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Research Article

Quick-dissolvable heat-sealable edible films made from orange peel powder and guar gum for instant beverage packaging

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ABSTRACT

Water-soluble films provide convenience, notably in scenarios requiring single-dose or on-the-go packaging, such as dissolvable sachets for individual servings of beverages, effectively minimising excess packaging waste. The main aim of this study was to create edible films that are water-soluble and heat-sealable by utilising a blend of guar gum and orange peel powder.

The study investigated the impact of varying orange peel powder content on guar gum edible films' properties. Physical (thickness, moisture content, swelling index, density, solubility), optical (colour, opacity, light transmittance), and barrier (water vapour transmission rate, water vapour permeability) properties of the films with different concentrations of orange peel powder were evaluated. Moreover, within the scope of utilising these films for packaging dry instant beverages, they were heat-sealed to form pouches and then filled with dry orange peel powder to evaluate their ability to dissolve instantly.

As the orange peel powder content in the films increased, thickness, density, and colour parameters such as redness, yellowness, ΔE, chroma, hue angle, and browning index also increased, resulting in more thick, vivid colours and significant colour changes. Conversely, moisture content, swelling index, and light transmittance decreased with higher orange peel levels, impacting the films' textural properties and rendering them more opaque for better protection against light, oxygen, and heat, essential for extending food product shelf life. Moreover, solubility increased as the orange peel content increased, indicating greater water interaction facilitated by the extract's potential plasticising effect.

Keywords: Orange peel, Guar gum, Edible films, Dissolvable packaging

Introduction

To protect the environment, it is necessary to reduce food packaging waste made of plastics such as polyethene, polyvinyl chloride, polypropylene, polystyrene, polyethene terephthalate and polyamide, and other wastes from food (Bellur Nagarajaiah & Prakash, 2015; Luzi et al., 2019). When plastic packaging materials are not disposed of properly after use, they cause very serious environmental problems (Milli, 2022). Moreover, plastic packaging materials continuously emit microplastics into our food and beverages. For example, modern tea bags are increasingly made from plastic rather than traditional paper, posing concerns about their safety when exposed to high temperatures. Brewing plastic tea bags at 95 °C can release staggering amounts of microplastics and nanoplastics into the beverage, raising potential health risks, and additionally, toxicity assays suggested adverse effects on human health (Hernandez et al., 2019; Jadhav et al., 2021). Therefore, there is a trend towards biodegradable polymers in academic and food practices (Kurt, 2019). As an alternative to synthetic polymers, polysaccharides, proteins and lidips, many by-products from microorganisms or agricultural residues are used (Karakuş et al., 2021). Shell and pulp, which are food wastes, also cause microbiological environmental pollution when disposed of incorrectly. These wastes can be used as raw materials to create products with high added value.

Humans can consume edible coatings or films without adverse effects and serve as primary packaging by directly contacting food items. Additionally, edible films incorporating active materials combined with biodegradable polymers are being produced (Silva et al., 2020). Synthetic polymers such as polyvinylpyrrolidone and polyvinyl alcohol were also used to produce edible films (Gökmen, 2022). Significant biological residues are generated due to the food industry's production processes. Despite 1.3 billion tons of edible food, it is wasted annually (Gustavsson et al., 2011). Edible biodegradable coatings and films create a natural layer to control food aroma, solute movement, and moisture loss, thereby preventing product spoilage (Embuscado & Huber, 2009). Water-soluble films present challenges in packaging high-moisture foods, but they offer benefits when packaging low-moisture food items (Akbaba, 2006). Water-soluble films can provide significant convenience in the ready-to-eat food and beverage industry (Ocak & Demircan, 2020).

In Türkiye, 1.550.000 tons of oranges were produced in 2023 (TSI, 2023), and it is estimated that approximately 760.000 tons of waste orange peel is generated in orange juice production facilities. It is known that a portion of the generated waste of orange peels is used as animal feed, a portion is dried and utilised, and the remaining portion is taken to urban solid waste disposal facilities. The pectin in waste orange peels presents significant potential for utilisation in the biodegradable packaging sector, contributing to the valorisation of these waste materials (Günkaya et al., 2016) and offering health benefits (Sharefiabadi & Serdaroğlu, 2020). Orange peel contains essential minerals such as calcium, iron, magnesium, potassium, and copper. It is also abundant in vitamin C, and its dry matter composition includes 3% protein, 8% carbohydrates, and an impressive 42% dietary fiber (Can, 2015). The water solubility of orange peel is attributed to its content of pectin, as pectin possesses water-soluble and biodegradable characteristics (Fishman et al., 2006). Orange peels also contain flavonoids such as hesperidin, neohesperidin, naringin, and tangerine (Cin & Gezer, 2017).

Guar gum is a polysaccharide primarily composed of complex carbohydrate polymers of galactose and mannose, and it possesses one of the highest molecular weights among all water-soluble polymers (Mudgil et al., 2014). Studies have indicated that guar gum exhibits good film-forming properties (Kumar, 2019). The barriers formed by guar gum-based films prevent food from being damaged by microorganisms, ultraviolet radiation, and oxidative stress. Additionally, it effectively contributes to the preservation of food quality and extends its shelf life (Jiang et al., 2022).

Recently, orange peel waste has been used in the production of biocomposite packaging films by blending it with various materials such as pectin jelly, thermoplastic starch, and clay; with fish gelatin; and with chitosan/polyvinyl alcohol, as reported in studies by Günkaya et al. (2016), Jridi et al. (2020), and Terzioğlu et al. (2021), respectively. However, the extant literature does not provide any comprehensive assessment concerning using these waste materials in rapidly soluble ready-to-drink beverages.

The primary objective of this research was to produce water-soluble and heat-sealable edible films through the combination of guar gum and orange peel powder. The other objective was to examine how varying quantities of orange peel powder (0%, 1%, 2% and 5% w/v of solution) impacted these films' physical attributes, appearance, and barrier properties. Furthermore, the films underwent heat-sealing to create pouches in the context of employing these films for packaging dry instant beverages. They were subsequently loaded with dry orange peel powder to assess their capacity for instantaneous dissolution.

Materials and Methods

Materials

Smart Kimya (Türkiye) company purchased orange peel powder and guar gum. At the same time, Folin-Ciocalteau reagent, sodium carbonate, 2,2-Diphenyl-1-picrylhydrazyl, glycerol, and ethanol were obtained from Sigma-Aldrich Chemie GmbH (Darmstadt, Germany).

