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Microstructure Characterization of Whey Films Using Different Concentrations of Chia Seeds and 35% Sorbitol as Plasticizer

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Abstract: SEM testing was used to evaluate the homogeneity of the film, including pores, cracks, and surface structure, as well as to determine the cross-section and surface structure and the homogeneity of the film solution mixture. The study aims to determine the microstructure characteristics of whey film by adding different concentrations of chia seed and 35% sorbitol as a plasticizer. This study employed three treatments: P1 with 0.5% chia seed, P2 with 0.75% chia seed, and P3 with 1% chia seed. The research method used was descriptive, providing a detailed description of the process. The results indicate that adding more polymer increases the viscosity of the film suspension during the gelatinization process. The film's microstructure was determined by the heating and drying process, as well as the contribution of chia seed gel to the whey film structure. All treatments achieved a Homogeneous film microstructure, but the 1% concentration treatment resulted in a swollen surface structure. The chia seed was evenly mixed into the whey protein matrix, resulting in a uniform structure.

Keywords: Chia Seed; Film; Sorbitol; Microstructure; Whey.

Introduction

The interest in biodegradable packaging materials arises from the need to reduce the use of environmentally non-degradable plastics. Over the past 50 years, the food industry has employed various synthetic plastics, leading to environmental problems that concern consumers and all participants in the food production chain [1,2]. As a result, consumers are increasingly demanding natural and synthetic compound-free foods. Researchers have collaborated to offer biodegradable packaging. One of the main trends is developing films from agricultural by-products and renewable natural resources to replace conventional plastics [3]. Edible packaging has also been developed using biopolymers such as proteins [4–6], carbohydrates [7], lipids [8] or composite [9–13].

Edible films have the potential to replace plastic packaging. They can act as a carrier matrix for active compounds, such as antioxidants or antimicrobial compounds [14,15] while increasing the packaged product's nutritional content [16]. These films are designed to perform specific functions that conventional packaging systems cannot [17]. Protein is an excellent base material for edible film due to its barrier properties against water vapour [18]. Studies have shown that whey protein is a promising option for edible film applications, as it can act as a barrier against moisture, oxygen, lipids, and aroma [19]. It can further enhance its barrier properties by blending whey protein with other polymeric materials [20–23]. However, films developed using whey protein isolate exhibited poor water vapour barrier properties because of their hydrophilic nature [24,25].

Edible polymers, such as hydrocolloids (polysaccharides and proteins), lipids (fatty acids, wax, resin), and composites, are classified according to their origin. Among these polymers, it is noteworthy that polysaccharides derived from plant seeds are one of the most essential hydrocolloids that can be used in the food industry due to their technological properties and food characteristics [26]. The reason for using polysaccharide-based films in film development is that they can be metabolized in the human body along with food and converted into edible films [2]. In this context, chia seeds (*Salvia hispanica*) meet the requirements for the formation of edible films. The functional properties of chia seeds indicate that this polymer has thickening properties, high viscosity in water, and produces beneficial metabolic effects. In addition, chia seeds have great potential for use in the food industry as stabilizers, thickeners, additives, or fat substitutes [27–29].

One strategy for enhancing the properties of developed films is combining polysaccharides and proteins. This combination can improve the surface structure by interacting the two components [30]. Edible films containing hydrocolloid components like chia seeds can mask or reduce macromolecular bonds, including polysaccharides, proteins, or lipids [31]. The production of elastic edible films is highly dependent on plasticizers. Sorbitol and glycerol, both polyol group plasticizers, are commonly used.

Scanning Electron Microscope (SEM) testing was used to evaluate the homogeneity of the film, as well as pores, cracks, and surface structure. The purpose of these observations was to determine the cross-section and surface structure, as well as the homogeneity of the film solution mixture. Additionally, observing the microstructure allows for the study of the relationship between the properties

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contained in the film. SEM observations focus on the shape and size of grains and the solid solution formed on the film. A smaller and finer grain size will increase the mechanical strength of the film, as well as a well-distributed solid solution, which will increase the tensile strength. This study aims to determine the microstructure characteristics of whey films by adding different concentrations of chia seed and 35% sorbitol as a plasticizer.

Research Methods

Tools and Materials

The research employed several tools, including a hot plate stirrer, magnetic stirrer, Erlenmeyer flask, measuring cup, thermometer, digital scale, and Petri dish. The materials used in the study were whey protein, chia seeds, sorbitol, distilled water, and ethanol.

