Potential of using chia seed gel extracted from chia seed as stabiliser in ice cream

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ABSTRACT

In the manufacture of ice cream, stabilisers are used as food additives to stabilise the structure of ice cream. Typically, commercial stabilisers used in ice cream include guar gum (GG), locust bean gum (LBG), carrageenan and carboxymethyl cellulose (CMC) which are usually designated with E-numbers on the nutrition panel of food packages. However, most of the consumers have little knowledge about the information on E-numbers and some consumers are sceptical of their presence as food additives in the frozen desserts. Current trends also show that consumers prefer functional food products with natural food ingredients that support better health and wellbeing. Thus, the present study investigated the potential of chia seed gel to replace commercial stabilisers in ice cream. Chia seed is a common household food ingredient, and the gel extracted from hydrated chia seed has strong water absorbing and swelling properties, which gives it the potential of being incorporated into ice cream formulation to replace commercial stabilisers.

The study comprised two main phases: extraction of chia seed gel and testing its performance in ice cream as a stabiliser using varying concentrations. In phase I, chia seed gel was extracted at three soaking temperatures (20 °C, 40 °C and 80 °C) using three seed: water ratios (1:10, 1:20, 1:30, w/w). The yield and apparent viscosity of extracted chia seed gel were determined by Linear Regression Analysis. The optimum extraction of chia seed gel was obtained using soaking temperature at 80 °C with a seed: water ratio of 1:10 (w/w), producing 9.943±0.75% (w/w) of dried chia seed gel with an apparent viscosity of 6.74±0.24 Pa·s.

In phase II, samples of chia seed gel extracted under the optimised conditions obtained in phase I were incorporated into ice cream formulations (CS_1, CS_2 and CS_3) at three varying concentrations (16.35%, 27.25%, 37.8%, w/w). Two control ice cream samples with/without commercial stabilisers (0.2% guar gum, 0.15% carrageenan, w/w) were also prepared (C_2 and C_1, respectively), giving a total of five ice cream samples. The frozen dessert samples were evaluated for the viscosity of the ice cream mix, overrun, fat globule size distribution, meltdown rate and hardness of ice cream. The ice cream samples were also evaluated by a focus sensory group consisting of five panellists from students at the School of Food and Advanced Technology, Massey University. The most promising ice cream was selected for further consumer sensory evaluation (using a 9-point hedonic scale). The sweetness, creaminess, melting, mouth feel, smoothness, firmness and overall acceptance of the selected ice cream samples were evaluated.

The addition of chia seed gel in ice cream increased the viscosity of ice cream mix, overrun, hardness, melting resistance and fat globule size of ice cream. Ice cream containing 27.25% chia seed gel (w/w) received the highest overall consumer sensory scores. The ice cream sample had an overrun of 41.02±0.89% which was slightly lower than the control sample (50.70±0.42%) that contained commercial stabilisers. The experimental frozen dessert was characterised by a hardness of 84.63±6.14 N and fat globule size distribution of 94.46±2.69 µm. The meltdown rate (0.44±0.01 g/min) was low compared to the control ice cream with commercial stabilisers.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of Variance
ALA	α-Linolenic Acid
BSG	Basil Seed Gum
CSG	Chia seed gel
CMC	Carboxymethyl Cellulose
CS	Chia seed
GG	Guar gum
FGSD	Fat Globule Size Distribution
LA	Linolenic Acid
LBG	Locust Bean Gum
PC	Partial Coalescence
PUFA	Polyunsaturated Fatty-acids
MDG	Mono/diglyceride
SAT	Saturated Fatty-acids
SEM	Scanning Electron Microscope
SMP	Skim milk powder
GLM	General Linear Model
SD	Standard Deviation
TDF	Total dietary fibre
TFA	Trans-Fatty Acids
TSS	Total Soluble Solids
XG	Xanthan G

$d_{4,3}$	Volume weighted mean diameter
τ	Shear stress
γ	Shear rate
k	Consistency index
n	Flow behaviour index (dimensionless)
N	Newton

Chapter 1 INTRODUCTION

1.1 Background

Ice cream is a milk-based frozen dessert which is widely consumed. Globally, the annual consumption of ice cream has been increasing rapidly in recent years. During the manufacture of ice cream, stabilisers are used as food additives to stabilise the structure of ice cream. Typical commercial stabilisers used in ice cream include guar gum (GG), locust bean gum (LBG), carrageenan and carboxymethyl cellulose (CMC) which are commonly designated with E-numbers on the nutrition panel of the packages. According to the European food additives regulation: E numbers ("E" stands for "Europe") are codes for substances used as food additives (Ullah et al., 2023). Most of the consumers have little knowledge about E-numbers, and some are sceptical of their presence as food additives in food including frozen desserts. Current trends show that consumers prefer functional food products with natural food ingredients that support better health and well-being. These trends have created an opportunity for investigating the potential for replacing the conventional stabilisers and emulsifiers used in ice cream with natural additives. Previous studies have shown that extracted chia seed gel has high water-holding and swelling properties with non-Newtonian shear-thinning behaviour (Campos et al., 2016; Goh et al., 2016; Timilsena et al., 2015). Thus, chia seed gel can be incorporated into ice cream formulation to replace commercial stabilisers (guar gum and carrageenan).

Chia seed is a common household food ingredient which has excellent functional properties, hence its popularity among consumers is rapidly growing. The stabilising ability of chia seed gel in ice cream has been reported in previous studies (Chavan et al., 2017; Feizi et al., 2021; Ürkek, 2021). The researchers used chia seed gel powder to replace conventional stabilisers in ice cream mixes. Overall, the ice cream samples had desirable hardness, smooth texture and creamy mouthfeel without sensation of ice crystals or off-flavour.

In previous studies, chia seed gel powder was obtained by dehydrating freshly extracted (hydrated) chia seed gel (Campos et al., 2016; Chavan et al., 2017; Feizi et al., 2021; Muñoz et al., 2012; Tavares et al., 2018). Typical dehydrating methods are oven-drying (50 ℃) and freeze-drying (-50 ℃) (Tavares et al., 2018). Campos et al. (2016) and Muñoz et al. (2012) used the hot-air oven to dry the freshly extracted mucilage overnight at 50°C with yields ranging from 5.09% and 6.79%. According to Tavares et al. (2018), oven-drying is associated with changes of the micro-structure of chia seed gel which can affect its stabilising ability. Other studies used the freeze-drying method to prepare the chia seed gel powder for nearly 3 days at <50°C with yields ranging from 3.40%-8.46% (Chavan et al., 2017; Feizi et al., 2021; Tavares et al., 2018). The limited available studies indicate that the drying process of chia seed gel may not be cost-effective and is time-consuming.

While chia seed gel powder may be a promising natural ingredient as an ice cream stabiliser, the cost of drying could be prohibitive. Therefore, there is need to investigate the potential of adding freshly extracted hydrated chia seed gel to stabilise ice cream, and this was the aim of the present study.

1.2 Specific objectives

1. To conduct a comprehensive literature review on:
   a. Technology of ice cream including the characteristics, ingredients, formulations, the trends and the manufacture;
   b. Chia seed including its chemical composition and food applications;
   c. Chia seed gel: extraction, micro-structure, chemical composition, rheological properties and food applications;

2. To determine the optimum extraction conditions of chia seed gel from chia seed;
   a. Extraction conditions included three soaking temperatures (20 ℃, 40 ℃, 80 ℃) and three seed: water ratios (1:10, 1:20, 1:30);
   b. Parameters determined were apparent viscosity, yield and total soluble solids of chia seed gel;

c. Tyndall effect test of chia seed gel;

3. To determine the optimum concentration of chia seed gel added into ice cream formulations;

a. Five ice cream samples were analysed using three test samples with chia seed gel at varying concentrations (16.35%, 27.25%, 37.8%, w/w) and two control samples with/without commercial stabilisers;
b. Parameters determined were the viscosity of ice cream mix samples, overrun, particle size distribution, hardness and meltdown rate of ice cream samples;
c. Focus group sensory evaluation and consumer sensory evaluation of the ice cream samples were also conducted.

Chapter 2 LITERATURE REVIEW

2.1 Ice cream

2.1.1 The description of ice cream

Ice cream is a frozen dessert, typically made from milk flavoured with sweeteners, sugar or other ingredients (Goff, 1997). Ice cream is also considered as a nutritious product containing proteins, vitamins and minerals. The definition of ice cream varies from country to country. In the United States, ice cream is defined by the standards set up by US government, in which it must contain not less than 10% milk fat, 20% total milk solids and must weigh a minimum weight of 0.54 kg/L (Arbuckle, 2013). However, according to Clarke (2015), the term "ice cream" covers a wider range of frozen desserts including dairy ice cream, non-dairy ice cream, gelato, frozen yoghurt, milk ice, sorbet, water ice and fruit ice. In the United Kingdom, the minimum content of fat and protein in ice cream are 5% and 2.5%, respectively (Clarke, 2015).

The study of ice cream consists of understanding its ingredients, processing, micro-structure, texture and the relationship between them. As a result, its study requires a range of scientific knowledge including physical chemistry, analytical chemistry, biochemistry, material science and even consumer science (Clarke, 2015).