Preparation of Film Solution

The preparation method for edible films followed the procedure outlined by Aydogdu et al. in 2020, with slight adjustments. Aqueous film solutions were created by mixing guar gum (0.9% w/v) and glycerol (0.4% w/v) in distilled water using a magnetic stirrer for 40 min. In the case of film solutions containing orange peel powder, orange peel powder (1%, 2% and 5% w/v) was blended with film solution through magnetic stirring. The abbreviations F0, F1, F2, and F5 correspond to edible films that include different proportions of orange peel powder (0%, 1%, 2%, and 5% w/v). The rationale behind selecting the percentages of 1, 2, and 5 is rooted in the observation that the solubility of orange peel, when added at a concentration of 6%, was significantly hindered due to its high density. Entrapped air bubbles were removed through ultrasonication (JY92-IIN; Ningbo Scientz Biotech Co Ltd., China) at 70% ultrasonic power for 2 min. The resulting film solution, weighing 6 grams, was poured into Petri dishes with a 6 cm diameter (made of low-density polyethene) and left to air-dry at room temperature (22 ºC) for 24 h. Subsequently, the films were stored in a desiccator containing a saturated magnesium nitrate solution, maintaining a relative humidity of 55% at 22 ºC for a minimum of 48 h before analysis. Before measurements, the films were carefully peeled from the petri dishes, and three replicates were prepared for each physical and barrier analysis.

Film Thickness

The thickness of the films was measured using a handheld digital micrometre (LYK 5202-25, Loyka, Ankara, Türkiye) with a precision of 0.001 mm. Average values were calculated by taking measurements at approximately 8 random locations on each film.

Moisture Content

To determine the moisture content of the film samples, films with a 6 cm diameter were subjected to drying in an electric oven (Nuve NO55, Ankara, Türkiye) at 105 °C until they reached a stable weight, following the method outlined in AOAC (1984). This analysis involved measuring the initial weight of the samples before placing them in the oven and the weight immediately after taking them out of the oven.

Swelling Index

The procedure for determining the swelling index was adapted from the method described by Basiak et al. (2015). Film samples, each with a diameter of 6 cm, were weighed initially (W_1). Subsequently, they were immersed in a beaker containing 30 mL of distilled water at a temperature of 22 °C for 10 seconds. After the films had been re-weighed (W_2) following the removal of excess water using filter paper, the amount of absorbed water was calculated using the following equation.

$$\text{Swelling index (\%)} = [\frac{(W_2 - W_1)}{W_1} x100] \qquad \text{Eqn.1}$$

Density

Film densities (g/mm³) were determined by dividing the film mass (g) by the film volume (mm³). The volume was obtained by multiplying the film area (mm²) by the film thickness (mm) (Gahruie et al., 2020).

Solubility

The solubility of films was evaluated using the method described by de Figueiredo Sousa et al. (2019), with minor changes. The films were dried in an electric oven (Nuve NO55, Ankara, Türkiye) at 105 °C for 24 h. Afterwards, the weights of the dried samples were measured and documented as W_1. Subsequently, the samples were immersed in three separate conditions: 30 mL of distilled water at 22 °C to assess room temperature solubility, at 4 °C to evaluate cold water solubility, and at 70 °C to determine hot water solubility, with each immersion lasting 2 min. Following these immersions, the films were again subjected to drying at 105 °C for 24 h, and the dry weight, denoted as W_2, was recorded. The calculation of solubility was carried out based on the mass loss using the following formula (Lal et al., 2017):

$$\text{Solubility (\%)} = [\frac{(W_1 - W_2)}{W_1} x100] \qquad \text{Eqn.2}$$

Water Vapour Transmission Rate and Water Vapour Permeability

The methodology described by Sobral et al. (2001) was employed to calculate water vapour permeability. The films were sealed onto cells containing silica gel, and these cells were subsequently placed in a desiccator containing distilled water, maintaining a relative humidity of 100%. The cells were weighed at 3-h intervals over 2 days. The water vapour transmission rate (WVTR) was determined from the slope of the weight-time graph. Following this, water vapour permeability (WVP) was calculated using the following equation, where A represents the film area, and ΔP signifies the difference between the partial vapour pressure of the atmosphere over the silica gel and that over pure water (2642 Pa at 22 °C).

$$\text{WVTR } (\text{g } m^{-2}h^{-1}) = \frac{\Delta w}{\text{A x } \Delta \text{t}} \qquad \text{Eqn.3}$$

$$\text{WVP } (\text{g mm } m^{-2}h^{-1}Pa^{-1}) = \frac{WVTR\ x\ thickness}{\Delta \text{P}} \qquad \text{Eqn.4}$$

Colour

The colour of the films was determined using a handheld colourimeter (TES 135A Color Reader, TES, Taiwan). Prior to analysis, calibration was performed with white and black references. The total colour distance (ΔE), chroma value (*C*), hue angle (H°), and browning index (BI) were subsequently computed according to the equations provided by Azab et al. (2022). ΔE was computed using white paper as the reference colour, with the following parameters: L^* = 97.39, a^* = -5.11, and b^* = 7.16.

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \qquad \text{Eqn.5}$$

$$C = \sqrt{(a^*)^2 + (b^*)^2} \qquad \text{Eqn.6}$$

$$°H = tan^{-1}[\frac{b^*}{a^*}] \qquad \text{Eqn.7}$$

$$BI = \frac{100}{0.17}[\frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} - 0.31] \qquad \text{Eqn.8}$$

Opacity and light transmittance

The opacity of the films was assessed using a UV-Vis spectrophotometer (T80+, UV/Vis. spectrophotometer, PG Instrument Ltd., China). Following a method adapted from Amado et al. (2020), film opacity was determined: Rectangular pieces of the films, measuring 1 x 4 cm, were placed in quartz cells. To calculate opacity, the absorbance values at 600 nm were measured and then divided by the thickness of the film in mm. Concurrently, transmittance was evaluated at 540 nm. This method quantifies how effectively the films block or transmit light, which can be essential in various applications, including packaging and optical materials.

Application of Films for Packaging Dry Instant Beverage

Packaging tests were carried out as follows: four edible films with 6 cm diameter were folded into two and sealed by a hand-held heat sealer machine. Instant orange beverage powder was manually transferred into the semi-finished sealed pouches, with each pouch containing 2.0 g of powder. These whole pouches were then heat-sealed immediately. Subsequently, the sealed pouches containing the powders were stored at 22 ±1 °C over silica gel for 7 days. In order to assess the solubility of the edible pouches in hot water, they were placed into cold water (4 °C) under gentle stirring.

Statistical Analysis of Films

Analysis of variance analysis (ANOVA) was applied to the data, and means were compared using the Tukey Pairwise Comparisons test at a significance level of p<0.05 using MINITAB Release 17.1 (Minitab Inc., State College, PA, USA).

Results and Discussion

Thickness

Film thickness is vital in assessing films' mechanical, optical, and barrier properties related to water vapour permeability. The thickness measurements for films containing various orange peel powder extracts can be found in Table 1. These measurements range from 0.03000 ±0.01000 mm to 0.2050 ±0.0229 mm. Notably, film F5, which contains 5% (w/v) of orange peel powder, stands out as the thickest and significantly differs from other formulations ($p < 0.05$) ase in film thickness is attributed to the higher solid content resulting from adding more powder to the film so versely, a film named F0, lacking orange peel powder, is observed to be the thinnest. This pattern of thickness increasing with greater extract quantity aligns with findings from previous studies involving various additives, such (Aydogdu et al., 2020), konjac in whey-based edible films (Fahrullah et al., 2020), Eriobotrya japonica leaf extract in ripe banana peels enriched starch-added films (Silva et al., 2020), as well as mango peel ethanolic extract and fish gelatin-based films (Adilah et al., 2018). However, it is worth noting that in some studies, the extract's quantity did not significantly impact film thickness (Pi˜neros-Hernandez et al., 2017; Eça et al., 2015).

