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Investigation of the possibility of producing a stabilized walnut oil emulsion with chia seed mucilage and its application in edible films

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ABSTRACT

In this study, walnut oil emulsions stabilized with chia seed mucilage with different oil percentages (10, 20, 30 and 50%) were prepared by the Pickering method. Then, the best emulsion was used in the preparation of bilayer and combined edible films based on sodium carboxymethyl cellulose, and the effect of this oil emulsion on the physical properties (permeability, contact angle, turbidity, tensile strength, strain at break and Young's modulus) of the produced films was investigated. The results showed that the walnut oil emulsion with 10% oil had the highest stability after 14 days. Moreover, the droplet size (D_{50}) of the emulsion (10% oil) was 886 nm, which was in the range of below one micrometer. Then, the walnut oil emulsion stabilized with chia seed mucilage (10% oil) was added to the edible films based on sodium carboxymethyl cellulose in bilayer and combined form. The results showed that adding walnut oil emulsion to sodium carboxymethyl cellulose films in a combined form increased turbidity and yellowness index compared to the bilayer films. There was no significant difference ($p>0.05$) in water vapor permeability between the bilayer and combined films, but the films containing walnut oil had lower water vapor permeability than the control sample. The results indicated a decrease in tensile strength in the bilayer and combined films with the addition of walnut oil emulsion. Furthermore, the bilayer film containing walnut oil emulsion had the lowest Young's modulus (41.68 MPa) and the highest strain at break point (0.18). In general, the findings of this study showed that valuable walnut oil in the form of an emulsion stabilized with chia seed mucilage m in the structure of sodium carboxymethyl cellulose edible films not only can create an edible film, but also improve the physical properties of the films.

1- Introduction

Walnut oil is one of the valuable sources of plant-based lipids, which holds a special place in human nutrition and health due to its richness in essential fatty acids, particularly unsaturated fatty acids such as linoleic acid (omega-6) and alpha-linolenic acid (omega-3). This oil is also rich in bioactive compounds such as phenols, tocopherols, and plant sterols, which enhance its antioxidant and anti-inflammatory properties. (Hosseini Adarmanabadi et al., 2023).

Emulsions are widely utilized due to their unique physical properties, such as the ability to improve texture, flavor, and carry active compound (Xia, Xue, & Wei, 2021). Among these, Pickering emulsions have been introduced as an innovative type of emulsion, where solid particles at the nano- or micro-scale are used to stabilize the phases instead of conventional emulsifiers. These solid particles, by adsorbing at the interface of the two phases, create a mechanical barrier that prevents droplet coalescence and emulsion instability. Due to their high stability, resistance to environmental changes such as temperature and pH, and reduced need for chemical additives, these emulsions have gained a special place in scientific research and industrial applications (Gao et al., 2022). Pickering emulsions are not only used in the formulation of healthier and more natural food products but also in the design of advanced systems for the controlled delivery and release of active compounds such as drugs, antioxidants, or nutrients. Furthermore, the use of natural and biocompatible particles such as proteins, polysaccharides, or mineral particles in stabilizing these emulsions has enabled the development of sustainable and biodegradable systems (Cheng et al., 2024).

Seed mucilage, primarily composed of polysaccharides with minor components such as proteins, has recently gained attention for its emulsifying properties in stabilizing Pickering emulsions. Chia seed mucilage is one such valuable biocompound that has attracted interest in various industries, including food, pharmaceuticals, and cosmetics, due to its unique characteristics. Chia seeds, native to Central America, are rich in nutrients such as omega-3 fatty acids, proteins, and soluble fibers. When in contact with water, these seeds form a natural, gel-like gum that has remarkable functional properties. (Orona-Tamayo & Paredes-López, 2024). Chia seed mucilage is recognized as a natural thickening agent, stabilizer, and emulsifier due to its high water absorption capacity and gel-forming ability. These properties make it an ideal option for use in the formulation of healthy and natural food products. (Mensah, Oludipe, Gebremeskal, Nadtochii, & Baranenko, 2024).

Edible films, primarily made from biodegradable and natural polymers, are considered a suitable alternative to non-biodegradable plastic packaging due to their environmental compatibility and biodegradability. (Karimi Sani et al., 2023) .In addition to their environmental benefits, these films can serve as carriers for active compounds such as antioxidants, antimicrobial agents, and nutrients, adding extra value to food products (Chawla, Sivakumar, & Kaur, 2021). Sodium carboxymethyl cellulose (CMC) is one of the most widely used biopolymers in the production of edible films. As a cellulose derivative, it has garnered attention for its unique properties, such as water solubility, biocompatibility, renewability, and film-forming ability. Films made from sodium carboxymethyl cellulose typically exhibit high transparency and good elasticity. However, limitations such as low mechanical strength and moisture sensitivity have made enhancing the

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properties of these films with additives and various compounds a key focus of scientific research. (Yildirim-Yalcin, Tornuk, & Toker, 2022) .One of the strategies to improve the physical properties of films is the incorporation of lipids into their structure. Various studies conducted in this field have generally utilized common edible oils, such as sunflower oil. (Erdem & Kaya, 2022) ،Corn oil(Xiao et al., 2019) ،Soybean oil(Sun, Wang, Chen, & Yin, 2023) Pomegranate seed oil (Mirzaee Moghaddam & Rajaei, 2021) and Canola oil (Amalia, Syarifuddin, & Langkong, 2023) have used. The use of valuable oils such as walnut oil can not only improve the physical properties but also enhance the nutritional value of the edible film.

