Sains Malaysiana 50(12)(2021): 3603-3615
http://doi.org/10.17576/jsm-2021-5012-12

Effects of Different Drying Methods on the Functional Properties and Physicochemical Characteristics of Chia Mucilage Powder (*Salvia hispanica* L.)

(Kesan Kaedah Pengeringan pada Sifat Fungsian dan Ciri Fizikokimia Serbuk Lendiran Chia (*Salvia hispanica* L.))

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ABSTRACT

Chia seeds are a healthy source of omega-3 fatty acids and dietary fibre. The effects of different drying methods (freeze-drying and oven-drying) on the functional properties (water holding capacity, oil holding capacity and colour analysis) and physicochemical characteristics (scanning electron microscopy) of chia mucilage powder (Salvia hispanica *L.*) *including comparison with xanthan gum, hydroxypropyl methylcellulose (HPMC), and arabic gum were investigated. Chia mucilage dried in a freeze dryer (FD) showed significantly higher ($p<0.05$) values of water holding and oil holding capacities compared to chia mucilage dried in air convection heat oven (ACHO), xanthan gum, HPMC and arabic gum. It also showed a higher L* value (lightness) than ACHO, HPMC, and xanthan gum but lower values of a*, b*, c*, BI, and ΔE than ACHO and xanthan gum. The morphology of FD is smaller, more uniform in size, with a fine fibrous relative structure compared to ACHO. FD is a novel mucilage that could potentially be used as a functional and environmentally friendly hydrocolloid for human consumption and significantly better than commercial hydrocolloids. These results can also help to select successful drying methods for food products based on their functional and physicochemical characteristics.*

Keywords: Chia mucilage powder; freeze-drying; functional properties; oven-drying; physicochemical characteristic

ABSTRAK

Biji chia adalah sumber asid lemak omega-3 dan serabut diet yang sihat. Kesan kaedah pengeringan yang berbeza (pengeringan beku dan pengeringan ketuhar) terhadap ciri-ciri fungsian (muatan simpanan air, muatan simpanan minyak dan analisis warna) dan ciri fizikokimia (mikroskopi elektron pengimbasan) serbuk lendiran chia (Salvia hispanica *L.*) *termasuk perbandingan dengan gam xantan, hidrosipropil metilselulosa (HPMC) dan gam arab telah dikaji. Lendiran chia yang dikeringkan dalam pengering beku (FD) menunjukkan peningkatan secara signifikan ($p<0.05$) nilai muatan simpanan air dan muatan simpanan minyak tertinggi berbanding dengan lendiran chia yang dikeringkan dalam pengeringan ketuhar (ACHO), gam xantan, HPMC dan gam arab. Ia juga menunjukkan nilai L * yang lebih tinggi (kecerahan) berbanding dengan ACHO, HPMC dan gam xantan tetapi lebih rendah nilai a *, b *, c *, BI dan ΔE berbanding dengan ACHO dan gam xantan. Morfologi FD lebih kecil, ukurannya lebih seragam, dengan struktur berserat halus berbanding ACHO. FD sebagai lendiran baru, berpotensi digunakan sebagai hidrokoloid berfungsi dan mesra alam untuk penggunaan manusia dan jauh lebih baik daripada hidrokoloid komersial. Hasil ini juga dapat membantu memilih kaedah pengeringan yang berjaya untuk produk makanan berdasarkan ciri fungsian dan fizikokimia mereka.*

Kata kunci: Ciri fizikokimia; pengeringan beku; pengeringan ketuhar; serbuk lendiran chia; sifat fungsian

INTRODUCTION

Hydrocolloids are commonly made of high-molecular biopolymers extracted from plants, algae or produced by microbial synthesis and currently used in the food, pharmaceutical, and cosmetics industries. The hydroxyl groups increase the water affinity within the biopolymer structure, leading to viscous aqueous dispersion. Hydrophilic polymers distributed in water form suspensions with colloid properties, leading to the formation of hydrocolloids. Such products are used in various fields, from biomedical to food processing (Goff & Guo 2020; Vecchies et al. 2018; Williams & Phillips 2009). Hydrocolloids are widely used as dietary fibres, thickeners, gelling agents, emulsifiers, stabilisers, replacers of fatty products, clarifiers, flocculants, clouding, and whipping agents. The study of the rheological properties of hydrocolloids or hydrogels is vital in the food industry, as fluid handling in plants can be affected by varying flow behaviour and viscosity patterns. Natural polymers which offer a versatile degree of flexibility in many applications

are the most useful hydrocolloids in the food industry (Cuomo et al. 2019; Perugini et al. 2018).

Hydrocolloids are also utilised in the areas of edible films, flavour encapsulation and inhibition of crystallisation (Cargill 2020; Li & Nie 2016; Viebke et al. 2014). Furthermore, hydrocolloids have provided for the recuperation, recycling and maintenance of high-value food supplements due to the physical and functional properties of plant gum exudate and seed mucilage from various sources used in the production of suitable hydrocolloids for crops and food disposal (Archana et al. 2013; Li & Nie 2016; Munir et al. 2016; Rezaei et al. 2016). Mucilages extracted from seeds is a source of low-cost natural hydrocolloids and an ideal product for developing and improving healthcare products. Mucilage has a high potential as pharmaceutical excipient in different pharmaceutical formulations (Bansal et al. 2013; Huanbutta et al. 2016; Joseph et al. 2012; Nayak et al. 2015).

