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Rheological and physicochemical properties of chia (*Salvia hispanica* L.) low fat sugar free ice milk

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Abstract

Chia seeds as a fat substitute and stabilizer were used to produce low fat chia ice milk. Sucralose was also used to have a sugar free low glycaemia chia ice milk. Chia seeds as ground or as a whole were added in ratios 2, 3 and 4 % to obtain 7 treatments including control. Treatments were analyzed for chemical, physicochemical, rheological and sensory properties. Addition of chia increased TS, TN, ash, fiber, radical scavenging activity (RSA) and Total Phenolic Content (TPC). Chia whole seeds treatments have prolonged flow time more than that of ground seeds. Ice milk treatment of 2 % chia whole seeds possessed the highest overrun among all treatments. Rheological properties of all ice milk treatments showed shear thinning pseudoplastic behaviour. Increasing the added chia ratio resulted in lower melting rate. All chia treatments have melted with no serum separation. Chia seed gel not only has good emulsification activity but also forms stable emulsions. All chia ice milk treatments were more accepted than the control. The most accepted ice milk treatments were those of 2 % ground chia and 3 % whole chia seeds.

Keywords: Ice milk ; chia ; sucralose ; rheological properties ; low fat ; sugar free.

1. Introduction

Ice milk is one of the most beloved popular desserts of dairy products. Ice milk is a highly complex food matrix that includes an emulsion of proteins, fat, sugar and stabilizers. In addition it can be produced to contain health-promoting constituents such as vitamins, minerals, fiber or nutraceuticals and omega fatty acids. Seeds of *Salvia hispanica* L., commonly known as chia seeds, which is native to southern Mexico and northern Guatemala, cultivated in Egypt since few years ago. Chia have a high nutritional value with high contents of protein mainly globulins with no gluten. All proteins identified in chia seeds and their peptide sequences have auspicious biological potentials, mainly antioxidative, antihypertensive, and hypoglycemic properties **[1].** Chia have an oil content maintain a balanced serum lipid profile, composed of 64 % omega-3 (ω3) essential fatty acid that can't be synthesized by the human body. Moreover, 21% of chia oil content is omega-6 (ω6) fatty acid **[2, 3].** In addition, dietary fiber content of chia can help to reduce the digestion time of carbohydrates and assisting to control blood sugar levels that may also reduce the risk of obesity and hypertension. Chia mucilage as a fat replacer and stabilizer is a complex of high molecular weight soluble dietary fiber **[4].** Chia seeds are also promising source of polyphenols and natural antioxidants **[5].** As well as chia is an excellent source of minerals such as Ca, Mg, P, Mn, Zn and Cu **[6].** Chia have a high nutritional content in the fetus, it may helps in the development of retina and brain **[7].** Chia seeds are a prebiotic and suggest its use as a functional food in human daily diet **[8].** Sucralose is a low-calorie, high-intensity sweetener. Sucralose is non-interference in absorption or metabolism of carbohydrates and secretion of insulin due to its structure prevents digestive enzymes from breaking it down. Most consumed sucralose (85%) is not absorbed, small amount (15%) could be absorbed, none is broken down for energy **[9].** So, sucralose does not provide any calories in the diet.

Life changes have a demand for reduced calories products with multiple health benefits especially ice milk as a dairy nutraceutical dessert. Ice milk is a delicious food containing conventional sugar and fat that can increase the risk of hyperglycemia and obesity. Therefore, this study has been investigated to

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produce a palatable, nutritious and healthful functional low fat sugar free ice milk with a favourable and desirable quality.

2. Materials and Methods

2.1. Materials

Fresh cow's skim milk and fresh cream for this study were procured from Faculty of Agriculture, Cairo Univ., Giza, Egypt. Sucralose was obtained from Shandong Kanbo Biochemical Technology Co., Ltd, china. Sodium Carboxymethyl Cellulose (CMC) was obtained from BDH chemicals Ltd Poole, England. Milk Protein Concentrate (MPC) used in this study was obtained from Master-trade Co., Giza, Egypt. Chia seeds and vanillin were purchased from the local market, Giza, Egypt.

2.2. Methods:

2.2.1. Methods of manufacture:

2.2.1.1. Preparation of ground chia seeds:

Ground chia seeds were prepared by grinding the seeds in a milling machine (Braun mincer, Germany). Ground seeds were sieved through a 0.1 mm mesh sieve and packed in polyethylene bags then kept in the refrigerator. Chemical composition of used chia seeds for grinding was 26.945 fat, 2.974 TN, 5.356 ash and 48.8 dietary fibers as (g/100 g).

2.2.1.2 Manufacture of chia ice milk:

Chia ice milk batches were manufactured according to the method described by **[10]**. Ice milk treatments were prepared to contain 12 % milk solids non-fat (MSNF), 2 % fat, 0.025 % sucralose, 1.5 % MPC, 0.1 % vanillin, 0.2 % CMC and 2, 3 & 4 % chia seeds either as ground or whole to obtain 6 treatments of chia. Control treatment was manufactured to contain the same composition with no added chia. All ingredients were weighted individually. Electric blender Moulinix – France was used for mixing and blending mixtures. Ice cream maker (Model: BL1380) was also used for whipping ahead of time for their use permits foam to dissipate. The mixtures were prepared as given in Table 1. and Fig. 1.

Table 1: Formulations (kg/ 100 kg mix) of ice milk treatments with ground chia seeds (G) and whole chia seeds (W).

