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Ginger essential oil-infused pectin-alginate films for extending sliced bread shelf life

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Abstract: This study examines composite films made from pectin and alginate, enhanced with ginger essential oil (GEO) at 0, 0.5, 1, and 1.5% concentration. The films were analysed for their structure, physical properties, antioxidant and antibacterial activities, and effectiveness in preserving sliced bread over 0, 2, 4, 6, and 8 days. The outcomes presented that incorporating GEO upgraded pectin-alginate films' properties. SEM images revealed increased essential oil distribution on the film surface with higher GEO concentrations, indicating good compatibility. Higher GEO concentrations enhanced the films' abilities to scavenge free radicals DPPH, 2,2-diphenyl-1-picrylhydrazyl; and ABTS, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) and inhibit bacteria (*Listeria monocytogenes* and *Escherichia coli*). Furthermore, increasing GEO concentrations in the films helped maintain key quality attributes of sliced bread, such as moisture content, water activity, microbial counts, and firmness. Films with 1.0 and 1.5% GEO concentrations were the most effective in preserving bread, potentially inhibiting mould formation and maintaining sensory properties over the 8-day storage period. This study demonstrates that pectin-alginate films supplemented with GEO at 1 and 1.5% concentration are suitable for storing sliced bread.

Keywords: antioxidant; bread preservation; ginger essential oil; pectin–alginate film; physical properties

Food can be damaged during processing, transportation, and storage due to microbial contamination, posing potential risks to consumer health and causing significant economic losses. However, active packaging has been shown to prolong the expiration date of foods effectively. Traditional packaging substances, including polyester, polyethylene, and polypropylene, are widely used due to their cheapness. However, these materials negatively impact the environment and may pose risks to consumer health (Zhou et al. 2022). Consequently, developing biodegradable food packaging substances has become increasingly urgent to mitigate environmental pollution.

Synthetic films derived from polysaccharides, lipids, and proteins have been extensively studied as alternatives. Among these, pectin and sodium alginate are two widely used substances for creating food-safe wrapping films because of their excellent functional properties. However, films made from pectin and sodium alginate

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are often susceptible to environmental factors, exhibit low ductility, and possess limited biological activity (Tong et al. 2023). To address these limitations and enhance the functional properties and biological activity of synthetic films, plant essential oils have been incorporated into the film formulations.

Ginger essential oil (GEO) is a plant-based essential oil known for its potent antibacterial activity. It has been authorised by the U.S. Food and Drug Administration and classified as 'Generally Recognized as Safe' (Tanveer et al. 2020). Incorporating essential oils like GEO into films creates interactions between the essential oil, the polymer, and the plasticiser (Tong et al. 2023). These interactions help to regulate the release of biological compounds from the ginger essential oil into food, therefore prolonging the expiration dates of food products (Nisar et al. 2018).

Bread is a popular and widely used food in the world. Bread is a rich source of iron, calcium, protein, and various vitamins, making it an excellent energy source. However, mould and fungi are the primary causes of significant financial losses in packaged bread products. These microorganisms lead to spoilage and produce mycotoxins, which pose serious health risks to consumers. Bread spoilage contributes substantially to global food waste. For instance, in 2015, 34.7% of all bread in Germany was discarded due to spoilage (Alpers et al. 2021). Bread's high moisture content and water activity make it particularly prone to microbial contamination and spoilage. Without preservation measures, bread typically has a short shelf life of only 3–4 days, leading to economic losses (Noshirvani et al. 2017).

Southeast Asian countries, including Vietnam, experience an average temperature of 25 °C, accelerating bread spoilage. Utilising GEO in bread introduces an innovative approach to extending bread shelf life. This study aims to assess the influences of varying levels of GEO on the structural properties of pectin-alginate films. Furthermore, it examines the impact of these films on the preservation of sliced bread by analysing their microstructural characteristics at different GEO concentrations. The research also investigates the effects of the films on key quality parameters of bread during an 8-day storage period, including moisture content, water activity, total viable bacterial count, total mould count, hardness, and sensory attributes.

MATERIAL AND METHODS

Material. Fresh ginger rhizomes (8 months old) were sourced from Go Vap market in Ho Chi Minh City, Vietnam. The rhizomes were dried using a heat pump dryer at 45 °C for 16 h. Ginger essential oil was extracted using a Clevenger-type apparatus with a solvent-to-material ratio of 2 : 1 ($L \cdot kg^{-1}$) at 130 °C for approximately 180 min, starting from the collection of the first drop.

Chemicals. High-methoxyl pectin, sodium alginate, Potato Dextrose Agar (PDA), Muller Hinton Agar (MHA), Muller Hinton Broth (MHB), and Plate Count Agar (PCA) (HiMedia, India). Glycerol and Tween 80 (Xilong, China). ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)); DPPH (2,2-diphenyl-1-picrylhydrazyl) and DPPH (2,2-diphenyl-1-picrylhydrazyl) (Sigma, USA). *Listeria monocytogenes* CIP 106, and *Escherichia coli* NRRL B-409 were provided by the Institute of Applied Technology and Sustainable Development at Nguyen Tat Thanh University. Deionised water and all other testing chemicals used met the required research standards.

Preparation of pectin-alginate film combined with ginger essential oil. Solutions of 5% pectin and 2% alginate were prepared by magnetic stirring at 500 rpm for 12 h at room temperature. The pectin-alginate film formulations supplemented with ginger essential oil (GEOPA) were as follows: GEOPA-0.0 (pectin – 87%, alginate – 7%, GEO – 0%); GEOPA-0.5 (pectin – 86.75%, alginate – 6.75%, GEO – 0.5%); GEOPA-1.0 (pectin – 86.5%, alginate – 6.5%, GEO – 1%); GEOPA-1.5 (pectin – 86.25%, alginate – 6.25%, GEO – 1.5%), with glycerol (5%) and Tween 80 (1%) fixed. A rotor-stator homogeniser (T25, Ika Werke, Germany) was used to homogenise the film-forming solution at 15 000 rpm for 3 min. The solution (15 mL) was put in a 9 cm diameter sterile plastic petri dish and dried for 48 h at 45 °C in a convection oven (UF160, Memmert, Germany). The films were then removed from the petri dish and stored at 25 °C at 50% RH (relative humidity).

