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Preparation and Characterization of Whey Protein Edible Coating with Potato and Mango Peels extract: Application in Processed Cheese

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Abstract

Using active packaging to prevent harmful microorganisms from growing on the surface of processed cheese may increase its freshness, lengthen its shelf life, and enhance its quality. This research aimed to develop a functional edible film from whey protein isolate (WPI), potato peel extract (PPE), and mango peel extract (MPE). Both the total phenolic content and the antioxidant activity of the extracts (PPE and MPE) were measured. Using HPLC, we were able to characterize extracts and their primary components quantitatively. The physical, chemical, tensile, and microscopic features of the films were studied to learn more about them. The surfaces of processed cheese were kept in the refrigerator at 4 degrees Celsius for three months and coated with them. Despite variations in total phenolic and flavonoid content, the antioxidant activity of the two infusions was quite comparable. Polyphenols were found in their phytochemical study. It found noticeable variations in film thickness and moisture content between the films with increasing amounts of PPE and MPE. Mechanical characteristics of films are dramatically affected by the incorporation of PPE or MPE infusion, with PPE- and MPE-reinforced films showing notable improvements over the control film.

Keywords: Whey protein isolate, Potato peel extract, mango peel extract, edible film, tensile properties, permeability, processed cheese

1. Introduction

Processed cheese is made by combining natural cheese with emulsifying salts and other dairy and non-dairy components, then heating and continuing mixing to create a homogenous product with a long shelf life [1]. According to SØRENSEN [2], processed cheese is one of the world's most popular cheeses, utilized as a component in various cuisine dishes (processed foods and food service). Processed cheese's prevalence may be attributed to its multiple end-use applications. The functional characteristics of a cheese (when used in a specific meal) refer to the performance of the cheese during all stages of food preparation and consumption, which ultimately contribute to the flavour and visual appeal of that prepared food [3]. The required functional features of processed cheese are divided into two groups based on their end-use application: unmelted texture properties and melted texture properties.

The packaging and food industries are concentrating on creating edible packaging materials to decrease waste due to the recent rise in environmental consciousness and customer desire for stable, nutritious, and safe meals [4]. As a cutting-edge sustainable packaging option, edible films and coatings have a lot of promise to act as a functional barrier between food and the environment, maintaining food safety and quality [5]. One of the most promising edible biopolymers for food packaging is whey protein. Whey protein edible film has lately attracted attention for its abundance, safety, and biodegradability, as well as for serving as an

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environmentally benign substitute for synthetic polymers [6]. The two main types of whey protein used in creating edible films and coatings are whey protein isolate and concentrate. Compared to polysaccharides and other protein polymers, films/coatings composed of whey proteins are colourless, odourless, flexible, and transparent, with exceptional mechanical and barrier qualities. A three-dimensional gel-like network of dry, strongly interacting polymers makes an edible whey film. Compared to other protein films, they exhibit excellent oxygen permeability, poor tensile strength, and high water vapour permeability [7]. Whey protein-based films/coatings are effectively used in several meals as carriers of active substances (antimicrobials, antioxidants, probiotics, etc.) [8]. Utilizing unusual and sustainable material sources, such as leftovers from producing fruits and vegetables, is popular today [9,10]. Mango peels and kernels are by-products of the mango processing industry. Peel, a result of fruit processing, accounts for around 15% to 20% of the weight of the whole fruit. Mango peel is utilized as raw material to create biodegradable packaging [11]. Also, mango peels are high in beneficial compounds such as phenolic compounds, minerals, and fibre [12]. Mango peels' have antioxidant activity due to bioactive ingredients such as gallates, xanthones, gallic acid, flavonoids, benzophenones, and their derivatives [13]The main by-product of the potato processing industry is potato peels, which may be apprehended as an origin of bioactive compounds, especially polyphenolic ingredients receiving more attention [14]. So, potato waste is a potential source of inexpensive resources, and its collection and recycling within the food chain might be a long-term solution to the problems facing the industrialized world today [15]. The nutritional and pharmacological qualities as well as the antioxidant capacity of these molecules may be preserved when bioactive components, particularly polyphenols, are extracted from potato skin using gentle technology [16]. Bioactive compounds isolated from potato peel waste are able to slow down the oxidative breakdown of various fatty food matrices [17, 18]. However, to the best of our knowledge, there is no information in the literature on their potential use of potato and mango peels for storing minimally processed cheese.

This work aimed to create active edible packaging materials using WPI, potato peel, and mango peel extracts. We utilized potato peel and mango peel extract infusions to provide a more realistic approach. We assessed the antioxidant activity, the quantity of flavonoids, and the total phenolic compounds of the extracts. Biopolymer films were utilized as packaging for processed cheese for three months in cold storage at 4 °C to determine the influence of WPI edible films on cheese quality and shelf-life. The physical and chemical characteristics of films include their thickness, solubility in water, moisture content, and tensile Properties such as tensile strength, Young's modulus, and elongation at break.

2. Materials and Methods

Anhydrous glycerol (purity ≥ 99.5%) and salts were used to prepare saturated solutions for the determination of water vapour sorption isotherms, including lithium chloride, potassium acetate, magnesium chloride, potassium carbonate, magnesium nitrate, sodium nitrate, sodium chloride, sulfate ammonium, barium chloride, Folin's phenol reagent and ethanol were supplied from Himedia, India. Whey protein isolates BiPRO (WPI, ~95% protein) was purchased from Davisco Foods International Inc. (La Sueur, MN, USA). Matured cheddar cheese (6 months) was imported from New Zealand by Khaled Khoshala Co. for Food Industries & Cooling, Egypt. Ras cheese (1 month) was Purchased from Mariam Co., Giza, Egypt. The Fonterra butter was obtained from Sakr Group Co., Egypt. Skim milk powder grade "A" was purchased from dairy America, USA. Egy Phos S_2 emulsifying salts were obtained from The Egyptian Company for Dairy Products and Food Additives "EGYdairy" Egypt.

2.1. Extraction of Phenolic Compounds from wastes

To obtain potato peel extract (PPE) powder and mango peel extract (MPE) powder which goes into preparing edible coating films [19]. Freshly mango peel from a single batch (*Mangifera indica L.*) was collected from Global Industries Company. The potato (*Solanum tuberosum*) cultivar was purchased from the local market and cleaned with tap water, and the peel was removed. The cleaned peel of potatoes and mangos were spread in trays and dried at 45 ± 2 °C for 48 hours using a cross-flow drier (Model PTD-48E, Premium Industries Ltd., Ahmadabad, India).