Materials	Treatments*						
	C	G1	G2	G3	W1	W2	W3
Chia	-	2.00	3.00	4.00	2.00	3.00	4.00
Fresh milk	91.598	89.421	88.333	87.244	89.421	88.333	87.244
Skim milk	4.287	4.518	4.634	4.749	4.518	4.634	4.749
Fresh cream	2.290	2.236	2.208	2.182	2.236	2.208	2.182
MPC	1.50	1.50	1.50	1.50	1.50	1.50	1.50
CMC	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Sucralose	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Vanillin	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

***C :** Control
G 1 : 2% Chia ground seeds
G 2 : 3% Chia ground seeds
G 3: 4% Chia ground seeds
W1 : 2% Chia whole seeds
W2 : 3% Chia whole seeds
W3 : 4% Chia whole seeds

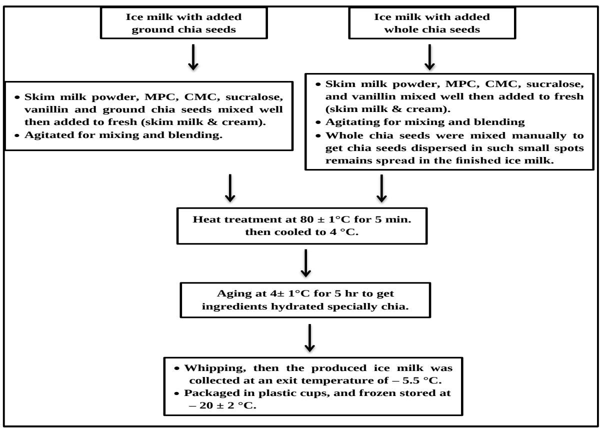

Fig. 1. Manufacture of ice milk treatments with ground chia seeds (G) and whole chia seeds (W).

2.2.2. Methods of analysis:

2.2.2.1. Fourier transform infrared (FTIR) spectroscopy of chia seeds:

Fourier transform infrared (FTIR) spectroscopy of chia seeds were measured in KBr pellets in the transmission mode in the range of 400-4000 cm^{-1} using Perkin-Elmer 2000 spectrophotometer, USA, according to **[11].**

2.2.2.2. Water-holding capacity WHC:

The water-holding capacity of ground chia and whole chia seeds were determined according to **[12]** with some modification**.** Two g of ground or whole chia seeds were mixed with 25 ml of distilled water. A vortex mixer (Hoidolph, Reax top, Germany) was used for 1 min to get homogeneous suspensions, then kept for 2 hours at room temperature before centrifugation at 1590 ×g for 10 minutes. Supernatant was weighed and the following equation was used:

$$\textbf{WHC (g/100g)} = \frac{[A\,(g) - S\,(g)]}{D\,(g)} \times 100 \quad (1)$$

Where *: **A*** is Added water, ***S*** is Supernatant and ***D*** is Dry weight

2.2.2.3. Chemical Analysis of ice milk samples:

Chia ice milk samples were chemically analyzed for total solids (TS), fat, ash and fiber contents according to **[13].** Total nitrogen (TN) content was determined using semi micro-Kjeldal method as mentioned by **[14].**

DPPH radical scavenging activity (Inhibtion %) :

Free radical scavenging activity (RSA) of ice milk samples was measured according to the method of [15]. An aliquot 100 µL of the sample solution was mixed with 2.9 ml of 1,1- Diphenyl-2-Picrylhydrazyl (DPPH) solved in methanol. The mixture was shaken by vortex stirring for 5 s and hold for 30 min in dark. The resulting solution was measured for absorbance at 517 nm by UV spectrometer. The percentage of radical scavenging activity (RSA %) was calculated according to the following equation:

$$\textbf{RSA \%} = \frac{Ab_B - Ab_S}{Ab_B} \times 100 \quad (2)$$

Where: Ab_B the absorbance value of blank and Ab_S is the absorbance value of the sample.

Total Phenolic content (TPC):

Content of total phenolic compounds in ice milk samples as mg gallic acid equivalents (GAE)/100g were determined using Folin-ciocalteu's reagent and catechin served as a standard according to **[16].**

2.2.2.4. Physico-Chemical properties:

pH values:

pH values were measured by direct insert of the electrode into ice milk samples using a digital laboratory Jenway 3510 pH meter, UK. Bibby Scientific LTD. Stone, Stafford shire, ST 15 OSA.

Flow time:

Flow time as mentioned in **[17]** were recorded as sec. required to discharge 50 ml pipette of ice milk mixtures at 5 °C under atmospheric pressure.

Freezing point:

Freezing point for ice milk mixtures as (– °C) were recorded using an electronic thermometer precision Modeled 15th, Kreuzwertheim, Germany as described in **[18].**

Specific gravity:

Specific gravity values of ice milk mixes and the final frozen product were determined at 20 °C using pycnometer according to **[19].**

Overrun:

The overrun of resultant ice milk as percent was calculated as reported by **[20].** by weight according to:

$$\textbf{Overrun \%} = \frac{W_1 - W_2}{W_2} \times 100 \quad (3)$$

Where: W_1 is the unit volume weight of mix and W_2 is the unit volume weight of ice milk

2.2.2.5. Rheological properties:

Rheological Properties of ice milk mixes were measured using a Brookfield Digital Rheometer, (Brookfield Engineering Laboratories INC), HA DVIII ultra rheometer, USA. Measuring device spindle HA-07 was selected for the samples measurement. The rheological parameters of ice milk mixes were studied at 20°C and the speed of spindle was ranging from 10 to 100 rpm.