Prepare to preserve sliced bread. Bread containing basic ingredients (flour, margarine, salt, sugar, and yeast) and no preservatives was purchased from a bakery in Ho Chi Minh City, Vietnam. The bread was cut into slices of uniform size (10 cm long, 9 cm wide, and 1 cm thick). For testing, the slices were wrapped in pectin-alginate films containing different concentrations of GEO. As controls, bread slices were packaged in commercial polypropylene (PP) plastic and in pectin-alginate films without GEO. All bread samples were preserved for 8 days at 25 °C and 75% RH.

Thickness. A thickness gauge (Mitutoyo, Japan) with a precision of 0.02 mm was used to measure the uniformity and integrity of the film thickness. Three measurement points were randomly selected for each film.

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Elongation at break (*EAB*) and tensile strength (*TS*). Elongation at break and tensile strength of the films were measured by using the ASTM D882-18 method.

Film colour. A chroma meter (CR-400, Konica Minolta, Japan) was used to measure the colour of the film samples. The CIE Lab scale was applied for colour analysis. Films were placed on white calibration plates, and the values of L^*, a^*, b^*, and ΔE were recorded.

Moisture content of the film *(MCF).* 25 × 25 (mm) is the size of the film sample prepared for mass weighing and moisture content measurement. Then, the film was dried to constant mass at 105 °C for 24 h in a convection oven. After drying, the mass of the film samples was calculated, and the MCF was calculated using the following formula:

$$MCF = \left(1 - \frac{W_2}{W_1}\right) \times 100\% \quad (1)$$

where: W_1 – mass before drying of the film (g); W_2 – mass after drying of the film (g).

Water solubility *(WS).* Following the procedure for MCF determination, the dried film samples were put in deionised water (25 mL) for 24 h at 25 °C. After soaking, the wet films were dried and weighed, and the *WS* was calculated using the following formula:

$$WS = \left(1 - \frac{W_3}{W_2}\right) \times 100\% \quad (2)$$

where: W_2 – mass of the initial film (before stirring with deionised water, g); W_3 – final mass (after stirring with deionised water and drying, g).

Water vapor permeability *(WVP).* Testing *WVP* of the films was determined using to the method of Peng and Li (2014), with some modifications. Beakers (with a contact area of 23.95 cm^2) were filled with 5 g of anhydrous $CaCl_2$. The beakers were sealed with the test film samples and placed controlled cabinet (25 °C and 60% RH). After 24 h, the mass of the beakers was recorded again.

Transmittance and opacity. Optical transmittance was measured using a UV spectrophotometer (1100, Dlab, USA). The rectangular films were placed in cuvettes, and measurements were taken within the 200–800 nm wavelength range. Empty cuvettes were used for background correction. The film's opacity is determined by a wavelength of 660 nm (Fasihi et al. 2019).

Microstructure. The morphology of the film's surface was determined using a field-emission scanning electron microscope equipment, brand named S-4800 (Hitachi, Japan). The film was fixed to a carbon adhesive tape and then coated with a thin layer of platinum. Images were collected at a magnification of 500× using an acceleration voltage of 5 kV.

DPPH assay. The DPPH radical scavenging assay of pectin-alginate films was determined using a method similar to that of Bhatia et al. (2023), with some modifications. Briefly, 2 mL of absolute methanol was used to dissolve 0.1 g of the test film sample. After 12 h, the solution was filtered. Then, 0.01 mL of the filtered solution was added to 0.19 mL of DPPH solution. This solution was incubated in the dark for 0.5 h, and the absorbance was measured at 515 nm.

ABTS assay. With some modifications, the ABTS radical elimination assay of pectin-alginate films was determined using the method described by Bhatia et al. (2023). Briefly, 0.1 g of the test film sample was dissolved in 2 mL of absolute methanol for 12 h. Then, 0.01 mL of the filtered film solution was added to 0.19 mL of ABTS solution and incubated in the dark for 0.5 h. The absorbance of the solution was measured at 734 nm.

Antibacterial activity. The antibacterial activity of the tested films was determined by the colony dilution method based on colony-forming units (Sharma and Bhardwaj 2020). Two bacterial strains, *L. monocytogenes* and *E. coli*, were used for the experiment. These two bacterial strains were grown in MHB medium and incubated in a thermostatic shaking cabinet (IST-4075, Jeio Tech, Korea) at 200 rpm at 37 °C for 12 h. The microbial suspension was diluted 100-fold and recultured in a thermostatic shaking cabinet for 3 h. The microbial suspension was mixed with 0.5 g of UV-sterilised test films, and the mixture was incubated for 1 h at 37 °C. Finally, 0.1 mL of this bacterial suspension was spread evenly on a petri dish containing MHA medium. After 24 h, the petri dishes were observed and photographed.

Moisture content *(MC)* and water activity *(a_w)* of sliced bread. 5 g bread samples were dried in an oven at 105 °C. After 24 h, the mass of the bread samples was weighed again to determine MC. Additionally, the aw of the bread samples was determined using a water activity analyser (Novasina AG, Switzerland) at 25 °C.

Microbiological. The total viable count *(TVC)* of sliced bread was determined according to the national standard (TCVN 4884-1:2015). Briefly, bread slices were diluted in a 0.9% NaCl solution to appropriate concentration ranges. Next, 0.1 mL of this dilution was supplemented to petri dishes containing PCA medium and spread evenly. These petri dishes were kept in an incubator at 37 °C for 1 day, and colony formation was recorded to calculate *TVC*. Similarly, the total mould count *(TMC)* of sliced bread was determined according to national standards (TCVN 8275-2:2010).

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The dilution procedure was similar to that for the *TVC* test. However, a PDA medium was used for culture, and incubation of the petri dishes took place at 25 °C for 72-hour period.

Firmness. The change in firmness of bread slices over storage time was determined using a texture analyser (Stable Micro Systems, UK) with a P36R probe. The firmness of bread slices was analysed at a speed of 3.0 mm·s^{-1}, a deformation level of 0.5 cm, and an impact force of 5 × g.

Sensory. During the sensory evaluation, 30 people aged 20 to 45, including 15 men and 15 women, tested bread samples according to TCVN 3215–79. The sensory attributes of the bread slices, including colour, flavour, taste, and texture, and the evaluation of overall acceptance were conducted using a nine-level scale for assessing hedonic appeal, where 1 showed extreme dislike, and 9 indicated extreme liking. The sensory score for each criterion was the average score of the evaluators.

