Research Article

Production of Edible Films from Whey-Chia Seed Combinations with Different Plasticizers: Effects on Physicochemical Properties

Produksi Edible Film dari Kombinasi Whey dan Biji Chia dengan Plasticizer yang Berbeda: Pengaruh terhadap Sifat Fisikokimia

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Abstract: The utilization of natural polymer-based feeding films has emerged as an alternative to plastics and as a solution to the problem of environmental pollution. Concurrently, these films maintain the function of maintaining the shelf life, quality, and safety of food products. The objective of this study was to ascertain the effect of varying proportions of whey-chia seed combinations and types of plasticiser on the physicochemical characteristics of food films. The present study employed a completely randomised factorial design, comprising Factor A: whey-chia seed combination (A1 = 1:0.5; A2 = 1:0.75 and A3 = 1:1) and Factor B: type of plasticizer (B1 = sorbitol and B2 = polyethylene glycol/PEG). The interaction between the whey-chia seed combination and the type of plasticizer did not show a significant effect ($P>0.05$). However, the whey-chia seed combination itself had a significant impact ($P<0.01$) on film elongation and tensile strength. The utilisation of sorbitol as a plasticiser resulted in enhanced flexibility of the film, thereby rendering it more appropriate for utilisation in healthy and environmentally friendly food applications. The optimal treatment was determined to be a mixture of whey-chia seeds in a 1:1 ratio with sorbitol plasticizer, yielding an elongation at break of 74.23%, tensile strength of 3.997 MPa, and crude fibre content of 15.67%.

Keywords: Chia Seed, Edible Film, Physicochemical, Plasticizer, Whey

Abstrak: Pemanfaatan kemasan makanan berbahan dasar polimer alami telah muncul sebagai alternatif pengganti plastik dan sebagai solusi untuk masalah pencemaran lingkungan. Pada saat yang sama, film-film ini mempertahankan fungsi menjaga umur simpan, kualitas, dan keamanan produk makanan. Tujuan dari penelitian ini adalah untuk mengetahui pengaruh dari berbagai proporsi kombinasi whey-chia seed dan jenis pemlastis terhadap karakteristik fisikokimia edible film. Penelitian ini menggunakan rancangan acak lengkap faktorial, yang terdiri dari Faktor A: kombinasi whey-chia seed (A1 = 1:0.5; A2 = 1:0.75 dan A3 = 1:1) dan Faktor B: jenis pemlastis (B1 = sorbitol dan B2 = polietilena glikol / PEG). Interaksi antara kombinasi whey-chia seed dan jenis plasticizer tidak menunjukkan pengaruh yang signifikan ($P>0,05$), namun faktor kombinasi whey-chia seed berpengaruh ($P<0,01$) terhadap pemanjangan dan kuat tarik film. Penggunaan sorbitol sebagai pemlastis menghasilkan fleksibilitas film yang lebih baik, sehingga lebih sesuai untuk digunakan pada aplikasi makanan yang sehat dan ramah lingkungan. Perlakuan optimal ditentukan sebagai campuran whey-chia seed dengan rasio 1:1 dengan pemlastis sorbitol, yang menghasilkan perpanjangan putus 74,23%, kekuatan tarik 3,997 MPa, dan kandungan serat kasar 15,67%.

Kata kunci: Biji Chia, Edible Film, Fisikokimia, Pemlastis, Whey

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INTRODUCTION

In the context of mounting global concern regarding the environmental impact of conventional plastic usage, numerous industries are undertaking initiatives to innovate and develop packaging solutions that are more environmentally sustainable. A notable innovation that has garnered significant attention is the development of edible films. It is evident that this packaging has the potential to replace single-use plastic packaging, which has been demonstrated to contribute to pollution and environmental damage due to its recalcitrant nature with regard to decomposition (Aleksanyan, 2023; Muñoz-tébar et al., 2022). A salient development trend in the field of edible films involves the utilisation of agricultural by-products and renewable natural resources as substitutes for conventional packaging materials. In recent years, significant progress has been made in the development of food films derived from various polymers. These polymers include proteins (Nisar et al., 2018), carbohydrates (Galus & Lenart, 2019; Moghadam et al., 2020; Mouzakitis et al., 2022), lipids, and composites (Fahrullah et al., 2021, 2022, 2024).