The weight of 10 g of each Potato peel powder (PP) and mango peel powder (MP) was added of each to 200 mL of ethanol: water (80:20) and placed in an ultrasonic pan for 3 minutes at room temperature. Then, the samples were centrifuged at 4500 Xg for 5 minutes. The extraction procedure was done three times, and the supernatant was separated and collected in a container. The solvent was evaporated using the rotary evaporator (Büchi R20, Switzerland) under vacuum 0.1mPa and 50 °C ± 2, and the residue was dried using the freeze dryer (Labconco cooperation, Kansas City, United States) at –52 °C for 48 h under 0.1 mPa and stored at –18°C **[19].**

2.2. High-Performance Liquid Chromatography (HPLC)

Fifteen phenolic compounds, gallic acid, chlorogenic acid, catechin, methyl gallate, coffeic acid, syringic acid, pyro catechol, rutin, coumaric acid, vanillin, ferulic acid, naringenin, daidzein, quercetin, and cinnamic acid were purchased from Sigma-Aldrich Chemical (St. Louis, MO, USA) and respectively dissolved in methanol to a final concentration of 100 µM. For HPLC analysis of MPE and PPE, used an Agilent 1260 series was utilized. Column C18 Eclipse (4.6250 mm i.d., 5 m) was used for separation. The mobile phase included water (A) and 0.05% trifluoroacetic acid in acetonitrile at a flow rate of 1 mL min^{-1} (B). The mobile phase was timed as follows: 0 min (82% A), 0 min to 5 min (80% A), 5-8 min to 6 min, 8 min to 12 min, 12 min to 15 min, and 15 min to 16 min (82% A). At 280 nm, the multi-wavelength detector was seen. The injection volume for each of the sample solutions was 10 µL. The column was maintained at a constant temperature of 35°C [20]. All solvents were filtered with a 0.22 µm membrane filter. Each injection was described before. Triplicate tests were conducted for each sample. The level of each compound was expressed in $\mu g \cdot g^{-1}$ dray matter powder.

2.3. Preparation of Film-Forming Solutions

The aqueous film solution of 8% dry matter was obtained by mixing WPI with distilled water and heated at 80 °C for 30 min using the magnetic stirrer (IKA—Werke GMBH & Co., Staufen, Germany) rotating at 270 rpm. Glycerol was added as a plasticizer at 50% to the protein. The potato and mango peel extract powder were added to WPI polymer at different concentrations of 0.5, 1, and 1.5 % (w/w). The mixtures were homogenized for 3 min at 24,000 rpm using the IKA—Werke GMBH & Co., Staufen, Germany. The WPI polymer, without adding other substances, was used as a control **[21]**.

2.4. Films Preparation

The WPI, WPI-MPE, and WPIPPE were poured on a Petri dish in a constant amount and dried at 50% relative humidity and 25 ◦C for 24 h in the oven. Dried films were collected and saved at 25 ◦C and a relative humidity of 50% before testing **[22]**.

2.5. Thickness

With an accuracy of 1 µm, the film thickness was measured using an electronic gauge from Metrison S.A. in Mo'sciska, Poland. The finished film had a thickness of 80 ± 5 µm **[22]**.

2.6. Colour

Color was measured using a Minolta colorimeter (model CR-300, Konica Minolta, Tokyo, Japan) in the CIE **(D_{65})** L*a*b* system, where L* represents brightness and a* and b* are trichromatic coordinates. A normal white plate with the colour values L* = 95.99, a* = - 0.14, and b* = 2.04, served as the reference material. The overall colour difference between the film and the white reference was estimated using Sobral et al **[23]**:

$$\Delta E = \sqrt{(L^* - L)^2 + (a^* - a)^2 + (b^* - b)^2}$$

where D*E*= difference of total colour; *L**, *a**, *b**= parameters for white plate; *L*, *a*, *b* = films parameters.

2.7. Water Vapour Permeability

Based on the gravimetric technique described by Debeaufort et al. **[24]**, the water vapour permeability was carried out three times. The samples were sealed in unique twist-off glass containers with an open cover by sandwiching them between two open rings. For a 100% relative humidity, distilled water was utilised. The samples were put into a climate chamber model KBF 720 made by Binder in Tuttlingen, Germany, with a relative humidity of 10% and a temperature of 23 °C. For seven days, sample mass measurements were taken twice daily with an accuracy of 0.0001 g. In order to stabilise the process, the initial data were excluded from the calculation of the weighting of sampling over time using linear regression. The calculated water vapour permeability was given in $g \cdot mm \cdot m^{-2} \cdot d^{-1} \cdot kPa^{-1}$.

2.8. Oxygen Permeability

Using an OXTRAN 2/21 MH modular system (Mocon, Inc., Minneapolis, MN, USA) with a coulometric sensor based on ASTM F **[25]**, oxygen permeability was evaluated at least twice in accordance with the standard test technique for measuring oxygen gas transmission rate through plastic film and sheeting. An opening testing area of

5 cm^2 on a stainless steel mask was used to mount a film sample. At 25 °C and 50% relative humidity, the sample was subjected to the flow of nitrogen gas on one side and the flow of oxygen on the other.

2.9. Water solubility

The method for calculating water solubility (WS) was modified from that reported by Gontard **[26]**. Three film samples (2 cm, weighed 0.10-0.25 g) were immersed in 100 mL of distilled water and their weights recorded. The system was sealed and agitated at 100 rpm for 24 hours at 20 °C (Ferca, TT400 model, Argentina), and the residual undissolved film was dehydrated at 105 °C for 24 hours after being filtered using Whatman No1 filter paper (previously dried and weighed). It was determined that WS as follows:

$$\mathrm{WS} = \frac{\left[\left(P_0^*(100 - \mathrm{MC})\right) - P_f\right]^* 100}{\left[\left(P_0^*(100 - \mathrm{MC})\right)\right]}.$$

where MC = moisture content (%), Pf = final dry film weight (g), P0 = initial film weight (g).

2.10. FT-IR (Fourier transform infrared) spectra

Infrared spectroscopy (Spectrum Two PerkinElmer Inc, USA) was used to determine the alterations in functional groups caused by the interaction of WPI and PPE or WPI and MPE **[27]**. The spectra were taken with a resolution of 4 cm^{-1} and ranged from 400 to 2000 cm^{-1}.

2.11. Antimicrobial Activity of the WPI, WPI-PPE, and WPI-MPE films

The agar disc diffusion method was used to assess the antimicrobial properties of edible films against *Staphylococcus aureus* ATCC 13565 and *Bacillus cereus* EMCC 1080, two gram-positive typical bacteria, and *Salmonella typhi* ATCC 15566 and *Escherichia coli* ATCC 51659, two gram-negative typical bacteria [28]. Additionally, fungi like *Penicillium verrucosum* NRRL 695, *Aspergillus nigr* ATCC 56091, *Aspergillus flavus* ITEM 698, and *Aspergillus carbonarius* ITEM 5010 have been identified. On the Mueller-Hinton agar plate, 100 L of a bacterial suspension (10^7 CFU/mL) or 10^4 fungus spores/mL were uniformly spread (Aladdin Reagent Co., Shanghai, China). On the inoculated plate's centre, a 10-mm-diameter disc with the WPI, WPI-PPE, and WPI-MPE films was placed. After being sealed and left to stand for 30 minutes, the agar plates were incubated at 37°C for 24 hours for bacteria and 36 hours for fungi. Using a calliper, the inhibition zones' diameters (mm) were measured (Deli Co., Ninghai, China). For each sample, three duplicates were made.

2.12. Scanning Electron Microscopy (SEM)

S-3400N Scanning electron microscopy (VEGA 3, TE SCAN, Czech Republic) was used to examine the edible films' surface and cross-section. A tiny coating of gold was sputtered onto the surface of the bronze stubs, onto which the film samples had been affixed horizontally for electrical conductivity. The measuring tool of choice was a silicon probe with a 125-mm cantilever length from Hitachi in Tokyo, Japan. About 100 kHz was chosen as the resonant frequency. The specified scan rates were 0.5~1.0 Hz **[22]**.