Lipids are typically used in an emulsified form within the structure of films. Walnut oil stabilized with chia seed mucilage, through interactions with the film-forming polymers, can improve the structural properties of the films (Sibele Santos et al., 2023). An important point to consider is the method of incorporating the emulsion into the film structure. The emulsion can be added to the film using either a layering or blending method, and the way the emulsion is incorporated can also affect the properties of the film (Niu et al., 2023). Therefore, considering the high nutritional value of walnut oil and chia seed mucilage, the aim of this research was initially to produce a stable walnut oil emulsion using the Pickering method. Subsequently, the application of the walnut oil emulsion in the structure of sodium carboxymethyl cellulose films was studied using both layering and blending methods, and some of the physical properties of the produced sodium carboxymethyl cellulose films were also investigated.

2. Materials and Methods

2.1 Materials Used

Sodium carboxymethyl cellulose, Tween 80, and glycerol were purchased from Merck, Germany. Walnut oil was obtained from Kamjad Company, Iran, with the following fatty acid profile: C16:0 5.8%, C18:0 3.1%, C18:1 24.7%, C18:2 49.6%, and C18:3 0.15%. Chia seeds were purchased from the local market in Shahrud. The other materials used in this study were of high purity.

2.2 Preparation of Pickering Walnut Oil Emulsion

2.2.1 Preparation of Chia Seed Mucilage

The method of Sibele Santos et al. (2020) with slight modifications was used to prepare chia seed mucilage. Chia seeds were soaked in distilled water at a ratio of 1:40. The mixture was stirred at 150 rpm for 10 minutes at 25°C. The mucilage was separated from the chia seeds using a suitable cloth. The sample was then centrifuged at 4000 rpm for 5 minutes. The mucilage solution was poured onto a tray and dried in an oven at 50°C for 10 hours. Finally, the dried mucilage was packaged in plastic containers (Sibele Santos et al., 2020).

2.2.2 Preparation of Walnut Oil Emulsion

The method of Mirzaee Moghaddam (2019) with slight modifications was used to prepare a Pickering walnut oil emulsion stabilized with chia seed mucilage. Initially, 1 gram of chia mucilage powder was dissolved in 200 milliliters of distilled water for 30 minutes and poured into a separate container. Then, 10%, 20%, 30%, and 50% oil along with 0.5% (w/w) Tween 80 were slowly added to the chia solution under ultrasonic waves. Finally, the emulsion was homogenized at 70 watts for 5 minutes (Mirzaee Moghaddam, 2019).

2.2.3 Creaming Test of Emulsion

After the preparation of the emulsions, 10

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milliliters of each emulsion (with oil percentages of 10%, 20%, 30%, and 50%) were separately poured into vials. The vials were stored at 25°C for 14 days, and the creaming percentage of the emulsions was determined using Equation (1) (Vicente, Pereira, Bastos, de Carvalho, & Garcia-Rojas, 2018).

$$CI\ (\%) = \frac{HR}{HT} \times ۱۰۰ \qquad (1)$$

In Equation (1): HR is the height of the creamed layer, and HT is the total height of the emulsion.

2.2.4 Morphological Analysis of the Produced Emulsion Using SEM

The morphology of the produced particles was analyzed using a scanning electron microscope (SEM), model MIRA 3 (Tescan) (Mirzaee Moghaddam & Rajaei, 2021).

2.2.5 Measurement of Emulsion Droplet Size Using DLS

The droplet size of the emulsion was measured using a DLS device (Anton Paar, Austria). For this purpose, 0.2 grams of the sample was diluted with distilled water at a 1:50 ratio and added to a specialized cell up to the marked line. The cell was then placed in the device, and the particle size results were recorded using the software (Amiri, Nemati, Tirgarian, Dehghan, & Nasiri, 2021).

2.2.6 Rheological Test of Emulsion

The rheological test was conducted using a rheometer (Anton Paar, Austria) equipped with coaxial cylinders at a temperature of 25°C. In this test, viscosity was evaluated at different shear rates (Rahman et al., 2020).

2.3 Preparation of Edible Films Containing Walnut Oil Emulsion

2.3.1 Preparation of Edible Film Based on Sodium Carboxymethyl Cellulose

The sodium carboxymethyl cellulose (CMC) film was prepared using the method of Chang et al. (2009) with slight modifications. In this method, 1.5 grams of sodium carboxymethyl cellulose and 1 milliliter of glycerol were dissolved in 250 milliliters of distilled water at 90°C for 10 minutes using a magnetic stirrer. To ensure complete dissolution of the sodium carboxymethyl cellulose in water, an Ultra-Turrax homogenizer (12,000 rpm) was used for 30 seconds. The solution was then left at room temperature for 30 minutes to cool. To prevent bubble formation in the edible film, the solution was centrifuged for 5 minutes. Finally, the solution was transferred to plastic plates (Chang, Yu, & Ma, 2009).

