

# Functional Properties of Chia Seed Mucilage Supplemented In Low Fat Yoghurt

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## ABSTRACT

Modern diet lifestyle demands of healthy natural foods represent a challenge for food manufacturers to lead towards the healthy new trends. This work aimed to study the microstructure of chia seed (*Salvia hispanica* L.) and its mucilage, provide chemical and functional properties of mucilage before supplementation in low-fat yoghurts and evaluate its impact on products' composition, texture, and acceptance. The micro morphology of chia seed and its mucilage were described via scanning electron microscope (SEM). For physical functional properties evaluation; functional groups were studied using Fourier Transform Infrared (FTIR) spectroscopy; the thermal behavior was analyzed using Thermogravimetric Analyzer (TGA), and Water/ Oil Holding capacities (WHC/ OHC) were assessed. The gross chemical composition of mucilage was studied before supplementation with various concentrations (1, 1.5 and 2%) at different ratios of fat content (1, 2 and 3%) yoghurts, monitoring mucilage effect on chemical, rheological (using Texture Analyzer) and organoleptic properties of yoghurts. Chia mucilage micrographs showed fine fibrous network structure supported by high fiber, protein, ash and fat values (12.4, 10.68, 9.64, and 3.10% respectively). The FTIR analysis indicated the presence of uronic acids, mannose, carboxylic acid, pyranose, glucopyranose, xylopyranose groups in mucilage polysaccharides, which influenced its thermal stability. Mucilage showed comparable high WHC/OHC values (5.25g water, 5.85 g oil/ g sample) that nominate it to perform as a stabilizer and emulsifier. Along with increased chia mucilage concentrations in fortified yoghurt, fiber content elevation subsequently reflected on higher values of springiness, and descendant hardness values that produced "soft" yoghurts as described in sensory evaluation.

**Key words:** FTIR; Microstructure; SEM; Texture analysis; TGA.

## INTRODUCTION

Chia seeds have been widely applied in food applications such as yoghurt, cereals, juices or cakes in different countries all over the world including New Zealand, Canada, Chile, Mexico, Australia and USA (Ali *et al.*, 2012). Due to unique properties of forming a gelatinous mass when soaked in water due to the

presence of high amount of mucilage and gums, chia can be employed in the food industry targeting better texture and stabilization. The mucilage lays in the three first layers of the seed coat and mucilage fibers start to be visible when full hydrated, and it is exceptionally rich especially in polysaccharides (71.22%) (Muñoz *et al.*, 2012). Therefore, chia and its mucilage be friendly for the gut health because soluble fiber prolongs the gastrointestinal transit time that aids in improved digestion which consequently related to gradual increase in post-prandial blood glucose levels and decrease in insulin resistance over a period of time (Suri *et al.*, 2016).

Low fat ratios are highly recommended in food production since this may aid in reduced risk of many syndromes such as cardiovascular disease (CVD), hepatic steatosis, and obesity (Felisberto *et al.*, 2015). Fat replacers consist of lipid-, protein-, or carbohydrate-based ingredients replaced with fat in low fat food products. Food hydrocolloids are added to food systems mainly to modify rheological properties, increase the stability, or reduce calories. Several previous trials were carried out on yoghurt fortification applying plant-based mucilage such as, okra fruits, quince seed and psyllium seed (Hussein *et al.*, 2011; Khalifa *et al.*, 2011; Nikoofar *et al.*, 2013).

So, the objective of the current work was to study microstructure of chia seed (*Salvia hispanica* L.) and its mucilage, provide gross chemical composition, characterization of physical and functional properties of chia seed mucilage before supplementation in low fat yoghurt and evaluate the effect of this fortification on product composition, texture profile and consumer acceptance. This would provide useful information contributing industrial innovative applications of chia seed mucilage as reach natural fat mimetic, thickening and gelling agent.

## MATERIALS AND METHODS

### Materials

Organic dark chia seeds (*Salvia hispanica* L.) (Hunter Foods Group Limited BVI, U.K.), was purchased from local market Dubai, United Arab of

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Emirates. Milli-Q water was used in all the experiments (Siemens Ultra Clear Water Purification Systems, Series 2000). Corn oil purchased from a local store and stored at room temperature. For application, pasteurized skimmed milk (8.5% SNF), cream (25% fat) and skimmed milk powder (SMP) were obtained from the local market. Yoghurt commercial starter culture Yo-Mix 495 (*Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*) was obtained from Danisco Egypt.

### Chia mucilage extraction

Chia mucilage extraction was performed according to the method proposed by (Avila-de la Rosa *et al.*, 2015) with some modifications. A sample of 40 g of whole chia seeds was placed in a 1 L beaker and warm Milli-Q water was added at ratio (1:20 w/v), stirred with a magnetic stirrer for 3 h at a constant temperature of 60°C. The mucilage was separated from the seeds by high speed centrifuge (Pro-Centrifuge, Centurion Science Limited, UK) for 20 min at 3382 xg, and then lyophilized *via* vacuum freeze-dryer (Model FDF 0350, Korea), stored at -80°C for characterization.

### Microstructural and functional characterization of chia seed and its mucilage

#### Scanning electron microscope

The surface morphology of whole seeds, seeds powder, and freeze-dried mucilage (M1) was analyzed using a scanning electron microscopy (SEM- Joel Jsm 6360LA, Japan). The fracture surfaces were vacuum coated with gold for scanning electron microscope (Munir *et al.*, 2016).

