiqomah, Melania Anggraini, Herlina Herlina, Sih Yuwanti, Asmak Afriliana*

Agricultural Product Technology Study Programe, Faculty of Agricultural Technology, University of Jember, Jember, East Java, Indonesia

**Corresponding author: lindriatitriana@unej.ac.id*

Citation: Lindriati T., Mutimmah S., Istiqomah M.H., Anggraini M., Herlina H., Yuwanti S., Afriliana A., Sukoco A. (2026): Preparation and characterisation of antioxidative edible films based on cocoa pods extract incorporating black or green tea extract. Czech J. Food Sci., 44: 306–314.

Abstract: Cocoa pods are an underutilised agro-industrial waste rich in pectin and polyphenols. This research developed cocoa pod extract as a base material for antioxidant edible films by incorporating black or green tea extracts as solvents. Five formulations were prepared, which differ in solvent: distilled water, 50% *v/v*, and 100% *v/v* of black or green tea extract. Using tea extracts as a solvent significantly ($P \leq 0.05$) increased total polyphenol content, antioxidant activity, and tensile strength, while reducing solubility, elongation, and water vapour transmission rate. Green tea extract showed higher effects than black tea extract. The edible film prepared with 100% v/v green tea extract exhibited the highest polyphenol content [18.09 ± 1.49 mg gallic acid equivalents (GAE)·g^{-1}] and DPPH (2,2-diphenyl-1-picrylhydrazyl) inhibition (52.28 ± 2.6%), and effectively prevented peroxide formation in peanut oil. Fourier transform infrared spectroscopy (FTIR) analysis revealed enhanced hydrogen bonding between macromolecules upon incorporation of tea extracts, thereby improving mechanical strength and water barrier properties. These results show the potential of cocoa pod extract, when incorporated with green tea extracts, to produce a good physical and mechanical performance while preserving antioxidant properties.

Keywords: mechanical properties; water vapour transmission rate; total polyphenol; antioxidant properties; FTIR

Plastics are widely used for food packaging due to their low cost and practicality; however, concerns about their environmental impact and food safety have driven the search for alternatives. Edible films have been shown to be a promising solution because they are eco-friendly, safe, and capable of incorporating active compounds, such as polyphenols, to inhibit oxidation. The incorporation of polyphenols into edible films offers an effective packaging solution to extend shelf life (Gao et al. 2019; Lei et al. 2019; Lindriati et al. 2015, 2025).

Supported by the University of Jember Internal Grant through the KeRis-Dimas Grant programme, Project No. 4241/UN25.3.1/LT/2022.

https://doi.org/10.17221/81/2025-CJFS

Edible films, which are usually made from natural food sources such as carbohydrates and proteins, can be made more sustainable and efficient by using agricultural waste. One underutilised part of agricultural waste is cocoa pods. Cocoa (*Theobroma cacao* L.) is one of Indonesia's primary plantation commodities, and cocoa pods account for 70–75% of the cocoa fruit's total weight (Sarah et al. 2022). Cocoa pods are rich in pectin, containing between 7.49 to 11.31% (Hennessey-Ramos et al. 2021), and polyphenols, which range from 46 to 69 mg GAE·g^{-1} (Vásquez et al. 2019). Many studies have explored the valorisation of the cocoa pod (Meza-Sepúlveda et al. 2025; Santiago-Gómez et al. 2025; Vu et al. 2025). However, its exploration as an antioxidative edible film still remains.

The research of Desniorita et al. (2019) demonstrated the use of pectin from cocoa pods as an edible film component, focusing on water content, thickness, water vapour transmission rate, and colour. Other studies have applied pectin from cocoa pods as an edible coating to extend the shelf life of tomatoes (Susilowati et al. 2017). There are no studies examining the whole cocoa pod extract, even though valuable polyphenolic compounds are often wasted during pectin extraction. To fully utilise the benefits of both pectin and polyphenols, the whole cocoa pod extract can be used as an antioxidant and as an edible film-based material.

Antioxidant activity can be enhanced by incorporating polyphenol-rich extracts, such as tea extracts. Both green and black tea contain high concentrations of polyphenols, but black tea has lower levels because fermentation alters the decomposition of polyphenols (Kopjar et al. 2015). Green tea is richer in catechins (16–30%), particularly epigallocatechin gallate (50–80% of total catechins), whereas black tea contains lower catechin levels (3–10%) and is dominated by theaflavins and thearubigins (Chen et al. 2023). Differences in polyphenol composition offer opportunities to modify the properties of edible films. Previous study showed that green tea extract can enhance the physical and mechanical properties of edible films through cross-linking interactions, including hydrogen bonding and hydrophobic forces, thereby strengthening the film structure (Lindriati et al. 2015; Ruan et al. 2019).

Our research studied antioxidative edible films prepared with cocoa pod extract as the primary film-forming material and green or black tea extract as the solvent, enabling the matrix to exhibit intrinsic antioxidant properties. The effects of tea extract on tensile strength, elongation, solubility, water vapour permeability, and antioxidant properties were evaluated. The interactions between components were analysed using Fourier transform infrared spectroscopy (FTIR). A preliminary application was evaluated using peanut oil to study the potential of these films to inhibit rancidity. Overall, this research offers a smart strategy for valorising agricultural waste into valuable antioxidative packaging.