2.1.2 Ingredients and formulations of ice cream

The formulation of ice cream varies from country to country due to different regulations and traditions, therefore it can be found with many variations (Clarke, 2015; Goff and Hartel, 2013; Motyl et al., 2019):

• Regular ice cream (usually defined by minimum levels of fat, which may be dairy or non-dairy, and also minimum levels of either food solids or milk protein or milk solids, alone or in combination) (Goff and Hartel, 2013);

• Higher-fat premium-type, although these usually also meet the normal definitions of ice cream;

• Low-fat or non-fat versions or no-sugar-added or sugar-free versions, which may or may not meet the usual definitions of ice cream;

All these categories are available in multiple flavours and shapes (Goff and Hartel, 2013). A basic composition of ice cream most often included: 9-12% milk solids, non-fat milk, sweetening substances in the amount of 12-16%, and 0.3-0.5% stabilising and emulsifying substances (Motyl et al., 2019). Kilara and Chandan (2013) also reported that three categories of ingredients were necessary to make a dairy ice cream mix. A concentrated source of milk fat was the first category, the second category was a concentrated source of milk solids-not-fat (MSNF) (also known as liquid solids), and the third category was the balancing ingredients including stabiliser and emulsifier. Similar results were also reported by Clarke (2015) and Homayouni et al. (2018). Table 2.1 shows a typical ice cream formulation. Main ingredients in one typical ice cream include: fat, milk protein, lactose, sugars, food additives and water. The total solids of ice cream are in the range of 28%-40% (w/w). Each of the ingredients plays an important role in the structure and taste of ice cream (Goff and Hartel, 2013).

Table 2.1 Composition of one typical ice cream (Clarke, 2015)

Ingredient	**Amount (% w/w)**
Fat	7-15
Milk protein	4-5
Lactose	5-7
Other sugars	12-16
Stabilisers, emulsifiers and flavours	0.5
Total solids	28-40
Water	60-72

2.1.2.1 Fat

Fat is one of the key ingredients in ice cream and helps to add rich flavour to ice cream as well as contributes to the physicochemical structure of ice cream, thus producing desirable texture and melting properties (Goff and Hartel, 2013). The fat in ice cream mix helps to lubricate the freezer barrel while whipping and freezing the ice cream mix in the freezer barrel (Clarke, 2005; Goff and Hartel, 2013). Furthermore, during the freezing of ice cream, the fat globules existing in the mix will partially coalesce (destabilize) under the synthetic action of emulsifier, air bubbles, ice crystals, and high shear forces of the dasher and scraper blades in the freezer barrel (Goff and Hartel, 2013). Partial coalescence is essential to build the structure and texture in ice cream. Therefore, the selection of fat for ice cream is significantly important (Goff, 1997b). The fat used in ice cream can be characterised as dairy or non-dairy fat according to the source (Goff, 1997).

Milk Fat

Milk fat is the most frequently used fat in ice cream (Goff, 1997). It mainly consists of triglycerides fatty acids which can contribute to the dairy and creamy flavour in ice cream (Goff and Hartel, 2013). Milk fat globules dispersed in milk usually have a size range of 0.2 to 15 μm (Walstra et al., 2005). Sources of milk fat used in ice cream mix include fresh cream, butter, plastic cream, anhydrous milk fat, and ghee (Arbuckle, 2013). The best source of milk fat is fresh cream separated from fresh milk. It provides the best flavour and easy to be processed due to its liquid trait (Goff and Hartel, 2013). Other dry ingredients including skim milk powder, sugar, stabilisers and emulsifiers can be easily dissolved into the fresh cream. However, fresh cream is likely the most expensive fat source and it also needs special storage because it can easily promote the growth of microorganisms (Goff and Hartel, 2013).

Unsalted butter or sweet butter is another good source of milk fat. It is less expensive than fresh cream, can be transported at low cost, can be stored at 4 °C or lower with little loss of quality (Arbuckle, 2013; Goff and Hartel, 2013). However, the use of butter for ice cream mix usually leads to undesirable freezing properties without proper homogenization and emulsification. Furthermore, butter may bring unpleasant flavour to ice cream. Another major problem of butter is the difficulty to handle and mix it with other dry ingredients because of its solid trait (Goff and Hartel, 2013). It should be melted before being blended into the liquid mix; however, it is difficult to dissolve.

"Plastic" cream which is separated twice from milk is also a source of fat for ice cream mix. It contains about 80% milk fat which is similar with butter (Arbuckle, 2013). It is also stored and handled in the same way with butter (Goff and Hartel, 2013). Anhydrous milk fat (AMF) is another common source of milk fat used especially in those countries without supply of dairy ingredients. Absence of moisture content in AMF makes it easier and cheaper to transport. Other milk fat sources are seldom used (Goff and Hartel, 2013).

None-dairy Fat

Fat from vegetable source is consistently used in the ice cream mix preparation. Vegetable fat has the advantage over milk fat for those who have a vegan preference lifestyle or have lactose intolerant issues and milk protein allergies (Goff, 2006). Furthermore, they are less costly than milk fat. Commonly used vegetable fat includes palm kernel, palm oil, peanut oil, sunflower oil and coconut oil (Clarke, 2005). Five factors can affect the selection of vegetable fat: the rate of crystallization, the crystal structure and the melting profile of fat; the content of high-melting triglycerides; and the flavour and purity of the oil (Goff and Hartel, 2013).

2.1.2.2 Milk solids non-fat (MSNF)

Ice cream has a high concentration of milk solid non-fat (MSNF) which contains lactose, casein micelles, whey proteins, minerals (ash), vitamins, acids, enzymes, and gases of the milk (Goff, 1997). The MSNF contributes significantly to the flavour and texture of ice cream (Goff and Hartel, 2013). Proteins in ice cream mix help to develop the structure in ice cream due to its emulsification, whipping, and water holding capacity. Emulsification properties of proteins in the mix takes place during homogenization as they can adsorb fat globules (Goff et al., 1989). Whipping properties of proteins in ice cream can help to form the initial air bubbles in the ice cream mix. The water holding capacity of proteins can enhance the viscosity in the ice cream mix, thus contributing to the body of the ice cream, increasing the meltdown time of ice cream and reducing iciness (Goff, 1997). Furthermore, the milk proteins have nutritional values containing all the essential amino acids and are important sources of tryptophan and lysine (Clarke, 2015).

Lactose from MSNF adds total solids to the formula, adds sweetness to ice cream as well as contributes to the freezing point depression of other sugars (Clarke, 2015). However, lactose can cause problems to those consumers who are lactose intolerant. Therefore, lactose content should be limited to less than 6-7% in the mix (Goff and Hartel, 2013).

2.1.2.3 Emulsifier

Emulsifiers have been used in ice cream mix manufacture for many years. Emulsifiers can improve the dispersion of fat and uniform distribution of fat particles as well as improve the stability of the emulsion (Goff, 2003). The mechanism of the function of emulsifiers in ice cream may be described as follows: they can lower the interfacial tension of fat/water in the ice cream mix, resulting in protein displacement from the surface of fat globules, thus reducing the stability of the fat globule thereby allowing fat partially coalesced during the whipping and freezing process (Goff, 2003). The formation of aggregated fat structure in the frozen product contributes greatly to the texture and meltdown properties of final products (Goff and Jordan 1989; Goff and Hartel 2013).

Egg yolk was commonly used as the emulsifier in ice cream, but it has since been replaced by the monoglycerides and diglycerides and the sorbitan esters (Clarke, 2015). Figure 2.1 shows that monoglycerides are esters of glycerol with one fatty acid molecule, while diglycerides are esters of glycerol with two fatty acid molecules (Clarke, 2015). Monoglycerides and diglycerides are surface-active with a hydrophilic (glycerol) end and a hydrophobic (fatty acid) end (Clarke, 2015). Mono- and diglycerides are derived from the controlled re-esterification of hydrolysed fats or fatty acids of animal or vegetable origin with an excess of glycerine (Goff and Hartel, 2013). The sorbitan esters differ from the monoglycerides in that they have fatty acids esterified to a sorbitol molecule whereas the monoglycerides have fatty acids esterified to a glycerol molecule (Clarke, 2015). To make the sorbitan esters water soluble, polyoxyethylene groups are attached to the sorbitol (Clarke, 2015). Thus polysorbate 80, the most common of these sorbitan esters used in ice cream manufacture, is polyoxyethylene sorbitan monooleate. Polysorbate 80 is a very active drying agent in ice cream and is used in many commercial stabiliser/ emulsifier blends (Goff, 1988; Marshall and Arbuckle, 1996).