2.3.2 Preparation of Bilayer Film Based on Sodium Carboxymethyl Cellulose Containing Walnut Oil Emulsion and Chia Seed Mucilage

To prepare the bilayer film, after the sodium carboxymethyl cellulose solution was prepared, the solution was poured into a plate and left at room temperature for 1 day to allow the film to form a gel-like structure. Subsequently, the walnut oil emulsion was added to the gelled film, and the film was dried at room temperature for 48 hours.

2.3.3 Preparation of Composite Edible Films Based on Sodium Carboxymethyl Cellulose Containing Walnut Oil Emulsion and Chia Seed Mucilage

After preparing the sodium carboxymethyl cellulose solution, the solution was poured into a beaker. The walnut oil emulsion and chia seed mucilage were then added to the solution. Using ultrasonic waves, the emulsion was dispersed into the solution for 1 minute at a power of 70 watts. Finally, the

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mixture was poured into a plastic plate and dried at room temperature for 48 hours.

2.3.4 Tests Related to the Produced Edible Films

2.3.4.1 Measurement of Contact Angle of the Produced Films

The contact angle is the angle formed between the edge of a droplet of liquid and the surface it rests upon. To determine the contact angle of the films, they were placed on a glass slide, and 2 microliters of distilled water were deposited on the surface of the film. After 5 seconds, a photograph of the water droplet was taken using a Canon MV50 camera, and the contact angle was measured using software. This test was repeated three times for each film (Li, Wang, & Xue, 2019).

2.3.4.2 Evaluation of Film Permeability to Water Vapor

The permeability of the film to water vapor can provide insight into the ability of these films to transfer water vapor between the air and the food product in packaging, which plays a significant role in the spoilage and shelf life of food products. To measure water vapor permeability, the ASTM 96-95 method was used. Glass vials were employed for this test. Initially, the vials were weighed, and then 15 milliliters of distilled water were added to each vial. The different films were then securely sealed over the openings of the vials. The vials were weighed at regular intervals over a 72-hour period. It is worth noting that the relative humidity of the air during these 72 hours was also measured (Moore & Akoh, 2017). Then, the water vapor permeability was calculated using the following equation (2).

$$\mathrm{WVP} = \frac{\Delta W \times FT}{S \times \Delta p} \quad (2)$$

In equation (2): ΔW is the weight loss of the vial (g), FT is the thickness (mm), S is the surface area (m²), and Δp is the pressure difference (kPa).

2.3.4.3 Measurement of the Yellowness Index and Turbidity of the Produced Films

The color of food packaging is an important parameter in consumer acceptability and the overall appearance of the product. In this study, to evaluate the color of the produced films, digital camera photos were taken in 3 repetitions from the samples. Then, with the L* and b* values, the yellowness index (Equation 3) was calculated (Ojagh, Rezaei, Razavi, & Hosseini, 2010). The turbidity of the films at a wavelength of 600 nm was calculated using equation (4), with the film thickness taken into account (Álvarez et al., 2021).

$$\mathrm{YI} = \frac{142.86\ \mathrm{b}}{\mathrm{L}} \quad (3)$$

In these equations, YI is the yellowness index, which was obtained using the values of L* and b*

$$\mathrm{Turbidity} = \frac{A_{600}}{x} \quad (4)$$

In equation (4): A_{600} represents the absorbance of the films at 600 nm, and x is the thickness of the films in millimeters.

2.3.4.4 Tensile Properties of the Produced Films

Measuring the tensile properties of edible films is one of the most important indicators in food packaging. Edible films need to be resistant in terms of these properties to maintain the quality of food products during transportation, storage, and handling. To measure the tensile properties of the produced films, a tensile test was conducted using a material testing machine (STM-20, Sentam, Iran). The films were cut to a width of 2 cm and a length of 5 cm. They were then conditioned for 48 hours in a desiccator with a relative humidity of 50% to allow conditioning. The distance between the two grips was 30 mm, and the speed of the grips was 1 mm per second. The maximum tensile strength, elongation at break, and Young's modulus were determined based on the stress-strain curves obtained from the material testing machine (Kaewprachu, Osako, Tongdeesoontorn, & Rawdkuen, 2017).

2.4 Statistical Analysis

In this study, the differences between the various treatments were determined based on a completely randomized design using analysis of variance (ANOVA) at a 95% confidence level. The comparison of the means was performed using Duncan's multiple range test with the help of SPSS software. Additionally, the graphs were plotted using Excel 2019 software.

3. Results and Discussion

3.1 Evaluation of Walnut Oil Emulsion

3.1.1 Emulsion Stability

The creaminess percentage of the emulsions is shown in Figure (a-1). Figure (b-1) also displays a view of the prepared emulsions. The emulsions were stable on the first day, and after 14 days, creaming was observed in the 20%, 30%, and 50% emulsions. The 10% emulsion exhibited the highest stability, with no creaming observed, while the highest degree of creaming occurred in the 50% emulsion.