Statistical. The mean ± SD of the three replications of the data is displayed. SPSS version 22 software (SPSS Inc., USA) was used to conduct a one-way ANOVA, and the Tukey test was used to examine if there was a difference that was statistically significant at the 5% level of significance. The graphs were generated using Origin Pro 2024b software (Origin Lab, USA).

RESULTS AND DISCUSSION

Physical properties of the films

Thickness. The thickness of the GEOPA-0.0 film is 0.141 mm (Figure 1A). When the amount of GEO was added from 0.5 to 1.5%, the film thickness enhanced significantly ($P < 0.05$). GEO is hydrophobic. When GEO was added to the pectin-alginate film solution, the GEOs broke the bonds between macromolecular chains and created a looser film matrix. This makes the structure less tight when drying, and the thickness of the film is increased.

Tensile strength and elongation at break. The *TS* value of the film decreased significantly when supplemented

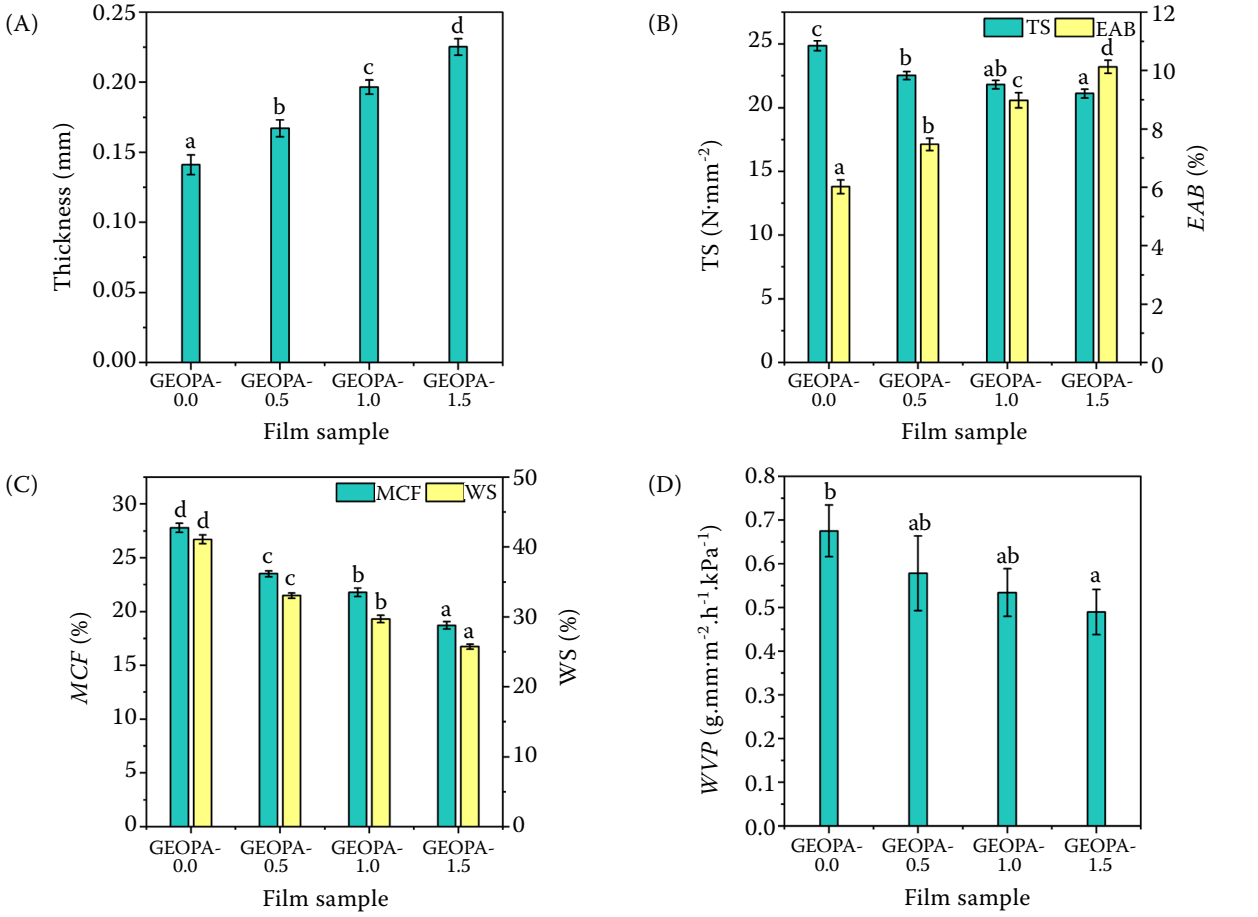

Figure 1. The physical properties of films: (A) thickness, (B) tensile strength *(TS)* and elongation at break *(EAB)*, (C) moisture content of film *(MCF)* and water solubility *(WS)*, (D) water vapour permeability *(WVP)*

[a–d]different letters indicate statistically significant difference ($P < 0.05$)

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with GEO. Adding essential oils disrupted the film structure, reducing the composite film's *TS* value. Besides, the results from Figure 1B also show that when increasing the GEO concentration, the *EAB* value of the film also increases significantly ($P < 0.05$). At room temperature, GEO exists in a liquid state, and when incorporated into a film, GEO will exist as small, deformable oil droplets. This has helped increase the *EAB* value and improve the film's ductility.

Moisture content and water solubility. The results show that the *MCF* and *WS* of the tested films tend to decrease (Figure 1C). Specifically, the *MCF* of the GEOPA-0.0 film is 22.77%; when the amount of GEO is added to 1.5%, the MCF of the film decreases to 18.72% ($P < 0.05$). Similarly, when the amount of GEO increased from 0 to 1.5%, the *WS* value of the film dropped from 41.09 to 25.77% ($P < 0.05$). The water-repellent characteristics of the ginger essential oil and the interaction of GEO components with the hydroxyl group of pectin reduced the *MCF* and *WS* of the film.

Water vapour permeability. *WVP* decreased significantly when the amount of GEO added increased from 0 to 1.5% (Figure 1D). This may be because adding essential oils increased the hydrophobicity of the film. Adding oil to the film caused the polymer chains to become less mobile and the diffusivity of water reduced, which led to a reduction in the value.