For plotting shear stress - shear rate curve, the shear rate was calculated using the following equation **[21]:**

$$\gamma = \left[\frac{2\pi R_c^2}{60\,(R_c^2 - R_b^2)}\right] RPM \quad (4)$$

Where: γ is the shear rate, s^{-1} , R_c is the radius of container, cm , R_b is the radius of spindle, cm

2.2.2.6. Melting properties:

Melting properties of ice milk treatments were determined according to **[22]** by carefully cutting the foamed ice milk samples (~ 50 gm). Samples were placed to drain onto wire mesh over a glass funnel fitted on conical flask at room temperature 22 - 23 °C. The melted portion of the ice milk were weighed every 10 min until the entire sample had completely melted. Melting rate as (%) was calculated by the equation of:

$$\textbf{Meltdown \%} = \frac{M_1}{M_2} \times 100 \quad (5)$$

Where: M_1 is the weight of melted ice milk, M_2 is the weight of ice milk before melting

2.2.2.7. Colour measurement:

Colour measurement of ice milk samples were measured using Spectrophotometer (MOM, 100 D, Hungary). Color coordinates of the CIE/LAB were: (L*, a*, b*) values recorded five times for each sample and the mean value were recorded for the colour. Where L* [brightness to darkness], a* [shade of red (+ a*) to green (- a*)] and b* [shade of yellow

(+ b*) to blue (- b*)]. Values of a* and b* were used to calculate the Hue angle (H) refers to the degree of the dominant spectral component, such as red, green, and blue, and ranges from 0◦ to 360◦ according to **[23].** Chroma (C), that indicates the colour saturation or intensity of the sample according to **[24],** as follows: $H = \tan^{-1}(b^*/a^*)$, and $C = (a^{*2} + b^{*2})^{0.5}$. The coordinates of L*, a* and b* can be used to calculate the (ΔE), which indicates the difference in the ‘‘perception’’ of colour, including brightness, tone and saturation as shown in equation:

$$\Delta E = (\Delta a^{*2} + \Delta L^{*2} + \Delta b^{*2})^{0.5} \quad (6)$$

Where**,**

ΔL^* = (L^* control sample) – (L^* treated sample),
Δa^* = (a^* control sample) – (a^* treated sample),
Δb^* = (b^* control) – (b^* treated sample).

2.2.2.8. Sensory properties:

Ice milk treatments were sensory evaluated after hardening at – 20 ± 2 °C for 24 h by regular scoring panel members at Dairy Research Department and Packing Research Department, Food Technology Research Institute. Scores were carried out according to **[25].** A hedonic scale 9 – 1 point was used to determine the degree of liking of the samples as: 9 = Extreme like, 5 = Neither like nor dislike, 1 = Extreme dislike. The samples were evaluated for flavour, texture, colour and overall acceptability.

2.2.2.9. Statistical analysis:

Statistical analysis was performed according to **[26],** using General Linear Model (GLM). The one-way analysis of variance ANOVA was carried out to determine statistical significance among means of three replicates of samples at $p \leq 0.05$.

3. Results and Discussion

a. Fourier transform infrared (FTIR) spectroscopy of chia seeds:

The main components of chia seeds are protein, fats and carbohydrate as fibers and they are shown as function groups by FTIR spectra illustrated in Fig. (2). The small peak at 3302.32 with transmission ratio of approximately 58% represent a stretching for the N–H group of amino acids. Transmission broad bands between the most significant bands were attributed to hydrogen vibration of hydroxyl group –OH stretching at wave number 3010.34 cm^{-1}. The aliphatic C–H stretching vibration given at wave number 2926.45 to 2856.06 cm^{-1} is a sign for the C–H stretching of methyl group (with transmission ratio of approximately 25% and 30%) representing fat content of chia seeds. The peak at wave number 1745.26 cm^{-1} is a strong peak (approximately 23% transmission) and indicates the presence of amide I group that is characteristic for protein molecules in chia seeds.

Transmission peak at wave number 1651.73 cm^{-1} is a sign for the presence of mannose ring stretching in the mucilage of chia seeds. Bands at 1542.77 and 1457.92 cm^{-1} could be referred to the carboxylic group COOH of the uronic acids as backbone for the polysaccharides content of chia seeds. The peaks present in the region of 1238 to 1162. 87 cm^{-1} depict the stretching and bending of C=O and C–O–C groups present in the pyranose ring of sugar units in the chia seeds mucilage which indicates the presence of two functional groups in the structure.

Further functional groups present in chia seeds are the C–O–C group at wave number of 1058 cm^{-1} the glucoside 1→4 bond in the ring units of poly saccharide chains as well as the peak at wave number 720.28 cm^{-1} with a transmission ratio of approximately 62 - 63% representing the stretching of CH_2 groups in polysaccharide molecules with more than 7 carbon atoms.

In conclusion the FTIR spectrum of chia seeds represents the main functional groups indicating the dominance of fibres and carbohydrates molecules among other functional groups typical for gums and mucilage FTIR spectra. The obtained results were in accordance with that reported by **[27-32].**

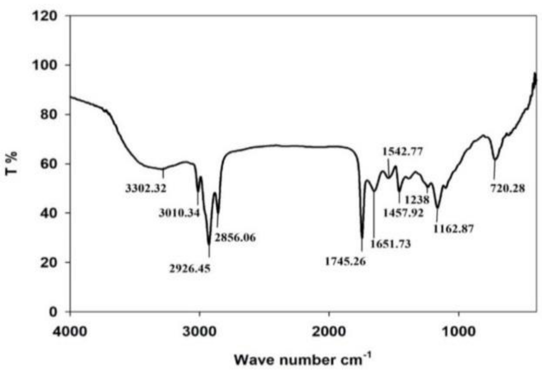

Fig. 2. Fourier transform infrared (FTIR) spectroscopy of chia seeds

b. Water-holding capacity (WHC) of chia seeds:

Water-holding capacity refers to the medium ability to hold water. The water-holding capacity of a medium is controlled by its texture, composition, and amount of organic matter content. This comprises water that is connected, hydrodynamic, or physically trapped **[33].** The data showed that WHC of ground chia and whole chia seeds were 775 and 800g/100g respectively **[33].** This means that the whole chia seeds have a greater ability to retain water. This could be due to the fibrous structure.

c. Chemical composition of ice milk treatments:

Chemical composition and pH values of ice milk treatments with added ground or whole chia seeds are presented in Table (2):

Total solids (TS):

Table (2) presents the total solids (TS) of ice milk with added chia seeds samples. Total solids (TS) of ice milk with added ground chia seeds were ranged from 18.16 to 21.50; meanwhile, it was 17.26 for the control. At the same time, TS for ice milk with added whole chia seeds samples were ranged from 18.72 to 20.92. These data cleared that, there were a significant differences in TS values among all treatments being increased by increasing the added chia ratio either a ground or a whole, these results are in agreement of **[34,35].**

Table 2: Chemical composition, RSA as (%), TPC (mg/100g) and pH values of ice milk treatments with ground chia seeds (G) and whole chia seeds (W).