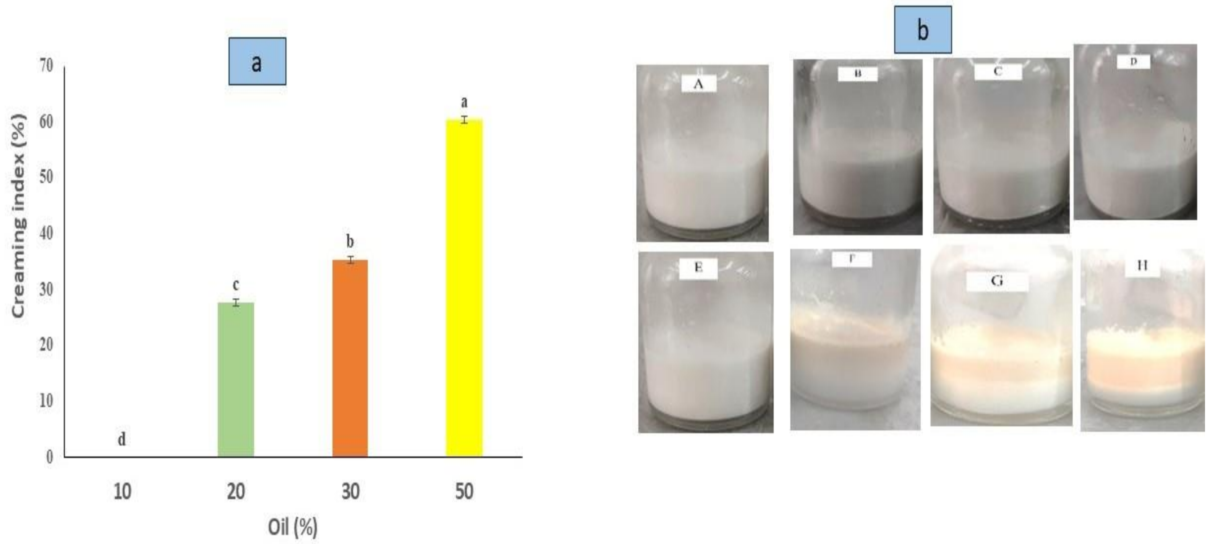

Figure 1. Creaming index of emulsions (a), Appearance of walnut oil emulsion stabilized with chia seed mucilage at different oil ratios (10%, 20%, 30%, 50%) on the first day (a, b, c, d) and on the fourteenth day (e, f, g, h) respectively (b).

Loi et al. (2019) found in their research that a narrow droplet size distribution contributes to the homogeneity and stability of emulsions. Additionally, larger droplets, compared to smaller ones, have a higher creaming rate and, according to Stokes' law, separate due to gravity. (Loi, Eyres, & Birch, 2019). Hong et al. (2018) discovered in their studies that the droplet size of an emulsion is related to the creaming index. According to Stokes' law, smaller droplet sizes increase emulsion stability and reduce the creaming index. (Hong, Kim, & Lee, 2018). Based on this, it can be concluded that by reducing the oil percentage and

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increasing the amount of polysaccharide, the stability of the emulsion against creaming can be improved.

3.1.2 Viscosity of Chia Seed Mucilage Solution and Walnut Oil Emulsion

The viscosity of the 5% chia seed mucilage solution and the walnut oil emulsion stabilized with chia seed mucilage (containing 10% oil) was examined at 25°C, and the results are shown in Figure 2. Both the walnut oil emulsion and the chia mucilage solution exhibited Newtonian flow behavior, particularly at high shear rates. Borrin et al. (2016) stated in their study that the high water content in emulsion production leads to Newtonian behavior in the emulsion (Borrin, Georges, Moraes, & Pinho, 2016). Based on Figure 2, it can be observed that the viscosity of the walnut oil emulsion was lower compared to the chia seed mucilage solution at various shear rates. This suggests that the effect of ultrasound waves and the addition of Tween 80 to the emulsion may have led to a decrease in viscosity compared to the chia seed mucilage solution.

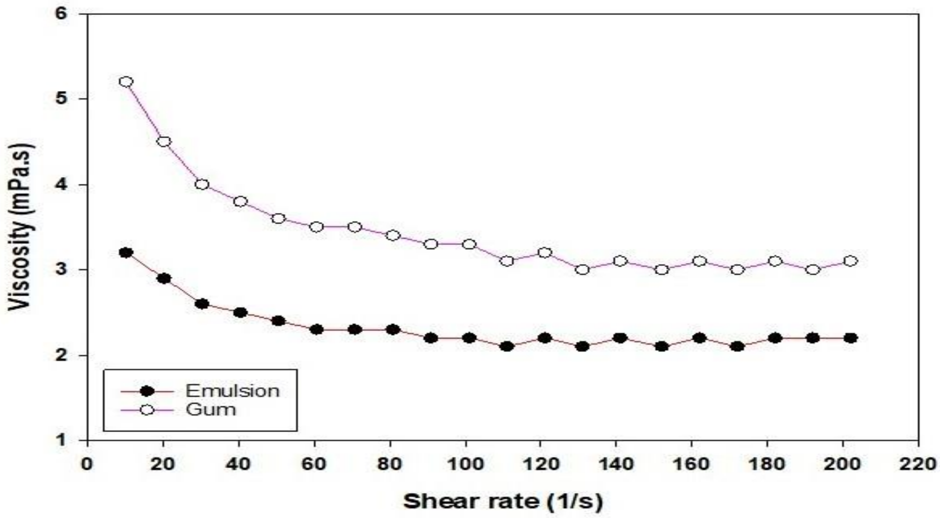

Figure 2. Viscosity of chia seed gum solution and walnut oil emulsion stabilized with chia seed mucilage at different shear rates.