Film colour. The results indicated that the added GEO significantly ($P < 0.05$) influenced the colour values of pectin-alginate films (Table 1). The GEOPA-0.0 film has a higher brightness than the film samples supplemented with GEO, meaning a higher L^* value. This is also further demonstrated in Figure 2, where the GEOPA-0.0 film shows a lighter colour and is more transparent. The increase in ΔE value is due to the change in colour values *(L^*, a^*,* and *b^*)* of the film samples. The decrease in L^* and a^* values is due to the phenolic compounds of essential oils absorbing light at lower wavelengths. Reducing the L^* value can help limit the impact of ultraviolet rays on the colour of packaging films and the quality of nutrients in food (Liu et al. 2024). Due to the natural yellow colour of GEO, the b^* value of the film samples increased when essential oils were added.

Transmittance and opacity. GEOPA-0.0 film has the highest optical transmittance (Figure 3A). However, when the amount of GEO increases from 1 to 1.5%, the optical transmittance of the film is reduced. Besides, films combined with GEO have better blocking ability at 200 to 275 nm UV rays. This means that the film's light-blocking ability and UV-blocking properties are improved when GEO is added. When GEO was added to the film, the oil droplets distributed in the pectin-alginate film network scattered light. The results show that the control film has the lowest opacity, with a value of 1.56 (Figure 3B). The tested films' opacity significantly increased ($P < 0.05$) when GEO increased from 1 to 1.5%. The film's opacity was boosted as the added essential oil concentration increased, which was consistent with the trend of some papers (Sadadekar et al. 2023).

Microstructure. The results presented that GEO added to the film created significant differences on the

Table 1. Effect of ginger essential oil concentration on the colour values of films

Film sample	L^*	a^*	b^*	ΔE
GEOPA-0.0	91.81 ± 0.41^{c}	−0.32 ± 0.02^{d}	5.41 ± 0.06^{a}	6.26 ± 0.38^{a}
GEOPA-0.5	89.76 ± 0.66^{b}	−0.84 ± 0.05^{c}	7.05 ± 0.12^{b}	8.91 ± 0.60^{b}
GEOPA-1.0	88.77 ± 0.43^{b}	−1.10 ± 0.06^{b}	9.52 ± 0.27^{c}	11.20 ± 0.37^{c}
GEOPA-1.5	86.86 ± 0.44^{a}	−1.47 ± 0.07^{a}	11.27 ± 0.27^{d}	13.82 ± 0.44^{d}

$^{a–d}$ different letters indicate statistically significant difference ($P < 0.05$)

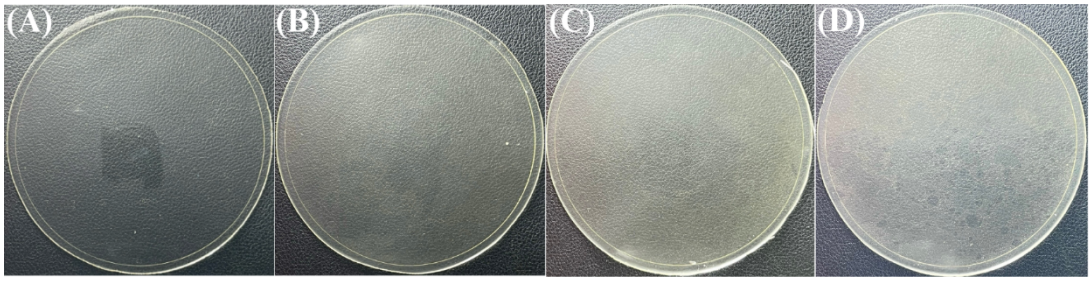

Figure 2. Images of the physical appearance of the films: (A) GEOPA-0.0, (B) GEOPA-0.5, (C) GEOPA-1.0, (D) GEOPA-1.5

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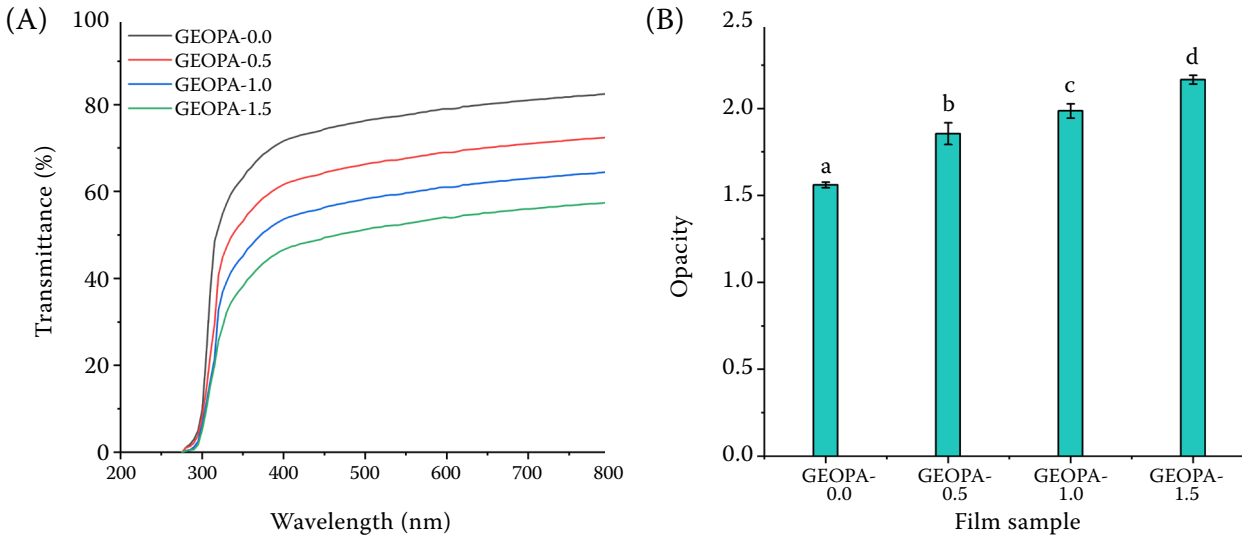

Figure 3. The properties of films: (A) transmittance and (B) opacity

[a–d] different letters indicate statistically significant difference ($P < 0.05$)

surface of a film composed of composite materials (Figure 4). The control film without GEO addition showed a relatively homogeneous structure. SEM images show the presence of oil droplets and the appearance of phase separation (oil and polymer) on the surface of the films supplemented with GEO. When the amount of GEO was increased from 0.5 to 1.5%, the appearance of oil droplets on the film surface increased, creating cracks and inhomogeneities on the film surface. The same observations were also shown for pectin films incorporating clove essential oil (Nisar et al. 2018).