Salvia hispanica, which is native to Mexico and Guatemala, is an annual herbaceous plant species from the Lamiaceae family (Whistler 1982). The nutritional properties of chia have been reported to contain high levels of ALA, ω-3, and ω-6 fatty acids, which are beneficial for the human cardiovascular system (Ding et al. 2018; Muñoz et al. 2012; Scheer 2011; Valdivia-López & Tecante 2015). The high level of polyunsaturated fatty acids which are sources of omega-3, fibre and protein renders chia seed extremely valuable in human nutrition and health benefits (Martínez-Cruz & Paredes-López 2014). The cuticles are disintegrated and the cell material, a transparent mucilaginous gel consisting essentially of soluble fibres, gradually exudes when chia seeds are soaked in water (Capitani et al. 2013). Muñoz et al. (2012) reported that the mucilage is released from the seed coat during hydration, showing that it can be easily extracted and hydrated to retain the water of up to 27 times its weight, rendering its great potential as a thickener in food. León-Martínez et al. (2011) confirmed that fresh mucilage, which has shelf life of a few days (2 to 3 days) at 25 °C, is vulnerable to microbial growth due to its high water activity (> 0.8) and composition. Therefore, multiple preservation processes are needed to extend the shelf-life of the mucilage. Besides, the use of mucilage depended on its specific functional characteristics, including solubility, emulsion stability and rheological characteristics. These functional properties are sensitive to preparation methods and could be significantly modified by the drying process (Wang et al. 2010).

The selection of drying methods depends mainly on the dehydration process, which was a crucial process affecting the physicochemical characteristics of polysaccharides such as monosaccharide structure, molecular weight, conformation, and bioactivity (Ma et al. 2013; Nep & Conway 2011; Wang et al. 2015). Hence, different drying methods have been proposed for dry polysaccharides depending on their complex physicochemical characteristics (Huang et al. 2017; Ma et al. 2013; Nep & Conway 2011). The oven-drying was the most basic and standard method used for drying, however, changes in sample quality may occur (Wang et al. 2019). The colour of oven-drying gum powder showed a low L* value, while the ΔE value increased as the temperature increased (40-80 °C) (Salehi & Kashaninejad 2014). Ma et al. (2013) and Wu et al. (2014) stated that freeze-drying could avoid deterioration and provide a better polysaccharide consistency in the final result for *Inonotus obliquus* and *Agaricus blazei* Murrill.

To date, studies that investigated the effect of different drying methods and temperature on the functional properties and physicochemical characteristic of chia mucilage powder (*Salvia hispanica* L.) are lacking. Among the various drying methods mentioned in the literature, freeze-drying and oven-drying were the chosen methods based on the preliminary experiments prior to this study. Therefore, the purpose of the present study was to investigate the influence of different drying methods (oven drying (40 °C) and freeze-drying) on the functional properties (water holding capacity, oil holding capacity and colour analysis) and physicochemical characteristic (scanning electron microscopy) of chia mucilage powder (*Salvia hispanica* L.) compared to hydroxypropyl methylcellulose (HPMC), xanthan gum and arabic gum which are commonly used in the food industry.

Materials and Methods

Materials

The black chia seeds (*Salvia hispanica* L.), were provided by The Chia Co. (Victoria, Australia). The commercial hydrocolloids which were hydroxypropyl methylcellulose (HPMC), xanthan gum and arabic gum were purchased from BWY Holding Sdn Bhd. (Bangi, Malaysia).

Mucilage extraction

Mucilage was prepared according to Marin Flores et al. (2008) with some modification at the end of the treatment. Whole chia seeds (10 g) were soaked in

distilled water (1:20) (w/v) for 1 h at room temperature and manually stirred to induce the mucilage exudation.

The mucilage extraction method used in this study was selected based on a preliminary study using different ratios of seed and water (1:10 to 1:20; w/v). From the trials, the result shows a higher yield and crude fibre content of chia mucilage when using a 1:20 (w/v) ratio of seed and water.

The extracted mucilage was separated from water by vacuum pump, 220 V (Millipore, model XX5522050, United States) through filter paper (Whatman, No. 42 Ashless, size 110 mm). Samples of 40 g extracted mucilage were placed in a microwaveable plastic container (4 × 12 × 17cm) and dried using two methods: freeze-drying and oven-drying.

For the freeze-drying method, samples were frozen at -20 °C for 96 h (4 days) in a freezer (Sanyo- Medical freezer, model MDF-U332, United States) followed by freeze-drying in a freeze dryer (Alpha 1-2LD plus, model 101521, Germany) at -50 °C, 0.060 mbar for 48 h (2 days). The oven-drying method was carried out by drying the samples at 40 °C for 20 h using air convection heat oven (Memmert, model UFB, Germany). The oven-drying method used in this study was selected based on a