3.1.3 Measurement of Emulsion Droplets with DLS

The measurement of emulsion droplets (containing 10% oil) was performed using DLS, and the results are shown in Figure 3. As seen in Figure 3, the D50 size of the emulsion droplets was 886 nanometers, which is below one micrometer. Additionally, the Span value was 0.629, indicating the homogeneity of the emulsion. The small droplet size and good homogeneity were attributed to the use of ultrasound waves in the preparation of the emulsion, which helped reduce the oil droplet size.

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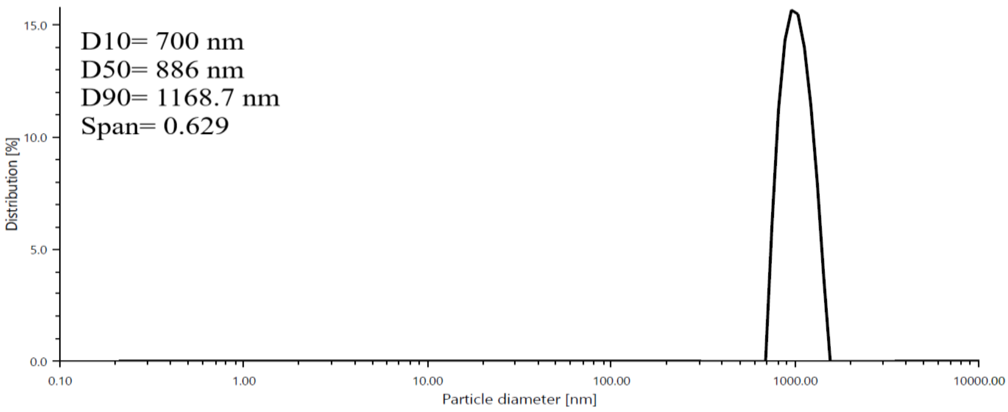

Figure 3. Droplet size distribution of walnut oil emulsion (10% oil) stabilized with chia seed mucilage

Li and Xiang (2019) investigated the stability and emulsifying properties of a 5% coconut oil emulsion in water and stated that high-pressure homogenization and ultrasonic treatment effectively reduced the droplet size and distribution range of the emulsion. The researchers' findings showed that the emulsion created by ultrasonic treatment remained stable during 30 days of storage (Li & Xiang, 2019).

3.2 Investigation of the Physical Properties of Films Containing Walnut Oil Emulsion

3.2.1 Investigation of the Contact Angle of the Produced Films

Contact angle is generally divided into four categories: If the surface contact angle is less than 10 degrees, the surface is superhydrophilic and has high wettability. If the contact angle is between 10 and 90 degrees, the surface is hydrophilic. If the contact angle is between 90 and 120 degrees, the surface is hydrophobic, and if the contact angle is above 120 degrees, the surface is superhydrophobic and has low water absorption. Figure (4) shows the contact angle of the edible films.

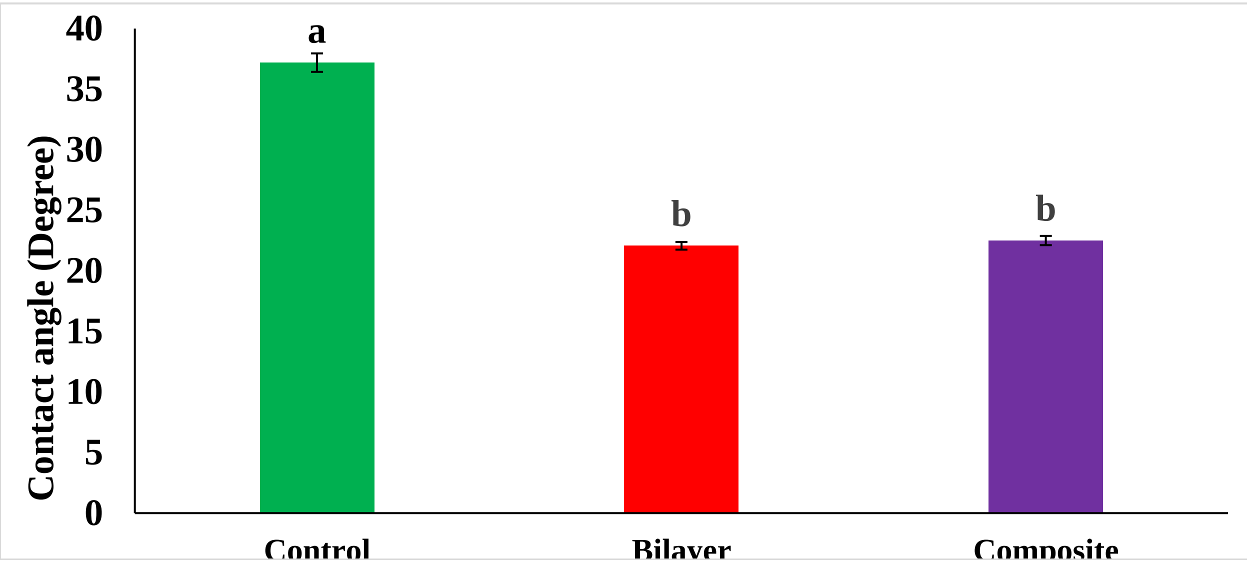

Figure 4. Contact angle of produced edible films.