Antioxidant activity. The results show that the GEOPA-0.0 film can still remove DPPH and ABTS. This is because the film-forming ingredients (pectin and alginate) have antioxidant properties. The DPPH radical elimination ability of the pectin-alginate film enhanced significantly ($P < 0.05$) when the amount of GEO added rose from 0 to 1.5% (Figure 5A). The ABTS free radical scavenging activity of the control film was 6.23%, and the ABTS free radical scavenging ability of the synthetic film was 11.51, 15.86, and 23.71% when the amount of GEO was added at the same level: 0.5, 1, and 1.5%, respectively. The results show that the antioxidant capacity of pectin-alginate films depends on the amount of GEO added. Adding GEO significantly improved the film's antioxidant activity, which was consistent with the trend of some studies (Shojaee-Aliabadi et al. 2013).

Antibacterial activity. Figure 5 B–I illustrates the antibacterial activity of pectin-alginate composite films incorporating increasing concentrations of GEO against *L. monocytogenes* (corresponding to Figure 5B–E) and *E. coli* (corresponding to Figure 5F–I). In Figure 5B and 5F (GEOPA-0.0), both bacterial strains displayed dense, confluent growth on the agar surface, indicating negligible inhibitory activity in the absence of GEO. As the GEO concentration increased (Figure 5C–D and Figure 5G–H), the number and size of visible bacterial colonies decreased markedly, reflecting a concentration-dependent improvement in antimicrobial efficacy. Notably, at 1.5% GEO, no colonies of either *L. monocytogenes* (Figure 5E) or *E. coli* (Figure 5I) were observed, demonstrating complete inhibition under the

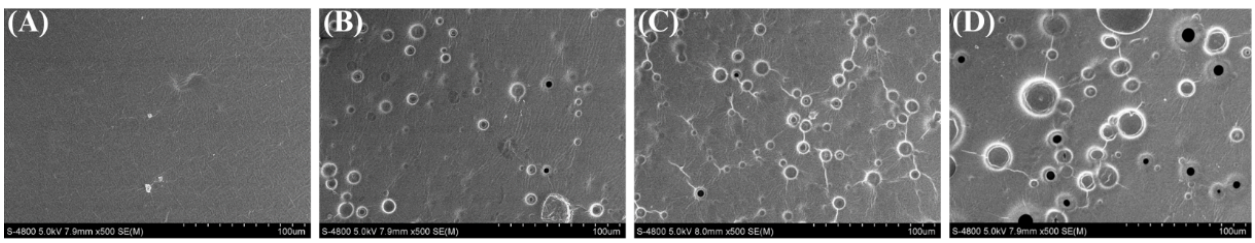

Figure 4. Microstructure of films: (A) GEOPA-0.0, (B) GEOPA-0.5, (C) GEOPA-1.0, (D) GEOPA-1.5

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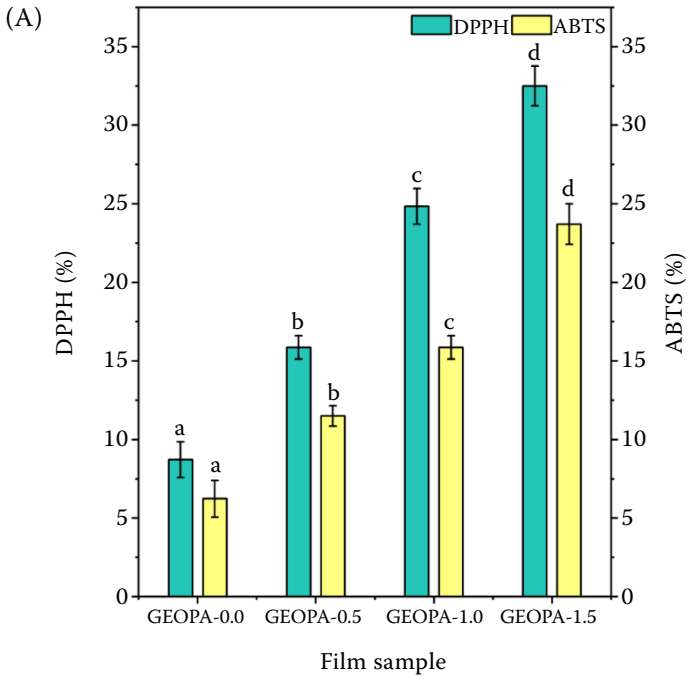
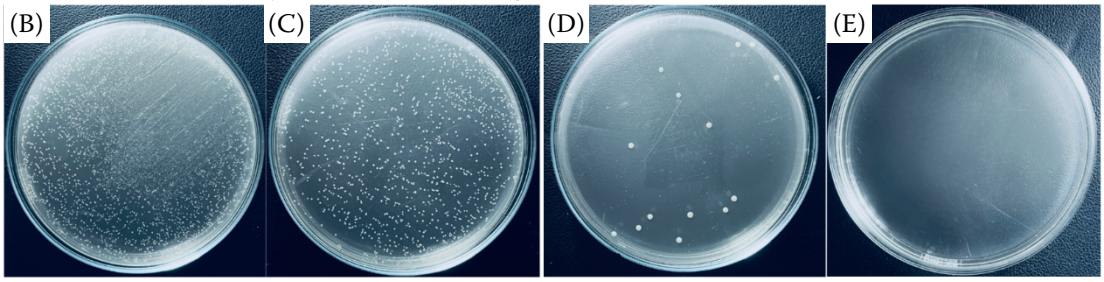