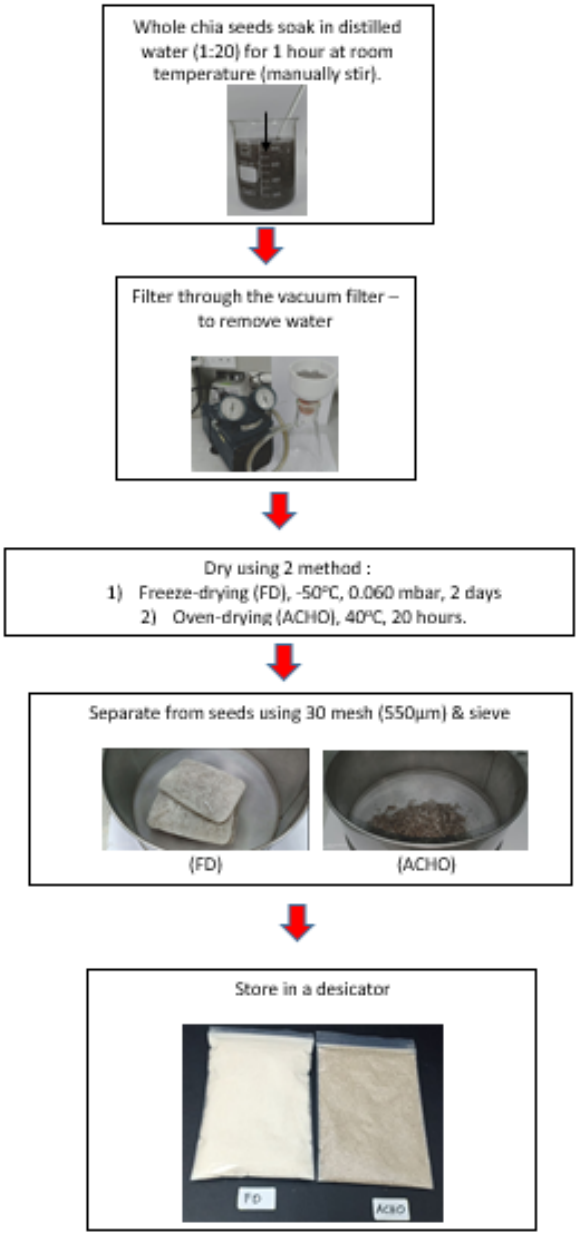

FIGURE 1. Flow chart of the extraction procedure of mucilage from chia seeds

preliminary study using different temperatures and time (40 °C, 10 h; 40 °C, 20 h; 50 °C, 10 h; 50 °C, 20 h). From the trials, a sample completely dried and light coloured sample was obtained at 40 °C for 20 h. The temperature and time used in this study have not been applied to any of the drying oven method used in previous studies.

Both dried mucilages were separated from the seeds using a 30 mesh (550 µm) sieve to produce a fine powder. The powdered mucilages were packaged in hermetically sealed plastic containers and stored in a desiccator to avoid humidity (Figure 1).

FUNCTIONAL PROPERTIES

WATER HOLDING CAPACITY (WHC)

The WHC was determined according to the method by Thanatcha and Pranee (2011) with some modifications. About 0.25 g of the dried chia seed mucilage was mixed with 25 mL distilled water using a magnetic stirrer (Velp Scientifica, model AM4, Europe) for 15 min, and the sample was centrifuged for 30 min (10,000 × g) using a centrifuge (Eppendorf centrifuge, model 5810R, Germany). The supernatant was removed, the precipitate was weighed and WHC was calculated using the following equation:

$$Water\ Holding\ Capacity\ \left(\frac{g\ water}{g\ dry\ sample\ weight}\right) = \frac{Precipitate\ weight\ (g) - Dry\ sample\ weight(g)}{Dry\ sample\ weight\ (g)} \quad (1)$$

OIL HOLDING CAPACITY (OHC)

The OHC was determined according to the method of Raghavendra et al. (2007) with some modifications. About 0.5 g samples were weighed into a centrifuge tube. A volume of 10 mL refined oil was mixed with the sample by vortex (Velp Scientifica, model Zx3, Europe) for 1 min. The mixture was then kept at room temperature (27 °C) for 30 min. The samples were then centrifuged for 30 min (10,000 × g) using a centrifuge (Eppendorf centrifuge, model 5810R, Germany). Then, the supernatant was removed and the centrifuge tube was kept upside down for 1 min. Finally, the precipitate was weighed and OHC was calculated using the following equation:

$$Oil\ Holding\ Capacity\ \left(\frac{g\ oil}{g\ dry\ sample\ weight}\right) = \frac{Precipitate\ weight\ (g) - Dry\ sample\ weight(g)}{Dry\ sample\ weight\ (g)} \quad (2)$$

COLOUR ANALYSIS

Colour analysis of the samples was performed using a chromameter (Konica Minolta, model CR-400, Japan) with a CIE Lab colour system (L*, a* and b*), according to the method by Bertoncelj et al. (2007). In this study, L^* (lightness = darkness ranging from 0 to 100), a^* (redness = greenness ranging from -120 to 120), and b^* (yellowness = blueness ranging from -120 to 120) values were determined. The angle of hue (°), hue = $\tan^{-1}$ (b / a), expresses the nuance of colour, and values are described as follows: red-purple: 0°, yellow: 90°, bluish-green: 180°, and blue: 270° (Gonçalves et al. 2007). In the following equation, the sample hue angle (H) was calculated (Bhat et al. 2013):

$$H = tan^{-1}(b^*/a^*)\ when\ a^* > 0\ and\ b^* > 0 \quad (3)$$

$$H = 180^o + tan^{-1}(b^*/a^*)\ when\ a^* < 0 \quad (4)$$

$$H = 360^o + tan^{-1}(b^*/a^*)\ when\ a^* > 0\ and\ b^* < 0 \quad (5)$$

The following equations were used to measure the changes in colour (ΔE) of the total colour differences and C* (chroma) for saturation (Liu et al. 2010).

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (6)$$

$$C* = \sqrt{(a^*)^2 + (b^*)^2} \quad (7)$$

One of the most important parameters recorded in both enzymes and non-enzymes browning processes is the Browning Index (BI). This index shows the purity of the brown colour that can be measured by the following procedure (Pathare et al. 2013):

$$BI = 100 \times \left(\frac{x - 0.31}{0.172}\right) \quad (8)$$

$$x = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} \quad (9)$$

PHYSICOCHEMICAL CHARACTERISTIC

SCANNING ELECTRON MICROSCOPY (SEM)

Surface morphology of whole chia seeds before and after extraction, chia mucilage dried in a freeze dryer (FD), chia mucilage dried in air convection heat oven (ACHO), hydroxypropyl methylcellulose (HPMC), xanthan gum and arabic gum were determined by placing the samples on aluminium stubs and covered with gold in a fine coat ion sputter (Polaron, model SC7680, United Kingdom). A scanning electron microscope (VPSEM, model 1450, United Kingdom) was used to display the SEM image of the samples with a voltage of 15 kV (Munir et al. 2016).