#### Fourier transform infrared (FTIR) spectroscopy

The FTIR spectra of whole seeds, seeds powder and freeze-dried mucilage were acquired by using a Fourier transform infrared spectroscopy (Shimadzu FTIR-8400 S, Japan) equipped with (ATR 8000A) in the spectral range of 4000–400 cm<sup>-1</sup> (Cerqueira *et al.*, 2011).

#### Thermogravimetric analysis (TGA)

Thermal characteristics of whole seeds, seeds powder, and freeze-dried mucilage during the heating process were monitored using a thermogravimetric analyzer (Shimadzu TGA-50, Japan). All individuals were heated at a rate of 20 °C/ min under flow of N<sub>2</sub> up to 800 °C (Cerqueira *et al.*, 2011).

### Water-Holding (WHC) and Oil-Holding Capacity (OHC)

The WHC/ OHC were determined as described by (Alfredo *et al.*, 2009). Briefly, 0.1 g of whole chia seeds, powdered chia seeds or freeze-dried mucilage was stirred into 20 mL of Milli-Q water or corn oil for two minutes at room temperature. The resultant suspensions

were centrifuged at 699 xg for 30 min (Pro-Centrifuge, Centurion Science Limited, UK), the supernatant volume was measured. Water-holding capacity was expressed as g of water/ g sample, and oil-holding capacity was expressed as g of oil held/ g sample.

### Chia yoghurt application

#### Chia yoghurt preparation

Pasteurized milk (8.5% SNF) was standardized using SMP to reach (14% SNF), divided into three portions to adjust fat content up to 1, 2 and 3% fat using cream (25% fat), wormed to 42°C, and then inoculated with 1-2% of common yoghurt culture Yo-Mix 495. Counting on a preliminary experiment, the standardized inoculated milk was replaced with (20%) chia mucilage dispersions with concentrations (1, 1.5 and 2%), and then distributed into cups. The cups were incubated at 42°C until set coagulation (about 4 h), and then cooled and stored at 4°C. The yoghurt making and applied calculations using Pearson's square were performed as described by Tamime and Robinson (1999). The chia yoghurt formulations and replacements of chia seeds mucilage dispersions are shown in Table (1).

### Gross chemical composition of chia seed mucilage and chia yoghurt

The gross chemical composition analysis of chia freeze-dried mucilage and chia yoghurts was determined according to AOAC (1990). Crude fiber content was determined using Crude Fiber Analysis in Feeds - Filter Bag Technique A2000 - AOCS Approved Procedure Ba 6a-05 (Ankom Technology Corp., Macedon, NY).

#### Texture profile analysis (TPA)

Textural properties of chia yoghurt were evaluated using a texture analyzer (TA1000, Lab Pro (FTC TMS-Pro), USA). Samples were tested in their cups using Perspex cone P/45C, samples were allowed to stand at ambient temperature for at least 1h before testing. A two-bite penetration test was performed and operated at a crosshead speed 50 mm/sec. Hardness, adhesiveness, cohesiveness, springiness and gumminess were evaluated as described by Bourne (2002) and Szczesniak *et al.*, (1963).

#### Sensory evaluation

Ten staff members, (8 men and 2 women, aged between 27 to 51 years), performed sensory evaluation on fresh chia yoghurt samples at Food Technology Dept., Arid Lands Cultivation Research Institute, SRTA-City, Alexandria, Egypt. The criterion for selection depended on their experience and background related to yoghurt products. The samples were allowed to rest at room temperature (25°C), 10 min before evaluation. Panelists were instructed to evaluate the chia yoghurt with respect to their degree of acceptance as follows; smell and taste