The utilisation of natural-based edible films, such as those derived from whey and chia seed, presents a viable alternative that is not only ecologically sustainable but also nutritionally advantageous. This assertion is supported by the inherent nutritional value of both ingredients, which are rich in protein, fibre, and essential fatty acids (Charles-Rodríguez et al., 2020). Whey, a by-product of the processing of cheese, is characterised by its high protein content and has been identified as a potential raw material for edible films (Chen et al., 2019). The utilisation of protein as a base material for edible film is highly advantageous due to its capacity to function as a barrier against water vapor (Cinelli et al., 2014) and against moisture, oxygen, lipids and aromas (Schmid, 2013). Conversely, chia seeds have been shown to be rich in fibre, which has been demonstrated to engender health benefits (Zettel & Hitzmann, 2018). Consequently, the combination of whey and chia seeds not only provides an environmentally friendly alternative packaging solution, but also serves to enhance the nutritional value of the packaged product.

A recurrent challenge encountered during the fabrication of edible films pertains to the phenomenon of peeling and a propensity towards a rigid texture. In order to produce an edible film of a satisfactory quality, it is necessary to add a plasticizer. Plasticizer is a constituent that is added to edible film at a specific concentration in order to enhance its flexibility (Fahrullah et al., 2020). This process has been shown to result in the production of a film that is characterized by its softness, elasticity and flexibility (Haq et al., 2016). The type and concentration of plasticizer employed can influence the physical and chemical characteristics of edible films. Polyols, including sorbitol and polyethylene glycol (PEG), can be utilized as plasticizers in the manufacturing of edible films. This study is of great significance in the transition from plastic packaging to biodegradable packaging, as it explores a more sustainable alternative.

The methodological approach to be used in this study involves the preparation of edible films from a combination of whey and chia seed, followed by the addition of plasticizer. The physicochemical properties of the resulting films, including elongation, tensile strength, and fibre content, will be analysed to ascertain the effect of the combination whey-chia seed and plasticizer employed. It is therefore the purpose of this study to evaluate the effect of a plasticizer on the physicochemical properties of an edible film composed of a blend of whey and chia seeds.

Furthermore, the study will determine the most effective plasticizer for enhancing the performance of edible film.

MATERIALS AND METHODS

Material and Tools

The materials utilised in this research include whey, chia seed, sorbitol, polyethylene glycol, silica gel, distilled water, and ethanol. The apparatus employed in this study comprises a hot plate stirrer, a magnetic stirrer, an Erlenmeyer flask, a measuring cup, a desiccator, a petri dish and a thermometer.

Extraction of Chia Seeds

The chia seeds were initially subjected to a thorough cleansing process involving at least four washes with ethanol, a measure intended to ensure the complete elimination of extraneous matter. Subsequent to this cleansing procedure, the chia seeds were subjected to a mechanical agitation process, resulting in the fragmentation of the seeds into smaller particles. The chia seed granules were then subjected to a maceration process, involving the soaking of the granules in ethanol for a period of three days, with the aim of conducting a pro analysis. Following this initial maceration, the chia seed granules were filtered using filter paper (Whatman 41), with the objective of obtaining the chia seed filtrate. The chia seed filtrate was subsequently introduced into an evaporation apparatus (Heidolph Rotary Evaporators - Hei-VAP Value Digital G3) in order to yield a chia seed solution (Khazaei et al., 2014).

Preparation of Whey-Chia Seed Edible Film

Whey and chia seed (according to the treatment) were mixed according to the treatment, then distilled water was added to the final volume of 15 mL. The whey + chia seed solution was added with 30% plasticizer then heated at 90˚C ± 2˚C on a hot plate and stirred with a magnetic stirrer at 250 rpm for 30 minutes. The film solution was poured into a petri dish and then allowed to stand at room temperature for 24 hours while calculating the gelation time. The finished edible film was packaged using wrapping paper before testing. Modification (Fahrullah et al., 2020; Maruddin et al., 2018).