MATERIAL AND METHODS

Material. Cocoa pods were obtained from local farmers in Jember, East Java, Indonesia, at a certain maturity (red colour). The composition of cocoa pods was crude protein (7.21 ± 0.22%), fat (1.83 ± 0.07%), carbohydrate (33.47 ± 0.33%), pectin (11.76 ± 0.28%), ash (7.83 ± 0.61%), and polyphenols [47.54 ± 0.78 mg gallic acid equivalents (GAE)·g^{-1}]. Soy protein isolate (SPI) and food-grade glycerol were purchased from a local distributor. The SPI composition was crude protein (91.54 ± 0.32%), lipid (0.65 ± 0.07%), fibre (0.12 ± 0.03%), ash (4.36 ± 0.12%), and carbohydrate (3.33 ± 0.21%). Green and black teas ('Cap Kepala Jenggot') had phenolic levels of 235.21 ± 7.81 and 152.27 ± 6.37 mg GAE·g^{-1}, respectively. DPPH (2,2-diphenyl-1-picrylhydrazyl) and gallic acid were obtained from Sigma-Aldrich (USA), while other analytical-grade chemicals were purchased from Merck (Germany).

Pretreatment. Upon arrival, cocoa pods were washed, cut into 0.5–1 cm thick slices, and dried at 50 °C for 20 h. The dried slices were then crushed to a 40-mesh size to obtain a low-moisture-content powder (11–13%) with uniform particle size.

Tea extract preparation. Specifically, 4.8 g of dried tea was extracted in 200 mL of distilled water for 30 min at 80 °C under continuous stirring (120 rpm). After cooling, the extract was filtered and stored at 4 °C for use as a solvent in the preparation of edible films. The process followed Lindriati et al. (2015) for maximum polyphenol concentration.

Preparation process of cocoa pod extract. The cocoa pod extract was prepared by microwave-assisted extraction (MAE), with cocoa pod powder dissolved with solvent at a 1: 20 (*w/v*) ratio (5 g in 100 mL), followed by MAE at 360 W for 15 min. The slurry was filtered (Whatman No. 2) and stored at 4 °C for use as an edible film material, resulting in a filtrate rich in pectin. The method was adapted from Sarah et al. (2022), with modifications to the solvents: 100% distilled water, 50% *v/v* black tea extract, 50% *v/v* green tea extract, 100% black tea extract, and 100% green tea extract.

https://doi.org/10.17221/81/2025-CJFS

Pectin content of cocoa pod extract. Ethanol was added to the cocoa pod extract at a 1 : 3 ratio, then centrifuged at 1 200 rpm for 10 min, and filtered. The wet pectin was oven-dried at 50 °C for 24 h, resulting in dried pectin. The pectin content was calculated as the percentage ratio of dried pectin weight to the initial cocoa pod powder weight.

Edible film preparation. Edible films were prepared according to the method of Pająk et al. (2019), with modifications. SPI (8 g) was added to 25 mL of solvent, stirred at 250 rpm for 2 min at room temperature, then 75 mL of cocoa pod extract was added, and the mixture was heated to 80 °C for 10 min. Glycerol (2.5 g) was added, and the mixture was further heated and stirred at 60 rpm and 80 °C for 10 min. 60 mL of the film-forming solution was cast onto 18 × 13 cm^2 Teflon plates and dried at 50 °C for 18 h. The films were removed and kept in a desiccator at 25 °C and 40% relative humidity (RH). Five film types were produced based on solvent variation: distilled water (EF), 50% *v/v* black tea extract (BTE 50), 50% *v/v* green tea extract (GTE 50), 100% black tea extract (BTE 100), and 100% green tea extract (GTE 100).

Solubility. The solubility was measured using a modified version of the method described by Gontard et al. (1994). A 20 × 20 mm^2 of film was immersed in 30 mL of distilled water at 25 °C for 24 h. Before and after immersion, the edible film was dried at 105 °C for 24 h and then weighed. Measurements were done in triplicate. Solubility (%) was calculated as:

$$Solubility\,(\%) = \left(W1 - W2\right) / W1 \times 100\% \tag{1}$$

where: $W1$ – the initial dry weight; $W2$ – the dry weight after immersion.

Tensile strength and elongation. Tensile strength and elongation at break were measured following ASTM D882-00 method, as in Pająk et al. (2019). Film strips (80 mm × 25 mm) were tested using an AZ-SX texture analyser (Shimadzu, Japan). Tensile strength was calculated by dividing the maximum tensile force (N) by the cross-sectional area of the specimen (mm^2). Elongation was expressed as a percentage of increase in length at break divided by the initial length. Each sample was tested in five replicates.

Water vapour transmission rate. The water vapour transmission rate (*WVTR*) was measured according to ASTM (2003), as Siripatrawan and Harte (2010). Edible films were applied to glass cups (3.5 cm in diameter) containing 10 g of silica gel, and the cups were placed in a desiccator containing 40% (*w/v*) NaCl solution to maintain 75% relative humidity at 25 °C. The weights of cups were evaluated hourly for 8 h using an analytical balance (A200S, Sartorius, Germany). *WVTR* was presented as a ratio of the slope of the linear relationship between weight gain and time to the film's cross-sectional area, expressed in $(g\cdot m^{-2})\cdot h^{-1}$. There were three replications for each sample.