Moisture Content

The moisture content of the water-soluble film samples was assessed to determine the amount of retained moisture within each sample. The moisture content data is presented in Table 1 and ranges from 8.28 ±2.62% to 24.95 5±1.365%. Notably, an increase in the orange peel content within the films correlates with a decrease in moisture content. For instance, moisture content was approximately 30% in a study involving chitosan-based films. This content ranged from 13% to 25% in films containing chitosan and aloe vera, and in films incorporating chitosan, aloe vera, and beeswax, it varied from 11% to 21% (Amin et al., 2019). Comparable trends were observed in another study on edible films containing pectin, where the moisture content of films produced from mulberry molasses increased more significantly as molasses concentration decreased, similar to the findings in this study (Akşehir, 2013). Molecular interaction studies have offered insights into the film's weak moisture retention properties and high gas barrier characteristics associated with pectin films (Sistla & Mehraj, 2022). Regarding how moisture content information influences other characteristics, there is a relationship between a material's moisture content and its glass transition temperature (Tg). When the moisture content increases, the Tg values tend to decrease (Rivero et al., 2010). This decrease in Tg signifies that the material transitions from a rigid or glass-like state to a more flexible and rubbery state at a lower temperature. Consequently, this leads to enhanced flexibility and reduced material stiffness at temperatures typically encountered during its use. Lower Tg values are often associated with materials that exhibit improved stretchability and toughness, which can be advantageous in specific applications, such as those involving flexible packaging or elastomers. As a result, it is evident that when the amount of orange peel powder increases to a certain level, the moisture content of the samples decreases considerably, potentially leading to undesirable changes in their textural properties.

Swelling Index

The swelling index of films denotes the capacity of an edible film to absorb moisture within a specified timeframe. It serves as an indicator of the film's resistance to water, its biodegradability, and its ability to absorb water. Additionally, the swelling index can provide insights into predicting the preservation of food product quality during storage (Srinivasa et al., 2007). In this study's context, the films' swelling index ranged from 167.43 ±2.43% to 411.81 ±6.02%, as detailed in Table 1. Notably, an increase in the quantity of added orange peel powder reduced the swelling index of the films. The process may be due to the cross-linking of guar gum, which reduces polymer relaxation and water dispersion within the polymer matrix. Consequently, this led to a decrease in the swelling index of the films. Comparative studies have also revealed similar trends (Yu et al., 2015; Saberi et al., 2017). For instance, in research involving pectin-based films, the swelling index ranged from 270% to 360% (Cabello et al., 2015), indicating that films based on pectin, much like those in this study, exhibit high swelling indices. Conversely, a study utilising dried pomegranate peels and curry leaves to produce films showed no significant difference in the swelling indices among films made solely with gluten, those with pomegranate peels, and those with curry leaves, with all indices were around 2.1% (Kumari et al., 2017). However, this study observed noticeable differences in the swelling index values among films with varying formulations.

Density

The density of film samples varies between 0.000103 ±0.000001 and 0.002885 ±0.000016 g/cm^3 (Table 1). As the content of orange peel powder increases, the density of the films also increases. Similarly, in a study using pomegranate peel powder and curry leaves, the density increased compared to films made solely with gluten (Kumari et al., 2017).

Water Solubility

The solubility data for films incorporating varying quantities of orange peel powder under different conditions, including room temperature, hot water (70 °C), and cold water (4 °C), are presented in Table 2. Specifically, the solubility of films at room temperature ranged from 17.345 ±0.488% to 37.420 ±0.594%, while in hot water, it varied from 13.085 ±0.120% to 28.250 ±0.354 %, and in cold water, it spanned from 20.100 ±0.141 % to 35.475 ±0.672 %. Generally, as the extract's content increased, the films' solubility increased as well ($p < 0.05$). In a separate study, the solubility of the edible films made from Persian gum, sodium caseinate, and Zingiber officinale extract varied between 38.15% and 60.15% (Khezerlou et al., 2019). This increased hydrophilic content made the film more prone to interacting with water, facilitating its dissolution. It is possible that the extract acted as a plasticiser in the films, resulting in reduced matrix adhesion and increased water solubility within the film structure (Nogueira et al., 2022). The solubility values fell within an optimal range of 33.64% to 37.56%, suitable for producing edible films derived from starch and its derivatives (Lopez-Rubio et al., 2008; Chandla et al., 2017).

Water Vapour Transmission Rate and Water Vapour Permeability

Water vapour transmission rate (WVTR) measures how quickly moisture infiltrates and traverses a material, significantly determining the shelf life of food products. The WVTR values for the films are detailed in Table 2, spanning from 32.810 g/m^{2}h to 49.215 g/m^{2}h. The findings suggest that the quantity of orange peel powder does not substantially influence WVTR ($p < 0.05$). Water vapour permeability quantifies the mass of water vapour moving across a defined area within a unit of time under specified temperature and humidity conditions. Water vapour transmission in hydrophilic films is contingent upon the diffusion and solubility of water molecules within these films (Gontard & Guilbert, 1994). Edible films characterised by low water vapour permeability contribute to reduced drying rates, consequently extending the shelf life of food products (Otoni et al., 2017). A separate study determined that the film with the most favourable combination exhibited the lowest permeability level (Rai et al., 2019). Similarly, in a study involving incorporating chitosan nanoparticles into banana puree and pectin films, voids in the films may have diminished, leading to reduced permeability (Martelli et al., 2013).

Colour

Table 3 displays the results of the colourimetric analysis (*L**, *a**, *b**, ΔE, *C*, °H, BI). With an increasing quantity of orange peel powder, the *L** value decreased, while the values for *a**, *b**, ΔE, *C*, °H, and BI significantly increased. The lightness, indicated by the *L** value, exhibits an inverse relationship with the darkness of the sample. Hence, higher values imply a whiter appearance, a trait validated by both the guar gum film and the guar gum film with 1% orange peel addition (Table 3). However, including 2% and 5% orange peel powder conferred a brownish tint to the films, resulting in a darker and more opaque appearance than the guar gum films. In most cases, the introduction of additives into the films leads to changes in colour parameters, as observed in previous studies (Silva et al., 2020; Bari & Giannouli, 2022; Pérez-Vergara et al., 2020; Lin et al., 2022). When comparing samples containing varying ratios of orange peel powder, it was observed that a higher proportion of orange peels resulted in a more pronounced red colour (*a** values), increasing from 2.765±0.235 to 8.500± 0.420 and then to 14.630±0.137 in samples containing 0%, 2%, and 5% orange peel powder, respectively. Regarding yellowness (*b**), the results indicated a significant increase ($p < 0.05$) with higher levels of orange peel, with values ranging from -0.875 ±0.353 for 0% orange peel powder to 35.500 ±0.625 for 5% orange peel powder. These findings suggest that the redness and yellowness of the food increased as the orange peel powder, a source of carotenoid pigments known for its yellow and orange hues, was added to the samples.