**Table 1. Gross chemical composition of lyophilized chia mucilage and different formulations of chia yoghurt**

Sample	Formulations		Proximate analysis								
	Fat%	Mucilage%	Fat%	Protein%	Fiber%	Ash%	TS%	pH	TA%	SNF%	F/DM%
Chia mucilage	-	-	3.10	10.68	12.47	9.64	89.35	6.41	ND	ND	ND
<b>Chia yoghurt</b>											
T1 (Control1)	1	0	1.09 <sup>a</sup>	3.34 <sup>a</sup>	0.01 <sup>b</sup>	6.98 <sup>a</sup>	12.30 <sup>b</sup>	4.71 <sup>a</sup>	0.63 <sup>a</sup>	11.21 <sup>b</sup>	8.87 <sup>a</sup>
T2	1	1	1.05 <sup>a</sup>	3.23 <sup>a</sup>	1.02 <sup>a</sup>	6.85 <sup>a</sup>	12.06 <sup>b</sup>	4.47 <sup>a</sup>	0.72 <sup>a</sup>	11.01 <sup>b</sup>	8.69 <sup>a</sup>
T3	1	1.5	1.10 <sup>a</sup>	3.20 <sup>a</sup>	1.12 <sup>a</sup>	6.80 <sup>a</sup>	13.26 <sup>a</sup>	4.45 <sup>a</sup>	0.75 <sup>a</sup>	12.16 <sup>a</sup>	8.30 <sup>b</sup>
T4	1	2	1.07 <sup>a</sup>	3.21 <sup>a</sup>	1.40 <sup>a</sup>	7.00 <sup>a</sup>	13.09 <sup>a</sup>	4.43 <sup>a</sup>	0.76 <sup>a</sup>	12.02 <sup>s</sup>	8.20 <sup>b</sup>
T5 (Control2)	2	0	2.03 <sup>a</sup>	3.33 <sup>a</sup>	0.00 <sup>b</sup>	6.82 <sup>a</sup>	12.26 <sup>b</sup>	4.62 <sup>a</sup>	0.65 <sup>a</sup>	10.23 <sup>b</sup>	16.53 <sup>a</sup>
T6	2	1	2.07 <sup>a</sup>	3.24 <sup>a</sup>	1.16 <sup>a</sup>	6.85 <sup>a</sup>	13.10 <sup>a</sup>	4.48 <sup>a</sup>	0.71 <sup>a</sup>	11.04 <sup>a</sup>	15.76 <sup>b</sup>
T7	2	1.5	2.08 <sup>a</sup>	3.27 <sup>a</sup>	1.19 <sup>a</sup>	6.91 <sup>a</sup>	13.39 <sup>a</sup>	4.49 <sup>a</sup>	0.71 <sup>a</sup>	11.32 <sup>a</sup>	15.50 <sup>b</sup>
T8	2	2	2.06 <sup>a</sup>	3.27 <sup>a</sup>	1.42 <sup>a</sup>	6.72 <sup>a</sup>	13.01 <sup>a</sup>	4.46 <sup>a</sup>	0.72 <sup>a</sup>	10.95 <sup>a</sup>	15.81 <sup>b</sup>
T9 (Control3)	3	0	3.11 <sup>a</sup>	3.30 <sup>a</sup>	0.01 <sup>b</sup>	6.59 <sup>ab</sup>	13.95 <sup>ab</sup>	4.52 <sup>a</sup>	0.67 <sup>a</sup>	10.84 <sup>ab</sup>	22.28 <sup>a</sup>
T10	3	1	3.03 <sup>a</sup>	3.24 <sup>a</sup>	1.04 <sup>a</sup>	6.76 <sup>a</sup>	13.73 <sup>b</sup>	4.50 <sup>a</sup>	0.68 <sup>a</sup>	10.70 <sup>b</sup>	22.07 <sup>ab</sup>
T11	3	1.5	3.09 <sup>a</sup>	3.23 <sup>a</sup>	1.30 <sup>a</sup>	6.47 <sup>ab</sup>	14.18 <sup>a</sup>	4.47 <sup>a</sup>	0.68 <sup>a</sup>	11.09 <sup>ab</sup>	21.77 <sup>bc</sup>
T12	3	2	3.04 <sup>a</sup>	3.22 <sup>a</sup>	1.37 <sup>a</sup>	6.33 <sup>b</sup>	14.16 <sup>a</sup>	4.44 <sup>a</sup>	0.70 <sup>a</sup>	11.13 <sup>a</sup>	21.44 <sup>c</sup>

Results represent the means of duplicates

<sup>a,b,c...</sup> Means values in the same column (of each control group) marked with unlike letters are significantly different ( $p < 0.05$ )

(1-4), body and texture (1-2), and appearance (1-4). The sensory evaluation procedure was modified from the method described by Allam *et al.*, (2017). The average was calculated.

### Statistical analysis

Statistical analyses were performed using Analytical Software SPSS® 13.0 (Statistical Package for the Social Sciences) (2005). Differences were considered significant at  $p < 0.05$ .

## RESULTS AND DISCUSSION

### Morphological and Microstructure of chia seed and its mucilage

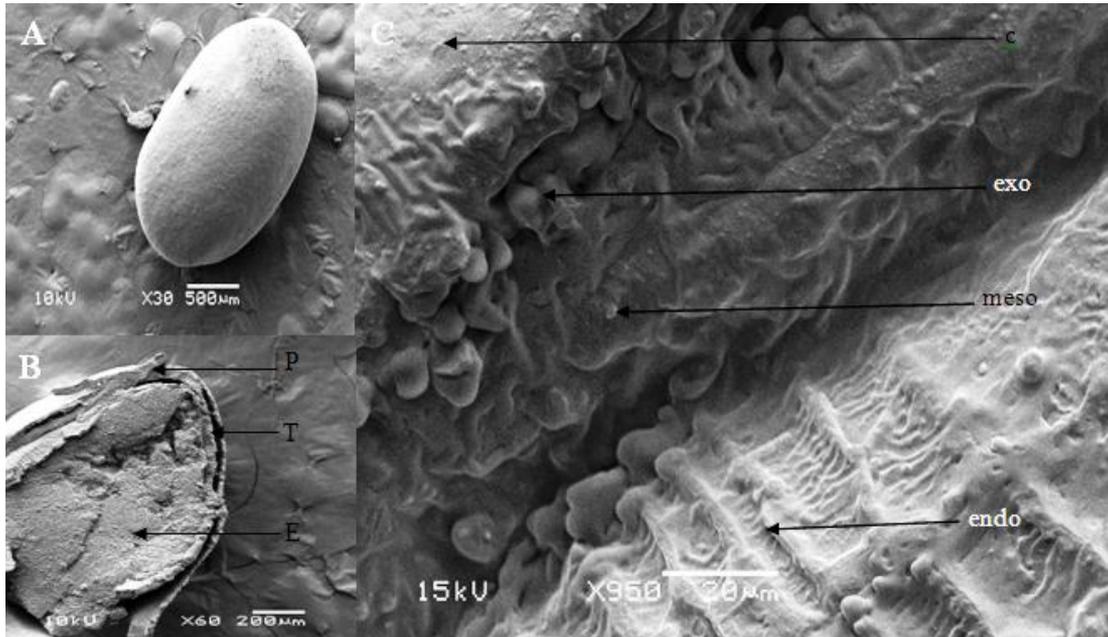
Figures (1 and 2) show SEM micrograph of chia seed and its freeze-dried mucilage. Fig (1. A) shows the whole seed, that facilitated the seed size calculation from SEM microscopy which was  $2.01 \pm 0.07$  mm length,  $1.15 \pm 0.03$  mm width, and  $0.72 \pm 0.02$  mm thickness. These dimensions agreed with those reported by (Capitani *et al.*, 2013). Regarding seed structure, Fig. (1. B) showed seed longitudinal section marking, pericarp, testa (seed coat) and endosperm. For more details, Fig. (1. C) of pericarp longitudinal section showing that after cuticle, the seed consists of three layers of cells, exocarp, mesocarp, and endocarp (inner epidemis). In addition, it can be observed that, the latter layer (epidemis) constituting approximately 80% of the seed, and formed of rough surface cells with an irregular geometric shape arranged in a grid, which is responsible of producing large quantities of mucilage, by the rupture