2.13. Manufacture of processed cheese (PC)

The technique of Ibraheem **[29]** was followed to make processed cheese at 85 °C for 8 minutes using a double jacket pan, while the concentrations of the necessary components as described by Dimitreli & Thomareis **[30]** were calculated to make processed cheese spread. The prepared item was cut into slices and placed into plastic jars at a temperature of 5 to 12 °C. The constituents in the mixture under investigation were as follows: 2% milk protein concentrate, 15% skim milk powder, 7% cheddar cheese, 24.5% butter, 2.8% emulsifying salt (S4), 0.8% salt, 0.1% xanthan gum, 0.1% guar gum, 0.1% myprogene, 0.1% potassium sorbate, and 0.03% nisin.

2.14. Evaluation of Physicochemical Properties of Coated Cheese

Chemical analysis: Total solids, fat, protein, ash and salt were determined according to methods described by AOAC [31]. Lactose content was determined calorimetrically using phenol-sulphuric acid method as described by Barnett & Tawab **[32]**. The pH was measured using a pH meter (JENWAY 3505) equipped with the combined electrodes.

2.15. Weight Loss Measurement

Water loss is the key factor in cheese weight reduction. The difference between the original cheese weight (Wi) and the cheese weight as measured at various storage time intervals (Wf) was calculated in this experiment to indicate weight loss as a percentage **[33].** The equation looked like this:

$$\text{Weight loss (\%)} = \frac{Wi - W}{Wi} X100$$

2.16. Sensory evaluation

All samples of processed cheese were evaluated organoleptically for the different sensory properties provided already 20. Cheese scoring was carried out

for flavour (40 points), body and texture (40 points), and colour and appearance (20 points) by a score panel of 12 personal staff members of the Food Science and Technology Dep. Home Economic Faculty, Al-Azhar University, Tanta, Egypt **[34]**.

2.18. Statistical Analysis

SPSS 20.0 was used to conduct the statistical analysis (Chicago, IL, USA). The mean values and standard deviation (means SD) are shown for all graphs and tables. A one-way ANOVA was employed, and the significance of differences between the means was established using Tukey's test. The Duncan's multiple range technique was used to determine if any differences were significant ($p < 0.05$).

3. Results and Discussion

3.1. Antioxidant Activity

The scavenging activity of the WPI-based film solutions was significantly (p 0.05) changed by the addition of PPE or MPE, as illustrated in Table 1. However, with the addition of PPE or MPE, the coating solutions' both antioxidant activity (AA) and total phenolic content (TPC) increased. Furthermore, the AA increased as the ratio addition (0., 0.5, 1.0, and 1.5%) increased.

The percentage of TPC in solutions for edible coatings increased from 24.25 ± 0.52 to 62.12 ± 2.23, 119.78 ± 1.95, and 134.25 ± 2.09 (mg GAE/g film) after the addition of MPE extract at ratios of 0.5, 1.0, and 1.5 %, respectively. The percentage of TPC in edible coating solutions after the addition of PPE extract at ratios of 0.5, 1.0%, and 1.5% increased from 24.25 ± 0.52 to 72.98 ± 1.45, 135.85 ± 1.36, and 199.27 ± 1.25 (mg GAE/g film). The percentage of AA showed a similar trend. When the concentration of PPE or MPE was increased from 0.5% to 1.5%, the AA ratio increased significantly ($p < 0.05$). (Table 1). DPPH scavenging assays were used to determine the antioxidant activity of the edible coating emulsions. WPI-PPE emulsion demonstrated higher antioxidant activity than WPI-MPE emulsion in terms of DPPH radical scavenging activity. This happened because the WPI nanoparticles were better at getting rid of free radicals and because bioactive peptides were made when the polymer solution was made **[35]**.

Table 1
Shows the antioxidant activity and total phenolic content of WPI edible films alone and containing PPE or MPE in various ratios (0.5, 1.0, and 1.5%)

Samples	Total Phenolic Content (mg GAE/g)	Antioxidant Activity (%)
WPI	$24.25^{f} \pm 0.52$	$23.23^{e} \pm 1.29$
WPI-0.5% MPE	$62.12^{e} \pm 2.23$	$72.75^{de} \pm 2.75$
WPI-1.0% MPE	$119.78^{c} \pm 1.95$	$78.89^{c} \pm 2.15$
WPI-1.5% MPE	$134.25^{b} \pm 2.09$	$92.15^{b} \pm 1.58$
WPI-0.5 % PPE	$72.98^{d} \pm 1.45$	$73.45^{d} \pm 0.98$
WPI-1.0% PPE	$135.85^{b} \pm 1.36$	$89.98^{b} \pm 1.09$
WPI-1.5% PPE	$199.27^{a} \pm 1.25$	$98.50^{a} \pm 0.67$

Mean values in the same column with different small letters indicate significant differences according to Duncan's multiple range test ($p < 0.05$).

HPLC was used to perform an initial assessment of the PPE and MPE to establish which components were responsible for their remarkable antioxidant and antibacterial properties. Table 2 depicts the information for 15 identified components. Moreover, polyphenols such as gallic acid, coumaric acid, chlorogenic acid, vanillin, methyl gallate, coffeic acid, ferulic acid, naringenin, and derivatives of flavonoids such as catechin, daidzein, and quercetin were identified. The PPE contains high levels of Coffeic acid (23284.53 g/g), quercetin (516.48 g/g), and ferulic acid (15087.55 g/g). Also, the MPE containing high levels of ferulic acid (3521.14g/g), Gallic acid (3111.31 g/g), Naringenin (3565.91 g/g), Coumaric acid (1545.57 g/g).

Table 2
The main polyphenol compounds in mango peel extract and potato peel extract were identified using HPLC

Standard	MPE Conc. (µg/g)	PPE Conc. (µg/g)
Gallic acid	$3111.31^{c} \pm 9.91$	$863.49^{e} \pm 1.23$
Chlorogenic acid	$160.33^{j} \pm 1.95$	$2858.07^{d} \pm 2.92$
Catechin	$8929.97^{a} \pm 3.35$	$709.46^{f} \pm 1.75$
Methyl gallate	$288.00^{f} \pm 0.67$	$86.63^{j} \pm 0.97$
Coffeic acid	$198.25^{h} \pm 0.59$	$23284.53^{a} \pm 5.06$
Syringic acid	$1031.36^{e} \pm 1.68$	**ND**
Pyro catechol	**ND**	$437.33^{i} \pm 1.19$
Rutin	$100.02^{j} \pm 0.95$	$3012.52^{c} \pm 11.05$
Coumaric acid	$1545.57^{d} \pm 2.57$	$71.00^{k} \pm 0.85$
Vanillin	$28.76^{l} \pm 1.34$	$444.17^{i} \pm 2.37$
Ferulic acid	$3521.14^{c} \pm 7.11$	$15087.55^{b} \pm 5.57$
Naringenin	$3565.91^{b} \pm 4.95$	$640.15^{g} \pm 1.01$
Daidzein	$70.76^{k} \pm 0.79$	$529.11^{h} \pm 0.97$
Querectin	$220.21^{g} \pm 0.85$	$516.48^{h} \pm 0.85$
Cinnamic acid	**ND**	$35.20^{l} \pm 0.65$

Mean values in the same column with different small letters indicate significant differences according to Duncan's multiple range test ($p < 0.05$). ND; not detected

3.1. Microstructure

Figure 2 depicts the results of using the SEM to capture the surface and cross-section microstructures of the films. WPI had a smooth surface and cross-section, but the material also had

some pores and was evenly scattered with dispersed irregular particles. The surfaces of the WPI-PPE and WPI-MPE films were seamless and continuous. Meanwhile, both WPI-PPE and WPI-MPE-based films were found to have a uniform, compact inner structure free of pores. This demonstrated that PPE and MPE could be distributed uniformly in the dry protein network and that WPI-based emulsions could produce one-component hydrocolloid films with very well network architectures **[56]**.