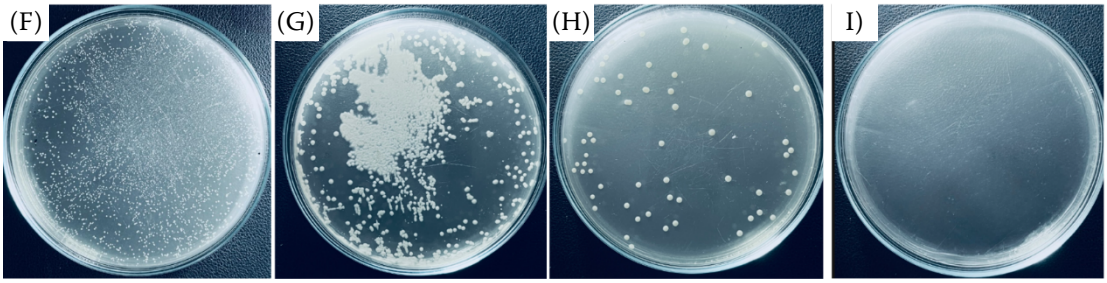
Figure 5. The properties of films: (A) antioxidant activity, (B–E) antibacterial activity on *Listeria monocytogenes,* (F–I) antibacterial activity on *Escherichia coli,* (B and F) GEOPA-0.0, (C and G) GEOPA-0.5, (D and H) GEOPA-1.0, and (E and I) GEOPA-1.5

[a–d]different letters indicate statistically significant difference ($P < 0.05$)
ABTS – 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid);
DPPH – 2,2-diphenyl-1-picrylhydrazyl

Film antibacterial activity on *Listeria monocytogenes*



Film antibacterial activity on *Escherichia coli*



test conditions. This pronounced antibacterial effect aligns with previous reports that GEO constituents can disrupt bacterial cell membranes, thereby suppressing microbial proliferation (Amalraj et al. 2020).

Preservation application for sliced bread

Moisture content and water activity. Bread slices stored with PP commercial plastic packaging tended to reduce *MC* and a_w less (Figure 6A and 6B). In addition, gradually increasing the GEO concentration in the pectin film improved bread's *MC* and a_w reduction trend. These results showed that the active film can help limit the movement of water vapor from the bread to the surrounding environment. As previously demonstrated, the WVP of the films was reduced with increasing GEO content in the pectin-alginate films. This has improved the water retention ability of bread when preserved with films supplemented with GEO (Alpers et al. 2021). The findings of the present study are consistent with those of Noshirvani et al. (2017), who reported that incorporating essential oils into composite films helped maintain the moisture content of sliced bread throughout storage.

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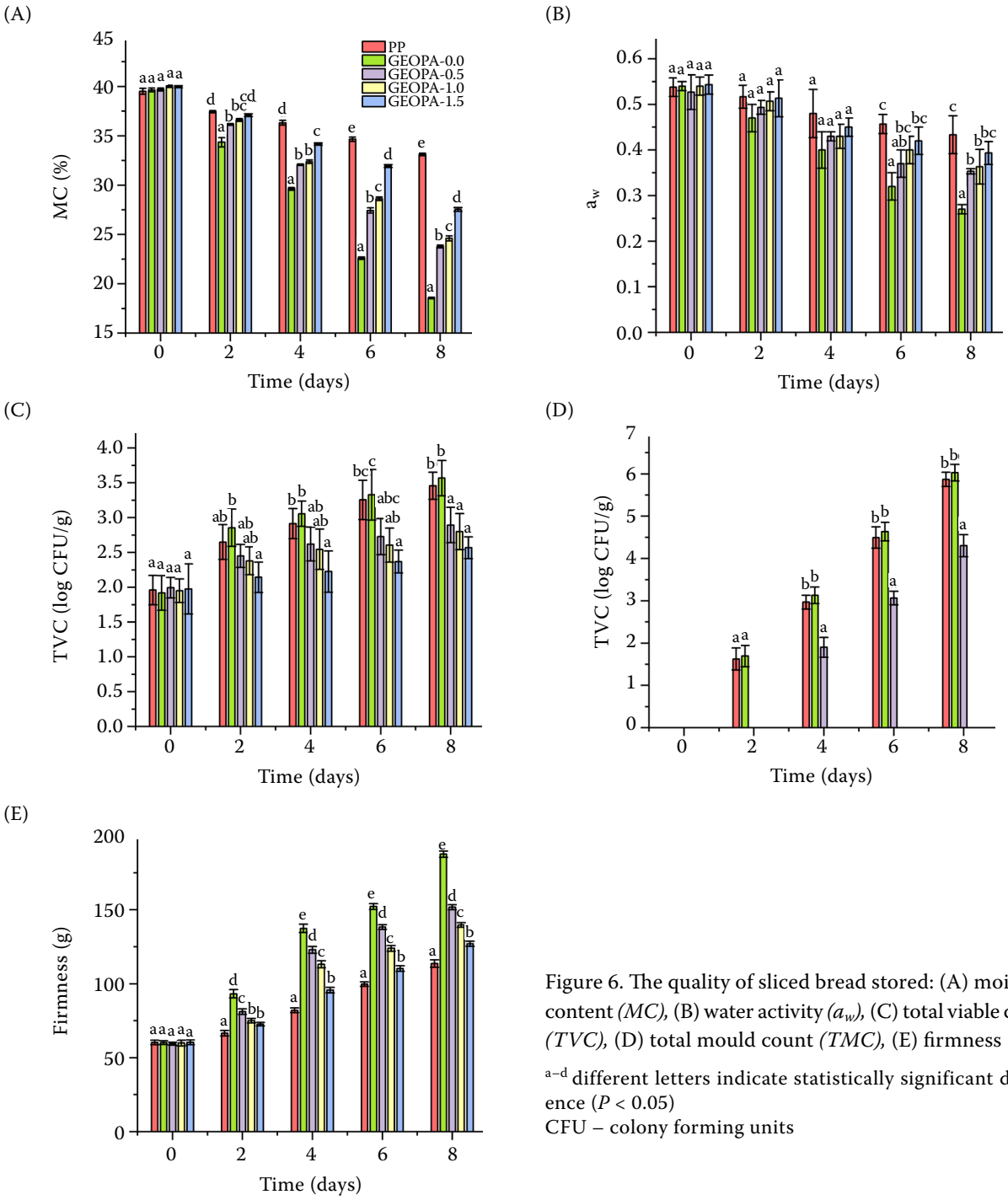