Measurement of total polyphenol content. The Folin–Ciocalteu method was used to determine total polyphenol as described by Ainsworth and Gillespie (2007). A 2.1 g of edible film was extracted in 100 mL of distilled water by stirring at 60 rpm for 30 min (Lindriati et al. 2015). A 0.1 mL of the edible film's extract was mixed with 0.5 mL Folin–Ciocalteu reagent and 1 mL ethanol, vortexed, and rested for 5 min at room temperature, then 5% Na_2CO_3 was added. The mixture was incubated in the dark room for 60 min. The absorbance was observed at 765 nm using a UV–Vis spectrophotometer (Genesys 10S, Thermo Scientific, USA). The total polyphenol content was expressed as mg $GAE\cdot g^{-1}$ using a gallic acid standard curve. There were at least three replications for each sample.

Antioxidant activity measurement. The edible film's antioxidant activity was measured using the DPPH radical scavenging method, as in Jouki et al. (2013). Briefly, 25 mg of edible film was extracted in 5 mL of distilled water. Then, 0.01 mL of the extract was mixed with 0.5 mL of 0.1 mM DPPH solution in ethanol. The mixture was placed in the dark at room temperature for 60 min, resulting in a colour change from violet to pale yellow. Absorbance was evaluated at 517 nm using a UV–Vis spectrophotometer. Antioxidant activity was presented as the percentage DPPH inhibition that calculated as:

$$Antioxidant\ activity = \frac{(A_0 - A_{sample})}{A_0} \tag{2}$$

where: A_0 – the absorbance of the control.

Each sample was measured in three replicates.

Measurement of lipid oxidation inhibition. Lipid oxidation inhibition was measured as described by Lindriati et al. (2015). Briefly, a 10 × 10 cm^2 edible film was placed in peanut oil, and the chamber was incubated at 50 °C for 14 days, with peroxide value evaluated on days 4, 7, 9, 11, and 14, according to method SNI 01-3555-1998. Then the peanut oil (3 g) was mixed with chloroform and glacial acetic acid, reacted with a saturated KI solution, and added to 1% starch as an indicator. The mixture was titrated with sodium thio-

https://doi.org/10.17221/81/2025-CJFS

sulfate until the blue colour disappeared. Peroxide value was presented as meq $O_2 \cdot kg^{-1}$ oil, and all measurements were done in triplicate.

Fourier transform infrared analysis. Fourier transform infrared (FTIR) analysis was performed according to the method of Lei et al. (2019). Firstly, ground samples were mixed with dry KBr and pressed into pellets for analysis using an FTIR spectrometer (Nicolet iS10, Thermo Scientific, USA). Spectra were recorded over 650–4 000 cm^{-1} with a resolution of 4 cm^{-1} and 32 scans per sample.

Data analysis. The Minitab version 17.1.0. (Minitab Inc, USA) was used to evaluate the data. There were triplicate experiments, and the results were expressed as mean ± standard deviation. The differences among groups were statistically assessed using analysis of variance (ANOVA) at a 5% significance level ($P < 0.05$), followed by Tukey's test for comparisons. The superscript letters (a, b, c) indicated significant differences.

RESULTS AND DISCUSSION

The concentration and FTIR spectra of pectin in cacao pod extract. The cocoa pod extract was produced by MAE using distilled water as the solvent at 360 W for 15 min. The result showed that the pectin content of the extract (15.23 ± 0.13% *w/w*) was higher than that of fresh cocoa pods (11.76 ± 0.28% *w/w*), due to moisture removal and cell wall disruption during drying, which promoted extractability. FTIR analysis was performed to assess pectin purity.

Table 1. Total polyphenol content and antioxidant activity of edible film from cocoa pod extract incorporated with tea extract

Sample	Total polyphenol content (mg GAE·g^{-1})	Antioxidant activity (%)
EF	8.71 ± 0.45^{a}	18.72 ± 0.33^{a}
BTE 50	11.17 ± 0.53^{b}	27.60 ± 1.24^{b}
GTE 50	13.02 ± 0.59^{c}	32.79 ± 0.86^{c}
BTE 100	14.37 ± 0.41^{c}	35.61 ± 1.69^{c}
GTE 100	18.09 ± 1.50^{d}	52.28 ± 2.68^{d}

$^{a-c}$ different letters indicate statistically significant differences among groups (P < 0.05, Tukey's test); EF – distilled water; BTE – black tea extract; GTE – green tea extract; GAE – gallic acid equivalents

The study of Wathoni et al. (2019) evaluated standard pectin exhibits characteristic peaks at 3 367.71 cm^{-1} (–OH), 2 939.52 cm^{-1} (C–H), 1 639.49 cm^{-1} (C=O), 1 442.70 cm^{-1} (–CH), and 1 161.15–1 153.43 cm^{-1} (C–O). The pectin extracted from cocoa pods in this study showed similar peaks at 3 262.60 cm^{-1}, 2 922.49 cm^{-1}, 1 726.84 cm^{-1}, 1 598.24 cm^{-1}, and 1 245.78–1 035.66 cm^{-1}, confirming the peaks of typical functional groups of pectin. Although slight shifts were observed due to differences in pectin source, which affect molecular characteristics such as molecular weight and methoxy content (Figure 1).