Elongation at Break

The elongation value was measured using a Universal Instrument Tensile Strength Meter. To this end, the edible film was cut into a 10x5 cm area, after which it was stretched at a speed of 50 mm/minute. The formula employed for length measurement was adopted from (Wardana & Widyaningsih, 2018):

$$Elongation\ (\%) = \frac{L}{L0} x100\%$$

Note:

L : length of the film at break (mm)

L0 : initial length (mm)

Tensile Strength

Tensile strength measurements were obtained by affixing an 8x3 cm edible film (1.5 cm diameter) to a clamp in a horizontal orientation. The maximum tensile strength was determined when the film exhibited indications of damage during the tensile test (Wittaya, 2013).

Crude Fibre Content

Calculation of crude fibre content using the Gravimetric method (AOAC, 2007).

Statistical Analysis

The present study employed a completely randomised design (CRD) with a factorial pattern consisting of Factor A: whey-chia seed combination (A1 = 1:0.5; A2 = 1:0.75 and A3 = 1:1) and Factor B: plasticizer type (B1 = sorbitol and B2 = polyethylene glycol), with six replications. The data were analysed using Analysis of Variance (ANOVA). In instances where a discernible difference was observed, the Duncan Multiple Range Test (DMRT) was employed, utilising the SPSS 24 application for statistical analysis.

RESULTS AND DISCUSSION

Elongation at Break

Elongation is a process of changing the maximum elongation at the time of pulling until the film breaks. The results of the effect of using the percentage of whey-chia seed with different types of plasticizer on the elongation of edible film in Table 1.

Table 1. Effect of using percentage of whey-chia seed with different types of plasticizer on elongation of edible film

Whey-Chia Seed	Plasticizer		Average
	Sorbitol	PEG	
1:0.5	70.06 ± 1.20	70.71 ± 1.25	70.38^{a}
1:0.75	71.42 ± 1.14	71.78 ± 2.25	71.60^{ab}
1:1	74.23 ± 5.36	73.89 ± 6.36	74.06^{b}
Average	71.90	72.13	

Note: Means in the same column with different superscripts differ significantly (P<0.05).

The findings of the analysis of variance demonstrated that the interaction between the combination of whey-chia seed with different types of plasticizers did not have a significant effect (P>0.05) on the elongation value of edible film. However, the average elongation value produced in this study ranged from 70-74%, which met the Japanese Industrial Standard (JIS, 1975) of at least 70%. The incorporation behaviour between whey and chia seeds was evaluated in order to ascertain the extent of their elongation. This parameter is of significant importance in the present study. A detailed analysis of this parameter will facilitate a more comprehensive understanding of the mechanical characteristics of the film, which is a prerequisite for its application in food products (Muñoz-tébar et al., 2022). A high elongation value indicates that the film is more flexible when subjected to mechanical stress, one of which is heat treatment. This process has been shown to separate the quaternary structure of the protein and denature the protein molecular chain (Fahrullah et al., 2021). This in turn can cause intermolecular interactions that do not occur in the original protein form.

The findings of the study on the utilization of a whey-chia seed combination exhibited a substantial impact ($P<0.05$) on the elongation value of the film. It is evident that an increase in the concentration of chia seeds results in a corresponding increase in the elongation value produced. This phenomenon can be attributed to the interaction between whey and chia seed during the gel formation process. The presence of chia seed as a polysaccharide indicates that aggregate formation can be caused by the force of attraction between whey proteins that are responsible for the structure and formation of the network. It has been demonstrated that films composed of a high polysaccharide ratio exhibit greater elongation in comparison to those with a low polysaccharide content (Muñoz-Tebar et al., 2021). Furthermore, the most effective treatment in this study was demonstrated to be the utilisation of glycerol as a plasticiser in conjunction with a mixture of whey and chia seeds in a 1:1 ratio. Glycerol functions as an effective plasticiser due to its ability to increase the flexibility and pliability of the film by reducing the intermolecular attractive forces in the polymer matrix. When combined with whey and chia seed in a balanced ratio, glycerol contributes to the strengthening of the polymer network formed through synergistic interactions between whey proteins and polysaccharides from chia seed.