ΔE values were determined using white paper as the reference base, revealing colour change values ranging from 9.372 ±1.556 to 50.019 ±0.803 across films containing 0% and 5% orange peel powder. Notably, there was a significant rise in ΔE values with increasing orange peel content within the films. Janjarasskul et al. (2020) developed edible films utilising whey protein isolate (WPI), which exhibits rapid dissolvability and sealability for packaging purposes. Despite achieving a transparent product with a low delta E value, it is noteworthy that no active component derived from waste materials is present in its composition. Therefore, compromising on colour can lead to a more functional packaging solution. Furthermore, as the orange peel content increased, chroma value (*C*), hue angle (H°), and browning index (BI) also exhibited a general increase. The chroma value represents the intensity or saturation of a colour. In other words, it measures how vivid or intense a colour appears. High chroma values indicate that the colour is very saturated and vivid, while low chroma values suggest that the colour is more muted or less intense (Athmaselvi et al., 2013). The browning index values represent the degree of browning or colour change in a substance. Higher browning index values indicate a more significant colour change or browning, while lower values suggest minimal or no colour change. As depicted in Figure 1, the films containing 5% orange peel exhibited intense, vivid and brownish colours.

Opacity and Light Transmittance

The evaluation of opacity depends on the ability of certain plant compounds to absorb specific wavelengths of light, protecting the food against the potentially harmful effects of light exposure. The opacity and light transmittance values for the films are presented in Table 2. Opacity ranges from 5.858 ±0.271 to 10.34 ±3.64, and no significant differences were observed among these values. Films with high opacity offer improved shielding against light, which can help reduce oxidation and prevent light-induced degradation reactions (Kirtil et al., 2021). The light transmittance of the films varies from 0.00892 ±0.00272 to 0.3162 ±0.0347. The film containing 5% orange peel powder exhibited the highest light transmittance. Notably, there were significant differences in light transmittance among the various films. While consumers might prefer transparent films, it is important to note that opaque films provide superior protection against light, oxygen, and heat, ultimately ensuring extended shelf life for food products (Mohammadi et al., 2020).

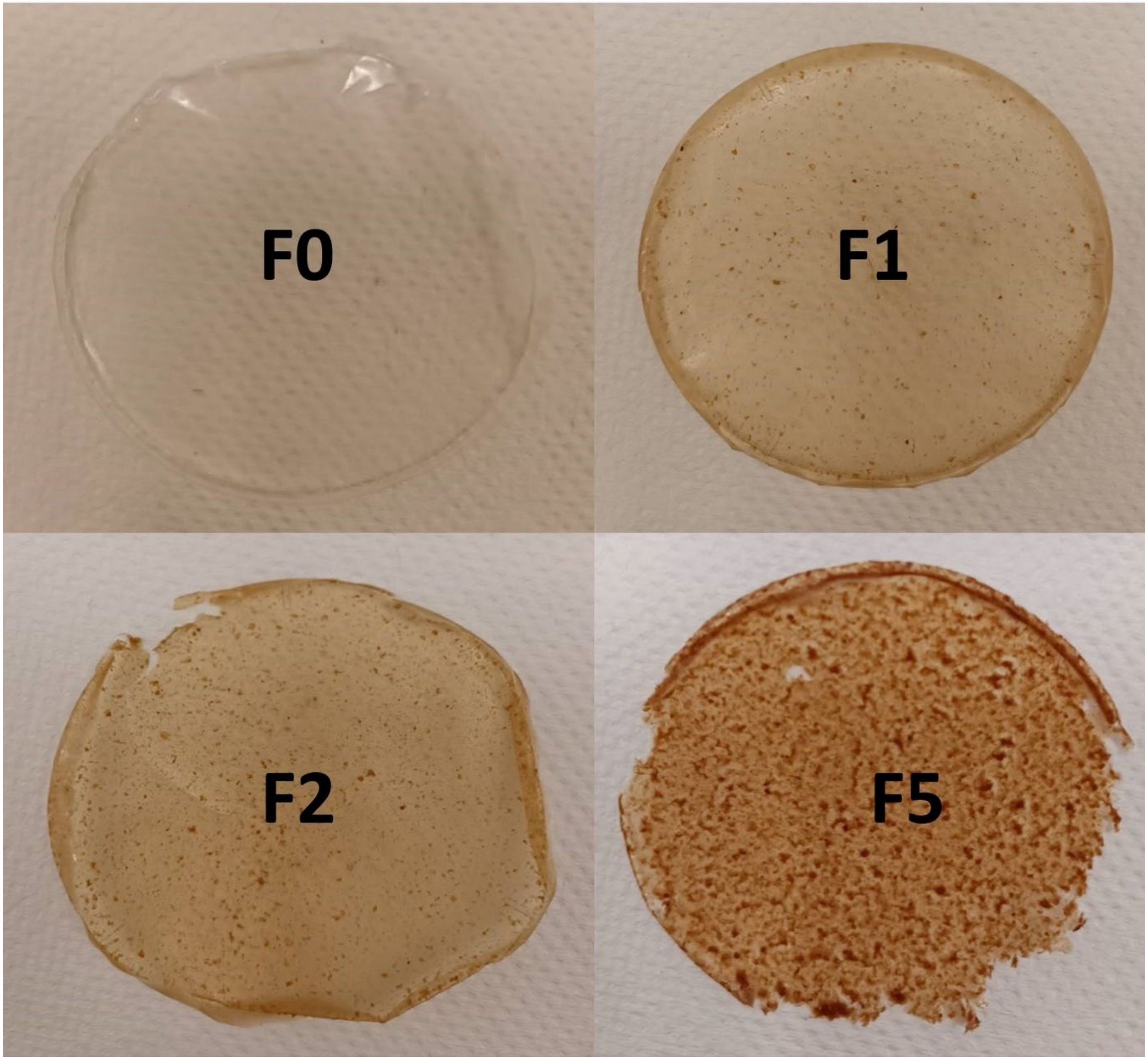

Figure 1. Film samples: (F0) Film without orange peel extract, (F1) Film containing 1% w/v orange peel powder, (F2) Film containing 2% w/v orange peel powder, (F5) Film containing 5% w/v orange peel powder

Table 1. Thickness, moisture content, swelling index, density , WVTR, and WVP of films