Total polyphenol content and antioxidant activity. Tea extracts significantly increased the total polyphenol content and antioxidant activity of cocoa pod extract edible films (Table 1), with GTE having a greater effect

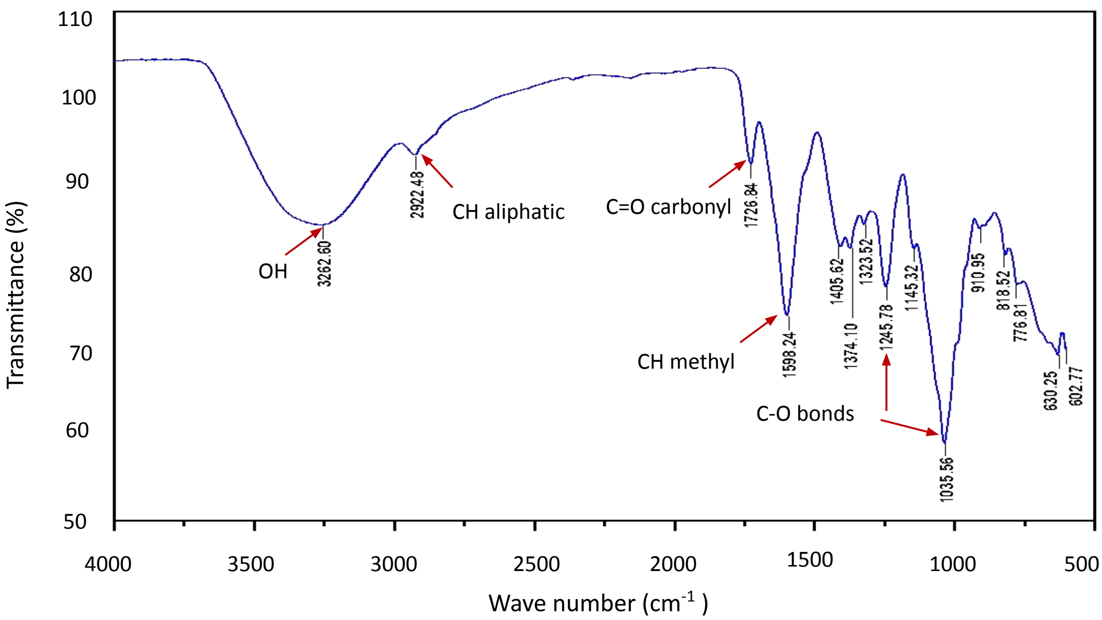

Figure 1. The FTIR (Fourier transform infrared spectroscopy) spectrum of pectin extracted from the cocoa pod

https://doi.org/10.17221/81/2025-CJFS

Table 2. Physical and mechanical properties of antioxidative edible film from cocoa pod extract incorporated with tea extract

Sample	Tensile strength (MPa)	Elongation (%)	*WVTR* [g·m^{-2}(h^{-1})]	Solubility (%)
EF	3.65 ± 0.01^{a}	36.29 ± 0.31^{e}	0.18 ± 0.02^{c}	34.12 ± 0.46^{c}
BTE 50	3.71 ± 0.02^{b}	27.42 ± 0.31^{b}	0.23 ± 0.01^{d}	46.18 ± 0.21^{e}
GTE 50	3.75 ± 0.02^{bc}	34.66 ± 0.26^{d}	0.15 ± 0.02^{b}	31.19 ± 0.34^{b}
BTE 100	3.87 ± 0.02^{c}	24.99 ± 0.20^{a}	0.19 ± 0.02^{c}	44.98 ± 0.04^{d}
GTE 100	3.97 ± 0.03^{d}	33.25 ± 0.53^{c}	0.05 ± 0.01^{a}	28.79 ± 0.16^{a}

$^{a-e}$different letters indicate statistically significant differences among groups ($P < 0.05$, Tukey's test); EF – distilled water; BTE – black tea extract; GTE – green tea extract; *WVTR* – water vapour transmission rate

than BTE. This is due to the higher polyphenol content of green tea (235.21 ± 7.81 mg GAE·g^{-1}) compared to black tea (152.27 ± 6.37 mg GAE·g^{-1}) (Kopjar et al. 2015), as well as its antioxidant activity. The fermentation process in black tea can reduce catechin content and change them into theaflavins and thearubigins, which have lower antioxidant activity (Chen et al. 2023).

The highest values were shown in GTE 100, with a total polyphenol content of 18.09 ± 1.50 mg GAE·g^{-1} and antioxidant activity of 52.28 ± 2.68%. These results are higher than those from rice starch–chitosan edible film with 10% GTE addition (2.374 mg GAE·g^{-1}) (Mangmee and Homthawornchoo 2016), from jack bean flour-based films with extract GTE as solvent (45.22%) (Lindriati et al. 2015), and dragon fruit peel films (14.21 ± 0.14 mg GAE·g^{-1}; 18.84 ± 0.73%) (Lindriati et al. 2025). The comparison shows that edible film from cocoa pod extract with GTE as solvent, indicating strong antioxidant potential.

Even without tea extract, the edible film demonstrated notable polyphenol content (8.71 ± 0.45 mg GAE·g^{-1}) and antioxidant activity (18.72 ± 0.33%), as cocoa pods naturally contain high polyphenol levels (46–69 mg GAE·g^{-1}) (Vásquez et al. 2019). However, there was a reduction in polyphenol content and antioxidant activity after film formation, due to the process of edible film preparation, such as dilution effects, soy protein isolate addition, heating, and drying, which may degrade oxygen-sensitive polyphenols.

Physical and mechanical properties of edible films from cocoa pod extract. The mechanical and physical characteristics of films are important for their performance and application (Cazón et al. 2017), wherein tensile strength, elongation, solubility, and water vapour transmission rate (*WVTR*) of edible films from cocoa pod extract (Table 2) were observed in this study.