of the outer cell wall when they are wet, as reported by Salgado-Cruz *et al.*, (2013).

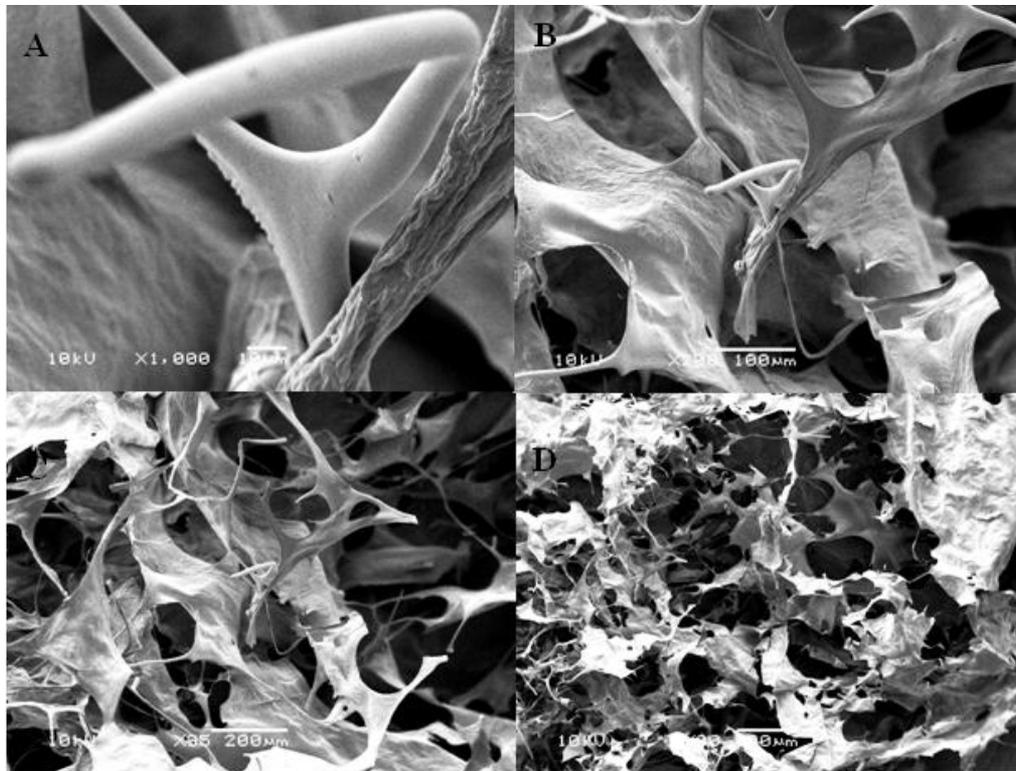
Figure (2) shows SEM micrograph of chia seed freeze-dried mucilage with different magnifications. These micrographs show fine fibrous structure of freeze-dried mucilage with overlapped sheets in the least magnification ( $500\mu\text{m}$ , X30 at 10 KV), which could be related to the least degradation during lyophilizing process that resulted in fine network structure. Similar observation about molecular structure of freeze-dried natural biopolymers originated from plants was reported by Mirhosseini and Amid (2012), in addition to better performance of functional properties such as foaming capacity and gel formation among differently dried seed gums.

### Fourier transform infrared spectroscopy (FTIR)

Figure (3) shows micrographs of seeds powder, whole chia seeds, and chia mucilage IR spectra, to facilitate marking changes in functional groups with water extraction. As expected, the chia seed and chia powder exhibited identical spectra, while chia mucilage showed less bands in the region between, 1700 and 1000  $\text{cm}^{-1}$  that represent only soluble amides (proteins) and polysaccharides (fibers) functional groups. Some plant mucilage was reported to be hydrocolloids of a complex polymeric substances of carbohydrate nature with branched structure of polar glycoprotein and exopolysaccharides (Oladoja *et al.*, 2017). Referring to gross chemical composition of chia mucilage represented in (Table 1), the mucilage main constituents



**Figure 1. SEM micrograph of chia seed microstructure. A: The whole seed (500µm, X30), B: Seed longitudinal section (200µm, X60), and C: Pericarp longitudinal section (20µm, X950)**  
 P: Pericarp; T: Testa; E: Endosperm; C: Cuticle; exo: Exocarp; meso: Mesocarp; endo: Endocarp.