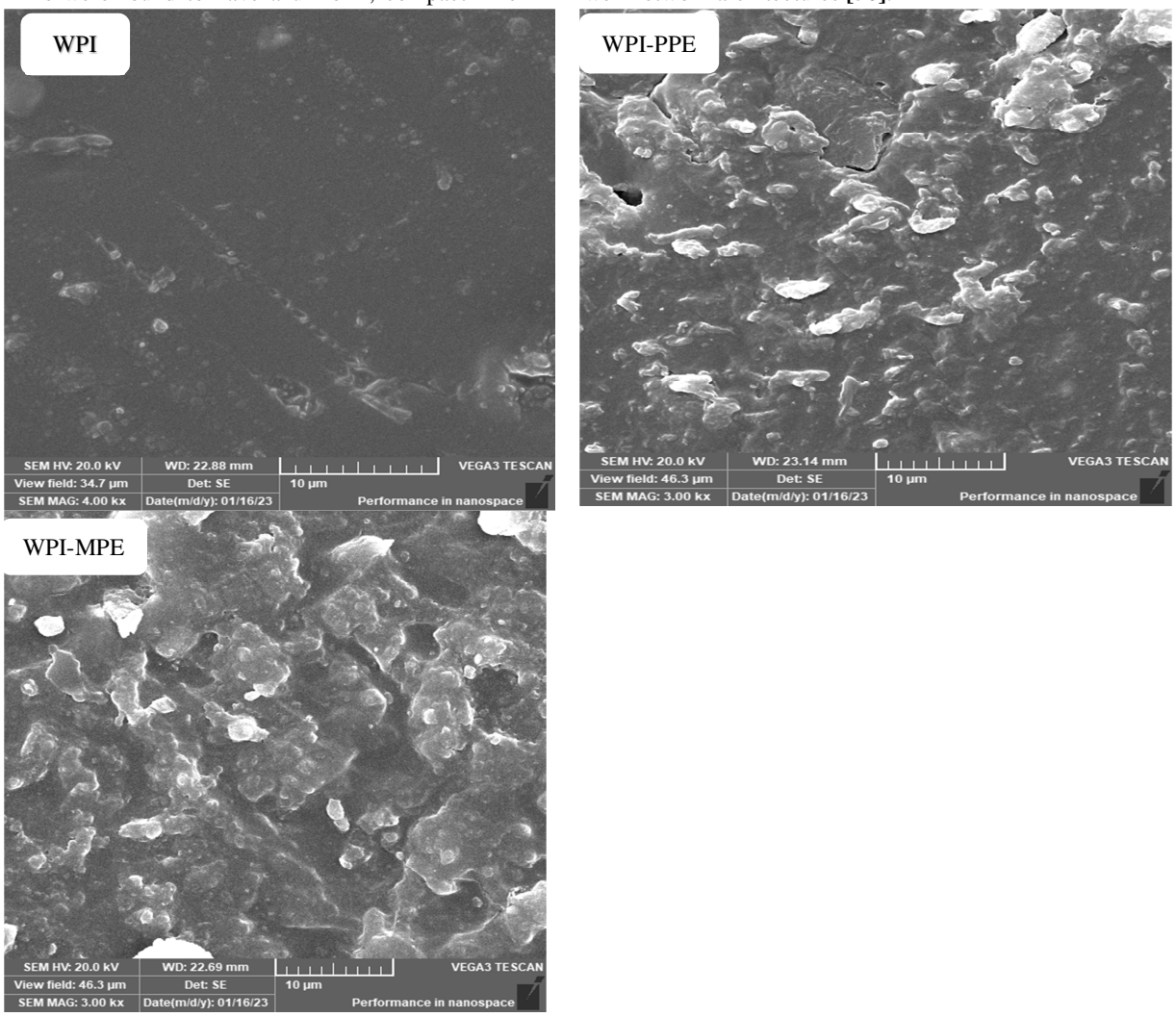


Figure 2: Scanning electron microscope of WPI, WPI-PPE, and WPI-MPE edible films

3.2. Films appearance

All films showed a continuous structure free of holes or fractures after air-drying. The films containing PPE were less transparent and somewhat brownish; the films containing MPE were clear and yellow; and the control films were translucent but hardly glossy. They were approximately 125 ± 10 mm thick. The casting plates and films may be readily detached.

3.3. Colour measurement

Despite the fact that opacity and colour have a direct influence on the look of coated food items and customer acceptance, films should have adequate light barrier qualities. As expected, the ingredients in the solutions used to make films have a big effect on the transparency and colour of the films.

Table 3 showed that the colour of films made of whey protein isolate was L* 40.14 ± 0.80, while a* of -0.62 ± 0.07 tended to be green, and b* 2.90 ± 0.48, which tended to be yellow. At the same time, these values changed by adding 0.5, 1.00, and 1.50 peel extracts of both mango and potato. It is noticed that all WPI films with MPE and PPE are incorporated, which increases the positive values of a* and b* with increasing addition of MPE and PPE while the value of L* decreases. From the results,

we find that the films' colour tends to be reddish-yellow, which is very similar to the colour of processed cheese, which was a catalyst for accepting the coating cheese. The control films had the greatest value, whereas films with 1.5% PPE or MPE, which were coloured yellowish red, had the lowest value. Elsayed **[35]** found comparable findings with whey protein films that included mango peel extract. The colour of MPE or PPE, which impacts how the film appears, is what causes the changes in colour parameters. However, all of the films under examination had a somewhat transparent look, which is desired for applications to cheese, where colour is an important factor in determining quality.