Tensile strength increased significantly when tea extract was used as a solvent. Edible film with GTE generally showed higher values than BTE, with the highest tensile strength (3.97 ± 0.03 MPa) being GTE 100, that significantly greater than BTE 100. Table 2 shows that no significant difference was observed between GTE 50 and BTE 50.

Elongation measurement showed an opposite trend compared to tensile strength, which decreased with the addition of both green and black tea extracts. The elongation of BTE 50 and BTE 100 was significantly lower than that of GTE 50 and GTE 100, while EF had the highest elongation (36.29 ± 0.31%). The different trend between tensile strength and elongation aligns with previous studies (Ruan et al. 2019).

Solubility and *WVTR* indicate resistance to water in the liquid and vapour phases, and both decreased with increasing tea extract incorporation, indicating greater water resistance. GTE treatments showed a pronounced effect compared with BTE, with the lowest solubility (28.79 ± 0.16%) and *WVTR* (0.05 ± 0.01 g·m^{-2}·h^{-1}) being shown in GTE 100. These results align with previous studies (Gao et al. 2019; Ruan et al. 2019), which show that polyphenol incorporation enhanced tensile strength and also reduced *WVTR* and solubility.

GTE 100 showed the best performance, with the highest polyphenol content, antioxidant activity, and tensile strength, along with the lowest elongation, solubility, and *WVTR* (Tables 1 and 2). This is probably due to polyphenol interactions with pectin or proteins via hydrogen bonding, ionic interactions, and hydrophobic forces, forming cross-links that strengthen the film matrix (Lei et al. 2019; Ruan et al. 2019; Wu et al. 2019). These interactions were further observed using FTIR spectroscopy.

Lipid oxidation inhibition. Peanut oil was used as a model to demonstrate the ability of edible films to inhibit lipid oxidation due to the oil's high unsaturated fatty acid content (81–94%), mainly oleic (45–53%) and linoleic acids (27–32%) (Ghazani and Marangoni 2016). These unsaturated fatty acids are highly suscep-

https://doi.org/10.17221/81/2025-CJFS

Table 3. Peroxide value of peanut oil during storage of 4, 7, 9, 11 and 14 days at 50 °C

Sample	Peroxide value (meq O_2·kg^{-1})					The slope
	4th day	7th day	9th day	11th day	14th day	
Control	4.30 ± 0.43^{e}	6.15 ± 0.27^{e}	9.21 ± 0.24^{e}	14.31 ± 0.32^{e}	23.57 ± 1.22^{e}	1.95^{d}
EF	3.28 ± 0.31^{d}	4.72 ± 0.59^{d}	6.06 ± 0.27^{d}	8.46 ± 0.48^{d}	15.01 ± 2.32^{d}	1.14^{c}
BTE 50	2.99 ± 0.18^{d}	3.93 ± 0.38^{c}	4.55 ± 0.20^{c}	7.11 ± 0.30^{c}	12.19 ± 0.24^{c}	0.90^{b}
GTE 50	2.17 ± 0.23^{c}	3.13 ± 0.29^{b}	3.75 ± 0.25^{b}	6.42 ± 0.25^{b}	11.12 ± 0.32^{bc}	0.88^{b}
BTE 100	1.35 ± 0.23^{b}	2.03 ± 0.30^{a}	3.39 ± 0.26^{b}	6.15 ± 0.20^{b}	10.05 ± 0.48^{ab}	0.89^{b}
GTE 100	0.91 ± 0.17^{a}	1.63 ± 0.27^{a}	2.69 ± 0.43^{a}	4.99 ± 0.26^{a}	8.93 ± 0.40^{a}	0.81^{a}

$^{a-e}$different letters indicate statistically significant differences among groups (P < 0.05, Tukey's test); EF – distilled water; BTE – black tea extract; GTE – green tea extract

tible to oxidation, which can lead to rancidity (Liu et al. 2019). The peroxide value was used to assess the rancidity, as peroxide is the primary indicator of early lipid oxidation (Wu et al. 2019).

The results (Table 3) show that, after 14 days of storage at 50 °C, peanut oil with BTE 100 and GTE 100 had peroxide values of 10.05 ± 0.48 and 8.93 ± 0.40 meq O_2·kg^{-1}, respectively, which are considered rancid when the peroxide value exceeds 10 meq O_2·kg^{-1} (Gilbraith et al. 2021). These results indicate that BTE 100 and GTE 100 effectively inhibited oxidation. In contrast, peanut oil with EF, BTE 50, and GTE 50 has peroxide values exceeding 10 meq O_2·kg^{-1}, indicating rancidity. Compared with previous studies under similar conditions, edible films from dragon fruit peel and jack bean flour were less effective at preventing rancidity (Lindriati et al. 2015, 2025). The results show that combining cocoa pod extract and tea extract provides enhanced antioxidant protection.

The film's ability was also evaluated based on the slope of a linear curve of peroxide value over time, with a lower slope indicating better oxidative stability. GTE 100 performed the lowest slope, indicating its superior ability to prevent rancidity. No significant differences (P > 0.05) were revealed among BTE 100, GTE 50, and BTE 50, indicating similar performance in preventing peanut oil rancidity.