Film	Thickness (mm)	Moisture content (%)	Swelling index (%)	Density (g/cm^3)	WVTR** (g/m^2h)	WVP*** (1000 g mm/m^2 h Pa)
F0	0.03000 ±0.01000[d*]	24.955 ±1.365[a]	411.81 ±6.02[a]	0.000103 ±0.000001[d]	41.01 ±11.60[a]	0.000435 ±0.000088[c]
F1	0.11333 ±0.00577[c]	11.73 ±1.60[b]	278.36 ±5.00[b]	0.000959 ±0.000004[c]	41.01 ±11.60[a]	0.001770 ±0.000395[b]
F2	0.16833 ±0.00764[b]	9.200 ±0.382[b]	260.13 ±3.94[c]	0.001225 ±0.000005[b]	32.810 ±0.000000[a]	0.002049 ±0.000088b
F5	0.2050 ±0.0229[a]	8.28 ±2.62[b]	167.43 ±2.43[d]	0.002885 ±0.000016[a]	49.215 ±0.000000[a]	0.003586 ±0.000198a

* Values are given as mean ± SD. Different letters indicate statistical differences among the samples ($p < 0.05$). **WVTR: Water vapor transmisson rate, ***WVP: Water vapor permeability.

Table 2. Solubility, opacity and light transmittance of films

Film	Solubility(%)			Opacity	Light transmittance
	at 22 °C	at 70 °C	at 4 °C		
F0	17.345 ±0.488d*	13.085 ±0.120[d]	20.100 ±0.141[c]	10.34 ±3.64[a]	0.00892 ±0.00272[d]
F1	37.420 ±0.594[a]	23.140 ±0.198[c]	22.455 ±0.643[b]	6.744 ±0.334[a]	0.092493 ±0.001686[c]
F2	25.425 ±0.601[c]	25.120 ±0.170[b]	21.450 ±0.025[b]	5.858 ±0.271[a]	0.17897 ±0.00865[b]
F5	29.330 ±0.467[b]	28.250 ±0.354[a]	35.475 ±0.672[a]	7.566 ±0.831[a]	0.3162 ±0.0347[a]

* Values are given as mean ± SD. Different letters indicate statistical differences among the samples ($p < 0.05$).

Table 3. Color analysis of films

Film	*L**	*a**	*b**	ΔE	Chroma (C)	Hue angle (H°)	BI
F0	84.020 ±1.575[a**]	2.765 ±0.235[c]	-0.875 ±0.353[d]	9.372 ±1.556[d]	2.914 ±0.237[d]	-17.49 ±6.90[b]	1.345 ±0.487[d]
F1	82.437 ±0.424[a]	7.320 ±1.343[b]	15.267 ±0.861[c]	21.534 ±0.104[c]	16.980 ±0.180[c]	64.35 ±5.37[a]	26.620 ±0.151[c]
F2	76.820 ±0.243[b]	8.500 ±0.420[b]	25.250 ±0.395[b]	32.886 ±0.176[b]	26.645 ±0.311[b]	71.391 ±1.045[a]	47.312 ±0.469[b]
F5	63.310 ±0.623[c]	14.630 ±0.137[a]	35.500 ±0.625[a]	50.019 ±0.803[a]	38.398 ±0.526[a]	67.598 ±0.544[a]	96.00 ±3.08[a]

** Values are given as mean ± SD. Different letters indicate statistical differences among the samples ($p < 0.05$).

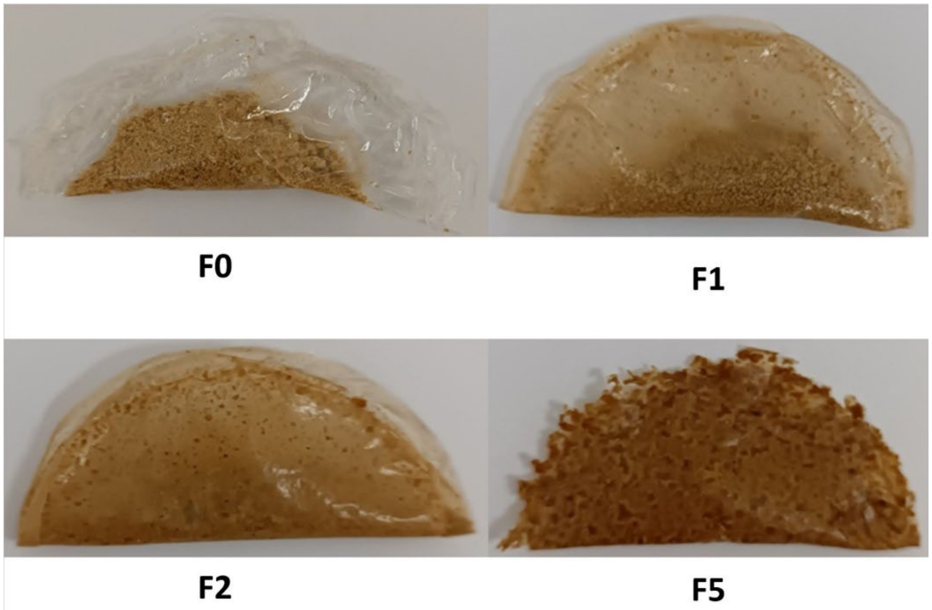

Figure 2. Heat sealed edible films with varying orange peel powder wrapped around instant orange peel powder. (F0) Film without orange peel extract, (F1) Film containing 1% w/v orange peel powder, (F2) Film containing 2% w/v orange peel powder, (F5) Film containing 5% w/v orange peel powder