Figure 6. The quality of sliced bread stored: (A) moisture content *(MC)*, (B) water activity *(a_w)*, (C) total viable count *(TVC)*, (D) total mould count *(TMC)*, (E) firmness

[a–d] different letters indicate statistically significant difference ($P < 0.05$)
CFU – colony forming units

Microbiological. *TVC* and *TMC* of bread slices stored in different films were determined (Figure 6C and 6D). During the 8-day storage period, the *TVC* of all treatments gradually increased. The *TVC* value of bread slices sealed in PP film and GEOPA-0.0 film tended to increase faster than that of bread slices sealed in pectin-alginate film with added GEO. In particular, when the amount of GEO in the film gradually increased from 0.5 to 1.5%, the *TVC* value of bread slices during the same storage time gradually decreased. The *TMC* values of bread slices stored in PP, GEOPA-0.0, and GEOPA-0.5 films tended to increase gradually with storage time. In particular, the *TMC* values of bread slices preserved with GEOPA-1.0 and GEOPA-1.5 films were 0 log CFU·g^{-1} during 8 days of storage. Obvious changes in the microbiological quality of sliced bread stored in the test films were further demonstrated in Figure 7. Bread samples stored

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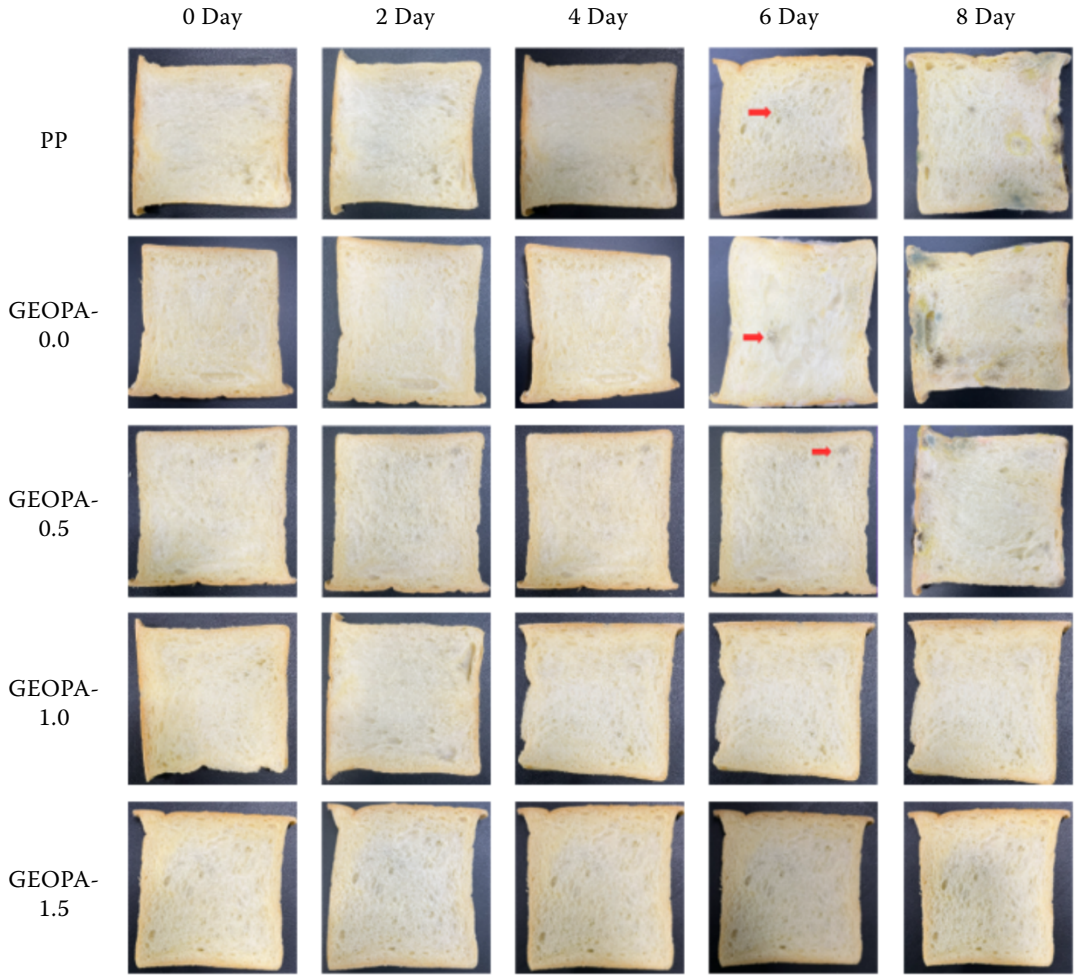

Figure 7. The visual appearance of sliced bread during storage

in PP, GEOPA-0.0, and GEOPA-0.5 films developed mould after 6 days of storage. However, sliced bread samples stored with GEOPA-1.0 and GEOPA-1.5 films did not show the presence of mould during the storage period. These findings are consistent with the results when analysing the *TVC* and *TMC* of sliced bread according to storage time. Additionally, some studies have reported that GEO has antibacterial and antifungal properties (Amalraj et al. 2020). When added to the film, GEO limits the growth of microorganisms on bread slices during storage. Similarly, Noshirvani et al. (2017) reported that the number of yeasts and moulds in bread was reduced through the application of carboxymethyl cellulose–chitosan–ZnO nanoparticle coatings during 15 days of storage. In addition, Balaguer et al. (2013) demonstrated that gliadin films incorporating cinnamaldehyde could extend the shelf life of bread from 5 days to 28 days by reducing the population of spoilage microorganisms.