Treatments*	TS	Fat	TN	Ash	Fiber	RSA	$^{\Delta}$TPC	pH
C	17.26^{e}	2.01^{a}	1.307^{a}	1.102^{a}	ND	1.45^{e}	11.79^{d}	6.608^{a}
G1	18.16^{de}	2.02^{a}	1.325^{a}	1.187^{a}	0.934^{b}	7.07^{c}	29.31^{c}	6. 414^{a}
G2	19.19^{cd}	2.05^{a}	1.529^{a}	1.250^{a}	1.453^{ab}	10.31^{b}	30.89^{bc}	6. 397^{a}
G3	21.50^{a}	2.09^{a}	1.680^{a}	1.351^{a}	1.952^{a}	13.75^{a}	32.46^{abc}	6.345^{a}
W1	18.72^{cd}	2.04^{a}	1.390^{a}	1.197^{a}	0.976^{b}	2.25^{de}	32.48^{abc}	6.545^{a}
W2	19.93^{bc}	2.06^{a}	1.540^{a}	1.273^{a}	1.464^{ab}	2.50^{d}	33.92^{ab}	6.523^{a}
W3	20.92^{ab}	2.10^{a}	1.587^{a}	1.347^{a}	1.949^{a}	2.81^{d}	35.43^{a}	6.481^{a}

*** The same as Table (1). ND : Not detected $^{\Delta}$TPC : Total Phenolic Content**
a, b, c: Means with the same letter among treatments are not significantly different.

Fat:

Fat contents of ice milk treatments that reported in Table (2) were 2.02, 2.05 and 2.09% for the treatments of added ground chia seeds 2, 3 and 4 % respectively. Fat contents were 2.04, 2.06 and 2.10% for that with added the same ratios of whole chia seeds in the same order. Fat content increased by increasing the added chia ratio in all treatments. This could be due to the high content of fat in chia **[2].** The control treatment was containing 2.01% fat being the lowest content among all treatments.

Total nitrogen (TN):

Table (2) depicts total nitrogen (TN) content of ice milk with added chia treatments. Total nitrogen content of control ice milk was 1.307%, and for that with 2, 3 & 4 % chia ground seeds were 1.325, 1.329 and 1.680%. Corresponding TN values of whole chia ice milk were 1.390, 1.540 and 1.587. By comparing these results, it can be found that, TN content increased by increasing the added chia ratio in all treatments. This could be due to the high content of proteins in chia **[2].**

Ash:

Ash content of the control and ice milk added 2, 3 and 4 % chia seeds are reported in Table (2). Ash content of the control treatment was 1.102 %, and were 1.187, 1.250, and 1.351% for the treatments with 2, 3 and 4 % ground chia seeds. On the other hand, ash content were 1.197, 1.273 & 1.347 % for 2, 3 and 4 % added whole chia seeds ice milk treatments. Ash content in all treatments were increased by increasing TS content. These results agree with **[4].**

Fiber content:

Fiber content of ice milk with added chia treatments in different ratios are also shown in Table (2). The data showed that fiber contents were 0.934, 1.453, 1.952 for 2, 3, 4 % chia ground treatments, and were 0.976, 1.464, 1.949 for 2, 3, 4 % whole chia treatments. The more added chia the more fiber content. These results agree with that obtained by **Coorey *et al.*, [2].**

DPPH radical scavenging activity (inhibition %):

DPPH radical scavenging activity (RSA) of ice milk samples are also reported in Table (2). Values of RSA cleared that, the control treatment has the lowest RSA content among all samples. The content of RSA was highly increased by increasing the added chia ratio. This could be due to the high RSA content of chia. **[36]** reported that chia seeds had high antioxidant activity (RSA) due to prevention of chain initiation, binding of transition metal ion catalysts, decomposition of peroxides and prevention of continued hydrogen abstraction and radical scavenging protecting against oxidative damage. So, adding chia seeds in foods could be beneficial to consumer health. Moreover, ice milk samples with added ground chia have RSA content higher than that of whole chia. For whole chia treatments this could be due to the decarboxylation or thermal decomposition of total polyphenols and tannins to a form that is insoluble, as well as interactions between these compounds and proteins or carbohydrate **[37].**

Total Phenolic Content (TPC):

Table (2) shows the total phenolic content (mg/100g) values of ice milk samples. The data displayed that all chia samples either ground or whole seeds have higher content than the control. Samples with 4 % whole chia seeds have the highest content of **TPC** meanwhile, that of 2 % ground chia has the lowest among all chia samples. Ice milk samples with added whole chia seeds have higher content of **TPC** than that of ground chia. This could be correlated to that phenolic compounds are existing in bound and soluble form. Therefore, the antioxidant activity of phenolic acids depends not only on the present amount of specific molecules but mainly on the structural conformation of the antioxidants, number and position of hydroxyl groups in the molecules. These results are in agreement of **[8].** Otherwise, during ingestion free and conjugated phenolic acid are rapidly absorbed in the stomach and small intestine, readily available to be metabolized in the human body as glucuronide, methylated and sulphated derivatives **[8].**

pH values:

Table (2) depicts the pH values of ice milk treatments with added chia seeds at ratios of 2, 3 and 4 %. The data revealed that, pH values decreased by increasing the ratio of chia seeds. For ground seeds treatments, pH values were 6.414, 6.397 and 6.345 at ratios of 2, 3 and 4 % added chia seeds, while values were 6.545, 6.523 and 6.481 for same added ratios of whole seeds treatments. The more incorporated chia seeds the more decreased pH values. Whole chia seeds treatments showed pH values higher than that of ground chia seeds. In addition, the control treatment has a pH value 6.608. These results are in agreement with **[4]** who found that acidity increased by the increase of TSS of the samples.

d. Flow time:

Flow time as (sec) of ice milk mixes manufactured with chia seeds is represented in Table (3). The data exhibited that, the control mix has the minimum flow time when compared. Flow time prolonged by increasing the added chia ratio especially for the mix of 4 % ground chia seeds. This could be due to the effect of chia mucilage acting as stabilizer to increase by increasing the added chia ratio. Increasing the level of added chia increased the water retention, so the viscosity of ice milk treatments increased **[38].** Fiber content has significant effect on ice cream viscosity in turn to reduce flow time **[39]**.

Mixes of chia seeds as a whole have prolonged flow time more than that of ground seeds. This could be due to that chia seeds being as a whole have water holding capacity (WHC) higher than ground chia, as reported by **[2].** The treatment of added 4 % chia as a whole seeds has the longest flow time compared by all other treatments including the control. This could be related to the effect of higher content of chia mucilage acting as a stabilizer.

Table 3: Flow time, Freezing point, Overrun and specific gravity (mixes & end product) of ice milk treatments with ground chia seeds (G) and whole chia seeds (W).

Treatments*	Flow time (sec)	Freezing point (-°C)	Specific gravity		Overrun %
			Mix	Ice milk	
C	72.63^{f}	-0.90^{b}	1.065^{a}	0.652^{a}	63.34^{bc}
G1	92.42^{ef}	-1.40^{a}	1.076^{a}	0.644^{a}	67.08^{b}
G2	100.39^{e}	-1.60^{a}	1.090^{a}	0.694^{a}	57.06^{cd}
G3	189.02^{d}	-1.90^{a}	1.093^{a}	0.763^{a}	43.25^{e}
W1	636.67^{c}	-1.50^{a}	1.078^{a}	0.617^{a}	74.72^{a}
W2	958.17^{b}	-1.70^{a}	1.090^{a}	0.639^{a}	70.58^{ab}
W3	1518.38^{a}	-1.90^{a}	1.092^{a}	0.709^{a}	54.02^{d}

***The same as Table (1).**

a, b, c: Means with the same letter among treatments are not significantly different.

3.5. Freezing point:

Freezing point of ice milk with chia seeds ground or as a whole are depicts in Table (3). It can be seen that, the freezing points were -1.4, -1.6 and -1.9°C for treatments of 2, 3 and 4 % chia as ground seeds respectively. Meanwhile, freezing points were -1.5, -1.7 and -1.9 for treatments with 2, 3 and 4 % chia as a whole seeds in order. By the comparison of ground chia treatments and that of whole seeds it can be found that, freezing points were decreased by increasing the added chia ratio. Moreover, the freezing points of whole seeds treatments were slightly decreased than that of ground seeds treatments. Control treatment has a less decreased freezing point, it was the least that when compared by all other treatments. It could be due to MSNF and sugar substitute, the principle effects on freezing point. **[40]** reported that low fat and no sucrose content in the formula influenced the molecules number reverts to the freezing point. Ice milk treatments of 4 % either ground or whole seeds showed the lowest freezing point among all treatments. These could be due to the effect of mucilage of chia seeds. More fiber content resulted more retention of water due to depression of freezing point **[39].**

3.6. Specific gravity:

Specific gravity of ice milk mixes and the resultant product with chia seeds are also shown in Table (3). As can be seen, from the results for ice milk mixes of ground chia seeds, specific gravity values were higher than the control, the highest was recorded for 4 % chia ground seeds treatment. For ice milk mixes with whole chia seeds the results showed gradual increase in specific gravity by the increase of added chia being the highest for that of 4 %. These could be due to the added stabilizer and TS content **[34].**

Specific gravity of the resultant ice milk treatments are also shown in Table (3). Treatments with ground chia seeds showed an increase in specific gravity by the increase of added chia seeds ratio. Specific gravity of all ice milk with ground chia treatments were higher than that of control. Differences among treatments were non-significant. Ground chia seeds treatments have higher specific gravity than that of whole chia seeds treatments at the same added ratios. Whole chia seeds treatment with 2 % has the lowest specific gravity. More contribution of chia resulting heavy and dense ice milk causes miss incorporation of air cells to increase the specific gravity.

3.7. Overrun:

Table (3) represents overrun as (%) of ice milk treatments with chia seeds. Overrun were decreased by increasing the added chia ratio ground or as a whole. Incorporation and stabilization of air was affected according to the ingredients of the mix such as hydrocolloids, proteins and fats **[24].** Ice milk treatments with that ground seeds have different values of overrun even at the same ratios as that of whole seeds. The treatment of 4% whole chia ice milk showed the lowest overrun compared to other chia treatments. **[24]** mentioned that when the viscosity increased the thickening of the mix could be causing difficulties to the air incorporation during stirring and freezing, this prevented the formation and stabilization of air cells,**.** Ice milk of 2 % chia whole seeds has the highest overrun among all treatments. Surfactants like milk protein and stabilizers improve whipping ability and decrease size of air cell **[25].** Otherwise, control treatment has lower overrun than that of 2 % whole and ground chia seeds.