The findings of the study on the utilisation of various types of plasticizers revealed no statistically significant impact ($P>0.05$) on the value of film elongation. The highest film elongation value was obtained with the addition of PEG plasticizer, which was 72.13%. The utilisation of polyethylene glycol (PEG) as a plasticizer within the composition of edible films, specifically those derived from a blend of whey and chia seeds, has been demonstrated to yield a heightened degree of elongation when compared to the use of sorbitol. This enhanced performance can be attributed to the inherent chemical characteristics and functional capabilities of PEG, which, due to its enhanced flexibility, contributes to an improved ability to withstand deformation during the process of film formation (Jiang et al., 2020). PEG possesses a more substantial molecular structure and augmented hydrophobic properties, enabling enhanced interaction with the film matrix and elevated flexibility (Kaewprachu et al., 2018). Based on elongation properties, both materials can serve as substitutes for conventional plastic materials. PEG possesses a more substantial molecular structure and augmented hydrophobic properties, enabling enhanced interaction with the film matrix and resulting in elevated flexibility.

Tensile Strength

Tensile strength is a measurement to quantify the specific strength of the film, where the scoring system starts from the maximum pull that can be achieved until the film remains before the film breaks or fractures. The greater the tensile strength, the better the edible film can resist mechanical damage. The results of the effect of using the combination of whey-chia seed with different types of plasticizer on the tensile strength of edible film are shown in Table 2.

Table 2. Effect of using different combination of whey-chia seed with different types of plasticizer on the tensile strength of edible film.

Whey-Chia Seed	Plasticizer		Average
	Sorbitol	PEG	
1:0.5	4.381 ± 0,108	4.343 ± 0,122	4.362[b]
1:0.75	4.273 ± 0,112	4.238 ± 0,220	4.255[b]
1:1	3.997 ± 0,526	3.868 ± 0,322	3.932[a]
Average	4.127	4.150	

Note: Means in the same column with different superscripts differ significantly (P<0.01).

The findings of the analysis of variance demonstrated that the interaction between the combination of whey-chia seed and various types of plasticizers did not exert a significant effect (P > 0.05) on the tensile strength value of edible film. However, the average elongation value produced in this study ranged from 3.932 to 4.362 MPa, which met the Japanese Industrial Standard (JIS, 1975) of at least 0.39226 MPa. The tensile strength of the film was evaluated in order to ascertain its specific strength. The tensile strength is defined as the maximum tensile force that the film can withstand before it breaks or cracks. It is evident that the tensile strength of an edible film is directly proportional to its resistance to mechanical damage. The incorporation of plasticizers into the film solution has been demonstrated to engender a reduction in the density of protein interactions, an augmentation in the mobility of the polypeptide chain, and a diminution in the film's resistance and its susceptibility to deformation (de Souza Silva et al., 2020). In general, films comprising whey-chia seeds and plasticizers have been shown to possess adequate tensile strength, thus suggesting their possible utilisation as edible packaging materials for a range of food products (Dick et al., 2016; Mekonnen et al., 2013).

The findings of the study on the utilisation of a whey-chia seed combination exhibited a substantial impact (P<0.01) on the tensile strength value of the film. It was found that an increase in the concentration of chia seeds resulted in a decrease in tensile strength values. The incorporation of chia seeds has been demonstrated to enhance the cohesiveness and stability of whey edible films. It has been hypothesised that the addition of polysaccharide-rich materials will result in an augmentation of stretch strength, thereby enhancing the stretchability of the films, whilst concomitantly decreasing their tensile strength (Timilsena et al., 2015). Crosslinking between hydrogen chains in chia seeds has been identified as a potential factor contributing to the integrity and strength of whey protein films (Muñoz-Tebar et al., 2021). The findings of the study on the utilisation of various types of plasticizers revealed no statistically significant impact (P>0.05) on the tensile strength value of the film. The tensile strength values produced with the use of different types of plasticizers ranged between 4.127 and 4.150 MPa. Sorbitol and PEG plasticizers possess a relatively substantial tensile strength value, as they possess the capacity to overcome or reduce the widening of the distance between molecules that bind to each other using the same concentration (Sanyang et al., 2016).