The results showed that antioxidant edible films made from cocoa pod extract, incorporating green or black tea extract, are particularly suitable for lipid-rich foods such as oils, nuts, and seeds, as well as for dried

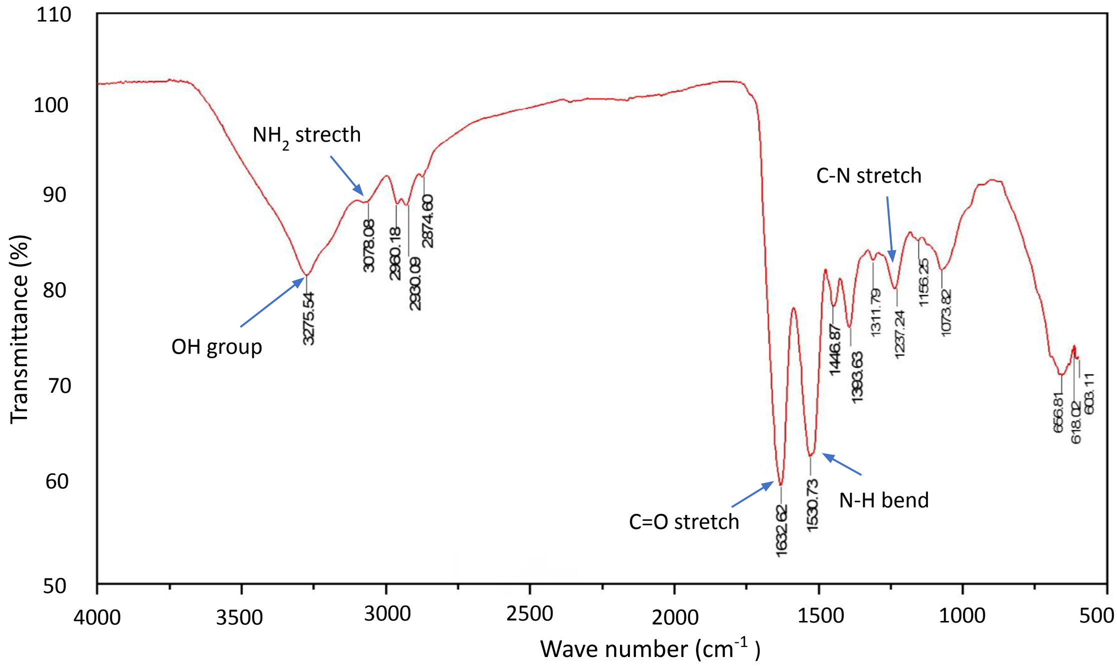

Figure. 2. The FTIR (Fourier transform infrared spectroscopy) spectrum of soy protein isolate (SPI) as an edible film material

https://doi.org/10.17221/81/2025-CJFS

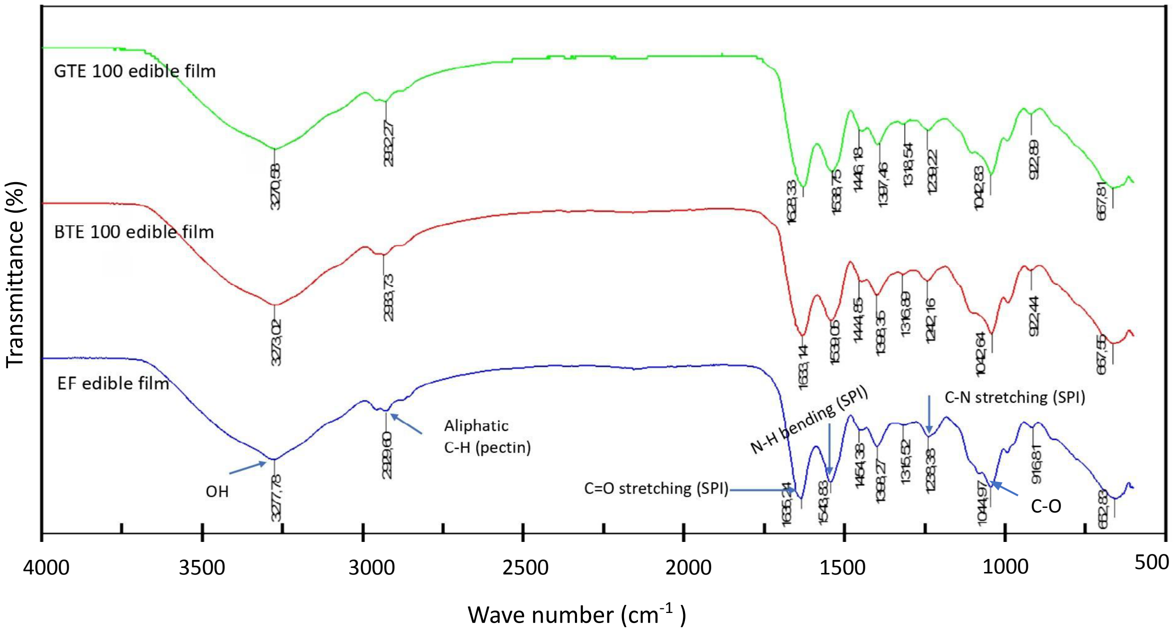

Figure 3. The FTIR (Fourier transform infrared spectroscopy) spectrum of edible film from cocoa pod extract

EF – distilled water; BTE – black tea extract; GTE – green tea extract; SPI – soy protein isolate

products. Using cocoa pods as a raw material reduces costs while providing intrinsic antioxidant activity.