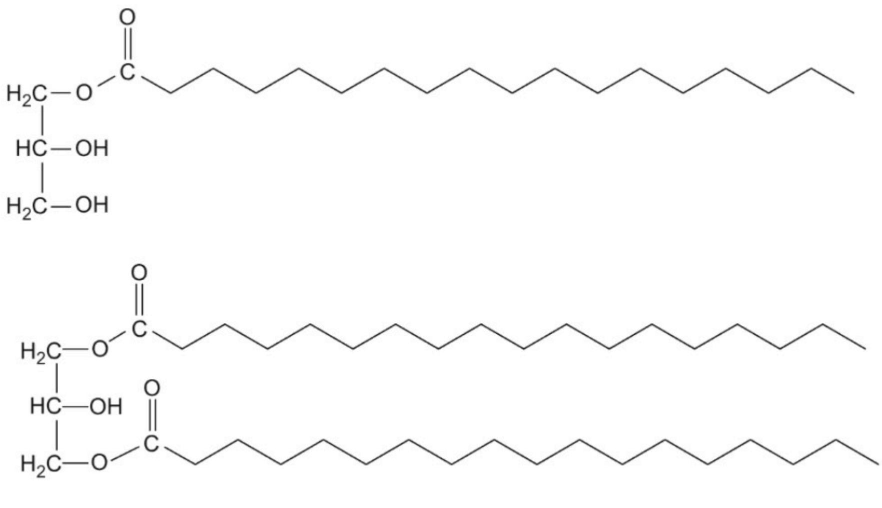


Figure 2.1 The chemical structure of mono-and diglycerides (Clarke, 2015)

2.1.2.4 Sugar/sweetener

Sweeteners have been commonly used in ice cream including cane and beetroot sugars, many types of corn sweeteners, maple sugar, honey, invert sugar, fructose, molasses, malt syrup, brown sugar, and lactose (Clarke, 2015). The main function of sweeteners is to increase sweetness thereby enhancing the pleasing creamy flavour and the delicate fruit flavours (Goff, 2003). Lack of sweetness produces a flat taste; too much tends to overshadow desirable flavours. The desired sweetness of ice cream is approximately 13–16% sucrose in a 36–38% total solids mix (Goff and Hartel, 2013). Apart from imparting sweetness to ice cream, sweeteners once dissolved, can also lower the freezing point of the ice cream mix, which leads to an increased rate of melting (Goff, 1997). In addition, Clarke (2015) reported that sugars have two major functions in ice cream: making it sweet and controlling the ice content which affects the texture of ice cream (the lower the sugar content, the higher the ice content and hence the harder the ice cream).

2.1.2.5 Stabiliser

Stabilisers are a group of ingredients including guar gum (GG), locust bean gum (LBG), carboxymethyl cellulose (CMC), xanthan gum (XG), which are commonly used in ice cream formulations (Clarke, 2015; Goff, 1997). Stabilisers must have a clean and neutral flavour, which do not bind to other ice cream flavours (Bahramparvar & Mazaheri Tehrani, 2011). Despite their natural sources, stabilisers are considered as food additives associated with E numbers under European law. Furthermore, A good stabiliser should be nontoxic and can easily disperse in the ice cream mix without producing excessive viscosity or separation or foam in the mix. A good stabiliser should not block strainers and filters, providing ice cream with desirable meltdown. In addition, a good stabiliser should be economical and not impart off-flavour to the ice cream mix (Bahramparvar & Mazaheri Tehrani, 2011).

Types of stabilisers in ice cream

Many substances have been used as stabilisers. Gelatin, derived from an animal-based protein, was the first ingredient used as stabiliser in ice cream, however it has largely been replaced by polysaccharide hydrocolloids in modern ice cream manufacture (Bahramparvar & Mazaheri Tehrani, 2011). Some of the common stabilisers include gelatin, guar gum, odium carboxymethyl cellulose, locust bean gum, carrageenan, xanthan, alginates, and microcrystalline cellulose (Bahramparvar & Mazaheri Tehrani, 2011). Most ice cream manufacturers use commercial stabiliser/emulsifier blends. These blends usually are combinations of stabilisers and emulsifiers. Most frequently used ingredients in mixtures for regular ice cream are guar gums and locust bean gums (LBGs), cellulose gum (the primary hydrocolloids), carrageenan (the secondary hydrocolloid), mono/diglycerides, and polysorbate 80 (the emulsifiers) (Clarke, 2015). The amount and type of stabiliser/emulsifier blend needed in ice cream varies with mix composition, ingredients used, processing times, temperatures, pressures, storage temperature and time, and many other factors (Clarke, 2015). Usually 0.2–0.5% of a stabiliser/emulsifier blend is used in the ice cream mix. Excessive use of stabiliser may lead to gumminess in ice cream (Goff, 1997).

Functions of stabilisers in ice cream

Stabilisers are primarily used to reduce ice crystal growth during storage especially when temperature fluctuates (Goff and Hartel, 2013). Further, stabilisers prevent ice cream from melting, thus prolonging its shelf-life which is achieved by interacting with water (Goff and Hartel, 2013). Similarly, according to Parvar and Goff (2013), stabilisers in ice cream impart specific and important functions, such as increasing the viscosity of the ice cream mix, enhancing smoothness, improving aeration of air cells, reducing ice recrystallization, and reducing the rate of structural collapse during melting. In the same lane, stabilisers are added to ice cream formulation to gain some purposes such as increase in viscosity, smoothness production in body and texture, reduction in ice and lactose crystal growth during storage, providing some degree of shape retention during melting and enhancement in air entrapment (Kot et al., 2021).

2.2 Global production and consumption of ice cream

2.2.1 Global production

Global production of ice cream was presented Table 2.2, increasing from about 15 billion litres in 2006 to over 16 billion litres in 2010. In 2010, 31% of the global production was in Asia Pacific, 29% in North America, 20% in Western Europe, 7% in Eastern Europe, and 6% in Latin America. The USA was the largest producer at 4.4 billion litres, followed by China at about 2.9 billion litres, Japan at just under 0.9 billion litres, Germany at 0.65 billion litres, and Italy at 0.6 billion litres, respectively (Euromonitor, 2011; Goff et al., 2013).

Table 2.2 Global production of ice cream from 2006- 2010 (million L) (Goff et al., 2013)

Country	**2006**	**2007**	**2008**	**2009**	**2010**
World	15,370.0	15,678.8	15,742.7	16,001.1	16,347.5
Asia Pacific	4,317.9	4,536.9	4,724.5	4,722.5	4,901.1
North America	4,898.2	4,793.8	4,592.7	4,726.9	4,742.9
USA	4,531.0	4,430.1	4,230.5	4,367.4	4,386.4
Western Europe	3,226.2	3,284.5	3,300.4	3,384.1	3,436.7
China	2,484.7	2,639.0	2,776.1	2,740.2	2,868.6
Eastern Europe	1,131.1	1,158.0	1,147.6	1,111.8	1,128.9
Latin America	874.7	949.9	991.5	1,031.7	1,075.3
Japan	873.9	880.9	887.5	886.1	884.0
Germany	674.3	677.1	659.9	656.1	651.7
Italy	546.1	572.6	561.8	594.2	607.0
Middle East and Africa	491.5	517.7	542.5	570.1	597.6
United Kingdom	495.4	488.1	496.2	515.1	531.7
Russia	555.4	540.8	517.7	505.6	499.1
Australasia	430.4	438	443.4	454	464.9
Australia	362.2	368.9	374.6	385.8	396.1
France	370.5	368.7	369.4	386.9	395.3
Brazil	267.3	310.2	325.4	345.3	369.2
Canada	367.2	363.6	362.2	359.5	356.5
Spain	337.7	342.8	349.3	349.8	350.9
South Korea	266.6	270.1	262.4	263.8	266.2
Turkey	125.8	156.2	179.7	190.9	203.5
India	95.1	115.3	137.6	158.7	183.3
Argentina	135.0	146.5	159.3	169.7	175.6
Ukraine	171.5	185.8	177.9	149.7	164.2
Poland	113.7	123.9	134.8	143.0	152.5
Indonesia	113.6	123.3	135.1	142.7	149.2
Chile	124.5	129.0	132.7	134.0	136.9
Iran	99.3	104.8	110.4	116.9	124.0

2.2.2 Global consumption

Global per capita consumption of ice cream is presented in Table 2.3. Both In 2010 and 2006 Australia ranked firstly at 17.9 L and 17.5, followed by New Zealand at 15.8 L and 16.3 L, the United States at 14.2 L and 15.2 L, Finland at 12.5 L and 12.8 L, Canada at 10.5 L and 11.2 L, and Italy at 10.0 L and 9.3 L, respectively. Many Western European countries fall into the range of 7–10 L per capita. Even though China and Japan were world-leading producers, their per capita consumption was much lower than North America and Western Europe, with Japan at 6.9 L and China at 2.1 L, below the World (2.4 L) in 2010 (Euromonitor data 2011; Goff et al., 2013).