Table 3
The total colour difference (DE), L*, a*, and b* of whey protein films, (WPI + PPE) and (WPI + MPE)

Film	*L**	*a**	*b**	Δ*E*
WPI	**40.14^{a} ± 0.80**	**-0.62^{e} ± 0.07**	**2.90^{d} ± 0.48**	**59.48^{d} ± 0.77**
WPI-0.5 % MPE	**34.60^{b} ± 0.33**	**1.37^{c} ±0.05**	**12.44^{a} ± 0.48**	**66.16^{c} ± 0.23**
WPI-1.0% MPE	**30.62^{c} ± 0.52**	**3.48^{b} ± 0.21**	**11.76^{a} ± 1.05**	**70.04^{b} ± 0.70**
WPI-1.5% MPE	**28.24^{d} ± 0.33**	**4.71^{a} ± 0.25**	**11.65^{a} ±1.23**	**72.43^{a} ± 0.14**
WPI-0.5 % PPE	**34.95^{b} ± 1.92**	**0.27^{d} ± 0.48**	**10.04^{ab} ± 0.88**	**65.39^{c} ± 2.03**
WPI-1.0% PPE	**30.42^{c} ± 0.18**	**3.59^{b} ± 0.20**	**9.96^{b} ± 0.09**	**69.95^{b} ± 0.24**
WPI-1.5% PPE	**27.78^{d} ± 1.74**	**4.15^{a} ± 0.15**	**6.35^{c} ± 2.34**	**72.21^{a} ± 1.52**

Mean values in the same column with different small letters indicate significant differences according to Duncan's multiple range test ($p < 0.05$)

The overall colour difference (DE) between the film and white standard increased statistically significantly when MPE was added from 59.48 ± 0.77 for control films to 66.16 ± 0.23, 70.04 ± 0.70, and 72.43 ± 0.14 for films with MPE and 65.39 ± 2.03, 69.95 ± 0.24, and 72.21 ± 1.52 for the film with PPE. Due to the initial colour of MPE or PPE and their distribution in the film matrix, which had an impact on the larger deviations from the white standard, the yellowing of whey films might explain this sharp rise in value. This finding may be attributed, in accordance with Galus [22], to greater polymer chain mobility and intermolecular spacing, which may improve the light's capacity to pass through edible films. Whey protein films with MPE showed a similar trend **[35]**.

3.4. Oxygen Permeability

Due to their exceptionally polar nature and the high degree of hydrogen bonding of highly polar proteins, whey protein edible films are often distinguished by having an excellent oxygen barrier. It is widely known that hydrogen bonds prevent polymer chains from moving around, leading to relatively low gas permeability [36], which is lower than that of conventional, petroleum-based packaging films like high-density polyethene (HDPE) or low-density polyethene (LDPE) **[37]**. Due to the various additions (0.5, 1.00, and 1.5%) of MPE showed a considerable reduction in the oxygen permeability of WPI film from 27.83 to 22.57, 13.81, and 0 CC/m2.day. While PPE had been reduced to 21.05 with a ratio of 1%, then increased to 48.60 CC/m2/day with a balance of 1.5%. (Table 4). This was mostly due to the WPI-based coating's ability to create hydrocolloid films that included just one component and had a tidy network structure. The WPI-MPE with glycerol-coated oxygen barrier exhibited the greatest performance in blocking oxygen. A potentially effective edible coating for food preservatio is whey protein (WP), which has recently attracted significant interest for its health, safety, biodegradability and a benign alternative to chemical polymers **[8]**. Additionally, edible coating materials generated from whey proteins have low viscosity, mechanical resilience, colorlessness, transparency, and flexibility **[8, 38, 39]**. Additionally, a recent industrial innovation attempts to provide customers with health advantages by including active chemicals (such as probiotics/prebiotics, antimicrobials, antioxidants, and taste compounds) into whey protein edible coating **[8, 40, 41]**. Many studies discovered that including mango peel extract significantly improved the physicochemical and biological properties of polysaccharide or whey protein coatings, including opacity, moisture content, thickness, oxygen, and water vapour barriers **[8, 35]**.

3.5. Water solubility

Table 4 illustrates the water solubility of glycerol-plasticized WPI-based films created by cross-linking proteins with PPE or MPE at different ratios (0.5, 1.00, and 1.50%) after 24 hours at 20 °C. Kim and Ustunol **[42]** had previously observed that glycerol-plasticized WPI films were only partly water-soluble. The water solubility of the films was significantly ($P < 0.05$) increased by the incorporation of (0.5, 1.0, and 1.5 %) PME or PPE in WPI-based films the water solubility of WPI film was 24.75 ± 4.5 increased to 27.45 ± 4.3 with 1.5 % MPE addition.

Table 4
Whey protein films' solubility, water vapour permeability (WVP), oxygen permeability, and thickening with (WPI + PPE) and (WPI + MPE)

Film	O_2 TR ($CC/m^2.day$)	WVPR ($g/m^2.day$)	Water solubility (%)	Thickens µm
WPI	$27.83^{b} \pm 0.30$	$1555^{b} \pm 115$	$24.75^{b} \pm 4.51$	$115^{d} \pm 12$
WPI-0.5 % MPE	$22.57^{c} \pm 0.22$	$1454^{b} \pm 100$	$25.57^{a} \pm 5.23$	$130^{c} \pm 10$
WPI-1.0% MPE	$13.81^{d} \pm 0.10$	$1528^{b} \pm 105$	$26.59^{a} \pm 4.51$	$133^{b} \pm 11$
WPI-1.5% MPE	0	$1706^{a} \pm 110$	$27.45^{a} \pm 4.30$	$135^{ab} \pm 9$
WPI-0.5 % PPE	$13.26^{d} \pm 0.15$	$1527^{b} \pm 96$	$25.77^{a} \pm 3.90$	$119^{d} \pm 5$
WPI-1.0% PPE	$21.05^{c} \pm 0.21$	$1440^{b} \pm 101$	$27.13^{a} \pm 4.27$	$135^{ab} \pm 8$
WPI-1.5% PPE	$48.60^{a} \pm 0.35$	$1313^{b} \pm 97$	$28.10^{a} \pm 5.00$	$140^{a} \pm 10$

3.6. Water Vapour Permeability

A film's barrier properties are among its most important qualities when used for food packaging because of gas migration during storage. Adding 0.5, 1.0, or 1.5% of PPE significantly reduced the water vapour permeability of the control film (WPI), which was 1555.10 g/m2.day.kPa, to 1527.83, 1440.16, or 1313.90 g/m2.day.kPa, respectively. Also, adding 0.5% and 1.0% MPE to the film lowered the WVP to 1454.48 and 1528.25 g/m2.day.kPa, respectively. But, when MPE was increased by 1.5%, the value of WVP increased significantly by 1528.25 g/m2.day.kPa (Table 4). The films' water vapour permeability decreases with the addition of PPE or MPE (polyphenols) due to WPI film improvement. The water vapour permeability (WVP), a crucial criterion, largely determines how suitable a material is for packaging food. The migration of water vapour from the air to the food items or the loss of moisture from the product to the environment is a factor that affects the stability and quality of packaged food throughout storage. Applying coatings may prevent the cheese from dehydrating **[8]**. According to Kontogianni **[43]** found the whey protein films were chosen to include rosemary and sage infusions because they had high total phenolic and flavonoid contents and strong antioxidant effects. According to different studies, adding mango peel extract significantly improved the physicochemical and biological properties of polysaccharide or whey protein edible films, including thickness, opacity, moisture content, water vapour barriers, and oxygen barriers **[8, 44, 45]**.

3.7. Thickness

At room temperature, the system may thicken and gel if MPE or PPE were added in various ratios of 0.5, 1.0, and 1.5% to a heat-denatured whey protein. Whey protein solution was heated to 70–90 °C for 5–60 min at a pH of 7 to produce filamentous protein aggregates without gelation. The interaction between the filamentous-type protein aggregates and polyphenols was improved after chilling and the addition of MPE and PPE. The content of polyphenols and proteins in the solution determines how significant these changes are. With the addition of more MPE or PPE, the thickness of the WPI film rose from 115 12 m to 140 10 m. (Table 4).