**Figure 2. SEM micrograph of chia seed freeze-dried mucilage with different magnifications. A: (10µm, X1000), B: (100µm, X200), C: (200µm, X85), and D: (500µm, X30)**

are fiber, protein and fat. The chia protein related bands are shown in the transmission measurements observed at 3200 to 3500  $\text{cm}^{-1}$  in all represented spectra, characterized in the broad bands at 3394, 3414 and 3402  $\text{cm}^{-1}$  representing the (N-H) stretching of proteins content. Between 1739-1537  $\text{cm}^{-1}$  and 1618-1915  $\text{cm}^{-1}$  region for chia seeds and mucilage, respectively is used to mark the presence of amide I groups that characterize protein (Muñoz Hernández, 2012). This result supports gross chemical analysis result of protein (12.5% Table 1). The broad band at 2872, 2933 and 2922  $\text{cm}^{-1}$  is attributed to C-H stretching of the aromatic rings and the methyl group representing fat content (Cerqueira *et al.*, 2011; Archana *et al.*, 2013).

Dietary fiber of plant material in the diet which includes cellulose, non-cellulosic polysaccharides such as hemicellulose, pectin, gums, mucilage (Dhingra *et al.*, 2012). The high fiber content of chia seeds and its mucilage were represented in more than a band group. The bands 1618-1915 at 1539  $\text{cm}^{-1}$ , 1444  $\text{cm}^{-1}$ , and 1419  $\text{cm}^{-1}$  in case of chia seed and mucilage are assigned to the carboxyl group (-COO-) of uronic acids which agrees with the presence of uronic acid detected in chia seed polysaccharides (Pongjanyakul & Puttipipatkachorn, 2007). The transmission bands at 1654  $\text{cm}^{-1}$  and 1618  $\text{cm}^{-1}$  for chia seed and its mucilage is assigned to mannose ring (Goh *et al.*, 2016). Additionally, the bands at 1739  $\text{cm}^{-1}$  and 1157  $\text{cm}^{-1}$  for chia seed, 1735  $\text{cm}^{-1}$  and 1155  $\text{cm}^{-1}$  for chia powder represent the C=O and C-O-C present in the pyranose ring. The band at 1058  $\text{cm}^{-1}$  in mucilage is assigned to C-O-C of 1 $\rightarrow$ 4 glycosidic bond ring vibration and C-OH bending and is recognized as the characteristic of polysaccharides. Furthermore, the band at 705  $\text{cm}^{-1}$  and 618  $\text{cm}^{-1}$  in case of chia seeds and mucilage respectively, corresponding to the CH<sub>2</sub> with more than 7 carbon atoms (Guillen & Cabo, 1997), represents the  $\beta$ -anomeric C-H deformation and glycosidic linkages related to glucopyranose and xylopyranose units (Kong & Yu, 2007).

In summary, the FTIR features of chia seed, chia powder and its mucilage represent main functional groups indicated the preponderance of fiber and carbohydrates groups among other groups that agreed with other gums and mucilage spectra (Toğrul & Arslan, 2003).

### Thermogravimetric analysis TGA

Thermogravimetric analysis (TGA) is an accurate procedure for studying the decomposition pattern and thermal stability of food polymers. Chia mucilage was characterized in order to study its applicability in different food preparations starting from fermented milk to bakery. The TGA curve shows the sample weight loss

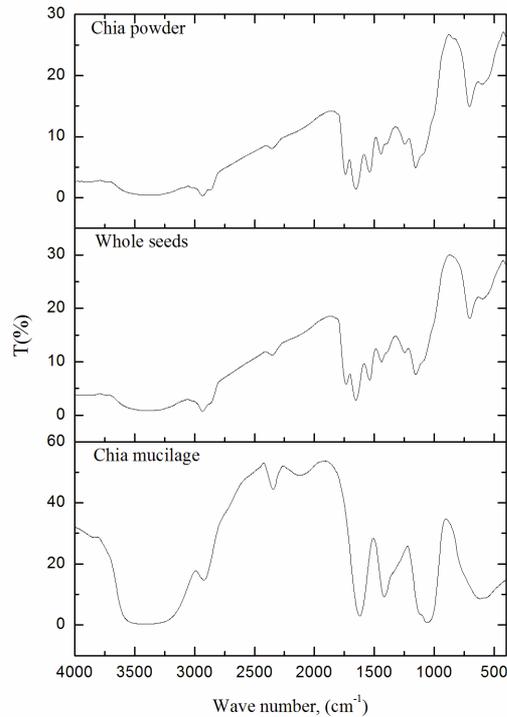
as a function of temperature (Hosseini *et al.*, 2013). Fig. (4a, b, and c) shows the thermal degradation behavior of whole seeds, seeds powder and freeze-dried mucilage. The weight loss was associated with three main stages for all samples. The first (~25– ~150 °C) is related to the evaporation of a fraction of free water contained in gum samples. Elevating temperature to 200°C, about 10% of the mass of samples was lost. The main volatilization peak appears near 250 °C. This second stage was characterized by significant higher rate of weight loss. Most of the released volatiles were mainly attributed to the degradation of the polysaccharide structure that composes the wall material to low molecular weight volatiles took place at this temperature range and a minor carbohydrate degradation (Peng *et al.*, 2001). The weight loss resulted in the third stage approximately at 504-800 °C and 392-800 °C for chia seed and its mucilage, respectively due to slow decomposition of the solid residue from the previous step. On the other hand, analysis of TGA results demonstrated that mucilage was less thermally stable with increasing temperature than the chia seeds and powder. As the required temperature for the whole chia seed and powder to lose their half weights (T50%) was 419.62°C and 405.53°C compared to 321.47 °C for mucilage.