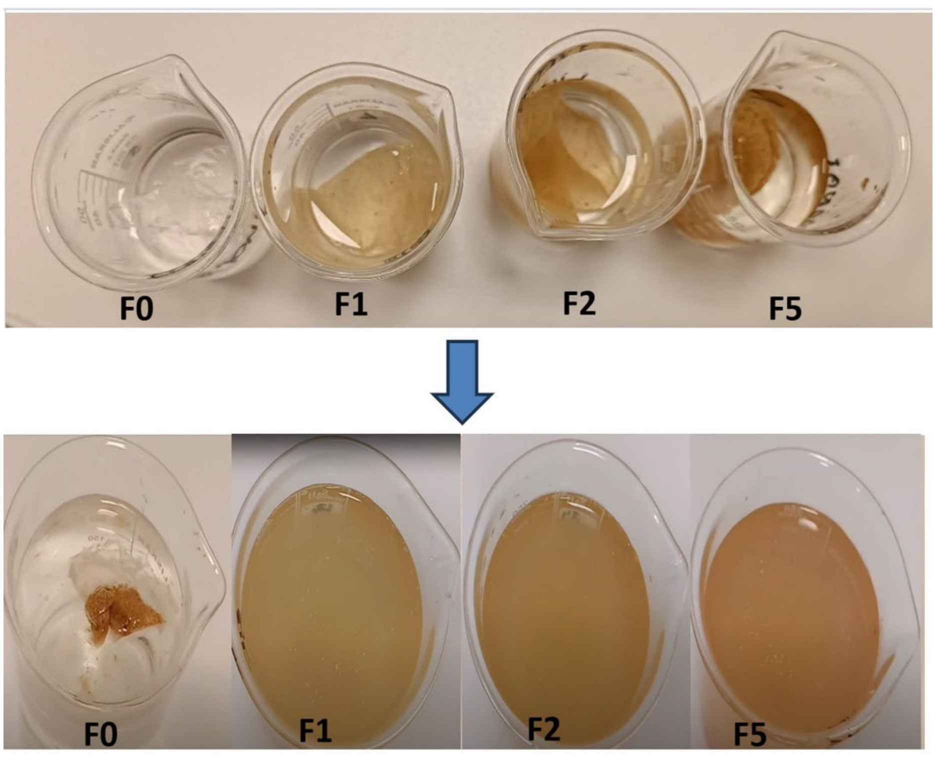

Figure 3. The pictures of cold water solubility of films. (F0) Film without orange peel extract, (F1) Film containing 1% w/v orange peel powder, (F2) Film containing 2% w/v orange peel powder, (F5) Film containing 5% w/v orange peel powder

Application of Films for Packaging Dry Instant Beverage

Photographs depicting instant orange beverage powder packaged in four different edible films with varying orange peel powder are presented in Figure 2, and their solubility in cold water is shown in Figure 3. In these pouches, dry orange powder retains its original colour. These images demonstrate that orange peel powder pouches dissolve rapidly within seconds and promptly release the enclosed powder. This observation underscores that adding guar gum does not impede the swift cold-water solubility of the orange peel films under the experimental conditions employed in this study. The pouches made from guar gum edible films did not dissolve and release their contents. In contrast, all the other films containing guar gum and varying amounts of orange peel powder were easily soluble in cold water and released their contents uniformly. Similarly, Janjarasskul et al. (2020) created edible films using whey protein isolate (WPI) that are fast-dissolving and sealable for packaging premeasured dry foods, and they dissolve rapidly when in contact with water, releasing their contents. However, this study incorporated orange peel powder in the film formulation as the active agent.

Conclusion

This study developed edible films by blending guar gum with orange peel powder. As the orange peel powder concentration in the films increased, several crucial parameters, including density, water vapour permeability, solubility, light transmittance, and various colour characteristics (a, b, ΔE, chroma, hue angle, BI), exhibited a consistent upward trend. The notable increase in solubility with higher orange peel powder content aligns with findings from previous research, with the highest solubility achieved when using cold water, suggesting its potential in producing cold beverages with orange peel powder. The significantly elevated swelling index values, ranging from 167.43 ±2.43% to 411.81 ±6.02%, are attributed to pectin in orange peel. Moreover, as the powder content increased, the films became less transparent, indicating their ability to block ultraviolet rays, making them suitable for protecting light-sensitive food items from oxidation. In summary, these films have promising applications as packaging materials for light-sensitive food products. In future studies, it would be beneficial to investigate potential modifications of orange peel powder or explore the incorporation of synergistic additives, aiming to enhance the properties of edible films further. This research could contribute to expanding the practical applications of these films in food packaging and preservation.

Compliance with Ethical Standards

Conflict of interests: The author(s) declares that for this article, they have no actual, potential, or perceived conflict of interest.

Ethics committee approval: Authors declare that this study includes no experiments with human or animal subjects. Ethics committee approval is not required for this study.

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References

Association of Analytical Chemists (AOAC) (1984). Standard Official Methods of Analysis of the Association of Analytical Chemists. 14th edition, S.W Williams (Ed), Washington, DC., p. 12.

Adilah, A. N., Jamilah, B., Noranizan, M. A., & Nur Hanani, Z. A. (2018). Utilization of mango peel extracts on the biodegradable films for active packaging. *Food Packaging and Shelf Life*, 16, 1–7. https://doi.org/10.1016/j.fpsl.2018.01.006

Akbaba, G., (2006). Yenilebilir ambalajlar, *Bilim ve Teknik Dergisi*, 30-32.

Akşehir, K. (2013). *Ak dut (Morus alba) ve kara dut (Morus nigra) meyvelerinden üretilen yenilebilir filmlerin karakterizasyonu*. Master's thesis. On Dokuz Mayıs University. Graduate School of Natural Sciences.

Amado, L.R., Silva, K.D.S., & Mauro, M.A. (2020). Effects of interactions between soy protein isolate and pectin on properties of soy protein-based films. *Journal of Applied Polymer Science*, 137(21), 48732. https://doi.org/10.1002/app.48732

Amin, U., Khan, M.A., Akram, M.E., Said Al-Tawaha, A. R.M., Laishevtcev, A., & Shariati, M.A. (2019). Characterızatıon of composite edible films from aloe vera gel, beeswax and chitosan. *Potravinarstvo*, 13(1). https://doi.org/10.5219/1177

Athmaselvi, K.A., Sumitha, P., & Revathy, B.J.I.A. (2013). Development of Aloe vera based edible coating for tomato. *International Agrophysics*, 27(4).

https://doi.org/10.2478/intag-2013-0006

Aydogdu, A., Radke, C.J., Bezci, S., & Kirtil, E. (2020). Characterization of curcumin incorporated guar gum/orange oil antimicrobial emulsion films. *International Journal of Biological Macromolecules*, 148, 110-120. https://doi.org/10.1016/j.ijbiomac.2019.12.255

Azab, D.E.S.H., Almoselhy, R.I., & Mahmoud, M.H. (2022). Improving the quality characteristics of low fat toffee by using mango kernel fat, pectin, and high-speed homogenizer. *Journal of Food Processing and Preservation*, e17235. https://doi.org/10.1111/jfpp.17235

Bari, A., & Giannouli, P. (2022). Evaluation of Biodegradable Gelatin and Gelatin–Rice Starch Coatings to Fresh Cut Zucchini Slices. *Horticulturae*, 8(11), 1031. https://doi.org/10.3390/horticulturae8111031

Basiak, E., Galus, S., & Lenart, A. (2015). Characterisation of composite edible films based on wheat starch and whey-protein isolate. *International Journal of Food Science & Technology*, 50(2), 372-380. https://doi.org/10.1111/ijfs.12628

Bellur Nagarajaiah, S., & Prakash, J. (2015). Chemical composition and bioactive potential of dehydrated peels of Benincasa hispida, Luffa acutangula, and Sechium edule. *Journal of Herbs, Spices & Medicinal Plants*, 21(2), 193-202. https://doi.org/10.1080/10496475.2014.940437

Cabello, S.P., Takara, E.A., Marchese, J., & Ochoa, N.A. (2015). Influence of plasticizers in pectin films: Microstructural changes. *Materials Chemistry and Physics*, 162, 491-497. https://doi.org/10.1016/j.matchemphys.2015.06.019

Can, F. (2015). Portakal kabuğu tozunun bisküvi hamuru ve bisküvi kalitesi üzerine etkilerinin incelenmesi. Master's thesis. İnönü University. Graduate School of Natural Sciences.