3.8. Rheological properties:

The consistency coefficient index (K) and flow behaviour index (n):

Consistency coefficient index K (Pa.s^n) and flow behaviour index (n) of the ice milk mixes produced by adding ground or whole chia seeds in different concentrations are reported in Table (4). The flow behaviour index (n) indicates the degree of non-Newtonian characteristics of the fluid. As a fluid becomes more shear thinning (n) decreases, as the fluid becomes more viscous, the consistency index (k) increases.

Ground chia ice milk mixes showed lower values than whole chia ice milk mixes, recorded higher values for consistency index being the highest for 4% whole chia seeds. For ground chia sample 4 % the flow behaviour index (n) decreases and the consistency index (k) increases. That means, as a fluid becomes more shear thinning, as the fluid becomes more viscous. All mixes of the treatments showed pseudoplastic behaviour pattern with (n) values ranged from 0.34 to 0.52, these results are agree with **[24].**

Table 4: The consistency coefficient index K (Pa.s^n), flow behaviour index (n) and R^2 values of ice milk mixes with ground chia seeds (G) and whole chia seeds (W).

Treatments*	K (Pa.s^n)	n	R^2
C	1.38	0.46	0.95
G1	1.92	0.34	0.95
G2	2.73	0.40	0.97
G3	4.54	0.35	0.97
W1	4.39	0.52	0.99
W2	5.94	0.40	0.99
W3	6.68	0.42	0.98

***The same as Table (1).**

Flow behaviour curves of shear rate (s^{-1}) in relation to shear stress (Pa) of ice milk mixes prepared with ground or whole chia seeds in different concentrations are shown in Fig. (3). All ice milk mixes for ground or whole chia seeds even the control have a shear thinning pseudoplastic behaviour under all shear rates and follow the power law equation:

$$\boldsymbol{\tau = k\gamma^n} \qquad \textbf{(7)}$$

Where, $\boldsymbol{\tau}$ is the shear stress (Pa), $\boldsymbol{\gamma}$ is the shear rate (s^{-1}), $\boldsymbol{k}$ is the consistency index and $\boldsymbol{n}$ is the flow behavior index.

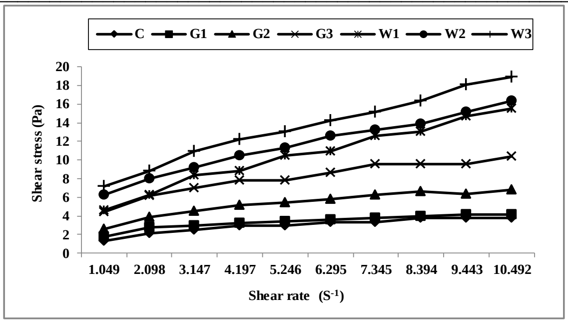

Fig. 3. Effect of shear rate on shear stress of ice milk mixes with ground chia seeds (G) and whole chia seeds (W).

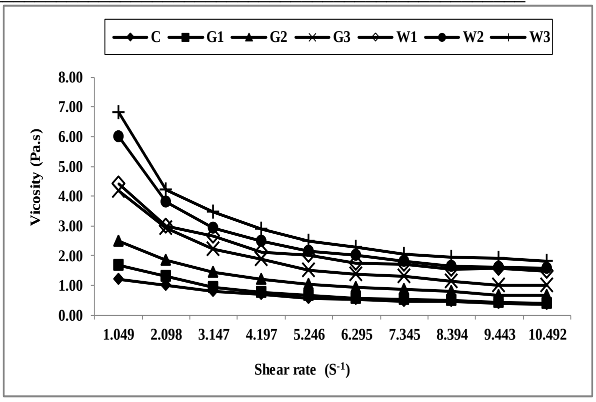

Fig. 4. Effect of shear rate on apparent viscosity of ice milk mixes with ground chia seeds (G) and whole chia seeds (W).

Effect of shear rate on the apparent viscosity of chia ice milk mixes:

Fig. (4) illustrate the apparent viscosity values (Pa.s) in relation to shear rate (s^{-1}) of ice milk mixes with ground and whole chia seeds. In ice milk mixes, the curves obtained exhibited a non-Newtonian pseudoplastic behaviour, as the viscosity strongly depends on shear rate **[41].** Viscosity values decreased by increasing the shear rate values for all ice milk mixes, it is well known that increasing shear rate breaks down the colloidal structure and therefore the viscosity is reduced **[42].** The relation between viscosity and shear rate was fitted to the following equation:

$$\mu = k\gamma^{(n-1)} \quad (8)$$

Where: μ is apparent viscosity (Pa.s.), γ shear rate (s^{-1}), K ($Pa.s^n$) is the consistency index, n is the flow behavior index.

The addition of both ground and whole chia seeds increased the apparent viscosity of the ice milk mixes with respect to the control; the same results were obtained by **[43]** when they used chia seeds mucilage as stabiliser in ice cream. In control sample the lowest viscosity values at all shear rates were obtained due to the lower content of TS and no fiber content **[39].** Furthermore, the viscosity of ice cream mixes correlates strongly with the concentration of ground and whole chia seeds in mixes formulations, these results are consistent with **[44].** On the other hand Fig. (4) shows that, the viscosity values of ice milk mixes formulated with whole chia seeds was higher than the viscosity values of ice milk mixes formulated with ground chia seeds. **[2]** found similar results when they compared gelling properties of chia seeds and chia flour. This may be due to the release of some oil in the ground chia, which reduces the ability of the ground seeds to hold water as reported also by **[38],** they found that partial defatted chia seeds gum showed a very good ability to hold water more than fatted chia seeds gum.