Crude Fibre Content

The results of the effect of using the combination of whey-chia seed with different types of plasticizer on the crude fibre content of edible film are shown in Table 3.

Table 3. Effect of using the combination of whey-chia seed with different types of plasticizer on crude fibre of edible film

Whey-Chia Seed	Plasticizer		Average
	Sorbitol	PEG	
1:0.5	15.63 ± 0.94	15.05 ± 0.66	15.34
1:0.75	15.17 ± 1.32	15.21± 0.83	15.19
1:1	15.67 ± 0.74	16.54 ± 0.97	16.10
Average	15.28	15.60	

The findings of the analysis of variance demonstrated that the interaction between the combination of whey-chia seed with various types of plasticizers did not have a significant effect (P>0.05) on the crude fibre content of edible film. The incorporation of chia seeds into edible films is attributable to the fact that they contribute to the crude fibre content of such films. It is well established that chia seeds are a good source of fibre, and when used in the manufacture of edible films, they can add additional nutritional value and functional properties (Hrnčič et al., 2020). In contrast, it is known that the use of whey and plasticizer types does not result in the presence of fibre in the polymer.

The findings of the study, which incorporated a blend of whey-chia seed and various types of plasticizers, revealed no statistically significant impact (P>0.05) on the crude fibre content of edible film. However, it was observed that an increase in the proportion of chia seed utilised resulted in a corresponding increase in the crude fibre yield. This is attributable to the high fibre content of chia seeds (Capitani et al., 2016), with a fibre fraction of 56.4 g/100 g of food, comprising 53.45 g/100 g insoluble fibre and the remainder soluble fibre (Ding et al., 2018). The utilization of PEG plasticiser exhibited elevated levels of crude fibre content in comparison to Sorbitol across all whey-chia seed ratios. The mean crude fibre value for sorbitol plasticiser was 15.28, while for PEG plasticiser it was 15.60. The observed discrepancy can be attributed to the inherent characteristics of the polyethylene glycol (PEG) plasticizer. The PEG plasticizer has a propensity to enhance the moisture retention and flexibility of the film, which may consequently impact the increase in the amount of crude fibre bound within the film matrix (Saberi et al., 2017). The present study demonstrated that an augmentation in the proportion of whey-chia seeds within the edible film raw material mixture resulted in a concomitant increase in the crude fibre content of the film. Furthermore, the utilization of PEG plasticizer was found to be more efficacious in enhancing the crude fibre content when compared with Sorbitol, particularly at the 1:1 ratio. The findings suggest that the amalgamation of whey-chia seed with a higher proportion of PEG plasticizer can yield edible films with optimal crude fibre content. These films have the potential to be utilised in food applications that are both healthier and more environmentally friendly.

CONCLUSIONS

The findings of this study demonstrated that the amalgamation of whey-chia seeds with polyethylene glycol (PEG) plasticiser yielded edible films characterised by enhanced elongation values and elevated crude fibre content, in comparison to sorbitol. However, no statistically significant impact was observed on tensile strength and the interaction between the two factors ($P > 0.05$). The incorporation of a greater proportion of chia seeds into the edible film blend resulted in an augmentation of the crude fibre content, thereby conferring health benefits. The utilisation of sorbitol as a plasticizer resulted in enhanced flexibility of the films, rendering them more appropriate for utilisation in healthy and environmentally friendly food applications. The optimum treatment was determined to be the incorporation of a glycerol plasticiser at a concentration of 1:1 with whey and chia seeds. However, further research is required to explore other types of plasticizers and to optimise the filmmaking process with a view to improving mechanical properties and nutritional content in food applications.

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