Chandla, N.K., Saxena, D.C., & Singh, S. (2017). Amaranth (*Amaranthus spp*.) starch isolation, characterization, and utilization in development of clear edible films. *Journal of Food Processing and Preservation*, 41(6), e13217. https://doi.org/10.1111/jfpp.13217

Cin, P., & Gezer, C. (2017). Citrus fruits as a functional food and the relation with metabolic syndrome. *Food and Health*, 3(2), 49-58. https://doi.org/10.3153/JFHS17007

de Figueiredo Sousa, H.A., de Oliveira Filho, J.G., Egea, M.B., da Silva, E.R., Macagnan, D., Pires, M., & Peixoto, J. (2019). Active film incorporated with clove essential oil on storage of banana varieties. *Nutrition & Food Science*, 49(5), 911-924. https://doi.org/10.1108/NFS-09-2018-0262

Eça, K.S., Machado, M.T.C., Hubinger, M.D., & Menegalli, F.C. (2015). Development of active films from pectin and fruit extracts: Light protection, antioxidant capacity, and compounds stability. *Journal of Food Science*, 80(11), C2389–C2396. https://doi.org/10.1111/1750-3841.13074

Embuscado, M.E., & Huber, K.C. (2009). *Edible films and coatings for food applications* (Vol. 9). New York: Springer. ISBN: 978-0-387-92823-4

Fahrullah, F., Radiati, L.E., & Rosyidi, D. (2020). The physical characteristics of whey based edible film added with konjac. *Current Research in Nutrition and Food Science Journal*, *8*(1), 333-339. https://doi.org/10.12944/CRNFSJ.8.1.31

Fishman, M.L., Coffin, D.R., Onwulata, C.I., & Willett, J.L. (2006). Two stage extrusion of plasticized pectin/poly (vinyl alcohol) blends. *Carbohydrate Polymers*, 65(4), 421-429. https://doi.org/10.1016/j.carbpol.2006.01.032

Gahruie, H.H., Mostaghimi, M., Ghiasi, F., Tavakoli, S., Naseri, M., & Hosseini, S.M.H. (2020). The effects of fatty acids chain length on the techno-functional properties of basil seed gum-based edible films. *International Journal of Biological Macromolecules*, 160, 245-251. https://doi.org/10.1016/j.ijbiomac.2020.05.136

Gontard, N., & Guilbert S. (1994). Bio-packaging: technology and properties of edible and/or biodegradable material of agricultural origin. *Food Packaging and Preservation*, 159-181. https://doi.org/10.1007/978-1-4615-2173-0_9

Gökmen, F.Ö. (2022). PVP/PVA blended hydrogels as a biofilm for use in food packaging applications. *Food and Health*, 8(3), 172-180. https://doi.org/10.3153/FH22017

Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., & Meybeck, A. (2011). Global food losses and food waste. Rome: Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i2697e/i2697e.pdf

Günkaya, Z., Demirel, R., & Banar, M. (2016). Portakal kabuğu atıklarından üretilen biyokompozit ambalaj filminin aflatoksinlere karşı etkisinin incelenmesi. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, *22*(6), 513-519. https://doi.org/10.5505/pajes.2016.92653

Hernandez, L.M., Xu, E.G., Larsson, H.C., Tahara, R., Maisuria, V.B., & Tufenkji, N. (2019). Plastic teabags release billions of microparticles and nanoparticles into tea. *Environmental science & technology*, 53(21), 12300-12310. ttps://doi.org/10.1021/acs.est.9b02540

Jadhav, E.B., Sankhla, M.S., Bhat, R.A., & Bhagat, D.S. (2021). Microplastics from food packaging: An overview of human consumption, health threats, and alternative solutions. *Environmental Nanotechnology, Monitoring & Management*, 16, 100608. https://doi.org/10.1016/j.enmm.2021.100608

Janjarasskul, T., Tananuwong, K., Phupoksakul, T., & Thaiphanit, S. (2020). Fast dissolving, hermetically sealable, edible whey protein isolate-based films for instant food and/or dry ingredient pouches. *LWT-Food Science and Technology,* 134, 110102. https://doi.org/10.1016/j.lwt.2020.110102

Jiang, H., Zhang, W., Chen, L., Liu, J., Cao, J., & Jiang, W. (2022). Recent advances in guar gum-based films or coatings: Diverse property enhancement strategies and applications in foods. *Food Hydrocolloids*, 108278. https://doi.org/10.1016/j.foodhyd.2022.108278

Jridi, M., Abdelhedi, O., Salem, A., Kechaou, H., Nasri, M., & Menchari, Y. (2020). Physicochemical, antioxidant and antibacterial properties of fish gelatin-based edible films enriched with orange peel pectin: Wrapping application. *Food Hydrocolloids*, 103, 105688. https://doi.org/10.1016/j.foodhyd.2020.105688

Karakuş, E., Balballı, E.K., İlknur, A.R.A., & Ayhan, Z. (2021). Polisakkarit ve Protein Bazlı Aktif Biyokompozit Malzemelerin Gıda Ambalajlama Açısından Değerlendirilmesi. *Akademik Gıda*, 19(1), 74-88. https://doi.org/10.24323/akademik-gida.927700

Khezerlou, A., Ehsani, A., Tabibiazar, M., & Moghaddas Kia, E. (2019). Development and characterization of a Persian gum–sodium caseinate biocomposite film accompanied by Zingiber officinale extract. *Journal of Applied Polymer Science*, 136(12), 47215. https://doi.org/10.1002/app.47215

Kirtil, E., Aydogdu, A., Svitova, T., & Radke, C.J. (2021). Assessment of the performance of several novel approaches to improve physical properties of guar gum based biopolymer films. *Food Packaging and Shelf Life*, 29, 100687. https://doi.org/10.1016/j.fpsl.2021.100687

Kumar, N. (2019). Polysaccharide-based component and their relevance in edible film/coating: A review. *Nutrition & Food Science*, 49(5), 793-823. https://doi.org/10.1108/NFS-10-2018-0294

Kumari, M., Mahajan, H., Joshi, R., & Gupta, M. (2017). Development and structural characterization of edible films for improving fruit quality. *Food Packaging and Shelf Life*, *12*, 42-50. https://doi.org/10.1016/j.fpsl.2017.02.003

Kurt, A. (2019). Rheology of film-forming solutions and physical properties of differently deacetylated salep glucomannan film. *Food and Health*, 5(3),175-184. https://doi.org/10.3153/FH19019

Lal, S. S., Tanna, P., Kale, S., & Mhaske, S.T. (2017). Kafirin polymer film for enteric coating on HPMC and Gelatin capsules. *Journal of Materials Science*, *52*, 3806-3820. https://doi.org/10.1007/s10853-016-0637-6

Lin, L., Peng, S., Shi, C., Li, C., Hua, Z., & Cui, H. (2022). Preparation and characterization of cassava starch/sodium carboxymethyl cellulose edible film incorporating apple polyphenols. *International Journal of Biological Macromolecules*, 212, 155-164. https://doi.org/10.1016/j.ijbiomac.2022.05.121