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The contact angle of the control film was higher than that of the composite and bilayer films, and a significant difference ($p<0.05$) was observed in the contact angle between the control film and the composite and bilayer films. Additionally, no significant difference ($p>0.05$) was found between the bilayer and composite samples. In the composite and bilayer films, the addition of the emulsion resulted in unexpected outcomes, which can be attributed to the inclusion of Tween 80 in the emulsion. This is because Tween 80 increases the film's tendency to interact with water molecules (Ghanbarzadeh & Almasi, 2011).

3.2.2 Investigation of the films' permeability to water vapor

In general, polymer films have high permeability to water vapor, which decreases when lipid emulsions are added to these polymer films. The results of the water vapor permeability of the films are shown in Figure (5). The control film had higher permeability to water vapor compared to the bilayer and composite films. Moreover, this film showed a significant difference ($p<0.05$) compared to the bilayer and composite films. No significant difference ($p>0.05$) was observed between the bilayer and composite films. The results indicated that the addition of the emulsion, due to its hydrophobic properties, reduced the water vapor permeability of the sodium carboxymethyl cellulose films, which naturally have high hydrophilicity. Xiao et al. (2016) investigated the effect of palm oil on the mechanical properties and water vapor permeability of gelatin-palm oil emulsion films and stated that all films containing palm oil had significantly lower water vapor permeability than pure gelatin films, clearly demonstrating an improvement in water vapor barrier properties. They mentioned that the weak water vapor permeability of gelatin-based films is due to the hydrophilic nature of gelatin molecules. Palm oil, as a hydrophobic and non-polar substance, incorporated into the gelatin network, naturally increased the hydrophobicity of the film and reduced its water vapor permeability (Xiao et al., 2016).

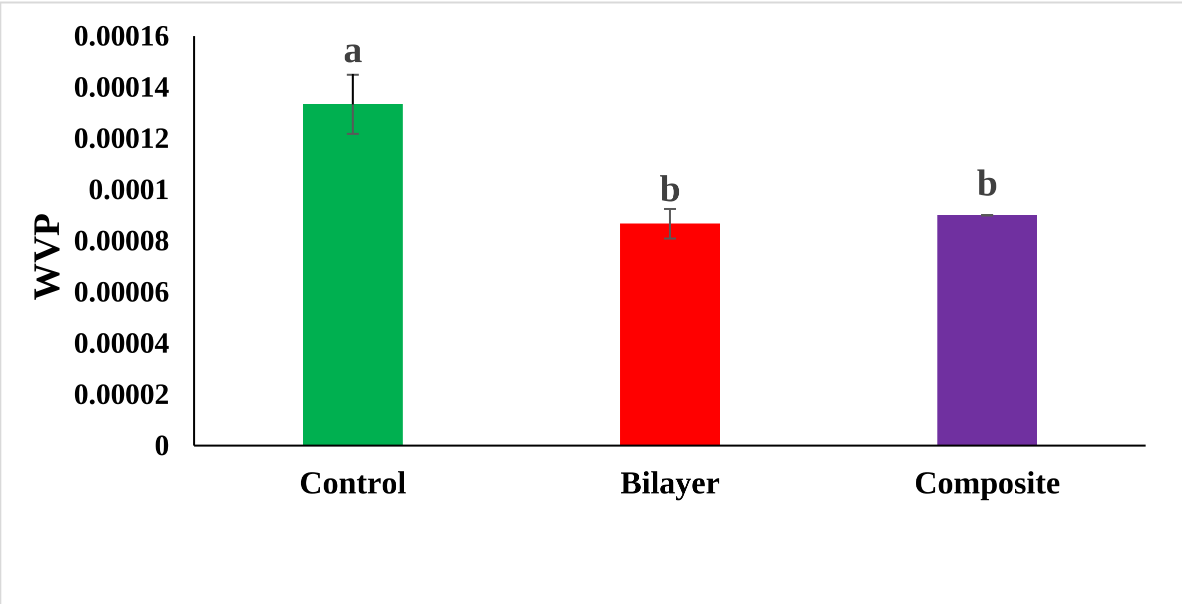

Figure 5. Water vapor permeability results of produced edible films.

3.2.3 Results of Opacity and Yellowness Index of the Produced Films

The results of the opacity of the films are shown in Figure (a-6). The control, bilayer, and composite films showed significant differences in opacity at the (P<0.05) level. The control film had the highest opacity, while the composite film had the lowest opacity. This result indicates that the addition of the emulsion to the composite film created a more opaque appearance compared to the bilayer film. As shown in Figure (b-6), the yellowness index (YI) of the control, bilayer, and composite films showed significant differences at the (P<0.05) level. Adding the emulsion to the control film increased the yellowness index. The yellowness index of the composite film was higher than that of the bilayer film. Pérez-Mateos et al. (2009) and Sahraei et al. (2017) stated in their studies that adding oil to edible films made the films appear more opaque (Pérez-Mateos, Montero, & Gómez-Guillén, 2009; Sahraee, Milani, Ghanbarzadeh, & Hamishehkar, 2017). Nilsuwan et al. (2016) investigated the effects of palm oil and glycerol on the properties of fish skin gelatin films and stated that the addition of oil increases the yellowness index. The gelatin films became more yellow and the yellowness index increased with the addition of palm oil (Nilsuwan, Benjakul, & Prodpran, 2016). Valencia et al. (2018) stated in their research that the addition of essential oil to bilayer films increases the yellow color in these films (Valencia-Sullca, Vargas, Atarés, & Chiralt, 2018).