STATISTICAL ANALYSIS

Three replications of each sample were analysed. All data were analysed using SPSS software version 23 by one-way ANOVA. The mean ± standard deviation was expressed to describe the significant difference between the samples using the confidence interval of 95%.

RESULTS AND DISCUSSION

FUNCTIONAL PROPERTIES

WATER HOLDING CAPACITY (WHC)

Table 1 shows that water holding capacity (WHC) for chia mucilage dried in a freeze dryer (FD) was 58.31 ± 0.36 g water/g sample which was significantly higher ($p<0.05$) than chia mucilage dried in air convection heat oven (ACHO), with 41.26 ± 0.33 g water/g sample. The findings indicated that the drying process had a significant ($p<0.05$) major effect on the WHC of chia mucilage powder. It could be due to significant variations in the chemical composition of polysaccharide gums depending on the drying phase (Mishra et al. 2009). Almost all hydrocolloids contain side units (mainly sugar units, or occasionally carboxyl groups, sulfate groups or methyl ether group); thus, affecting the functional hydrocolloid characteristics. Water molecules are organised around the sugar unit hydroxyl groups and anionic groups present in some gums (Mirhosseini & Amid 2013). To some extent, they move around with the gum molecules, increase volume and lead to swelling (Koçak 2010). Depending on their composition, the peripheral polar groups and the central hydrophobic stem of polysaccharide molecules exert various interactions to water and electrolytes (Iwe et al. 2004).

The WHC of FD was significantly higher ($p<0.05$) compared to xanthan gum (43.51 ± 1.40 g water/g sample), HPMC (4.56 ± 0.04 g water/g sample), and arabic gum (0.15 ± 0.09 g water/g sample). However, the WHC of ACHO was significantly lower ($p<0.05$) compared to xanthan gum and significantly higher ($p<0.05$) compared to HPMC and arabic gum. The WHC of arabic gum (0.17 ± 0.90 g water/g sample) reported by Hong and Ibrahim (2012) was higher than the value of arabic gum in this research. Thanatcha and Pranee (2011) reported that the WHC of xanthan gum and guar gum could not be analysed because the gums became a true solution in water that cannot be separated at any high centrifugation rate. The WHC of arabic gum and xanthan gum were different from the previous study, possibly due to the different methods used and materials purchased from different manufacturers.

A high value of WHC in chia mucilage could be due to high polysaccharides, which contributed to the greater affinity to absorb water compared to other gums (Noorlaila et al. 2015). This statement was supported by Naqvi et al. (2011), in which the WHC conveyed the amount of water retained by the sample (based on weight) and the ability of the polysaccharides to interact with water under a restricted water condition. A high amount of hydroxyl groups in the polysaccharide contributed to a significant potential for water binding and absorption. Darwish et al. (2018) also agreed that these properties could be connected to the high fibre and protein content of chia mucilage. The drying method also affected the sample fibre content, which was higher for the FD samples due to the degradation during the dehydration process at a high temperature (Antigo et al. 2020). Mirhosseini et al. (2013) reported that the drying process decreased the protein content of polysaccharides at elevated drying temperature due to the thermal denature of the protein fractions. The Maillard reaction occurred between the amine groups of amino acid from the protein fraction and sugar reduction found in the polysaccharide structure, which decreased the protein content.

The potential for WHC, due to the close association of protein molecules with the polar components and the hydrophilic interaction through hydrogen bonding, depends on the capillary (Shad et al. 2011). It should be noted that gum WHC does not only depend on the hydrophilic functional group of the polysaccharide fraction but the protein fraction present in gums. They also contain unique functional groups which can bind water molecules (Jaurigue 1981; Onweluzo & Odume 2007; Torio et al. 2006). The absorption capacity of water also depends on the amount and nature of the water-binding sites (Chau & Huang 2004). Chou and Morr (1979) also showed that WHC differs according to several functions factors such as protein-associated hydrophilic-hydrophobic amino acid balance in the protein molecule, lipid, and carbohydrate fractions.

Since WHC has a vital function in dietary fibre physiologically and technologically, the maximum WHC of FD may therefore be used as a potential source of dietary fibre.

OIL HOLDING CAPACITY (OHC)

Table 1 shows that the OHC of FD was 16.53 ± 0.38 g oil/g sample, which was significantly higher ($p<0.05$) than ACHO, at 11.63 ± 0.82 g oil/g sample. The results showed that the drying process had a significant ($p<0.05$) major effect on the OHC of chia mucilage. Mirhosseini

and Amid (2013) reported that there was a significant effect of the drying process on the hydrophobic fraction of durian seed gum (i.e. lipid and protein fraction). The OHC of food material is based on the type and content of the hydrophobic fraction present in the matrix structure (Hayta et al. 2002). Mirhosseini and Amid (2013) indicated that the potential trend towards oil absorption is due to the presence of trace fatty acid and hydrophobic amino acid in the structure of durian seed gum. Several non-polar side chains could bind hydrocarbon oil chains to increase OHC (Thanatcha & Pranee 2011). In the current study, FD exhibits a significantly higher ($p<0.05$) OHC than ACHO due to the less damaging impact of the freeze-drying process on the hydrophobic fraction present in FD compared to the effects induced by the oven-dried method at (40 °C). Freeze-drying is the best method of water removal to obtain an optimum quality of the final product. During freeze-drying, the solid state of water preserves the primary structure and form of the products while decreases the volume. Furthermore, the low temperature used allows the retention of optimum nutrients and bioactive compounds (Bhatta et al. 2020). ACHO has low OHC due to the thermal oxidation (40 °C) of trace lipid fraction found in ACHO (Mirhosseini & Amid 2013).