Lopez-Rubio, A., Flanagan, B.M., Gilbert, E.P., & Gidley, M.J. (2008). A novel approach for calculating starch crystallinity and its correlation with double helix content: A combined XRD and NMR study. *Biopolymers: Original Research on Biomolecules*, 89(9), 761-768. https://doi.org/10.1002/bip.21005

Luzi, F., Torre, L., Kenny, J.M., & Puglia, D. (2019). Bio- and fossil-based polymeric blends and nanocomposites for

packaging: Structure–property relationship. *Materials*, 12(3), 471.
ttps://doi.org/10.3390/ma12030471

Martelli, M.R., Barros, T.T., de Moura, M.R., Mattoso, L.H., & Assis, O.B. (2013). Effect of chitosan nanoparticles and pectin content on mechanical properties and water vapor permeability of banana puree films. *Journal of Food Science*, 78(1), N98-N104.
https://doi.org/10.1111/j.1750-3841.2012.03006.x

McKay, S., Sawant, P., Fehlberg, J., & Almenar, E. (2021). Antimicrobial activity of orange juice processing waste in powder form and its suitability to produce antimicrobial packaging. *Waste Management*, 120, 230-239.
https://doi.org/10.1016/j.wasman.2020.11.048

Mohammadi, M., Mirabzadeh, S., Shahvalizadeh, R., & Hamishehkar, H. (2020). Development of novel active packaging films based on whey protein isolate incorporated with chitosan nanofiber and nano-formulated cinnamon oil. *International Journal of Biological Macromolecules*, 149, 11-20.
https://doi.org/10.1016/j.ijbiomac.2020.01.083

Mudgil, D., Barak, S., & Khatkar, B.S. (2014). Guar gum: processing, properties and food applications-a review. *Journal of Food Science and Technology*, 51, 409-418.
https://doi.org/10.1007/s13197-011-0522-x

Nogueira, G.F., Soares, I.H.B.T., Soares, C.T., Fakhouri, F.M., & de Oliveira, R.A. (2022). Development and characterization of arrowroot starch films incorporated with grape pomace extract. *Polysaccharides*, 3(1), 250-263.
https://doi.org/10.3390/polysaccharides3010014

Ocak, Ö.Ö., & Demircan, B. (2020). Lezzet bileşenleri ve biyoaktif maddelerin yenilebilir film ve kaplamalar ile gıda sistemlerinde taşınması ve işlevselliğe etkileri. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, 26(7), 1245-1256.

Otoni, C.G., Avena-Bustillos, R.J., Azeredo, H.M., Lorevice, M.V., Moura, M.R., Mattoso, L.H., & McHugh, T.H. (2017). Recent advances on edible films based on fruits and vegetables—a review. *Comprehensive Reviews in Food Science and Food Safety*, 16(5), 1151-1169.
https://doi.org/10.1111/1541-4337.12281

Rai, S.K., Chaturvedi, K., & Yadav, S.K. (2019). Evaluation of structural integrity and functionality of commercial pectin based edible films incorporated with corn flour, beetroot, orange peel, muesli and rice flour. *Food Hydrocolloids*, 91, 127-135.
https://doi.org/10.1016/j.foodhyd.2019.01.022

Pérez-Vergara, L.D., Cifuentes, M.T., Franco, A.P., Pérez-Cervera, CE., & Andrade-Pizarro, R.D. (2020). Development and characterization of edible films based on native cassava starch, beeswax, and propolis. *NFS Journal*, 21, 39-49.
https://doi.org/10.1016/j.nfs.2020.09.002

Pi˜neros-Hernandez, D., Medina-Jaramillo, C., L´opez-C´ordoba, A., & Goyanes, S. (2017). Edible cassava starch films carrying rosemary antioxidant extracts for potential use as active food packaging. *Food Hydrocolloids*, 63, 488–495.
https://doi.org/10.1016/j.foodhyd.2016.09.034

Rivero, S., Garcia, M.A., & Pinotti, A. (2010). Correlations between structural, barrier, thermal and mechanical properties of plasticized gelatin films. *Innovative Food Science & Emerging Technologies*, 11(2), 369-375.
https://doi.org/10.1016/j.ifset.2009.07.005

Saberi, B., Vuong, Q.V., Chockchaisawasdee, S., Golding, J.B., Scarlett, C.J., & Stathopoulos, C.E. (2017). Physical, barrier, and antioxidant properties of pea starch-guar gum biocomposite edible films by incorporation of natural plant extracts. *Food and Bioprocess Technology*, 10, 2240-2250.
https://doi.org/10.1007/s11947-017-1995-z

Sharefiabadi, E., & Serdaroğlu, M. (2020). Pectin: Properties and utilization in meat products. *Food and Health*, 7(1), 64-74.
https://doi.org/10.3153/FH21008

Silva, V.D.M., Macedo, M.CC., Rodrigues, C. G., dos Santos, A.N., e Loyola, A.C.D.F., & Fante, C.A. (2020). Biodegradable edible films of ripe banana peel and starch enriched with extract of Eriobotrya japonica leaves. *Food Bioscience*, 38, 100750.
https://doi.org/10.1016/j.fbio.2020.100750

Sistla, Y.S., & Mehraj, S. (2022). Molecular simulations to understand the moisture, carbon dioxide, and oxygen barrier properties of pectin films. *Journal of Molecular Modeling*, *28*(4), 83.
https://doi.org/10.1007/s00894-022-05069-z

Sobral, P., Menegalli, F., Hubinger, M., & Roques, M. (2001) Mechanical, water vapor barrier and thermal properties of gelatin based edible films. *Food Hydrocolloids*, 15, 423–432.
https://doi.org/10.1016/S0268-005X(01)00061-3

Srinivasa, P.C., Ramesh, M.N., & Tharanathan, R.N. (2007). Effect of plasticizers and fatty acids on mechanical and permeability characteristics of chitosan films. *Food Hydrocolloids*, 21(7), 1113-1122.
https://doi.org/10.1016/j.foodhyd.2006.08.005

Terzioğlu, P., Güney, F., Parın, F.N., Şen, İ., & Tuna, S. (2021). Biowaste orange peel incorporated chitosan/ polyvinyl alcohol composite films for food packaging applications. *Food Packaging and Shelf Life,* 30, 100742.

(TSI) Turkish Statistical Institute. (2023). Statistics on plant production, 2023. Erişim:02.02.2024
https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-1.Tahmini-2023-49534

Yu, S.H., Tsai, M.L., Lin, B.X., Lin, C.W., & Mi, F.L. (2015). Tea catechins-cross-linked methylcellulose active films for inhibition of light irradiation and lipid peroxidation induced β-carotene degradation. *Food Hydrocolloids*, 44, 491-505.
https://doi.org/10.1016/j.foodhyd.2014.10.022