3.9. Melting rate:

Melting rate of ice milk with ground or whole chia seeds samples is represented in Fig (5). Control sample recorded no melting rate up to the min 50, to increase gradually and being the highest, it recorded melting rate higher than that of chia samples in different ratios. Heat shock effect for low fat ice milk was much greater on crystal size as the size increased significantly. In addition, sizes of ice crystals were bigger in low fat ice milk due to less total solids and high water content available for freezing **[39].** For the samples of 2% ground chia, it recorded the lowest melting rate among all samples of ground chia up to 70 min This could be due to the highest overrun. These results in agreement of **[25].** The sample of 4 % ground chia seeds being higher than ice milk of 2 and 3 % ground chia seeds samples and being lower than the control. The individual molecules of the hydrocolloids can move freely. However, in the concentrated systems, they have more contact with each other due to limiting the movement of water or ice crystals **[45].** From the min 90 of melting time and up to the end at 180 min all samples were in a gradual melting increment. The sample of 4 % ground chia has the lowest melting rate. **[24]** reported that the increase in added chia ratio caused a reduce of the melting rate due to the increase of chia mucilage. The aging process of base mix provides beneficial changes such as hydration of proteins which result as an increase of viscosity as well as resistance of melting, **[46].** All ice milk samples of whole chia seeds have a melting rate lower than that of ground chia seeds. Chia samples have melted with no serum separation. Chia seed gel not only has good emulsification activity but also forms stable emulsions. Good stability of chia seed gel results from its high WHC due to reduce available water that able to create ice crystals **[2].** At the end of melting time 180 min, the control ice milk when compared being the highest of all samples meanwhile, that of whole chia 4 % was definitely the lowest. **[39]** mentioned that samples with high overrun melted quickly whereas that with low overrun began to melt slowly and had a good melting resistance.

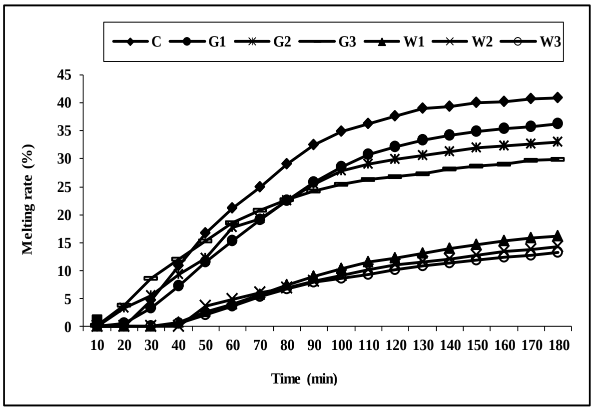

Fig. 5. Melting rate as (%) of ice milk treatments with ground chia seeds (G) and whole chia seeds (W).

3.10. Colour:

Colour of ice milk samples as a colour coordinates (L*, a*, b*), total color difference: ΔE, Chroma and Hue Angle are shown in Table (5). It was observed that L* values were decreased by increasing the added chia ratio. The colour was more opaque by increase the added chia. This could be attributed to the presence of some impurities such as natural pigments and tannins **[47].** In contrary the control treatment has the highest L* value due to more lightening. In ice milk samples with whole chia seeds, L* value were higher than that of ground chia. This could be contributed to the dispersion of TS particles due to reflectance of light and whiteness, according to **[48].** Moreover, in concern to the parameter a*, it was observed that samples of ground chia have negative a* values decreased by increasing chia ratio. Control sample was significantly different from chia samples to have the highest negative a* value due to more greenness colour shade. Although, the negative a* values decreased by increasing added chia seeds, samples of whole chia seeds have a higher negative a* values than that of ground chia where seeds being as a whole affected the colour to be more greenness. Regarding to b* values it can be seen that, the control has the lowest value comparing by chia samples. Chia samples have yellowish colour more than the control. The yellow colour increased when chia ratio increased. The b* values for whole chia seeds samples were higher than ground chia samples at the same order. Ice milk sample with whole chia 4 % has the most yellowish colour due to the highest b* value when compared. For the Hue angle and chroma values, it is clear that Hue angle and chroma values decreased by increasing the added chia. Values for whole seeds samples were higher than the values of ground chia samples at the same ratios of added chia. This could be due to the decrease in a* & b* values. In addition, increase of added chia as a whole improved the light reflection due to reduce the effect of chia pigments and impurities as a ground samples. The combination of low luminosity resulted in brown–coloured chia ice milk **[47].** From the table, it is clear that ΔE values for ground chia samples ranged from 14.05 to 21.34, indicated that addition of chia as ground to the ice milk caused significant differences in colour even at the lowest ratio 2%. For whole chia samples, ΔE values ranged from 4.05 to 16.62. That indicates the variations in colour were noticeable for the sample of 2 % comparing by significant differences in colour for 3 & 4 % whole chia samples.

Table 5: Colour parameters values of ice milk treatments with ground chia seeds (G) and whole chia seeds (W).

Treatments*	Colour parameters					
	L*	a*	b*	Hue angle	Chroma	ΔE
C	91.87^{a}	-15.95^{a}	3.62^{a}	167.213^{a}	16.355^{a}	0
G1	78.29^{b}	-9.59^{bc}	3.98^{a}	157.461^{ab}	10.383^{b}	14.05^{b}
G2	74.21^{b}	-8.95^{c}	4.37^{a}	153.975^{bc}	9.959^{b}	18.09^{ab}
G3	71.57^{b}	-6.86^{c}	4.90^{a}	143.660^{c}	4.453^{c}	21.34^{a}
W1	89.36^{a}	-13.93^{ab}	4.09^{a}	163.637^{ab}	14.518^{ab}	4.05^{c}
W2	77.89^{b}	-11.68^{abc}	4.56^{a}	158.674^{ab}	12.538^{ab}	14.64^{ab}
W3	76. 09^{b}	-10.90^{bc}	4.95^{a}	155.576^{ab}	11.971^{ab}	16.62^{ab}

***The same as Table (1).**

a, b, c: Means with the same letter among treatments are not significantly different.