Table 2.3 Global per capita consumption of ice cream from 2006- 2010 (L) (Goff et al., 2013)

Country	2006	2007	2008	2009	2010
Australia	17.5	17.5	17.5	17.7	17.9
New Zealand	16.3	16.3	16.1	15.8	15.8
USA	15.2	14.7	13.9	14.2	14.2
Finland	12.8	12.8	12.7	12.6	12.5
Canada	11.2	11.0	10.9	10.7	10.5
Italy	9.3	9.7	9.4	9.9	10.0
Norway	8.9	9.2	9.4	9.6	9.8
United Kingdom	8.2	8.0	8.1	8.4	8.6
Denmark	8.9	8.7	8.7	8.5	8.4
Chile	7.6	7.8	7.9	7.9	8.0
Germany	8.2	8.2	8.0	8.0	8.0
Sweden	8.0	7.5	7.6	7.7	7.7
Spain	7.7	7.7	7.8	7.7	7.6
Portugal	7.5	7.7	7.8	7.6	7.5
Ireland	7.9	7.6	7.3	7.3	7.2
Japan	6.8	6.9	7.0	6.9	6.9
Slovenia	5.7	6.0	6.2	6.4	6.5
Belgium	6.2	5.9	5.8	6.1	6.3
France	6.1	6.0	5.9	6.2	6.3
Netherlands	5.1	5.2	5.5	5.8	6.1
South Korea	5.5	5.6	5.4	5.4	5.4
Argentina	3.5	3.7	4.0	4.2	4.3
Russia	3.9	3.8	3.6	3.6	3.5
World	2.3	2.4	2.3	2.4	2.4
China	1.9	2.0	2.1	2.1	2.1

2.3 Consumer trends

Consumers prefer products with shorter ingredient list containing natural and familiar ingredients. However, in the traditional manufacture of ice cream, stabilisers are widely used as food additives designated with "E" numbers on the packages (Motyl et al., 2019) to produce products with desirable properties like creamy mouth feel (Goff, 1997). Typical stabilisers include Locust bean gum, guar gum, xanthan gum, and carboxymethyl cellulose. Locust bean gum (E410) is a natural polysaccharide obtained from the seeds of the locusts, also known as the carob tree. It is used mainly in the food industry as a food additive for thickening and stabilising products (Motyl et al., 2019). Guar gum (E412) is an organic chemical compound from the group of galactomannans, for instance, polysaccharides whose main chain is formed from mannose units with side monogalactosyl branches (Motyl et al., 2019). Other hydrocolloids used in the production of ice cream include xanthan gum (E415), carrageenan (E407), alginate (E401), pectin (E440), carboxymethyl cellulose (E466) (Motyl et al., 2019).

Consumers have long been sceptical about the presence of additives with unfamiliar and complex compounds designated with E-numbers on the label of ice cream. Preference is given to simple and natural ingredients which are considered as safer and healthier. Therefore, there is a need to develop ingredients that appeal to consumers to replace the commonly used additives in ice cream and produce products which may be more appealing to consumers. Furthermore, the modern consumers have become increasingly interested to the ingredients of the formulation used in their food. A study by Do Nascimento et al. (2018) reported that the number of consumers who considered the importance of the ingredient list had risen from 3% to 78% between 2011 and 2013. Those researchers also observed that the ingredient list was the second most important factor when choosing a product, after price. Consumers have a strong desire for simple and natural food contributes to the ‘clean label” trend. The demand for “clean label” in ice cream has been increasing rapidly (Motyl et al., 2019). Therefore, these trends have created opportunities for using natural and familiar ingredients to replace conventional stabilisers in ice cream. Chia seed is a super food ingredient and has long been used in the kitchen by people. Chia seed gel extracted from chia seed is a rich source of dietary fibre. It is a polysaccharide which has a good water-absorption and water retention capacity, which gives chia seed gel the potential of replacing commercial stabilisers to keep the quality of ice cream (Campos et al., 2016).

2.4 Manufacture of ice cream

Figure 2.2 summarizes the processing procedures for ice cream. The manufacture of ice cream consists of two main stages: mix preparation and freezing operation (Goff and Hartel, 2013).

In mix preparation, several important procedures are included as follows: weighing, blending, sterilization/pasteurization, homogenization, cooling and aging. For blending the raw materials, a mixing tank with heating capability and a high shear mixer is usually used (Figure 2.3) (Goff and Hartel, 2013). Dry ingredients are usually pre-blended and then added through a high shear venture mixer to ensure proper mixing and avoid the formation of lump in the mix (Clarke, 2015). After blending, the mix is homogenized and pasteurised. Pasteurisation not only destroys the pathogenic bacteria but also melts the fat in ice cream mix (Goff, 1997). Homogenization is responsible for formation of the fat emulsion by forcing hot mix through a small orifice under moderate pressure (Clarke, 2015). Homogenization can reduce average fat globule diameter from 3.3 to 0.4 μm and increase the number of fat globules. After mix manufacturing and before freezing, an aging time of more than 4 hours at 2-4 °C is recommended (Clarke, 2015). Aging contributes to the hydration of milk proteins and stabilisers (some viscosity increase occurs during the aging period), crystallization of the fat globules, and a rearrangement of molecules at the interface of fat globules, to produce a product with a smoother texture and better quality (Goff and Hartel, 2013).

After aging, the ice cream mix is transferred into a freezer and freezing operation begins. A typical freezer used is a continuous batch freezer (Hartel, 1996). The freezing operation includes two different stages: (1) passing mix through a swept-surface heat ex-changer under high shear stress conditions to promote extensive ice crystal nucleation and air incorporation, and (2) freezing the packaged ice cream under conditions that continue to promote rapid freezing and small ice crystals (Goff, 1997).

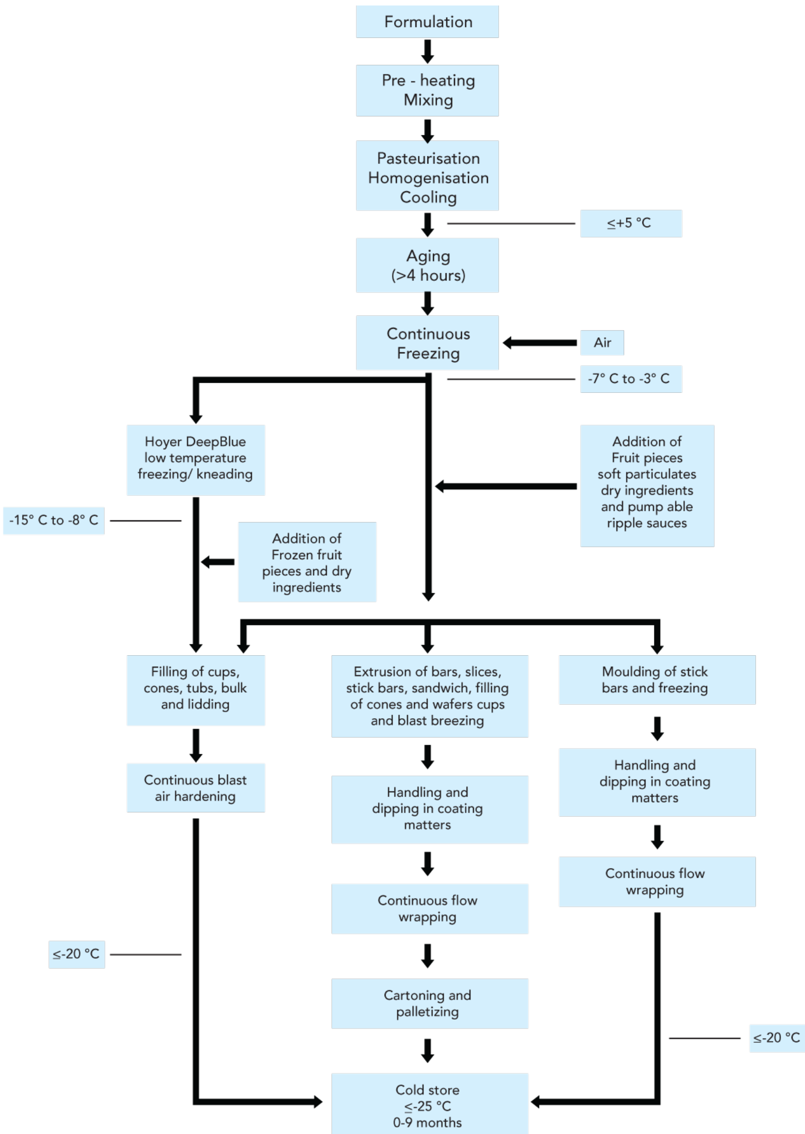


Figure 2.2 Overview of the processes involved in ice cream manufacture (Brennan and Grandison, 2012)

Figure 2.3 A high shear blender for incorporating dry ingredients into ice cream mix (Goff and Hartel, 2013)

2.5 Structure of ice cream

Ice cream is made from ice cream mix, which is a complex food colloid that consists of air bubbles, fat globules, ice crystals and an unfrozen liquid phase (Figure 2.4) (Goff, 1997). Aged ice cream mix consists of casein micelles, partially crystalline fat globules and mixed membrane of protein and emulsifier (Figure 2.5). During the freezing process, the structure of ice cream mix can change dramatically as shown in Figure 2.5. The changes are caused by the formation of ice crystals, the destabilisation of fat globules and the incorporation of air cells. Those bigger aggregates are surrounded by ice crystals, thus forming a stable emulsion. Similarly, according to Goff et al. (2013), ice cream is undoubtedly one of the most complex food products, which has multiple phases influencing the quality and attributes of final product. The formulation of ice cream mix is also complicated and commonly includes ingredients: water, fat, milk solids-not-fat (casein micelles, whey proteins, lactose, and milk salts), sugars, stabilisers, and emulsifiers. Air content is subsequently incorporated during the dynamic freezing of ice cream mix. All of these contribute to the structural elements in ice cream. Therefore, the structure of the final ice cream can be affected by several factors including the size of air cells, ice crystal size and fat globule size distribution (Goff and Hartel, 2013).