The OHC of FD and ACHO were significantly higher ($p<0.05$) than HPMC (1.69 ± 0.08 g oil/g sample), xanthan gum (1.61 ± 0.17 g oil/g sample), and arabic gum (1.64 ± 0.11 g oil/g sample). The values of OHC were 10 times higher than HPMC, xanthan gum and arabic gum. Oil absorption depended on the absorption capability of the sample surface. Mucilage had a high oil absorption value because many non-polar mucilage molecules can trap a large amount of oil particles (Thanatcha & Pranee 2011). For instance, when the oil absorption high in meat products, fibres will retain up to five times their mass in oil. The high fibre content of FD affects their oil absorption capacity (Thebaudin et al. 1997). It could be beneficial for food texture and help to reduce the loss of flavour and oil during meat cooking (Thebaudin et al. 1997). Olivos-Lugo et al. (2010) mentioned that the high OHC of chia seed gel indicates its ability to be used as an emulsifier and chia seed gel is better than guar gum and gelatine. Salgado-Cruz et al. (2013) and Suri et al. (2016) also mentioned similar results, rendering chia mucilage as a stabiliser and emulsifier. The OHC value shows that FD could play an essential role in food processing and could act as a stabiliser, thickener and emulsifier.

TABLE 1. Water holding capacity and oil holding capacity of FD, ACHO and other hydrocolloids

Samples	Water holding capacity	Oil holding capacity
FD	58.31 ± 0.36^{a}	16.53 ± 0.38^{a}
ACHO	41.26 ± 0.33^{c}	11.63 ± 0.82^{b}
HPMC	4.56 ± 0.04^{d}	1.69 ± 0.08^{c}
Xanthan gum	43.51 ± 1.40^{b}	1.61 ± 0.17^{c}
Arabic gum	0.15 ± 0.09^{e}	1.64 ± 0.11^{c}

$^{a-e}$ Means with different letters in the same columns are significantly different ($p<0.05$)

COLOUR ANALYSIS

Table 2 shows the significantly ($p<0.05$) different colour values (L*, a* and b*) of FD and ACHO. The drying temperature has a significant impact on chia mucilage colour. The FD and ACHO colour values (L *, a * and b *) were 73.84 ± 1.91, -0.07 ± 0.09, 8.89 ± 0.09 and 53.60 ± 1.14, 0.80 ± 0.06, 9.62 ± 0.41, respectively. The colour of FD was lighter than ACHO after the drying process (Figure 2). The colour of oven-dried chia mucilage was darker (lower L* value) compared to the freeze-dried chia mucilage (53.60 ± 1.14 to 73.84 ± 1.91). It should be noted that the long-term drying process at high temperature could result in degradation due to enzymatic browning or non-enzymatic browning reactions, thus affecting polysaccharide properties (Qian et al. 2012). For the measurement of the browning degrees in mucilage, L* and a* values may be used, where lower L* and higher a* values indicate browning (Castaner et al. 1999; Chung et al. 2009; Niamnuy et al. 2007; Wang et al. 2010). Hence, the low temperature drying (freeze-

drying) method formed a better mucilage colour based on the highest L* value and lower values of a*,b*, C*, BI and ΔE (Moniri et al. 2020). The temperature increase has a detrimental influence on the ΔE of the mucilage.

The L* value of FD and ACHO were significantly lower ($p<0.05$) than arabic gum (83.96 ± 0.30) due to higher purity of arabic gum used compared to the FD and ACHO (Hong & Ibrahim 2012). The L* value of FD was significantly higher ($p<0.05$) than HPMC (66.80 ± 0.48) and xanthan gum (65.58 ± 0.30). Meanwhile, the L* value of ACHO was significantly lower ($p<0.05$) than HPMC and xanthan gum. The a* value of FD was significantly lower ($p<0.05$) than HPMC (-0.13 ± 0.04), xanthan gum (-0.18 ± 0.03) and arabic gum (1.51 ± 0.20). Whereas, the a* value of ACHO was significantly higher ($p<0.05$) than HPMC and xanthan gum but significantly lower ($p<0.05$) than arabic gum. The b* value of FD and ACHO were significantly higher ($p<0.05$) than HPMC (4.72 ± 0.04) but significantly lower ($p<0.05$) than xanthan gum (10.12 ± 0.23) and arabic gum (11.28 ± 0.12). It might due to different drying methods used by the manufacturer of other hydrocolloids such as HPMC, xanthan gum and arabic gum.

The ΔE values ranged from 0.93 to 2.17 at various drying temperatures and methods. It should be noted that the freeze-dried mucilage has low ΔE values compared to oven-dried mucilage. During the drying of cress seed gum, high temperatures may increase the ΔE values (Moniri et al. 2020). The L* values decreased as drying temperature increased, indicating decreased mucilage brightness. The ΔE values of HPMC, xanthan gum and arabic gum ranged from 0.56 to 2.26.

The chroma is an indicator of chromaticity (C *), showing the intensity or saturation of colour (Gonçalves et al. 2007). The C* value of FD (8.89 ± 0.09) was significantly lower ($p<0.05$) than ACHO (9.65 ± 0.41) at varying drying temperatures and methods. Meanwhile, the C* value of FD and ACHO were significantly lower ($p<0.05$) than xanthan gum (10.12 ± 0.23) and arabic gum (11.38 ± 0.13) and were significantly higher ($p<0.05$) than HPMC (4.72 ± 0.04).