However, results from TGA curves imply that chia seed (*Salvia hispanica*, L.), powder and its mucilage showed an excellent thermal stability and provide an opportunity to be utilized in processes that involve high temperature.

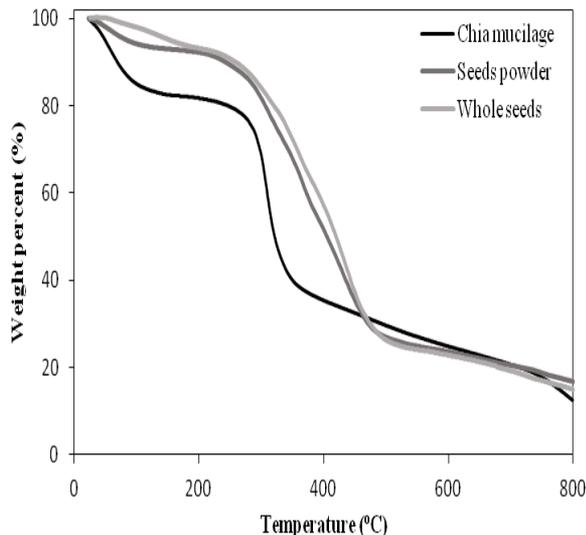
The WHC is the ability of material to retain water when subjected to centrifugal force or compression, this includes linked, hydrodynamic, and physically trapped water (Alfredo *et al.*, 2009). Fig (5) illustrates water/oil-holding capacity of chia mucilage compared with whole chia seeds and seeds powder.

The chia mucilage, whole chia seeds and seeds powder exhibited comparable WHC (5.25, 5, 5.5 g water/ g sample, respectively). The fibrous structure that was pronounced in the microstructure of chia seeds and its mucilage was expected to augment WHC referring to Alfredo *et al.*, (2009) results, who also suggested a physiological functional role in and blood sugar control relied on its high fiber's WHC. On the other hand, chia mucilage showed higher OHC (5.85 g oil/ g sample) than both whole seeds and powder (3.5, 2.5 g oil/ g sample) and was close to its WHC value. These results could nominate chia mucilage to perform as a stabilizer and emulsifier which previously mentioned by Salgado-Cruz *et al.*, (2013) and Suri *et al.*, (2016). These properties could be connected to the relatively high fiber

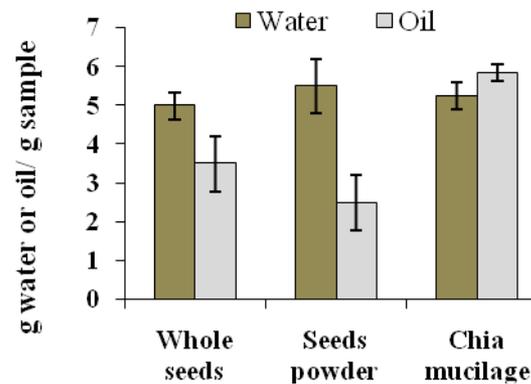
and protein content of chia mucilage (12.47 and 10.68% respectively) as shown in Table (1).



**Figure 3. Fourier transform infrared spectrophotometer (FTIR) of seeds powder, whole chia seeds, and chia mucilage**



**Figure 4. Thermal Gravimetric analysis (TGA) of chia mucilage, whole chia seeds, and seeds powder Water-Holding (WHC) and Oil-Holding Capacity (OHC)**



**Figure 5. Water/ Oil-holding capacity of chia mucilage compared whole chia seeds and seeds powder**

### Gross chemical composition of chia mucilage and chia yoghurt

Gross chemical composition of chia mucilage and chia yoghurt different formulations is given in Table (1). Confirming upraised physical characterization results, chia mucilage exhibited considerable values of fiber (12.47%), in addition to protein, ash and fat (10.68, 9.64, and 3.10% respectively), which reflected on total solids (TS%) content (89.35%). These data are in agreement with Capitani *et al.*, (2013). The collected yield was 7.24 g lyophilized chia mucilage/100 g of chia seeds, that was similar to value reported by (Felisberto *et al.*, 2015). Although chia mucilage pH is acidic tends to be near neutral (6.41), fortifying with chia mucilage dispersion to yoghurt products slightly lowered products' pH and elevated TA%, but these differences were insignificant. Supplementing yoghurt with chia mucilage dispersion did not significantly affect any of products' chemical parameters as compared to the control samples of each fat concentration group (1, 2, and 3%), except for expected significant increase in fiber content which subsequently reflected on significantly higher values of TS%, SNF% and F/DM%.