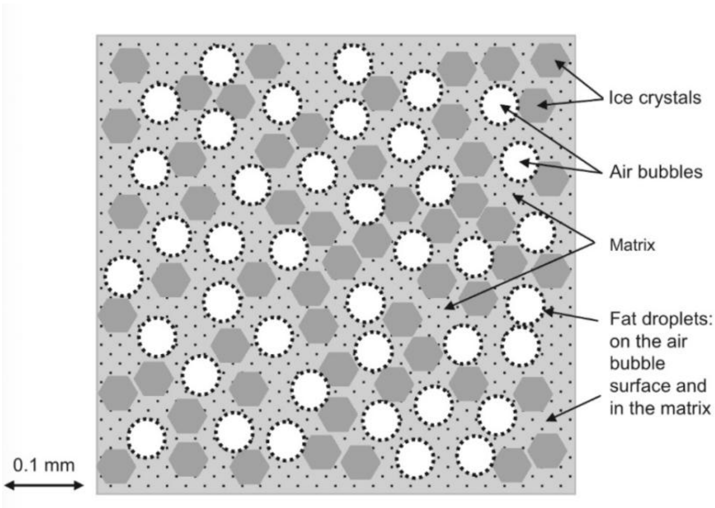


Figure 2.4 Micro-structure of ice cream under direct microscopy (Clarke, 2015)

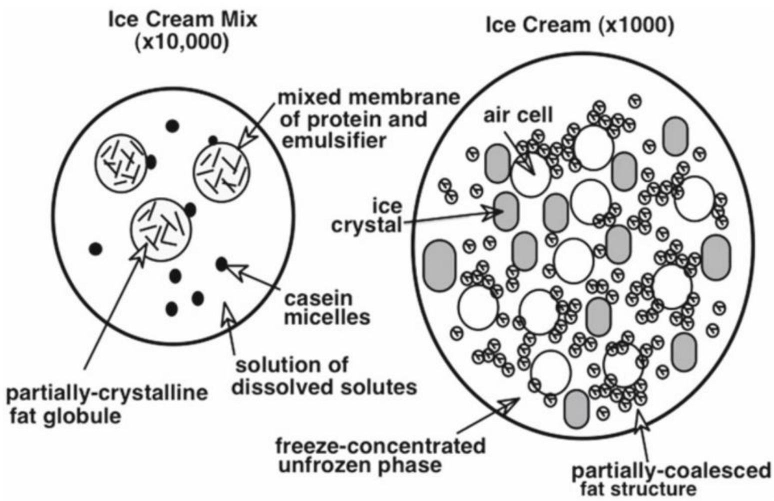


Figure 2.5 Illustration of the structure of ice cream mix and ice cream (Goff and Hartel, 2013)

2.5.1 Air cells

Air plays an important role in the structure of ice cream. Air cells are formed in the freezing process when air is incorporated. The size of air cell in cream has a wide range shown in Figure 2.6. The mean size of air bubbles is usually in the range of 20-50μm (Goff and Hartel, 2013). The air bubbles are usually partially coated with fat globules (Goff, 2003).

The air content of ice cream is measured by overrun, which is defined as the increase in volume during freezing resulting from aeration (Goff and Hartel, 2013). The increase in air incorporation usually occurs during the batch freezing process, which results in an increase in product volume within the freezer. Overrun is calculated by measuring the weight of ice cream and ice cream mix in a cup of known volume (Chang and Hartel, 2002). The overrun of ice cream typically varies from 30%-140% (Goff, 1997; Goff and Hartel, 2013).

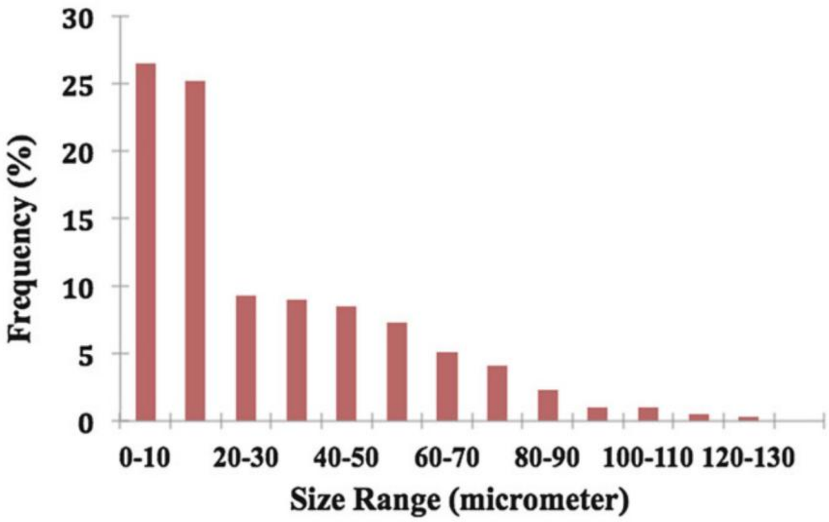


Figure 2.6 Air cell size distribution in ice cream (Goff and Hartel, 2013)

Air cell size distribution can affect the structure of ice cream. It is desirable that the size of air cell is smaller and evenly distributed in ice. Freezing was essential for the stabilisation of small air cells. Several factors can affect the air cell size distribution: the operation conditions in the freezer, the formulation of ice cream mix and the addition of stabiliser (Chang and Hartel, 2002).

Similarly, Sofjan and Hartel (2004) also reported that there are numerous factors affecting the development of air cells in ice cream. Upon freezing, shearing forces in the freezer break larger air bubbles into smaller ones (to break air cells down into small sizes, a high local shear stress is usually required). The mixing impeller and the apparent viscosity of the ice cream mix can affect the shear stress (Sofjan and Hartel, 2004).

As new air cell surface is formed during the freezing process of ice cream mix, it must be stabilized in some way to prevent coalescence (Sofjan and Hartel, 2004). Under electron microscope, the interface of air cells clusters numerous fat globules (Figure 2.5) (Goff and Hartel, 2013). The partially coalesced fat forms a network within the freeze-concentrated unfrozen phase, separating the air cells and keeping them from recombination. The air cells is also stabilised by the presence of ice crystals and a viscous liquid phase (Sofjan and Hartel, 2004).

2.5.2 Ice crystals

Ice crystallization

Ice crystals are formed from water during the freezing process of ice cream mix (Adapa et al., 2000). Normally, the mean ice crystal sizes ranged from 28.7 to 37.2 μm for all ice creams (Warren and Hartel, 2018). The maximum mean size of ice crystals was about 50 μm (Goff, 2013). The average size and distribution of ice crystals significantly affect the smoothness and tasting of ice cream. The freezing operation is critical in producing mostly small crystals, contributing to a smooth texture of ice cream (Goff and Hartel, 2013). The freezing point of ice cream mix is critical in producing a qualified ice cream. The freezing point should be high enough to form adequate and small ice crystals. If the freezing point is too low, a certain percentage of water in ice cream mix is frozen, thus increasing the effects of heat shock when temperature fluctuates during storage (Adapa et al., 2000), which may bring coarse texture to the final ice cream. Therefore, a proper freezing point of ice cream mix is suggested.

The freezing point of an ice cream mix depends largely on the formulation of ice cream mix (Adapa et al., 2000). Ingredients in ice cream mix can affect the freezing point: lactose, sweeteners, salts, and stabilisers (Moore & Shoemaker, 1981).

Ice recrystallization

In ice cream, ice crystals are extremely close together, mostly separated by within 10 µm. If ice crystals average 30–40 µm and are separated by within 10 µm, clearly neighbouring crystals can influence each other. Specifically, the region between two ice crystals becomes a region of instability, leading to formation of a bridge or neck between the two crystals (Clarke, 2015). Once a neck has formed between two crystals, recrystallization is prone to happen (Figure 2.7) (Goff, 1997).