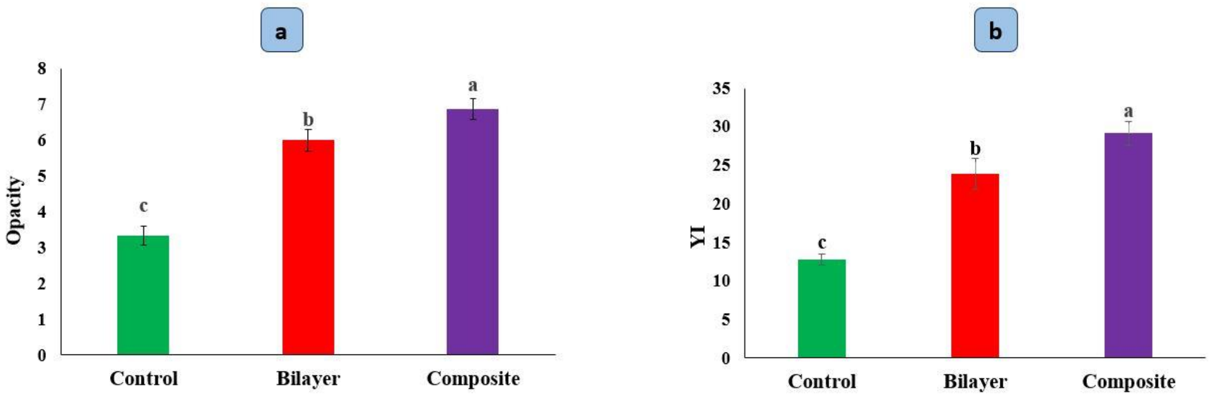

Figure 6. Turbidity (a) and yellowness index (b) of produced edible films

3.2.3 Analysis of the Properties Obtained from the Tensile Test of the Produced Films

As shown in Figure (a-7), there is a significant difference (p<0.05) in the strain at the breaking point between the control, composite, and bilayer films. It is also observed that the bilayer film exhibits higher strain compared to the control and composite films. It can be said that in the case of the composite film, the presence of oil in its structure leads to a reduction in strain. Thani et al. (2019) and Akhter et al. (2019) reached similar findings in their studies. These researchers stated that the addition of oil or essential oil to films leads to an uneven structure and discontinuity in the film, resulting in a decrease in the strain of composite films (Akhter, Masoodi, Wani, & Rather, 2019; Sani, Pirsa, & Tağı, 2019).

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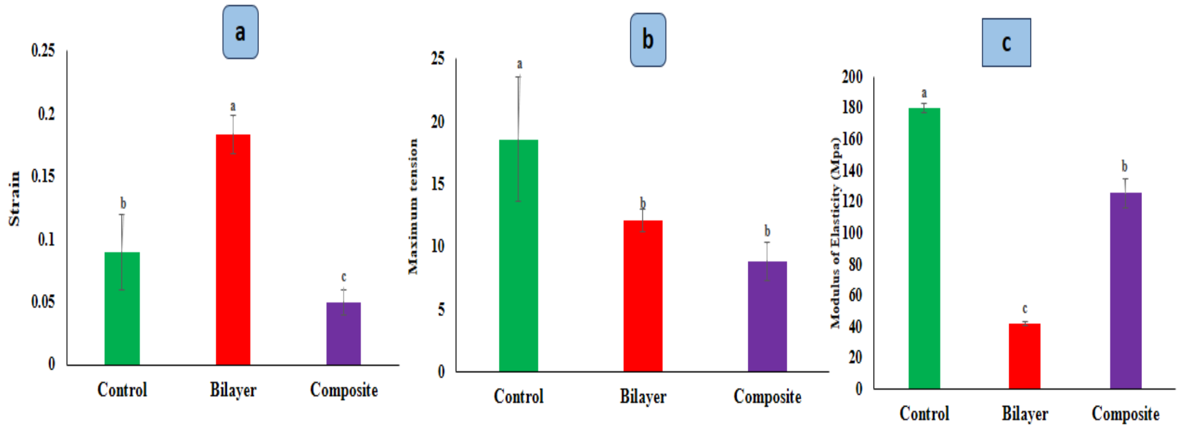

Figure 7. Strain (a), maximum stress (b) and Young's modulus (c) of produced edible films.