The hue angle is a ratio of a*and b* and was calculated to describe the colour property (Carr 1965). Table 2 shows that the hue angle values of FD, ACHO, HPMC, xanthan gum and arabic gum were between (0-180°) in the range of red-purple to bluish-green. The H* value of FD (175.36 ± 7.02) was significantly higher ($p<0.05$) than ACHO (0.21 ± 0.01) with no significant difference ($p>0.05$) with HPMC and xanthan gum. Meanwhile, the H* value of ACHO was not significantly different ($p>0.05$) with arabic gum. The hue value of the gum gel indicated that gum is suitable for use in food packaging, especially for packaged materials that are light-sensitive (Bhat et al. 2013).

During the drying process, the chia mucilage browning index of ACHO is increased by about 20.21 compared to the FD, with around 12.31, respectively. It could be due to the high temperature used for an extended time during the drying process. The BI values of HPMC, xanthan gum and arabic gum ranged from 6.93 to 15.97. A low browning index value is often a positive colour indicator for food products.

In conclusion, the browning mucilage index was higher when the L* value was low. Generally, the freeze-dried method has higher L* values due to the lower temperature used but lower a*, b*,c*, BI and ΔE values compared to the oven-dried method, indicating that the FD powder obtained from this method is better.

TABLE 2. Colour analysis of FD, ACHO and other hydrocolloids

Samples	L*	a*	b*	H*(°)	ΔE*	C*	BI*
FD	73.84 ± 1.91^{b}	-0.07 ± 0.09^{c}	8.89 ± 0.09^{d}	175.36± 7.02^{a}	0.93	8.89 ± 0.09^{d}	12.31
ACHO	53.60 ± 1.14^{d}	0.80 ± 0.06^{b}	9.62 ± 0.41^{c}	0.21 ± 0.01^{b}	2.17	9.65 ± 0.41^{c}	20.21
HPMC	66.80 ± 0.48^{c}	-0.13 ± 0.04^{c}	4.72 ± 0.04^{e}	179.20 ± 0.27^{a}	0.96	4.72 ± 0.04^{e}	6.93
Xanthan gum	65.58 ± 0.30^{c}	-0.18 ± 0.03^{c}	10.12 ± 0.23^{b}	178.32 ± 0.70^{a}	2.26	10.12 ± 0.23^{b}	15.97
Arabic gum	83.96 ± 0.30^{a}	1.51 ± 0.20^{a}	11.28 ± 0.12^{a}	0.13 ± 0.02^{b}	0.56	11.38 ± 0.13^{a}	15.25

$^{a-e}$ Means with different letters in the same columns are significantly different ($p<0.05$)

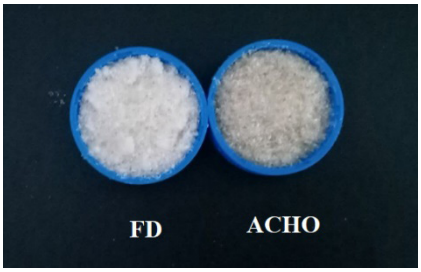

FIGURE 2. The color of chia mucilages using different drying methods

PHYSICOCHEMICAL CHARACTERISTIC

SCANNING ELECTRON MICROSCOPY (SEM)

Figure 3(A) shows the SEM micrograph of *Salvia hispanica* L. nutlet consisting of the seed and a pericarp surrounding the seed. Figure 3(C) and 3(D) shows the actual seed, consisting of a coat (testa), the endosperm and the embryo, which usually consists of two cotyledons. The pericarp of the chia seed consisted of exocarp, mesocarp, sclereid layer and endocarp. These dimensions observations were similar to Ixtaina et al. (2011). The epidermis or sclereid layer was 32.12 µm. It is observed that the sclereid layer constituted approximately 80% of the seed and consists of the rough surface, with an irregular geometrical form arranged in a pattern, responsible for generating a large amount of mucilage, as stated by Salgado-Cruz et al. (2013) when the outer cell wall was wet.

Figure 4 shows the micrograph of *Salvia hispanica* L. nutlets after mucilage extraction (after soaking for 1 h) at the magnification 150× (A) and 300× (B). The mucilage in the fully soaked (1 h) seed formed a continuous and transparent capsule, with an average thickness of 84.51 ± 1.38 µm. The transparent mucilaginous gel reached its maximum thickness after 1 h soaking in distilled water.

The morphology of the FD and ACHO samples were depicted in Figure 5. Different drying methods (spray-drying, freeze-drying and air-drying) affect the surface topography and structure of polysaccharides (Nep & Conway 2011). Morphological differences were observed between the FD and ACHO, whereby FD was smaller and more uniform in size (around 77.7 to 340.0 µm) than ACHO that was bigger and not uniform in size (around 141.4 to 459.0 µm) and has smooth surface particles that occurred during the drying phase. Choi et al. (2009) and Ma et al. (2013) stated that the freeze-drying method caused changes in the molecular weight, intermolecular distance, and interconnection which resulted in smaller particles. It could explain the smaller