### Texture profile analysis (TPA) of chia yoghurt

Texture profile analysis of chia yoghurt products are given in Table (2). Comparing the hardness of the three control samples, T1, T5 and T9 (110, 103 and 76g), revealed that hardness is inversely proportional with fat content. The same pattern was obtained when comparing amongst each control group, where softness significantly elevated directly proportional with increasing of chia mucilage concentration. Data of adhesiveness and gumminess values revealed significant descend following the same trend of hardness. On contrary, springiness showed significant increase accompanied with the increase of chia mucilage concentration. Back to springiness definition (originally called elasticity),

**Table 2. Texture profile analysis of chia yoghurt products**

Sample	Hardness (g)	Adhesiveness (g.mm)	Cohesiveness	Springiness (mm)	Gumminess (N)
T1 (C1)	110 <sup>a</sup>	71.32 <sup>a</sup>	0.38 <sup>a</sup>	4.86 <sup>b</sup>	42 <sup>a</sup>
T2	38 <sup>b</sup>	43.07 <sup>b</sup>	0.45 <sup>a</sup>	6.38 <sup>a</sup>	17 <sup>b</sup>
T3	30 <sup>c</sup>	29.32 <sup>c</sup>	0.42 <sup>a</sup>	5.87 <sup>c</sup>	13 <sup>c</sup>
T4	27 <sup>d</sup>	29.21 <sup>c</sup>	0.46 <sup>a</sup>	5.47 <sup>d</sup>	12 <sup>d</sup>
T5 (C2)	103 <sup>a</sup>	46.97 <sup>a</sup>	0.38 <sup>a</sup>	6.35 <sup>a</sup>	39 <sup>a</sup>
T6	65 <sup>b</sup>	43.24 <sup>b</sup>	0.36 <sup>a</sup>	6.52 <sup>a</sup>	23 <sup>b</sup>
T7	53 <sup>c</sup>	40.86 <sup>c</sup>	0.35 <sup>a</sup>	5.75 <sup>b</sup>	19 <sup>c</sup>
T8	51 <sup>d</sup>	37.03 <sup>d</sup>	0.36 <sup>a</sup>	5.93 <sup>b</sup>	18 <sup>d</sup>
T9 (C3)	76 <sup>a</sup>	28.56 <sup>c</sup>	0.41 <sup>a</sup>	4.90 <sup>b</sup>	31 <sup>a</sup>
T10	65 <sup>b</sup>	27.09 <sup>d</sup>	0.48 <sup>a</sup>	5.94 <sup>a</sup>	31 <sup>a</sup>
T11	53 <sup>c</sup>	22.15 <sup>a</sup>	0.44 <sup>a</sup>	6.32 <sup>a</sup>	23 <sup>b</sup>
T12	50 <sup>d</sup>	21.46 <sup>b</sup>	0.41 <sup>a</sup>	6.16 <sup>a</sup>	21 <sup>b</sup>

- Data are the mean of duplicates

- <sup>a,b,c...</sup> Means values in the same column (of each control group) marked with unlike letters are significantly different ( $p < 0.05$ )

**Table 3. Sensory evaluation of chia yoghurt products**

Treatments	Smell & Taste		Body & Texture		Appearance	
	Grade <sup>a</sup>	Description	Grade <sup>b</sup>	Description	Grade <sup>a</sup>	Description
T1 (C1)	3.00±0.48 <sup>a</sup>	Typical	1.53±0.24 <sup>a</sup>	Good	3.00±0.63 <sup>a</sup>	Good
T2	3.10±0.41 <sup>a</sup>	Typical	1.51±0.20 <sup>a</sup>	Soft	3.07±0.45 <sup>a</sup>	Good
T3	3.15±0.33 <sup>a</sup>	Typical	1.51±0.18 <sup>a</sup>	Soft	3.13±0.45 <sup>a</sup>	Good
T4	3.20±0.37 <sup>a</sup>	Good	1.44±0.13 <sup>a</sup>	Soft	3.15±0.37 <sup>a</sup>	Good
T5 (C2)	3.02±0.35 <sup>a</sup>	Good	1.44±0.28 <sup>a</sup>	Good	2.93±0.49 <sup>a</sup>	Good
T6	3.16±0.22 <sup>a</sup>	Good	1.53±0.17 <sup>a</sup>	Soft	3.04±0.19 <sup>a</sup>	Good
T7	3.29±0.27 <sup>a</sup>	Good	1.59±0.21 <sup>a</sup>	Soft	3.24±0.41 <sup>a</sup>	Good
T8	3.11±0.27 <sup>a</sup>	Good	1.52±0.17 <sup>a</sup>	Soft	3.00±0.40 <sup>a</sup>	Good
T9 (C3)	2.78±0.38 <sup>a</sup>	Fatty	1.24±0.19 <sup>a</sup>	Weak	2.47±0.28 <sup>a</sup>	Weak
T10	2.82±0.29 <sup>a</sup>	Fatty	1.37±0.19 <sup>a</sup>	Soft	2.69±0.41 <sup>a</sup>	Good
T11	2.89±0.33 <sup>a</sup>	Fatty	1.33±0.24 <sup>a</sup>	Soft	2.71±0.56 <sup>a</sup>	Good
T12	2.90±0.51 <sup>a</sup>	acidic	1.38±0.17 <sup>a</sup>	syneresis	2.58±0.47 <sup>a</sup>	syneresis

Data are the mean of 10 panelists ± SD

Grade<sup>a</sup> (1-4): 1: bad, 2: sufficient, 3: good, 4: very good.