The results of tensile strength (maximum stress) of the different films are shown in Figure (b-7). The tensile strength of the control film showed a significant difference ($p<0.05$) when compared to the bilayer and composite films. Additionally, no significant difference ($p>0.05$) in tensile strength was observed between the bilayer and composite films. The maximum stress (tensile strength) decreased in both the bilayer and composite films with the addition of walnut oil emulsion. As shown in Figure (c-7), a significant difference ($p<0.05$) was found between the control, bilayer, and composite films in terms of Young's modulus. The control films had a higher Young's modulus compared to both the bilayer and composite films. Additionally, the composite films exhibited a higher Young's modulus than the bilayer films. This suggests that the addition of the emulsion to the sodium carboxymethyl cellulose film resulted in a more compact structure in the composite films compared to the bilayer films. This could be attributed to the creation of discontinuities in the bilayer and composite films due to the addition of the emulsion. In a study, Mirzaee Moghadam (2019) reported that adding fish oil to gummy candies decreased their Young's modulus (Mirzaee Moghaddam, 2019). Ebrahimzadeh et al. (2021) in their research on bilayer films stated that the addition of essential oils to the film results in weaker interactions between the polymer and the essential oil compared to the strong interactions of biopolymer, leading to a decrease in tensile strength in the films containing essential oil. They also mentioned that adding essential oils to the bilayer film increases the elongation, which could be due to the plasticizing effect of the essential oil (Ebrahimzadeh, Bari, Hamishehkar, Kafil, & Lim, 2021). Galus et al. (2016) studied whey protein edible films with different percentages of canola oil and reported that the Young's modulus decreased with an increase in the canola oil content up to 2%, and then increased with the addition of canola oil up to 3%. This indicates that as the oil content increases in the whey protein film, the structure becomes more compact. This effect can be attributed to the discontinuities in the polymer network caused by the addition of oil (Galus & Kadzińska, 2016).

4. Conclusion

In this study, walnut oil emulsion at different oil concentrations was stabilized using chia seed mucilage, and the effect of the most stable walnut oil emulsion in both combined and bilayer forms on the physical

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properties of sodium carboxymethyl cellulose edible films was investigated. The results showed that the walnut oil emulsion stabilized with chia seed mucilage at lower oil ratios exhibited a lower creaming index. Additionally, the droplet size of the most stable walnut oil emulsion was below one micron. Furthermore, the flow behavior of the stable emulsion was nearly Newtonian. Contact angle results indicated that both bilayer and combined films had lower contact angles compared to the control films. Adding walnut oil emulsion to the sodium carboxymethyl cellulose film in a combined form increased opacity and the yellow index compared to the bilayer film. The mechanical properties of the films revealed that adding walnut oil emulsion to the carboxymethyl cellulose film in a bilayer form increased strain and decreased maximum stress. The findings of this study indicated that walnut oil in the form of an emulsion stabilized with chia seed mucilage can be used for producing edible films. Moreover, the results showed that the method of incorporating walnut oil into the edible film structure is an important factor affecting the physical properties of the film.

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مقاله علمی_پژوهشی

بررسی امکان تولید امولسیون روغن گردو پایدار شده با موسیلاژ دانه چیا و کاربرد آن در فیلمهای خوراکی

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چکیده

در این پژوهش ابتدا امولسیونهای روغن گردو پایدار شده با موسیلاژ دانه چیا با درصد های روغن مختلف (۱۰، ۲۰، ۳۰ و ۵۰ درصد) به روش پیکرینگ تهیه شد. سپس از بهترین امولسیون در تهیه فیلم های خوراکی دو لایه و ترکیبی بر پایه سدیم کربوکسی متیل سلولز استفاده شد و اثر این امولسیون روغن بر خواص فیزیکی(نفوذپذیری، زاویه تماس، کدورت، استحکام کششی، کرنش گسیختگی و مدول یانگ) فیلمهای تولیدی بررسی شد. نتایج نشان داد که امولسیون روغن گردو با ۱۰ درصد روغن بیشترین پایداری را بعد از ١٤ روز نگهداری داشت. همچنین، اندازه قطرات (D_{50}) امولسیون (۱۰ درصد روغن) ۸۸٦ نانومتر بود که درمحدوده زیر یک میکرومتر بود. سپس امولسیون روغن گردو پایدارشده با موسیلاژ دانه چیا (۱۰ درصد روغن) به فیلمهای خوراکی بر پایه سدیم کربوکسی متیل سلولز به صورت دولایه و ترکیبی اضافه شد. نتایج نشان داد که افزودن امولسیون روغن گردو به فیلم سدیم کربوکسی متیل سلولز به صورت ترکیبی باعث افزایش کدورت و شاخص زردی نسبت به فیلم دولایه شد. هیچ اختلاف معناداری ($p>0.05$) در نفوذ پذیری بخار آب بین فیلم های دولایه و ترکیبی وجود نداشت اما فیلمهای حاوی روغن گردو نفوذپذیری به بخار آب کمتری نسبت به نمونه شاهد داشتند. نتایج حاکی از کاهش استحکام کششی در فیلم های دولایه و ترکیبی با افزودن امولسیون روغن گردو بود. همچنین فیلم دو لایه حاوی امولسیون روغن گردو کمترین مدول یانگ (٤١/٦٨ مگاپاسکال) و بیشترین کرنش در نقطه گسیختگی (۰/۱۸) را داشت. به طور کلی، یافته های این تحقیق نشان داد که روغن ارزشمند گردو به فرم امولسیون پایدار شده با موسیلاژ دانه چیا در ساختار فیلم های خوراکی سدیم کربوکسی متیل سلولز می تواند علاوه بر ایجاد فیلم خوراکی باعث بهبود خواص فیزیکی فیلم ها نیز گردد.

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