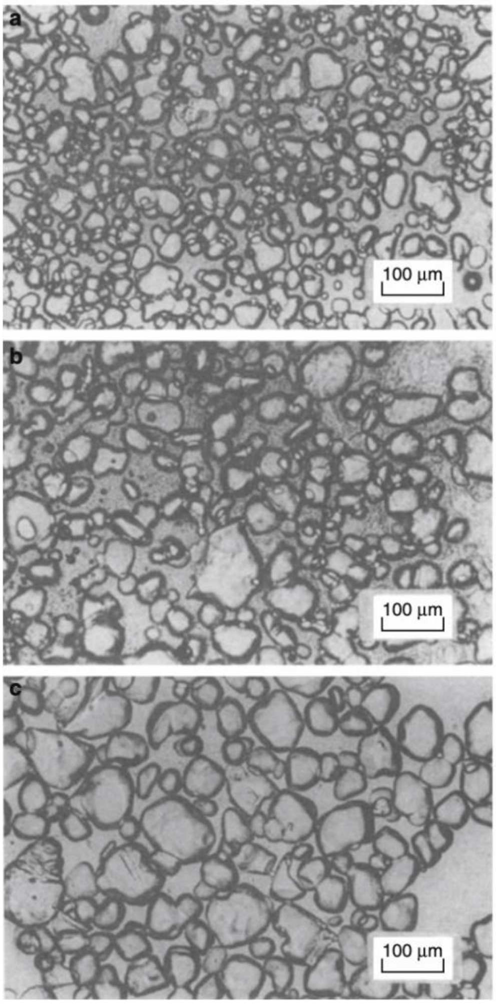


Figure 2.7 Photographs of ice crystal size during different storage time

a) day 1; b) day 22; c) day 200 (Goff, 1997)

Recrystallization means any change in the number, size, shape, orientation, or perfection of crystals following completion of initial solidification" (Goff, 1997). Ice recrystallization usually happens during the storage time of ice cream. The storage temperature can affect the rate of recrystallization. Higher temperatures lead to higher rate of recrystallization (Adapa et al., 2000). The reason is: the amount of unfrozen water in the ice cream at higher temperatures is greater and results in increased recrystallization (Adapa et al., 2000). There are several types of recrystallizations depending on the storage conditions. Recrystallization may lead to an overall increase in mean ice crystal size during storage. When the increase in ice crystal size reaches some point, a coarse texture in the ice cream may be tasted by consumers (Goff and Hartel, 2013). Therefore, when storing ice cream, the conditions should be strictly controlled to avoid bad recrystallization.

2.5.3 Fat globules

Fat is key to the structure of ice cream. Fat globules in the ice cream mix undergo partial coalescence during freezing, which leads to the formation of fat aggregates or partially coalesced fat. The state of dispersion of fat is significant to the stable structure of ice cream (Goff, 2003). The extent of agglomeration of fat can affect the meltdown rate significantly (Warren and Hartel, 2018). The meltdown rate decreases as the extent of agglomeration of fat increases (Warren and Hartel, 2018).

Fat globule size distribution (FDSD) shows the change of fat globule size, which provides information on the extent of agglomeration of fat. The FDSD is affected by several factors including the dasher speed, draw temperature and the addition of emulsifiers and stabilisers (Koxholt et al., 2001; Warren and Hartel, 2018). The agglomeration and partial coalescence of fat globules result from the damage of fat globules which is caused by the shear forces in combination with ice crystallization in the freezer (Koxholt et al., 2001). An illustration of partial coalescence and the change of fat structure is shown in Figure 2.8. During the freezing of ice cream mix, the membrane of fat globules was broken and coalesced partially. Afterwards, those partially coalesced fat move to the interface of air cells and forms a more complex 3-D fat network in ice cream (Goff, 1997). This complex 3-D structure can be stabilised by the addition of stabilisers (Clarke, 2015). The agglomeration of fat globules changes the fat globule size distribution; therefore, the extent of destabilized fat can be determined by the comparison between fat globule size distribution of ice cream mix and ice cream (Goff, 1997).

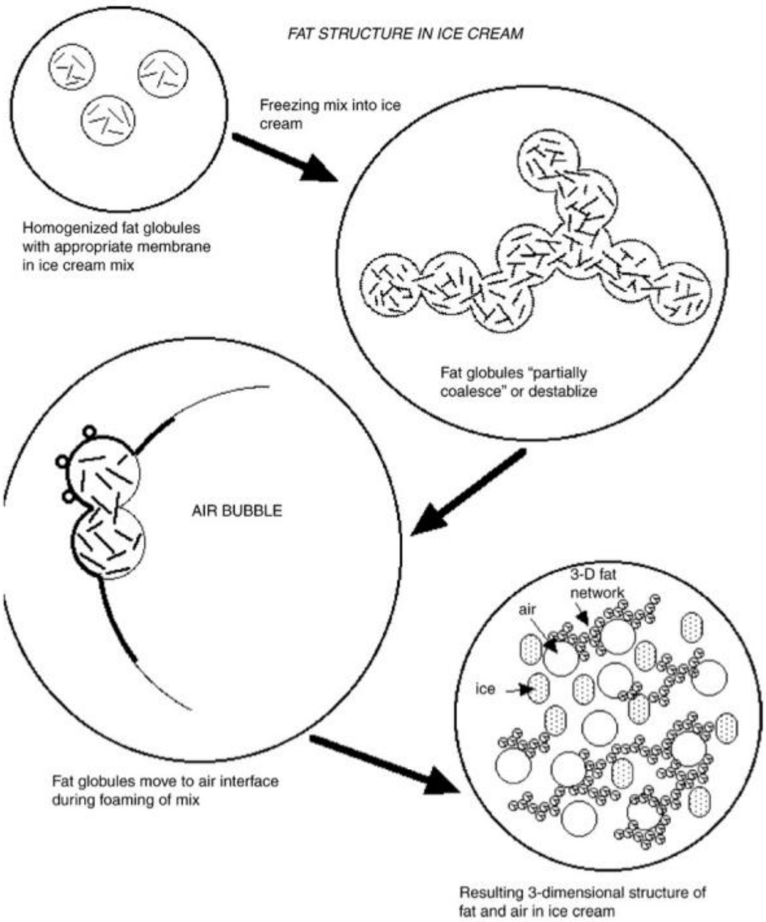


Figure 2.8 The development of fat structure in ice cream (Goff, 1997)

The size of fat globules in ice cream mix may affect the emulsion ability of ice cream. When the fat globules in the mix are very large, excess churning of fat may occur during the process of freezing (Goff and Hartel, 2013). The mean diameter of fat globules in the ice cream mix should be no more than 1μm and the distribution should be within 2-3 μm. Larger distribution sizes (>3μm) may result from improper homogenization (Clarke, 2015). The mean diameter of fat globules in the ice cream, however, is much larger than that in ice cream mix. Therefore, multi-peaks are usually observed on the graph of fat globule size distribution of ice cream (Goff, 1997).

2.6 The chia plant and seed

2.6.1 Background

Chia, known as Salvia hispanica L., is an annual herbaceous plant, originated from Southern Mexico and Northern Guatemala (Falco et al., 2017; Hrncic et al., 2019). It belongs to the genus Salvia (Hrncic et al., 2019), consisting of approximately 900 species, which have been widely distributed for thousands of years worldwide and its name comes from the latin word "salvere" (Falco et al., 2017; Hrncic et al., 2019). Nowadays, some species are still used due to their high nutritional values. Chia plant produces white and purple flowers with 3 to 4 mm diameter. The picture of chia plant is shown in Figure 2.9. It is important to mention that the plant itself can produce 500 to 600 kg seed/acre under appropriate agronomic conditions (Hrncic et al., 2019).

Figure 2.9 Chia plant

Source: https://www.pinterest.nz/pin/564920347009510808/

Chia seed is the product of chia plant and generally very small, the shape is oval, the size is usually 2mm long, 1-1.5 mm wide, and less than 1mm thick (Figure 2.10) (Hrncic et al., 2019; Melo et al., 2019; Munoz et al., 2012). The coat colour of commercialized chia seed today ranges from black, grey, or black spotted to white (Falco et al., 2017; Hrncic et al., 2019). Fibre is one important component in chia seed, consisting of two main fractions- insoluble fraction and soluble fraction (Falco et al., 2017). The soluble fraction can be used as stabiliser in food applications due to the physical properties of water-retaining capacity and viscosity. There is no big difference in the chemical composition between genotypes of chia seed whether they are black-spotted or white seeds, containing 16.9% protein and 32.6% fibre, 16.5% protein and 32.4% fibre, respectively. Environmental conditions and agricultural methods affect the chemical compositions in chia seed (Falco et al., 2017).

Figure 2.10 Chia seed

Source: bonappetit.com/test-kitchen/ingredients/article/chia-seeds

2.6.2 Chemical composition of chia seed

The chemical composition of chia seed has been studied in previous studies (Falco et al., 2017; Hrncic et al., 2019; Kulczynski et al., 2019; Melo et al., 2019). Basic content of chia seed includes carbohydrate, lid, protein, mineral, water and others shown in Figure 2.11 (Kulczynski et al., 2019). Chia seed contain a high content of fats (30-33%), protein (15-25%), carbohydrates (26-41%), dietary fibre (18-30%), ash (4-5%), minerals, vitamins and a high number of natural antioxidants (wet basis) (Falco et al., 2017; Hrncic et al., 2019; Melo et al., 2019).