3.11. Sensory evaluation:

Sensory evaluation of ice milk treatments with chia seeds as ground or as a whole are presented in Table (6). Sensory properties were attributed for:

Flavour:

As shown in Table (6), Ice milk with added ground chia seeds of 2 and 3 % scored 9 for flavour, meanwhile ice milk of 4 % scored 7. The treatments of 2 and 3 % have a balanced sweet flavour as rich as contain high fat and were acceptable for the panelists with no perception of odd flavour. Chia mucilage as a fat substitute can improve flavour and increase mouthfeel being well accepted**.** The treatment of 4 % were less acceptable due to presence of tannins slightly affected flavour acceptance. The cause of chia being as ground altering ice milk flavour, **[47].** Control treatment has scored 6.5 for flavour with icy and weak milky flavour.

For the treatments of whole chia seeds, the highest flavour score was recorded for that of 3 and 4 % that scored 9. Treatment of 3 % has a balanced sweet milky chia flavour. Moreover, that of 4 % has a desirable sweety clear flavour of chia seeds with no bitterness. That for the seeds being in a whole form that improved the flavour. Ice milk treatment of 2 % chia seeds scored 8.5, it has a slight chia flavour comparing by other chia treatments. Flavour character was decisively dominated by the level of added chia, according to **[4]**. From the data it is clear that, all chia samples have higher scores than the control and have flavourants reach to the maximum intensity and the mouth was more coated with a buttery feeling and creamy flavour.

Table 6: Sensory properties of ice milk treatments with ground chia seeds (G) and whole chia seeds (W).

Character Assessed 9 – 1	Treatments*						
	C	G1	G2	G3	W1	W2	W3
Flavour	6.5^{b}	9.0^{a}	9.0^{a}	7.0^{b}	8.5^{a}	9.0^{a}	9.0^{a}
Texture	6.0^{c}	8.0^{ab}	9.0^{a}	7.0^{bc}	8.5^{a}	9.0^{a}	8.0^{ab}
Colour	7.0^{c}	9.0^{a}	8.5^{ab}	7.5^{bc}	9.0^{a}	9.0^{a}	8.5^{ab}
Overall acceptance	6.0^{c}	9.0^{a}	8.5^{ab}	7.5^{b}	8.0^{ab}	9.0^{a}	8.5^{ab}

***The same as Table 1.**

a, b, c: Means with the same letter among treatments are not significantly different.

Texture:

Texture of ice milk with chia treatments is also represented in Table (6). Ice milk of 3 % chia seeds as ground recorded the highest score for texture, have a smooth velvety & creamy improved texture. Chia mucilage as a substitute of fat can play a similar role in the texture of frozen dessert **[24].** Chia treatments contain fiber and mucilage, helped to bound water to have a unique texture. An increase in viscosity of human digesta is associated with increased sensation of satiety. As the digestion process progressed, the digesta changed from irregular network and fibril structures to slightly less compact with larger pores due to more open and less compact structure. This behaviour suggests that chia mucilage could maintain its structure in the food matrix, makes it attractive for nutraceutical food products for health and wellness, according to **[49].** When the added chia increased to 4 % as ground seeds texture score decreased to 7. More mucilage and fiber content bound more water, texture being heavy and soggy. Chia whole seeds treatments have a better texture scores and the highest score was for that of 3 % followed by that of 2 %. Although, the treatment of 4 % whole chia seeds has lower score, it has a better texture than that of ground seeds at the same added ratio. Control treatment has the lowest score due to a coarse texture. This could be due to lower TS content especially protein to form ice needle crystals. **[50]** reported that ice crystal size decreased as TS level increased.

Colour:

Table (6) recorded the colour scores of ice milk with chia as ground or as a whole. For the ground chia treatments, it can be seen that, ice milk of 2 % ground chia seeds has the highest colour score followed by that of 3 % to have a shiny brown colour. By increasing the added chia up to 4 %, the darkness of brown colour increased with a little shiny. Pronounced colour could be due to the presence of some impurities such as natural pigments. Stirring during heating promotes the colour diffusion as a result a darker colour **[47].** For the treatments of whole chia seeds, the highest colour score were recorded for that of 2 and 3 % with a difference in seeds dispersion. Treatment of 3 % added chia has a more dispersion of seeds that has an attractive shiny white colour with brown spots. A little shiny colour recorded for ice milk of 4 %. Increase of chia added ratio caused an increase in ice milk brown colour. The control treatment has a clear semi-transparent colour. This could be due to the lower content of TS especially protein and fat.

Overall acceptance:

Overall acceptance of ice milk treatments with chia are recorded in Table (6). It can be seen that the most preferred treatment is that of 2 % added chia as a ground seeds. Ice milk with 3% ground chia was slightly less favourable. This could be due to the difference in colour due to the added chia. Control ice milk treatment was the least preferred treatment, that compared by chia treatments ground or a whole. Among treatments of ice milk with whole chia seeds, the most accepted treatment was that of 3 % added chia. Ice milk with added chia 4 % has a lower acceptance than that of 3 %. The treatment of 2 % whole chia seeds was slightly less preferred when compared by chia treatments. All ice milk treatments with added different chia ratios were acceptable, the most acceptable treatments were that of 2 % ground chia and 3 % whole chia seeds.

4. Conclusion

Low fat sugar free chia ice milk manufactured successfully by using chia seeds as ground or as a whole in different ratios. This study proved that, chia seeds can be used as a fat substitute and as a stabilizer in nutraceutical functional ice milk manufacture. The most preferable treatments with high quality attributes, texture & flavour and high overall acceptability are that of 2% ground chia and 3% whole chia seeds, gained the highest sensory scores.

5. Conflicts of Interest

Authors have no conflict of interest. We are agreed upon all the Ethic Rules applicable for this journal.

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