Extraction of Chia Seed

The chia seeds were washed four times with ethanol to remove foreign matter and crushed into smaller particles. Subsequently, the chia seed granules were macerated in ethanol pro analysis for three days. The resulting mixture was filtered using Whatman 41 filter paper to obtain the chia seed filtrate. The filtrate was then evaporated using a Heidolph Rotary Evaporator-Hei-VAP Value Digital G3 to receive the chia seed solution [32].

Preparation of Whey-Chia Seed Edible Film

According to the treatment, whey powder and chia seed (w/v) were mixed, and distilled water was added until the final volume reached 15 mL. The resulting solution was mixed with a 30% plasticizer and heated at 90°C ± 2°C on a hot plate while stirring using a magnetic stirrer at 250 rpm for 30 minutes. The resulting film solution was poured into a petri dish and allowed to stand at room temperature for 24 hours while the glass time was calculated. Finally, the edible film was packaged using wrapping paper before testing. [23,33].

Microstructure Film

The microstructure of the edible film was observed using a JEOL JCM-7000 scanning electron microscope (SEM). The films, prepared in 0.5 x 0.5 cm size, were coated with carbon and gold before being placed on the SEM device for observation.

Data Analysis

This study employed three treatments: P1 with 0.5% chia seed, P2 with 0.75% chia seed, and P3 with 1% chia seed. The research utilized a descriptive method to provide a detailed account of an individual, situation, symptom, or group.

Results and Discussion

This study aims to observe the microstructure of whey film by adding chia seed using a scanning electron microscope (SEM). The study aims to display the constituent particles of the material contained in whey film [34] and to investigate the relationship between the properties of materials and their structure and defects. The correct composition of materials and processes determines the properties of edible films. Observing the microstructure of a film is crucial in determining its properties. [35]. Figures 1, 2, and 3 show the microstructure resulting from different treatments, including the addition of varying concentrations of chia seed with 35% sorbitol plasticizer. The microstructure was observed at a magnification of 2000x.

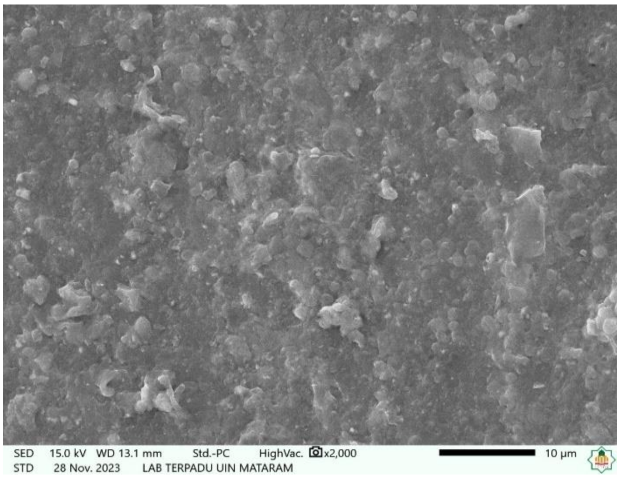

Figure 1. Microstructure of whey film with 0.5% chia seed concentration.

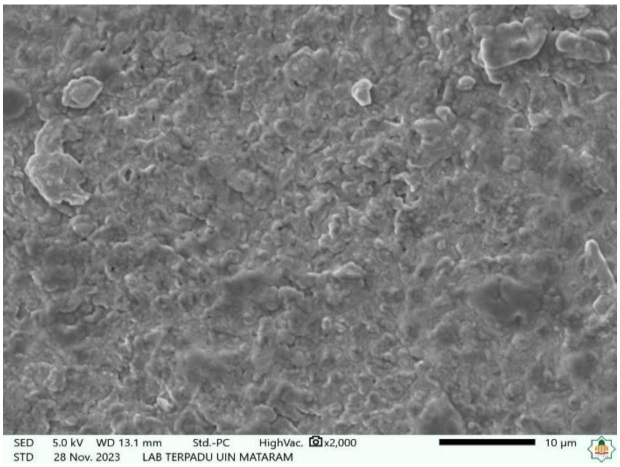

Figure 2. Microstructure of whey film with 0.75% chia seed concentration.