3.8. Mechanical properties

For edible films and film coatings, mechanical properties are crucial because they reveal the films' robustness and the coatings' capacity to improve the mechanical integrity of cheese. It is crucial to understand the effect of bioactive ingredients interacting internally and its relation to mechanical properties like tensile strength and elongation at break. Therefore, packing materials need to be strong, tough and elastic. Table 5 illustrates the tensile strength of the WPI-based films. The films' tensile strength was considerably decreased by the increased MPE and PPE ratio contents (p 0.05). As the concentration of MPE increased by 0.5, 1.0, and 1.50%, the tensile strength value reduced from 1.55 0.10 to 1.25 0.05, 1.04 0.02, and 1.41 0.07 MPa, respectively. Depending on how the components interact in the system, the tensile strength may be extrapolated from the adhesion at the interface between the matrix and fillers or higher or lower than that of each component. By occupying the space between the chains and eliminating intermolecular interactions in the protein matrix, the molecules of the thyme extract decreased the mechanical resistance of the film. Additionally, flexibility owing to a decrease in molecular concentration was decreased at the high extract concentrations **[46]**, leading one to believe that PPE and MPE function as a plasticizer and lowers the mechanical strength of WPI films. Similar findings have been published on the characteristics of the WPI film for the effects of natamycin **[47]** and cinnamon essential oil **[48]**.

The microstructure, which offers crucial information for comprehending the material's internal structure, has a significant impact on elongation at the break of the material. According to table 4, the increasing PME and PPE to WPI (0.5, 1.0, and 1.5%) raised the elongation value at the break of WPI-based films from 82.18 19.05 MPa to 139.86 17.33, 144.17

30.62, and 122.22 33.44 with MPE. It increases to 146.49, 43.51, 154.67, 22.95, and 283.27. Due to the PPE and MPE's low molecular weight, the films containing PPE and MPE displayed greater elongation. According to previous research, small molecular compounds in films may act as plasticizers to promote elongation **[49]**.

Table 5
Effect of MPE and PPE on Mechanical properties of WPI-based films

Film	Tensile strength (MPa)	Elongation at break (%)	Elastic modulus (MPa)
WPI	1.55^{a} ± 0.10	82.18^{d} ± 19.05	20.26^{b} ± 1.89
WPI-0.5 % MPE	1.25^{bc} ± 0.05	139.86^{c} ± 17.33	14.57^{c} ± 1.59
WPI-1.0% MPE	1.04^{c} ± 0.02	144.17^{bc} ± 30.62	11.90^{d} ± 1.35
WPI-1.5% MPE	1.41^{ab} ± 0.07	122.22^{cd} ± 33.44	26.45^{a} ± 3.85
WPI-0.5 % PPE	1.34^{b} ± 0.11	146.49^{bc} ± 43.51	14.77^{c} ± 3.91
WPI-1.0% PPE	1.05^{c} ± 0.13	154.67^{b} ± 22.95	13.20^{cd} ± 1.91
WPI-1.5% PPE	1.13^{c} ± 0.09	283.27^{a} ± 46.06	16.29^{c} ± 1.30

Additionally, the films with conjugates are much more flexible than other films, such as films made of starch **[50]**, whey protein, soy protein, and carboxymethyl cellulose **[51]**, which makes them better suited for food packaging due to their improved mechanical properties. According to table 4, the increasing PME and PPE to WPI (0.5, 1.0, and 1.5%) decreased the elastic modulus of WPI-based films from 20.26 ± 1.89 MPa to 14.57 ± 1.59, 11.90 ± 1.35, and 26.45 ± 3.85 MPa with MPE. Also, the same trend with PPE decreases to 14.77 ± 3.91, 13.20, and 16.29 ± 1.3 MPa, respectively. Due to the PPE and MPE's low molecular weight, the films containing PPE and MPE displayed greater elasticity. According to previous research, small molecular compounds in films may act as plasticizers to promote elastic modulus **[49]**.

3.9. FT-IR WPI with PPE or MPE

FT-IR spectroscopy was used to describe the functional groups in WPI, WPI-PPE and WPI-MPE, as shown in Figure 1. $\nu_{C=O}$ and δ_{NH} vibrations in the amide I band, NH and ν_{CN} vibrations in the amide II band, and ν CN and δ NH vibrations in the amide III band, respectively, are situated at lower wavelengths in the spectra of the WPI films (i.e., 1628, 1636, and 1136 cm1) [51]. The films showed a significant peak at around 1034 (GEL) or 1039 cm1 (WPI). Since this peak appears seldom in the WPI spectrum [52], glycerol's C-O stretching is most likely to be responsible for its appearance [53]. The contact between the phenolic group of PPE or MPE and the hydrophobic area of WPI causes a reduction in the vibration of the methyl and methylene groups. It was intriguing to see that in all WPI-PPE videos, the band vanished around 1636 cm1. The pyrocatechol ring of the PPE molecule became more active following the polarity modification of its microenvironment as a result of the interaction of the pyrocatechol rings with the WPI, as evidenced by the changed shape and increased intensity of the bands located at 1636 and 1136 cm1, which appeared as a blue shift of about 8 cm1. These findings suggest that there are a number of binding sites, particularly hydrophobic groups, involved in the interaction between PPE and MPE molecules and WPI. Similar findings were published by Liu [54], who found that the wall material (WPI), which was mostly found in the hydrophobic portions of the protein, was able to bond with the tryptophan or tyrosine residues of the core material (curcumin).

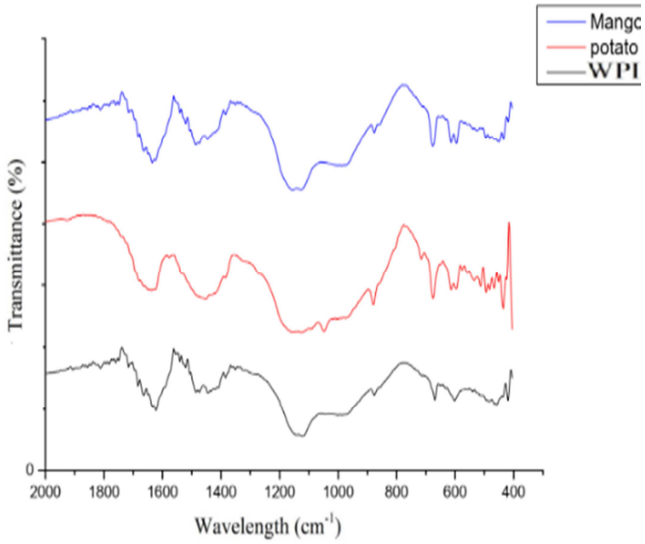


Figure 1: FT-IR of WPI, WPI-PPE, and WPI-MPE edible film

3.10. Antimicrobial activity

Table 6
Antibacterial and Antifungal Activity of WPI *films and fortified with MPE and PPE*

Bacteria/fungi	Inhibitory zone (mm) in film disks				
	WPI	MPE	PPE	Films WPI-PPE	Films WPI-MPE