Fourier transform infrared study. Figure 2 shows the FTIR spectrum of SPI formulated in edible film materials, which aligns with the findings of Su et al. (2010). According to Su et al. (2010), SPI exhibited absorption at 3 294, 1 636–1 680, and 1 533–1 559 cm^{-1}, associated with hydrogen bonding and N-H vibrations. Figure 2 shows that the peak at 3 275.54 cm^{-1} corresponds to O-H stretching, while the peak at 3 078.08 cm^{-1} is attributed to N-H stretching of NH_2 groups. The bands at 1 632.62 cm^{-1} and 1 530.73 cm^{-1} represent amide I and amide II regions, respectively. However, a difference was observed at 1 237.24 cm^{-1} (C-N stretching), likely because the SPI in our study was technical-grade rather than pure SPI in Su et al. (2010).

Comparison of FTIR spectra of pectin (Figure 1), SPI (Figure 2), and EF (Figure 3) shows that there are shifts in O-H peaks at 3 262.60, 3 275.54, and 3 277.78 cm^{-1}, respectively, where the EF peak appears at the highest wavenumber, indicating weaker hydrogen bonding between pectin and SPI. This is likely affected by the presence of glycerol as a plasticiser, which disrupts hydrogen bonding in macromolecules. The presence of glycerol is evidenced by peaks in the 800–1 150 cm^{-1} region (Guerrero et al. 2010).

Figure 3 is the FTIR spectrum of cocoa pod extract edible films incorporating tea extract, that show combination of characteristic peaks between pectin and protein, presenting broad O-H/N-H stretching (3 200–3 500 cm^{-1}), C-H stretching (~2 900 cm^{-1}), and amide I and II bands (~1 650 and ~1 540 cm^{-1}). These peaks indicate interactions between the cocoa pod macromolecule and the SPI matrix, evidence the formation of a composite edible film.

The spectra are vertically displayed (arbitrary units) and show similar peaks in BTE 100 and GTE 100 compared to EF, indicating that the polyphenols from the tea extract do not form new covalent or ionic bonds. However, a shift in the O–H peak from 3 277.78 cm^{-1} (EF) to 3 273.02 cm^{-1} (BTE 100) and 3 270 cm^{-1} (GTE 100) was shown. This shift to lower wavenumbers is due to hydrogen bonding between polyphenols and the hydroxyl groups of SPI or pectin (Dai et al. 2023). Unlike previous studies that reported cross-link formation between polyphenols and proteins or carbohydrates (Lei et al. 2019; Ruan et al. 2019; Wu et al. 2019), this study evidences that interactions are mainly through hydrogen bonding, which improved tensile strength and reduced elongation, solubility, and *WVTR*.

CONCLUSION

The results showed a significant increase ($P < 0.05$) in total polyphenol content and antioxidant activity of cocoa pod extract edible films when using green or black tea extract as a solvent, wherein green tea showed superior effects. Higher polyphenol levels

https://doi.org/10.17221/81/2025-CJFS

increased tensile strength while decreasing elongation, water vapour transmission rate, and solubility. It had also improved the film's ability to inhibit peanut oil rancidity for up to 14 days at 50 °C. Films without tea extract showed lower polyphenol content (8.71 ± 0.45 mg GAE·g^{-1}) and antioxidant activity (18.72 ± 0.33%). FTIR analysis confirmed that hydrogen bonds facilitated interactions among tea polyphenols, pectin from cocoa pod extract, and soy protein isolate, thereby improving film tensile strength while reducing elongation, water vapour transmission rate and solubility.

REFERENCES

Ainsworth E.A., Gillespie K.M. (2007): Estimation of total phenolic content and other oxidation substrates in plant tissues using Folin–Ciocalteu reagent. Nature Protocols, 2: 875–877.

Cazón P., Velazquez G., Ramírez J.A., Vázquez M. (2017): Polysaccharide-based films and coatings for food packaging: A review. Food Hydrocolloids, 68: 136–148.

Chen L., Wang H., Ye Y., Wang Y., Xu P. (2023): Structural insight into polyphenol oxidation during black tea fermentation. Food Chemistry: X, 17: 100615.

Dai F., Zhuang Q., Huang G., Deng H., Zhang X. (2023): Infrared spektrum characteristics and quantification of OH groups in coal. ACS Omega, 8: 17064–17076.

Desniorita, Nazir N., Novelina, Sayuti K., Jasril. (2019): Application of pectin extracted from cocoa pod in the production of edible film. IOP Conference Series: Earth and Environmetal Science, 347: 012060.

Gao H. X., He Z., Sun Q., He Q., Zeng W.C. (2019): A functional polysaccharide film forming by pectin, chitosan, and tea polyphenols. Carbohydrate Polymers, 215: 1–7.

Ghazani S.M., Marangoni A.G. (2016): Healthy fats and oils. In: Wrigley C., Corke H., Seetharaman K., Faubion J.: Encyclopedia of Food Grains. 2nd Ed. Volume 2. Cambridge, Academic Press: 257–267.

Gilbraith W.E., Carter J.C., Adams K.L., Booksh K.S., Ottaway J.M. (2021): Improving prediction of peroxide value of edible oils using regularised regression models. Molecules, 26: 7281.

Gontard N., Duchez C., Cuq J.L., Guilbert S. (1994): Edible composite films of wheat gluten and lipids: Water vapour permeability and other physical properties. International Journal of Food Science & Technology, 29: 39–50.

Guerrero P., Retegi A., Gabilondo N., de La Caba K. (2010): Mechanical and thermal properties of soy protein films processed by casting and compression. Journal of Food Engineering, 100: 145–151.