Grade<sup>b</sup> (1-2): 1: weak, 2: normal.

<sup>a,b,c...</sup> Means values in the same column (of each control group) marked with unlike letters are significantly different ( $p < 0.05$ )

that it is the rate at that a deformed sample returns to original size and shape after the force is removed (Trinh & Glasgow, 2012), that could be interpreted when referred to the fibrous nature of supplemented chia mucilage. On the other hand, cohesiveness (strength of internal bonds in the sample) did not significantly affect with chia mucilage supplementation. Overall TPA result indicted that yoghurt supplementation with chia mucilage dispersion, positively affected its texture to be softer and smoother with strong internal bonds that increased its springiness, which was connected to organoleptic evaluation when chia yoghurt described as “soft”.

### Sensory evaluation of chia yoghurt

Sensory evaluation of chia yoghurt products is exhibited in Table (3). Although, no significant differences were recorded, the chia mucilage positive effect was pronounced through supplemented samples that described as “soft”, confirming the TPA results. Depending on obtained results of the three groups contingent on fat concentration, it is recommended to apply chia mucilage fortification to low fat yoghurt products (1% and 2% fat), with concentrations of (1, 1.5 and 2%), while supplementation to a higher fat concentration (3%) may cause taste and texture to be ruined.

## CONCLUSION

Chia mucilage micrographs showed fine fibrous network structure supported with high fiber, protein, ash and fat values (12.4, 10.68, 9.64, and 3.10%, respectively) announced in its gross chemical composition. The FTIR analysis indicated the presence of uronic acids, mannose, carboxylic acid, pyranose, glucopyranose, xylopyranose groups in the chia mucilage polysaccharides, which influenced its thermal stability behavior. On the other hand, chia mucilage showed high OHC value (5.85 g oil/ g sample) and was close to its WHC (5.25 g water/ g sample) that nominate it to perform as a stabilizer and emulsifier. Along with increasing of chia mucilage concentrations in fortified yoghurts, fiber content elevation subsequently reflected on significantly higher values of springiness, and descendant hardness values that produced “soft” yoghurts as described by panelists in sensory evaluation. According to obtained results, chia mucilage is recommended as food additive in food industry due to its unique structural, physical and compositional properties. This outcome would provide useful information to manufacturers contributing innovative applications of chia seed mucilage as reach natural fat mimetic, thermal stable thickening and gelling agent, in addition to the use of a “clean label” claim when marketing the product.

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## الملخص العربي

### الخصائص التركيبية والوظيفية لمستخلص بذور الشيا (*Salvia hispanica L.*) والمستخدمة لتدعيم

#### الزيادي قليل الدسم

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المستخلص على الخواص الكيميائية، الريولوجية و الخصائص الحسية للزيادي. أظهر الميكروجراف لمستخلص الشيا شبكة ليفية دقيقة مدعومة بنسبة عالية من الألياف والبروتين والرماد والدهون (١٢,٤ ، ١٠,٦٨ ، ٩,٦٤ ، و ٣,١٠ % على التوالي). أشار تحليل FTIR إلى وجود أحماض uronic ، mannose ، carboxylic acid ، pyranose ، glucopyranose ، xylopyranose في سكريات المستخلص العديدة، والتي أثرت على استقرارها الحراري. أظهر المستخلص قدرة عالية للاحتفاظ بالماء و الزيت ( 5.25جم و 5.85 جم/ عينة على التوالي) التي ترشحها للأداء كمثبت ومستحلب. انعكس زيادة تركيزات مستخلص الشيا في الزيادي المدعم، على ارتفاع محتوى الألياف والحصول على قيم أعلى من الطراوة مع صلابة اقل والتي ادت الى إنتاج زيادي "ناعم" كما وصف في التقييم الحسي. الكلمات المفتاحية: بذور الشيا. المستخلص. SEM. FTIR. TGA. الزيادي.

متطلبات الحياة الغذائية الحديثة من الأطعمة الطبيعية الصحية، يمثل تحديا لصانعي الأغذية لتطبيق إتجاهات صحية جديدة. يهدف هذا البحث إلى دراسة التركيب المجهرى لبذرة الشيا (*Salvia hispanica L.*) ومستخلصها، تقدير الخواص الكيميائية والوظيفية للمستخلص وذلك قبل إضافته في الزيادي قليل الدسم وتقييم تأثيره على تركيب المنتج، والقوام، والقبول الحسي. تم توصيف الميكرومورفولوجي لبذور الشيا ومستخلصها باستخدام الميكروسكوب الإلكتروني الماسح (SEM). ولتقييم الخصائص الوظيفية، تمت دراسة المجموعات الوظيفية باستخدام التحليل الطيفي بالأشعة تحت الحمراء (FTIR)؛ و تم تحليل السلوك الحراري باستخدام محلل قياس النقل النوعي (TGA)، كما تم تقييم قدرة الاحتفاظ بالماء / بالزيت (WHC / OHC). تم دراسة تركيب المستخلص قبل إضافة بتركيزات مختلفة (١ ، ١,٥ ، ٢ %) إلى نسب مختلفة من محتوى الدهون (١ و ٢ و ٣ %) لمنتج الزيادي، ورصد تأثير