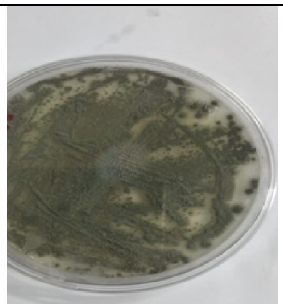
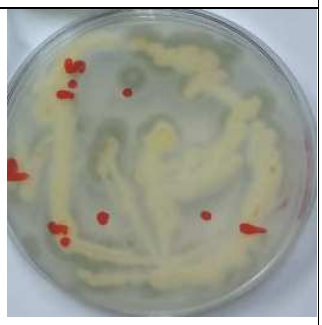
				0.5	1.0	1.5	0.5	1.0	1.5
Salmonella typhi ATCC 15566	ND	ND	$0.22^{d} \pm 0.05$	$1.56^{bc} \pm 1.31$	$3.51^{d} \pm 0.89$	$8.37^{cd} \pm 1.02$	$1.81^{ab} \pm 1.05$	$2.77^{c} \pm 0.56$	$3.18^{c} \pm 0.71$
E. coli ATCC 51659	ND	$0.12^{b} \pm 0.14$	$0.41^{d} \pm 0.17$	$0.77^{c} \pm 0.21$	$3.31^{d} \pm 0.34$	$6.05^{d} \pm 0.36$	$1.55^{b} \pm 0.43$	$1.88^{d} \pm 0.37$	$3.61^{c} \pm 0.28$
Staphylococcus aureus ATCC 13565	ND	$0.18^{b} \pm 0.1$	$0.42^{d} \pm 0.12$	$1.79^{b} \pm 0.67$	$6.08^{b} \pm 1.05$	$14.11^{ab} \pm 0.71$	$2.89^{a} \pm 0.10$	$3.38^{b} \pm 0.31$	$5.22^{b} \pm 0.48$
Bacillus cereus EMCC 1080	ND	ND	ND	$1.94^{ab} \pm 0.31$	$7.21^{a} \pm 1.05$	$15.66^{a} \pm 1.25$	$2.27^{ab} \pm 1.21$	$3.69^{ab} \pm 0.95$	$5.44^{b} \pm 1.21$
Aspergillus flavus ITEM 698	ND	ND	$2.34^{c} \pm 0.24$	ND	$2.81^{e} \pm 1.02$	$8.41^{cd} \pm 1.31$	ND	ND	$5.16^{b} \pm 1.05$
Aspergillus carbonarius ITEM 5010	ND	$2.05^{a} \pm 0.22$	$2.81^{b} \pm 0.37$	$1.77^{b} \pm 0.28$	$3.41^{d} \pm 0.67$	$9.71^{c} \pm 1.34$	ND	$2.19^{cd} \pm 0.81$	$5.08^{bc} \pm 0.81$
Penicillium verrucosum NRRL 695	$2.54^{b} \pm 0.28$	$2.44^{a} \pm 0.36$	$3.81^{ab} \pm 0.61$	$2.54^{a} \pm 0.37$	$5.31^{c} \pm 1.18$	$11.41^{bc} \pm 2.27$	$2.02^{ab} \pm 0.24$	$3.54^{b} \pm 0.52$	$7.04^{a} \pm 1.21$
A.nigr ATCC 56091	$3.77^{a} \pm 1.21$	$2.77^{a} \pm 0.49$	$4.21^{a} \pm 0.74$	$2.04^{ab} \pm 0.61$	$6.44^{ab} \pm 1.37$	$12.16^{b} \pm 1.05$	$2.51^{a} \pm 0.38$	$4.15^{a} \pm 0.31$	$8.11^{a} \pm 2.31$

The extensive and unchecked bacterial and fungal contamination has drastically decreased cheese products' shelf life. Particularly after being sliced, bacterial and fungal growth may decrease their quality by causing discoloration, textural changes, and the development of unpleasant flavours **[55]**. The efficacy of edible films to inhibit the growth of two gram-positive bacteria (Bacillus cereus EMCC 1080 and Staphylococcus aureus ATCC 13565) and two gram-negative bacteria (Salmonella typhi ATCC 15566 and E. coli ATCC 51659) are shown in Table 6. The absence of an antibacterial component in the WPI film resulted in zero inhibition zones against all microorganisms. While this was going on, it was interesting to see that the WPI-PPE and WPI-MPE films had a small inhibitory zone, likely as a result of the antioxidant properties of PPE and MPE **[56]**. WPI-PPE films have more antibacterial Activity than WPI-MPE films. The high concentrations of proanthocyanidins and gallates in the extracts were linked to these features.

Also, accurate spore dilutions from each fungal strain were employed, and colonies were counted on the film contact zone after an incubation period. The WPI film presented the same count as the dilution control plate, indicating no growth inhibition. In order to compare conditions, 100% growth on inoculated agar with WPI film was taken into account as the control count. The PPE and MPE activity against fungus strains associated with food deterioration is shown in Table 6. As can be observed, *Aspergillus flavus* ITEM 698, *Aspergillus carbonarius* ITEM 5010, *Penicillium verrucosum* NRRL 695, and *Aspergillus nigr* ATCC 56091 have an antifungal activity that is dependent on PPE and MPE concentrations. PPE and MPE's antifungal efficacy depends on concentration and the fungus strain being studied **[57]**. The plant extract's antibacterial properties are due to the phenols. These substances serve as a defense line against attacks from natural enemies and may increase microbial infection resistance **[58]**.

Bacteria/fungi	WPI/PPE/MPE	Films WPI-PPE	Films WPI-MPE
Salmonella typhi ATCC 15566			

***E. coli* ATCC 51659**			
***Staphylococcus aureus* ATCC 13565**			
***Bacillus cereus* EMCC 1080**			
***Aspergillus flavus* ITEM 698**			

***Aspergillus carbonarius* ITEM 5010**			
***Penicillium verrucosum* NRRL 695**			
***A.nigr* ATCC 56091**			

3.11. Processed cheese

The results shown in Table 7 illustrate the gross chemical composition of processed cheese (PC) while fresh and after storage, as coated by the use of different edible coatings (without coat control, WPI-0.5% MPE, and WPI-1.5% PPE) that contain the same amount of processed cheese but with different edible coatings. The influence of the edible coatings with PPE or MPE had a significant impact on the composition of the resulting PC. Protein content was increased in fresh cheese coated with WPI-0.5% MPE and WPI-1.5% PPE compared to control from 11.56 to 12.52 and 12.54%, respectively. Furthermore, the protein content, fat/dry matter, and ash increased with increasing storage duration of up to 3 months, although carbohydrates decreased. This was true in all PC treatments and might be attributed to moisture loss and the formation of acidity from lactose in the case of carbohydrate content.