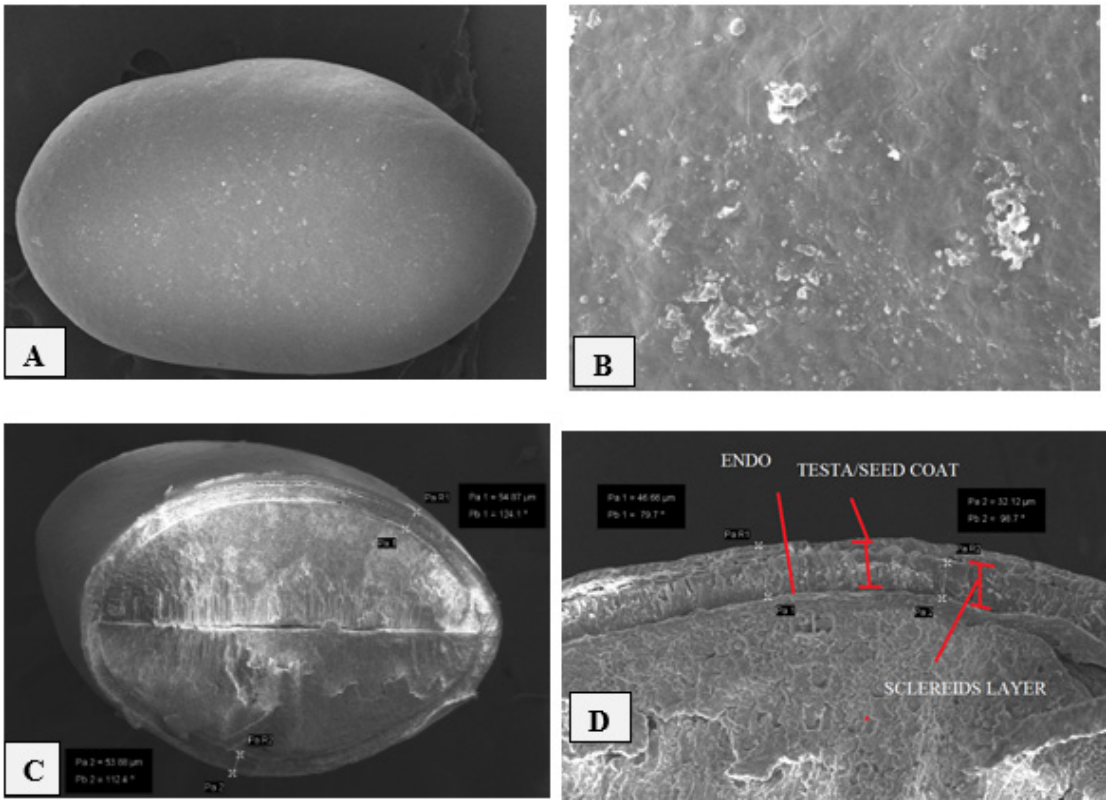

FIGURE 3. SEM microscopy of *Salvia hispanica* L. nutlets. (A) Whole nutlet (magnification -100 µm, × 30 at 15KV), (B) nutlet surface (magnification-10 µm, × 300 at 15KV), (C) Cross- section nutlet (magnification-100 µm, × 50 at 15KV) and (D) Cross- section nutlet (magnification-10 µm, × 150 at 15KV)

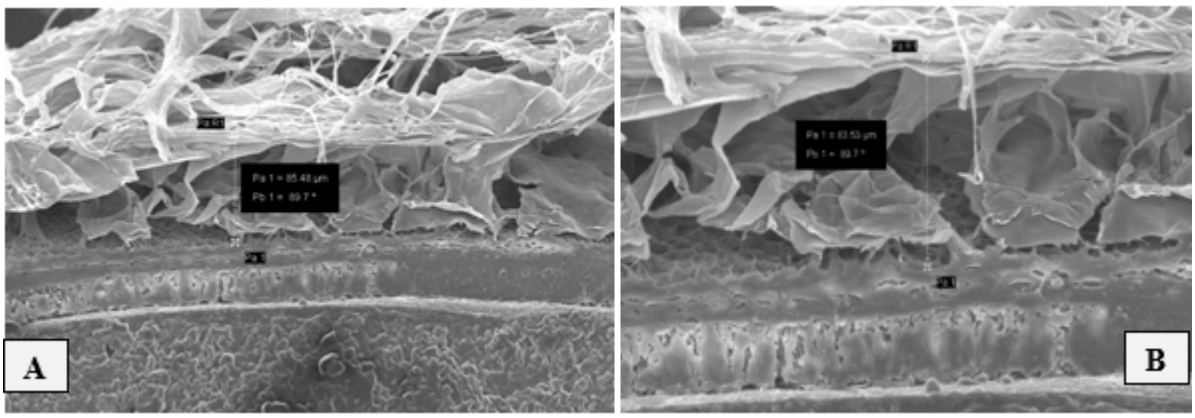

FIGURE 4. SEM microscopy of *Salvia hispanica* L. nutlets after mucilage extraction (after soak 1 hour) (A) Magnification -10 µm, × 150 at 15KV) and (B) Magnification-10 µm, × 300 at 15KV)