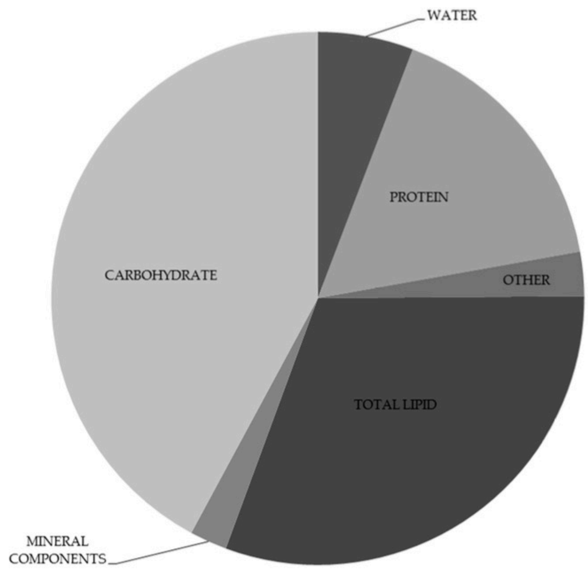


Figure 2.11 Basic content of chia seed (Kulczynski et al., 2019)

2.6.2.1 Lipids

Oil contents in chia seed range from 25%-40% (Melo et al., 2019). 60% of the oil contents is Ω-3 α-linolenic acid (ALA) and 20% is Ω-6 linolenic acid (LA), which are both polyunsaturated essential fatty acids (PUFA) (Melo et al., 2019). Dinçoğlu and Yeşildemir (2019) reported that chia oil has the highest content of α-linolenic acid among all the recognized natural sources. The ALA plays an important role in human's health: it lowers the levels of triglyceride and cholesterol, it has the properties of anti-inflammatory and anti-diabetic, and it prevents from arthritis and even cancer (Melo et al., 2019). The fatty acid composition of chia seed in different studies is summarized in Table 2.3.

Table 2.4 The fatty acid composition (%) of chia seed in different studies (Dinçoğlu and Yeşildemir, 2019)

Parameter	da Silva Marineli, 2014	Martinez, 2015	Timilsena, 2016	Jin, 2012	Reyes-Caudillo, 2008	Chicco, 2009	USDA, 2015
Palmitic acid (16:0)	7.07	7.46±0.12	6.21±0.05	-	6.89	6.60	2.17
Heptadecanoic acid (17:0)	0.07	0.13±0.01	-	-	-	-	0.06
Heptadecenoic acid (17:1)	0.03	-	-	-	-	-	0.00
Stearic acid (18:0)	3.36	2.98±0.07	1.89±0.01	-	2.36	2.80	0.91
Oleic acid (18:1)	7.04	7.18±0.12	5.68±0.05	-	6.73	6.80	2.20
Linoleic acid (18:2)	18.23	20.1±0.13	21.46±1.24	6.16	22.5	18.60	5.84
Linolenic acid (18:3)	62.80	61.8±0.38	64.39±2.31	16.40	60.35	64.60	17.83
Total saturated fatty acid	11.12	-	8.5	5.00	9.26	12.04	3.33
Total polyunsatu-rated fatty acid	81.59	-	85.85	22.80	82.85	83.20	23.67
Total monounsatu-rated fatty acid	7.29	-	5.68	2.96	-	7.44	2.31
n-6/n-3	0.29	0.33	0.33	0.32	0.37	0.29	0.33

2.6.2.2 Protein and amino acids

Chia seed is a rich source of both protein and amino acids compared with other conventional plant grains such as wheat and corn. In one study, the protein content in chia seed ranges from 15-25% (Dinçoğlu and Yeşildemir, 2019). 42% of basic amino acids are essential amino acids such as glutamic acid (Dinçoğlu and Yeşildemir, 2019; Melo et al., 2019). The amino acid composition of dried chia seed is shown in Table 2.4.

Table 2.5 The amino acid composition of chia seed (Dinçoğlu and Yeşildemir, 2019)

Amino Acid (g/100 g)			
Arginine	2.143	Phenylalanine	1.106
Glutamic Acid	3.500	Tyrosine	0.536
Threonine	0.709	Histidine	0.531
Tryptophan	0.436	Valine	0.950
Isoleucine	0.801	Alanine	1.044
Leucine	1.371	Glycine	0.943
Methionine	0.588	Aspartic acid	1.689
Lysine	0.970	Proline	0.776
Cystine	0.407	Serine	1.049

2.6.2.3 Dietary fibre

Total dietary fibre (TDF) in chia seed is higher than that of many other vegetables and fruits such as carrot, spinach, banana and apple, ranging from 23% to 41% (Dinçoğlu and Yeşildemir, 2019; Melo et al., 2019). Total dietary fibre has been an important part of the diet in human's daily life due to its physiological properties of swelling after water absorption (Falco et al., 2017). The TDF consists of two parts-insoluble fraction and soluble fraction, which is about 85% and 15% in chia seed respectively (Melo et al., 2019). Dinçoğlu and Yeşildemir (2019) also reported that insoluble fibre constituted the most content of the total dietary fibre in chia seed, which is 53.45g/100g.

2.6.3 Application of chia seed in food industry

Chia seeds can absorb a large amount of water and forms a stable seed water aqueous suspension, which provides food with consistent characteristic (Kulczynski et al., 2019). In addition, the emulsifying effect of chia seed has also been found in previous studies (Kulczynski et al., 2019; Falco et al., 2017; Melo et al., 2019). Therefore, chia seed can be applied and incorporated in many foods due to its nutritional and physicochemical properties.

2.6.3.1 Use in bakery products

The fibre fraction in chia seed has higher water holding, water absorption, emulsifying and emulsion stability than fibre source in other plant seed such as soybean and wheat (Dinçoğlu and Yeşildemir, 2019). Therefore, it can be used in bakery products such as bread and cookies because water holding, absorption and emulsion capacity are important features in those food products (Dinçoğlu and Yeşildemir, 2019). Moreover, breads enriched with chia seed fibre can increase the feeling of satiety of consumers, thus preventing diabetes and obesity (Dinçoğlu and Yeşildemir, 2019). Coelho and Salas-Mellado (2015) studied the addition of chia seed or chia flour in breads and reported that breads with chia seed or chia flour had higher ratio of polyunsaturated fatty acids (PUFA) to saturated fatty acids (SAT) than that of breads without chia seed or chia flour. In addition, chia gel can be used as egg or oil re-placer in cakes, which improved the sensory attributes of the baked products (Borneo et al., 2010; Gallo et al., 2020).

2.6.3.2 Use in animal products

Due to the physicochemical properties of chia seed as well as being a healthier lipid source, chia seed can be used as animal fat re-placer in the production of healthy meat products (Dinço ğlu and Yeşildemir, 2019). They reported that sausages produced with added chia seed had higher protein content than sausages without chia seed. Furthermore, chia oil and its by-products can also be used in animal feed industries to obtain animal products enriched with polyunsaturated fatty acids (Coates and Chia, 2009). They revealed that the n-3 quantities of egg and pig meat increased with the addition of chia seed in chicken and pig feed. In addition, in a study on rabbits feed with the addition of chia seed by Giorgio et al. (2008), the α-linolenic acid of rabbits' meat increased with the introduction of chia seed in the feed.

2.6.3.3 Use in other foods

In addition to the use of chia seed in bakery and meat products, chia seed oil can also be manufactured as omega-3 oil capsules to prevent chronic diseases related to diet (Falco et al., 2017). Moreover, chia oil can replace other oil such as soy oil or cream in bakery food products to increase polyunsaturated essential fatty acids in human's daily diet, which is rich in Ω-6 and saturated fatty acids (Melo et al., 2019). Apart from bakery and meat products, chia oil can also be used in sports drinks, cornflakes and chocolate.

The incorporation of whole chia seed flour in bread can increase its nutritional values with higher lipid, protein and fibre content (Melo et al., 2019). Furthermore, chia seed can be used in commercial marmalade and sources due to its gelling properties (Dinçoğlu and Yeşildemir, 2019). In addition, gum can be extracted from the dietary fibre fraction of chia seed and chia seed gum /gel has been studied to determine its potential use in food additives in some food products such as ice cream (Chavan et al., 2017; Campos et al., 2014).

2.7 Chia seed gel

When soaking chia seed in water, the chia seed can absorb 27 times its weight of water and forms a colloidal aqueous suspension (Bochicchio et al., 2015) (Figure 2.12). A layer of mucilaginous gel can be extracted from the colloidal aqueous suspension (Campos et al., 2016). Due to its water absorption and retention capacity, chia seed gel can form suspensions with a high viscosity, showing the potential of being used as the emulsifier and stabiliser in foods (Silva et al., 2022).

Figure 2.12 Chia seed gel

Source: https://elizabeth-reninger.com/cranberry-chia-chutney/

2.7.1 Extraction of chia seed gel

The extraction of chia seed gel has been found in previous studies (Campos, 2016; Feizi et al., 2021; Munoz et al., 2012; Tavares et al., 2018; Timilsena et al., 2015). Two extraction methods- hot and cold extraction of chia seed gel were developed by Tavares et al. (2018) (Figure 2.13). The process of chia seed gel extraction commonly includes immersion of seed, stirring the suspension, separating gel from seed and drying the gel. Typically, parameters analysed for the extraction of chia seed gel are apparent viscosity, yield and total soluble solids.

In one study by Munoz et al. (2012), the chia seed mucilage was localized in cellular structures in the first three layers of the seed coat and upon full hydration filaments (mucilage fibres) became apparent and conformed to a transparent “capsule” attached to the seed. To study the effect of chia seed gel extraction, different seed: water ratios (1:20 and 1:40), pH (4-8) and extraction temperature (4-80 ℃) were applied. Finally, the optimum yield obtained by them was 7% with an extraction temperature of 80 ℃ and a seed: water ratio of 1:40. Campos et al.