Table 7
Chemical composition of control processed cheese during the storage period

Cheese treatment	Storage period	Moisture (%)	Fat/ DM (%)	Protein (%)	Ash (%)	Carbohydrate (%)	Salt (%)
	Fresh	**$57.09^{a}\pm 0.04$**	**$50.03^{cd}\pm 0.05$**	**$11.56^{c}\pm 0.04$**	**$4.09^{a}\pm 0.03$**	**$4.60^{a}\pm 0.08$**	**$1.19^{a}\pm 0.02$**

	1 month	52.66^{d} ± 0.06	52.72^{ab} ± 0.08	2.07^{c} ± 0.03	4.27^{a} ± 0.02	4.20^{ab} ± 0.09	1.24^{a} ± 0.01
	2 months	50.94^{f} ± 0.09	53.63^{a} ± 0.07	12.27^{bc} ±0.02	4.34^{a} ± 0.02	3.88^{b} ± 0.03	1.26^{a} ± 0.03
	3 months	50.14^{f} ± 0.08	53.99^{a} ± 0.4	12.36^{b} ± 0.05	4.38^{a} ± 0.04	3.72 ± 0.07	1.28^{a} ± 0.02
WPI-0.5 % MPE	Fresh	55.97^{b} ± 0.04	49.10 ± 0.06	12.52^{b} ± 0.04	4.10^{a} ± 0.05	4.61^{a} ± 0.07	1.18^{a} ± 0.02
	1 month	53.44^{cd} ±0.06	50.64^{c} ± 0.05	12.84^{ab} ±0.04	4.20^{a} ± 0.03	4.43^{a} ± 0.08	1.21^{a} ±0.03
	2 months	52.46^{d} ± 0.07	51.22^{bc} ± 0.07	12.96^{a} ± 0.02	4.24^{a} ± 0.07	4.07^{ab} ± 0.05	1.22^{a} ± 0.03
	3 months	51.22^{e} ± 0.05	51.89^{b} ± 0.08	13.11^{a} ± 0.06	4.29^{a} ± 0.02	3.83^{b} ± 0.09	1.24^{a} ± 0.02
WPI-1.5 % PPE	Fresh	55.99^{b} ± 0.06	49.17^{d} ± 0.07	12.54^{b} ± 0.07	4.08^{a} ± 0.05	4.58^{a} ± 0.08	1.17^{a} ± 0.02
	1 month	54.05^{c} ± 0.08	50.42^{c} ± 0.08	12.76^{a} ± 0.6	4.16^{a} ± 0.03	4.37^{a} ± 0.06	1.19^{a} ± 0.01
	2 months	52.57^{d} ± 0.04	51.21^{bc} ± 0.09	12.97^{a} ± 0.08	4.22^{a} ± 0.04	4.04^{ab} ± 0.05	1.21^{a} ± 0.03
	3 months	51.40^{e} ±0.07	51.81^{b} ±0.06	13.12^{a} ± 0.05	4.27^{a} ± 0.02	3.90^{b} ± 0.03	1.23^{a} ± 0.02

The majority of cheese weight loss is due to moisture loss. Cheese shrinkage during storage may adversely affect the appearance and nutritional value of the product. In terms of weight reduction, coated cheese products outscored their uncoated counterparts **[59]**. Figure 3 depicts the impact of coating treatment on the weight loss of cheese slices stored at 4 °C for 10 days. Because the moisture in the cheese has constantly evaporated into the ambient environment, the weight loss has grown linearly with storage time in all situations **[60]**.

The gross chemical composition of cheese treatments revealed how the presence of a coating, and the impact of adding PPE or MPE to WPI-based edible film influenced cheese weight loss over three months.

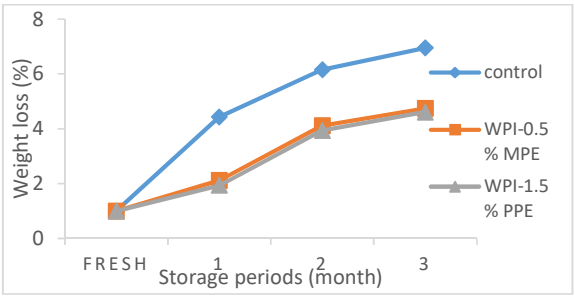


Figure 3: Weight loss of coated processed cheese slice throughout storage periods for samples kept at 4 °C for 3 months.

There were no differences in weight reduction ($P < 0.05$) amongst coated cheeses. However, WPI- PPE edible coating performed best.

Figure 3 shows an increase in weight loss for all instances during storage. This rise is significantly greater ($P < 0.05$) over the first month for all treatments. The control processed cheese without coating has the greatest moisture loss, followed by PC coated with WPI-0.5% MPE, and PC coated with WPI-1.5% PPE has the least moisture loss.

Sensory evaluation

Table 8 shows the sensory analysis results of processed cheese samples coated with WPI-0.5% MPE and WPI-1.5% PPE or without edible films. Freshly processed cheese was sensory evaluated for exterior characteristics (whole cheese evaluation) as well as interior cheese attributes (cheese pieces). Following the exterior examination, all of the cheese samples were physically washed and dried at room temperature to remove any contaminants from the cheese surface before being used for the internal sensory evaluation. Regarding exterior cheese assessment (Table 8), ocular examination revealed no differences ($P < 0.05$) between cheeses in aspects of form and rind color. Only color uniformity and hardness showed sensory differences ($P < 0.05$). While, after three months of cold storage for control, processed cheese had the lowest score value for all sensory parameters, But the coated processed cheese with WPI-0.5% MPE and WPI-1.5% PPE had high scores, and significant differences were not found between them. Pluta-Kubica, **[61]** noticed that using edible films as packaging positively influences homogeneity and overall processed cheese quality. Nevertheless, the films were not colourless and odourless. Some panellists thought that was unfavourable. These findings suggest that additional descriptive sensory techniques, such as the check-all-that-apply (CATA) questionnaire, would be interesting to perform if the developed films were tested on different types of cheese in the future **[61].**

Table 8

Sensory evaluation of processed cheese coated with WPI-0.5% MPE and WPI-1.5% PPE or without edible coatings

Samples	Storage period	Appearance (20)	Body & texture (40)	Flavour (40)
Control	Fresh	18.08^{a} ± 1.57	36.34^{a} ± 1.87	37.58^{a} ± 1.80
	Three months	14.67^{c} ± 2.23	29.76^{c} ± 3.45	28.97^{c} ± 3.28
WPI-0.5 % MPE	Fresh	18.19^{a} ± 1.58	36.08^{a} ± 1.06	36.15^{a} ± 1.71

	Three months	**16.45^{b} ± 1.97**	**32.74^{b} ± 1.76**	**30.23^{b} ± 2.79**
WPI-1.5 % PPE	Fresh	**17.95^{a} ± 1.48**	**36.08^{a} ± 1.96**	**36.99^{a} ± 0.76**
	Three months	**16.52^{b} ± 2.03**	**32.85^{b} ± 1.90**	**30.45^{b} ± 2.87**

4. Conclusion

Edible coating reduced water loss, hardness, and color changes, as well as microbiological growth, in processed cheeses stored for up to 3 months. The edible coatings, whether made from WPI alone or in conjunction with PPE or MPE, seemed to improve the quality retention of minimally processed cheese by delaying changes in weight loss, and bioactive components (i.e., fat separation and oxidation). Furthermore, WPI edible coatings based on MPE or PPE (WPI-PPE and WPI-MPE) suppressed microbial growth considerably. Significant variations were discovered between these coatings: WPI-MPE and WPI-PPE were better at lowering water and oxygen permeability during preservation, preserving processed cheese at higher quality levels than uncoated cheese.

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