Jouki M., Tabatabaei Y.F., Mortazavi S.A., Koocheki A. (2013): Physical, barrier and antioxidant properties of a novel plasticised edible film from quince seed mucilage. International Journal of Biological Macromolecules, 62: 500–507.

Kopjar M., Tadić M., Piližota V. (2015): Phenol content and antioxidant activity of green, yellow and black tea leaves. Chemical and Biological Technologies in Agriculture, 2: 1.

Lei Y., Wu H., Jiao C., Jiang Y., Liu R., Xiao D., Lu J., Zhang Z., Shen G., Li S. (2019): Investigation of the structural and physical properties, antioxidant and antimicrobial activity of pectin-konjac glucomannan composite edible films incorporated with tea polyphenol. Food Hydrocolloids, 94: 128–135.

Hennessey-Ramos L., Murillo-Arango W., Vasco-Correa J., Astudillo I.C.P. (2021): Enzymatic extraction and characterisation of pectin from cocoa. Molecules, 26: 1473.

Lindriati T., Simon B.W., Yunianta (2015): Edible film from jack bean flour for use as an antioxidative packaging incorporating extract of green tea. International Journal on Advanced Science, Engineering and Information Technology, 5: 344–348.

Lindriati T., Yuwanti S., Afriliana A., Sukoco A., Budianto I.R., Azizah W., Fadhiyah U.S. (2025): Development of antioxidative edible film from red dragon fruit peel extract with the addition of CMC and soy protein isolate. International Journal of Advances in Applied Sciences, 14: 164–174.

Liu K., Liu Y., Chen F. (2019): Effect of storage temperature on lipid oxidation and changes in nutrient contents in peanuts. Food Science & Nutrition, 7: 2280–2290.

Mangmee K., Homthawornchoo W. (2016): Antioxidant activity and physicochemical properties of rice starch-chitosan-based films containing green tea extract. Food and Applied Bioscience Journal, 4: 126–137.

Meza-Sepúlveda D.C., Hernandez-Urrea C., Valencia-Sanchez H. (2025): Thermochemical characterization of cellulose extracted from the cocoa pod husk of *Theobroma cacao* L. Industrial Crops and Products, 226: 120579.

Pająk P., Przetaczek-Rożnowska I., Juszczak L. (2019): Development and physicochemical, thermal and mechanical properties of edible films based on pumpkin, lentil and quinoa starches. International Journal of Biological Macromolecules, 138: 441–449.

Ruan C., Zhang Y., Wang J., Sun Y., Gao X., Xiong G., Liang J. (2019): Preparation and antioxidant activity of sodium alginate and carboxymethyl cellulose edible films with epigallocatechin gallate. International Journal of Biological Macromolecules, 134: 1038–1044.

Santiago-Gómez I., Carrera-Lanestosa A., González-Alejo F.A., Guerra-Que Z., García-Alamilla R., Rivera-Armanta J.L., García-Alamilla P. (2025): Pectin extraction process from cocoa pod husk (*Theobroma cacao* L.) and characterisation by Fourier transform infrared spectroscopy. ChemEngineering, 9: 25.

Sarah M., Hasibuan I.M., Misran E., Maulina S. (2022): Optimization of microwave-assisted pectin extraction from cocoa pod husk. Molecules, 27: 6544.

Siripatrawan U., Harte B.R. (2010): Physical properties and antioxidant activity of an active film from chitosan incorporated with green tea extract. Food Hydrocolloids, 24: 770–775.

Su J.F., Huang Z., Yuan X.Y., Wang X.Y., Li M. (2010): Structure and properties of carboxymethyl cellulose/soy protein isolate blend edible films crosslinked by maillard reactions. Carbohydrate Polymers, 79: 145–153.

Susilowati P.E., Fitri A., Natsir M. (2017): The effect of edible coating made from pectin of cacao fruit peel to the shelf life and quality of tomato (Penggunaan pektin kulit buah kakao sebagai edible coating pada kualitas buah tomat dan masa simpan). Jurnal Aplikasi Teknologi Pangan, 6: 1–4. (in Indonesian)

Vásquez Z.S., de Carvalho Neto D.P., Pereira G.V.M., Vandenberghe L.P.S., de Oliveira P.Z., Tiburcio P.B., Rogez H.L.G., Góes Neto A., Soccol C.R. (2019): Biotechnological approaches for cocoa waste management: A review. Waste Management, 90: 72–83.

Vu V.N.H., Cao T.Q., Thi T., Nguyen T.T.H., Nguyen L.T.N., Le P.H., Nguyen V. (2025): Extraction of bioactive compounds from cocoa pod husk (*Theobroma cacao* L.) using deep eutectic solvent assisted with ultrasound. Natural Product Communications, 20: 1–11.

Wathoni N., Yuan Shan C., Yi Shan W., Rostinawati T., Indradi R.B., Pratiwi R., Muchtaridi M. (2019): Characterization and antioxidant activity of pectin from Indonesian mangosteen (*Garcinia mangostana* L.) rind. Heliyon, 5: e02299.

Wu H., Lei Y., Zhu R., Zhao M., Lu J., Xiao D., Jiao C., Zhang Z., Shen G., Li S. (2019): Preparation and characterization of bioactive edible packaging films based on pomelo peel flours incorporating tea polyphenol. Food Hydrocolloids, 90: 41–49.

Received: May 29, 2025
Accepted: May 19, 2026
Published online: July 28, 2026