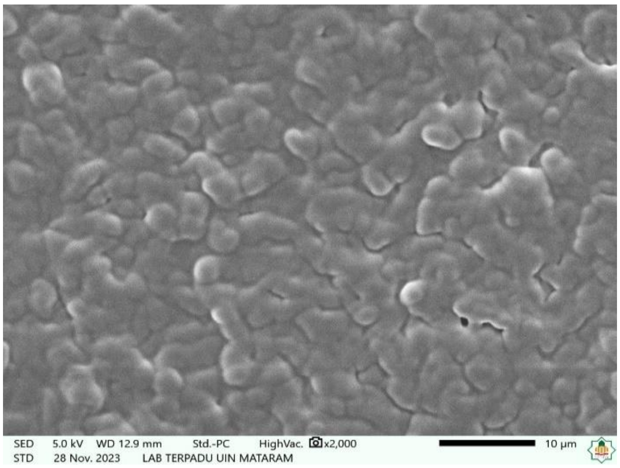

Figure 3. Microstructure of whey film with 1% chia seed concentration.

The microstructure of the film is a crucial determinant of its physical characteristics. Determining the nature of the film is also dependent on its microstructure [33]. SEM observation reveals a range of structures, including dense, tenuous, and wavy structures. The results indicate that the whey film's microstructure produced a crack-free surface. Furthermore, the study shows that the whey and chia seed polymers are seamlessly integrated, resulting in a uniform film solution with desirable characteristics. The film's microstructure, which can impact its mechanical properties, is determined by the arrangement of its components [36]. Therefore, the film's microstructure is closely related to its physical characteristics. A less compact film structure indicates weak characteristics, while the distribution of polymer molecules and molecular spaces indicates the elongation of the film at the break.

Figure 3 displays a swollen surface structure due to the increased concentration of chia seeds compared to Figures 1 and 2. This swelling is due to the gel structure of the network formed by the chia seed polymer. As the concentration of chia seeds increases, a gelatinization process occurs in the film matrix during physical agglomeration (heating process). Furthermore, this swelling or gelatinization results from chia seeds' hydrophilic properties. The film's swelling is influenced by various factors such as polymer concentration, particle size, viscosity, and interfacial forces between the film surfaces [37]. Adding chia seed polymer can increase the viscosity of the suspension film during the gelatinization process. This increase in viscosity leads to an increase in film thickness when the suspension film undergoes gel formation [23,35,38,39]. Heating water with polysaccharides results in the release and binding of water, forming a three-dimensional network that produces good gel strength. Polysaccharides maintain the cohesiveness and stability of the film.

The film prepared using sorbitol plasticizer exhibited crystal formation in each microstructure, as shown in Figures 1, 2, and 3. This is attributed to the heating process at 90°C and may affect the film's mechanical characteristics, such as tensile strength. The film's microstructure is influenced by the heating method, homogenization, emulsion composition, and structural arrangement of the different components at the end of the drying process [35]. The addition of sorbitol into the film matrix can cause a flat surface, as sorbitol has a relatively smaller molecular weight. The film's microstructure is affected by the molecular weight of the plasticizer. Compared to plasticizers with high molecular weight, those with lower molecular weights produce a more compact, homogenous, uniform, and denser film matrix [40]. Sorbitol is used as a plasticizer to increase these intermolecular distances in the film structure by reducing internal hydrogen bonds. The addition of plasticizers in the production of edible films aims to create flexible film properties and reduce protein chain interactions, resulting in increased film flexibility. The selection and concentration of the plasticizer have a significant impact on the mechanical properties and permeability of the film. Furthermore, including chia seed concentration has been found to enhance the bonding strength of edible films, resulting in reduced cracking and increased tensile strength. These results are supported by the findings of the tensile strength test conducted on the edible films, which demonstrated that higher levels of chia seed resulted in greater tensile strength.

Interactions between polysaccharides and proteins are responsible for forming proteins' structure and functional properties, such as their ability to form gels [23,39] in edible films. Incorporating chia seeds can help maintain the cohesiveness and stability of the film. Additionally, the increased amount of polysaccharides can enhance the tensile strength and elasticity of the film, making it more resistant to breaking [34,39,41]. The pH of the film-forming solution and the ingredient composition are crucial factors in preparing edible films, as they can affect the interactions between polysaccharides and proteins. The utilization of fundamental materials comprising proteins and polysaccharides can enhance the quality of food products and decrease the requirement for plastic packaging materials.

Conclusion

Combining whey and chia seed affected the film's microstructure, improving surface characteristics. The heating and drying process and the gel contribution of chia seed to the whey film structure determined the film microstructure. Homogeneous film microstructure was achieved in all treatments, but the treatment with 1% concentration resulted in a swollen surface structure. The chia seed distribution was evenly mixed into the whey protein matsrix, resulting in a uniform structure.

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