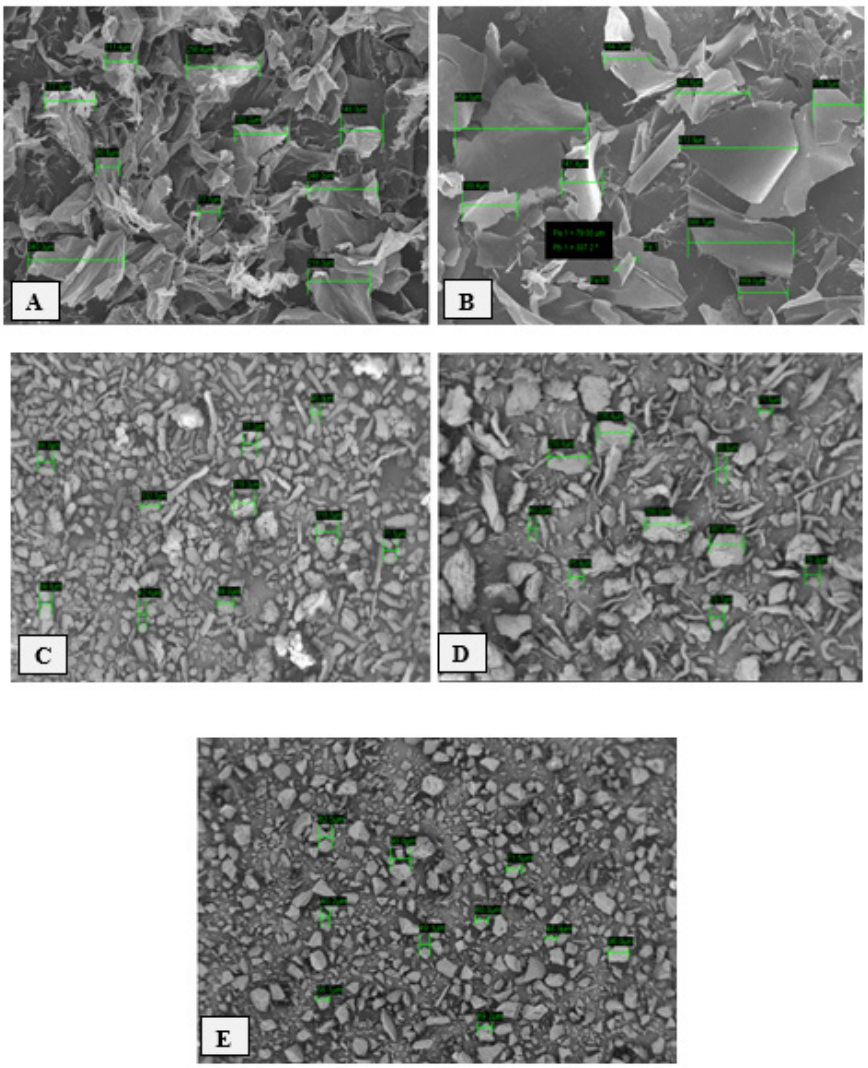

FIGURE 5. SEM of chia mucilages by different drying methods and other hydrocolloids: (A) FD, (B) ACHO, (C) HPMC (D) xanthan gum and (E) arabic gum (Magnification -100 µm, × 50 at 13KV)

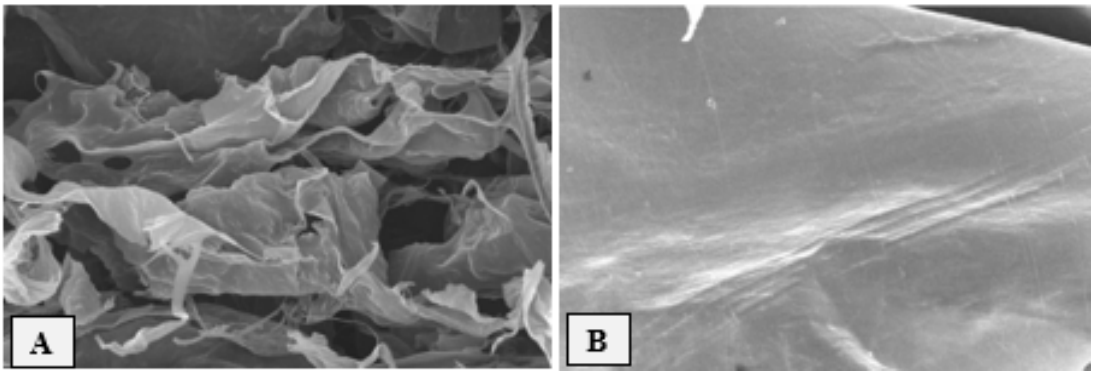

FIGURE 6. SEM microscopy of (A) FD-(Magnification -10 µm, × 300 at 15KV) and (B) ACHO- (Magnification -10 µm, × 300 at 15KV)

molecular weight of FD compared to ACHO. Figure 5 also shows the micrograph of commercial hydrocolloids such as HPMC (42.4-118.3 µm), xanthan gum (40.2-218 µm) and arabic gum (40.2-96.0 µm) which were smaller and more uniform than FD and ACHO. It could be due to the different drying methods used. The differences in particle size between FD, ACHO and other hydrocolloids were caused by the extraction, purification, drying method and treatment applied that could significantly affect the microstructure of mucilage (Capitani et al. 2013; Rohaya et al. 2013).

The micrographs in Figure 6 show the fine fibrous structure of FD, with overlapping sheets compared to ACHO. It could be due to the least degradation in the duration of the lyophilising process that resulted in the excellent fine network structure (Darwish et al. 2018). Mirhosseini and Amid (2012) reported that the molecular structure of freeze-dried natural biopolymers derived from plants was similarly observed. Additionally, different drying methods of seed mucilage can lead to improved performance of functional properties such as foaming capacity and gel formation. Therefore, FD is an excellent natural hydrocolloid obtained using the freeze-drying method, showing a fine fibrous structure and great potential in food applications.

Conclusion

Chia mucilage dried in the freeze dryer (FD) is a novel approach for mucilage production and has the potential to be used as a functional and environmentally friendly hydrocolloid in the food industry. The effects of different drying methods (freeze-drying and oven-drying) on functional properties and physicochemical characteristic of chia mucilage powder (*Salvia hispanica* L.) including comparison hydrocolloids commonly used in the food industry (hydroxypropyl methylcellulose (HPMC), xanthan gum and arabic gum) were investigated in this study. Although oven-drying is a low-cost drying method compared to freeze-drying, the current results indicated a lower quality result on the functional properties and physicochemical characteristic. The results of the freeze-drying method exhibited water holding and oil holding capacities indicated by the high values of FD. FD has a higher L* value (lightness) due to the lower temperature used during drying, but lower values of a*, b*,c*, BI and ΔE compared to ACHO. Furthermore, the morphology of FD was smaller, more uniform in size and fine fibrous structure than ACHO.

Acknowledgements

This project has been partly supported by the Universiti Kebangsaan Malaysia grants of Dana Impak Perdana (DIP-2018-036) and the Research University Grants (GUP-2018-018). The authors sincerely acknowledge the support of the staff at the Department of Food Sciences, Faculty of Science and Technology for providing the facilities to carry out the research work and the Ministry of Higher Education for the financial support.

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Received: 20 December 2020
Accepted: 20 March 2021