Firmness. The firmness value of the bread samples during storage gradually increased in PP, GEOPA-1.5, GEOPA-1.0, GEOPA-0.5, and GEOPA-0.0 films (Figure 6E), respectively. Generally, the firmness of all sliced bread samples increased with storage time. As demonstrated previously, the moisture content of bread during storage decreased as the GEO concentration in the film decreased. This proves that firmness is inversely proportional to moisture, and the higher the film's ability to retain moisture, the lower the firmness of the bread. Serving as a plasticiser, water helps maintain the softness of bread; when moisture decreases, hydrogen bonds form between starch–starch and starch–gluten, which leads to greater firmness (Sourki et al. 2010). Similarly, the low water vapor permeability of carboxymethyl cellulose–chitosan–ZnO nanoparticle coatings has been reported to help limit the increase in firmness of sliced bread during storage (Noshirvani et al. 2017). In addition, Oliveira

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Table 2. Sensory evaluation of bread slices

Sample	Days	Colour	Flavour	Taste	Texture	Overall acceptance
GEOPA-1.0	0	7.73 ± 1.26^{Aa}	7.70 ± 0.95^{Aa}	7.57 ± 1.10^{Aa}	7.87 ± 0.86^{aB}	7.70 ± 0.88^{Aa}
	2	7.70 ± 1.29^{Aa}	7.67 ± 1.09^{Aa}	7.53 ± 1.17^{Aa}	7.73 ± 0.94^{AaB}	7.43 ± 0.82^{Aa}
	4	7.57 ± 1.01^{Aa}	7.50 ± 0.97^{Aa}	7.47 ± 0.90^{Aa}	7.57 ± 0.86^{AaB}	7.53 ± 1.22^{Aa}
	6	7.50 ± 0.73^{Aa}	7.47 ± 1.11^{Ab}	7.43 ± 1.14^{Ab}	7.33 ± 0.84^{AaB}	7.57 ± 0.97^{Aa}
	8	7.47 ± 0.82^{Aa}	7.40 ± 0.93^{Ab}	7.27 ± 1.14^{Ab}	7.20 ± 0.96^{Aa}	7.43 ± 0.73^{Ab}
GEOPA-1.5	0	7.80 ± 1.06^{Aa}	7.67 ± 1.18^{aC}	7.63 ± 1.43^{aC}	7.83 ± 1.05^{Aa}	7.73 ± 1.20^{aB}
	2	7.77 ± 1.30^{Aa}	7.53 ± 1.07^{aC}	7.47 ± 1.17^{aC}	7.80 ± 1.00^{Aa}	7.67 ± 1.09^{aB}
	4	7.63 ± 1.19^{Aa}	7.37 ± 1.16^{aBC}	7.33 ± 1.24^{aBC}	7.70 ± 1.15^{Aa}	7.50 ± 1.25^{AaB}
	6	7.57 ± 1.07^{Aa}	6.67 ± 1.21^{AaB}	6.57 ± 1.14^{AaB}	7.50 ± 1.22^{Aa}	7.17 ± 1.37^{AaB}
	8	7.50 ± 1.20^{Aa}	6.23 ± 1.17^{Aa}	6.27 ± 1.20^{Aa}	7.37 ± 1.10^{Aa}	6.67 ± 1.32^{Aa}

$^{A–C}$ different letters indicate statistically significant differences in sensory indicators in the same analysed samples but different storage times ($P < 0.05$), $^{a–b}$ different letters indicate statistically significant difference in sensory indicators in the same storage times but different analysed samples ($P < 0.05$)

et al. (2020) also noted that highbarrier packaging helps reduce the firmness increase in bread.

Sensory. As demonstrated in the previous experiment, GEOPA-1.0 and GEOPA-1.5 films significantly improved the microbiological quality of bread slices compared to other film samples. Therefore, bread slices preserved with GEOPA-1.0 and GEOPA-1.5 films were subjected to sensory evaluation during 8 days of storage, and the sensory results are presented in Table 2.

There was no significant difference between the sensory evaluation colour scores of the bread slices during storage (Table 2). However, the flavour and aroma scores of the bread slices preserved with the GEOPA-1.5 film decreased significantly from day 6 onwards. This may be due to the release of volatile substances from the GEO in the pectin-alginate film into the bread slices, reducing the flavour and aroma of the native bread.

The texture score values of the bread slices decreased continuously during the 8-day storage period (Table 2). As demonstrated previously, the GEOPA-1.5 film significantly maintained the moisture and softness of the bread, providing confidence in its performance. However, in the sensory evaluation, the texture scores of the bread slices stored with GEOPA-1.0 film were not significantly different from those stored with GEOPA-1.5 film.

During the 8 days of storage, the overall acceptance values of the bread slices wrapped with GEOPA-1.0 film did not differ significantly (Table 2). However, the overall acceptance value of bread slices preserved with GEOPA-1.5 film on day 8 was significantly lower than those on days 0 and 2. Furthermore, after 8 days of storage, bread slices wrapped with GEOPA-1.0 film were significantly higher in overall acceptance than those wrapped with GEOPA-1.5 film. This was due to the excessive release of volatile compounds from the GEO in the pectin-alginate film into the bread slices, which reduced the overall acceptability of the sensory assessors.

Overall, the sensory attributes of bread slices wrapped with pectin-alginate film at 2 GEO concentrations (1.0 and 1.5%) all had mean values above 6. A product is determined acceptable by sensory characteristics using a 9-point hedonic scale with a minimum score of 6 (Arruda et al. 2016). Therefore, bread slices preserved with GEOPA-1.0 and GEOPA-1.5 films can be determined acceptable for the sensory parameters examined in the present study. Chang et al. (2025) reported that cassava starch-based films containing 1.25% clove essential oil were capable of releasing the oil and helping to limit the decline in the sensory quality of sliced bread over 12 days of storage. Similarly, BautistaEspinoza et al. (2023) noted that active coatings incorporating cinnamon and lemongrass essential oils helped maintain the texture of sourdough bread, thereby improving its sensory scores.

CONCLUSION

The effects of different GEO concentrations on the structural, physical, antioxidant, and antibacterial properties of the composite materials were studied. The results show that the film's thickness, *EAB*, ΔE, *WVP*, and opacity increased. On the contrary, the film's *TS, MCF, WS,* and transmittance values decrease as the GEO concentration increases. SEM images show that the number of oil droplets on the pectin-alginate film surface increases as the GEO concentration increases.

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The composite films all demonstrate positive antioxidant and antibacterial properties. During storage, the quality parameters of sliced bread, such as *MC* and a_w, continuously decreased. In contrast, values such as *TVC, TMC,* and the firmness of sliced bread continuously increased with storage time. Increasing the GEO concentration in the pectin-alginate films helped limit moisture loss, microbial growth, and the firmness of bread slices. In addition, the sensory properties of the sliced bread were maintained at an average level throughout the storage period. This study showed that pectin-alginate film supplemented with GEO is a potential packaging material for preserving sliced bread.

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