(2016) used an extraction temperature of 80 °C, extraction time 4 h, water: seed ratio 30:1 and achieved an extraction yield of 4.95g/100g. Feizi et al. (2021) carried out the research on the extraction of chia seed gel and got the average extraction yield of 3.4 ± 0.2% (w/w) at extraction temperature of 50 °C with a seed: water ratio of 1:20.

In previous studies, chia seed gel powder was obtained by dehydrating freshly extracted (hydrated) chia seed gel (Campos et al., 2016; Chavan et al., 2017; Feizi et al., 2021; Muñoz et al., 2012; Tavares et al., 2018). Typical dehydrating methods are oven-drying (50 ℃) and freeze-drying (-50 ℃) (Figure 2.13) (Tavares et al., 2018). Campos et al. (2016) and Muñoz et al. (2012) used the hot-air oven to dry the freshly extracted mucilage overnight at 50°C with yields ranging from 5.09% and 6.79%. According to Tavares et al. (2018), oven-drying is associated with changes of the micro-structure of chia seed gel which can affect its stabilising ability. The micro-structure of chia seed gel was examined by scanning electron microscopy (SEM) which showed that the macro molecular network structure formed by fibrous material contained in chia seed gel was maintained in the process of freeze-drying.

Other studies used the freeze-drying method to prepare the chia seed gel powder for nearly 3 days at <50°C with yields ranging from 3.40%-8.46% (Chavan et al., 2017; Feizi et al., 2021).

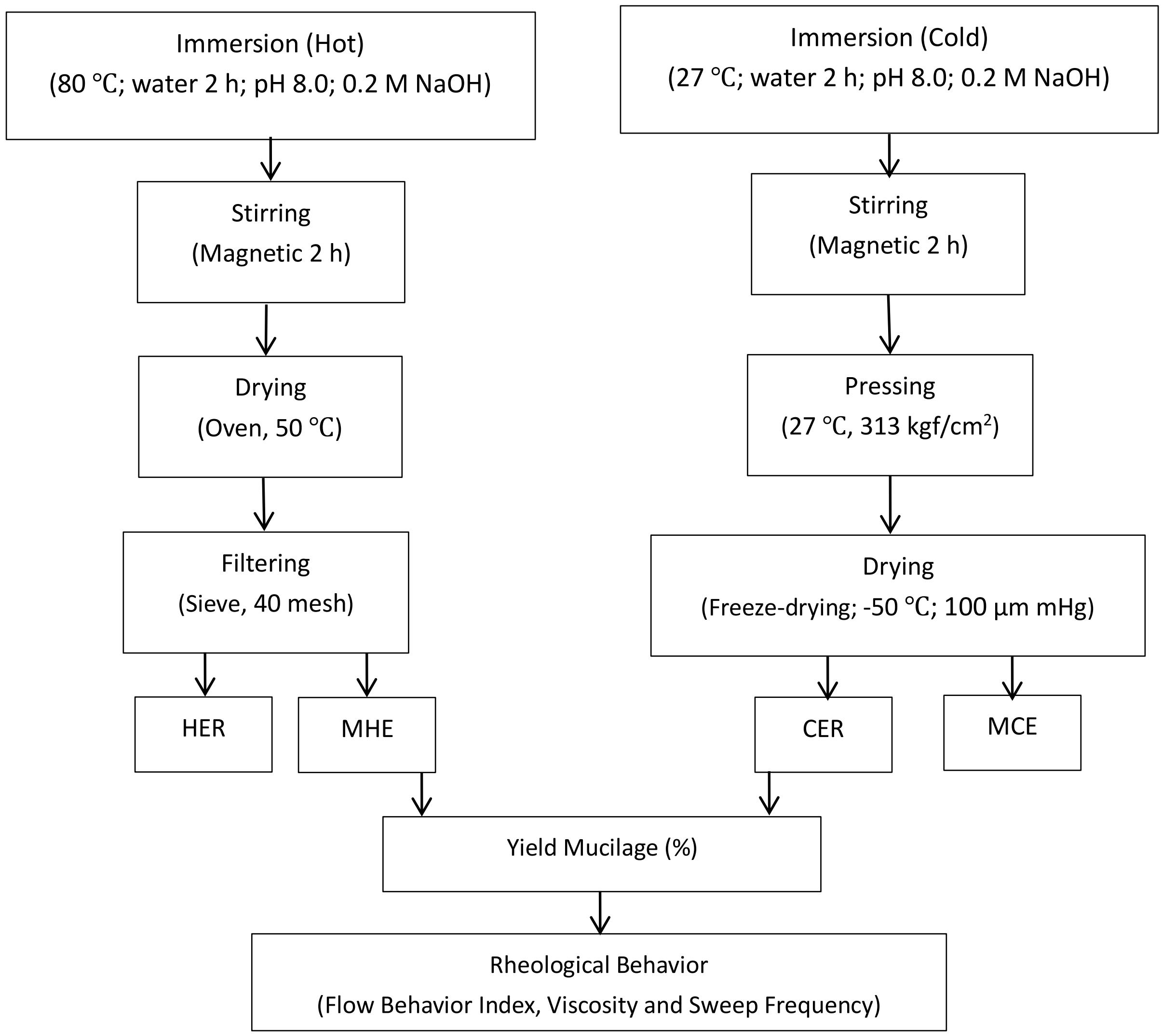


Figure 2.13 Hot and cold extraction of chia seed gel (Tavares et al.,2018)

MHE = mucilage hot extraction; HER = hot extraction residue; MCE = mucilage cold extraction; CER = cold extraction residue.

2.7.2 Micro-structure of chia seed gel

The micro-structure and chemical structure of chia seed gel have been reported in previous studies (Campos et al., 2016; Munoz et al., 2012; Silva et al., 2022).

Chia seed gel was a complex polysaccharide with high molecular weight (0.8–2×10^6 Da)

(Campos et al., 2016). The polysaccharide shows an irregular shape and fibrous micro-gel particles, showing soluble and insoluble fractions, mainly consisting of glucose and xylose (Silva et al., 2022). Munoz et al. (2012) studied the micro-structural features of chia seed gel using light and scanning electron microscope shown in Figure 2.14. The mucilage appeared to be firmly bonded to the seed after being hydrated and was difficult to be separated from seed. The appearance of the gel layer surrounding chia seeds resembles those observed in basil seeds, although basil seeds are slightly larger in size (Munoz et al.,2012).

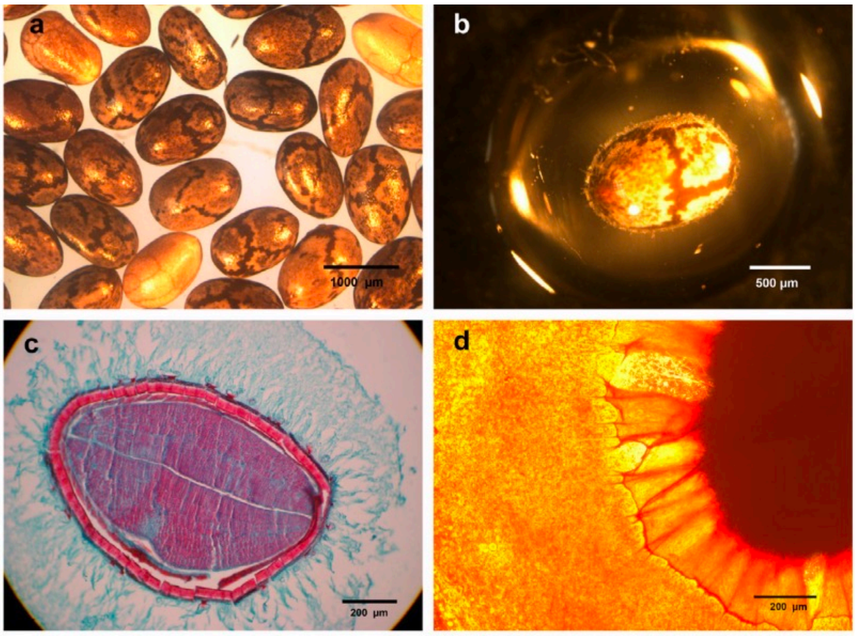


Figure 2.14 Optical images of chia seed
(a) dry seed (b, c, d) hydrated seed (Munoz et al., 2012)

Structurally, chia seed gel is composed of tetrasaccharide repeating units consisting of (→4)-β-d-Xylp-(1→4)-α-d-Glcp-(1→4)-β-d-Xylp units with a substitute of 4-O-methyl-α-d-GlcpA at O-2 position of alternate β-d-Xylp residue (Lin et al.,1994; Samateh et al., 2018). Thus, the proposed repeating unit structure for chia seed gel may be as shown in Figure 2.15. This long linear chain with a high molecular weight contributes to the high viscosity of chia seed gel (Lin et al., 1994).

From the study by Lin et al. (1994), it indicated that 4-O-methyl-D-glucuronic acid was a component of the polymer. In general, polymers with a high molecular weight, anionic charge, and linear configuration can present great abilities to form hydrogen-bond and swell. The chia seed gel polymer showed a higher mucoadhesive activity (Lin et al., 1994).

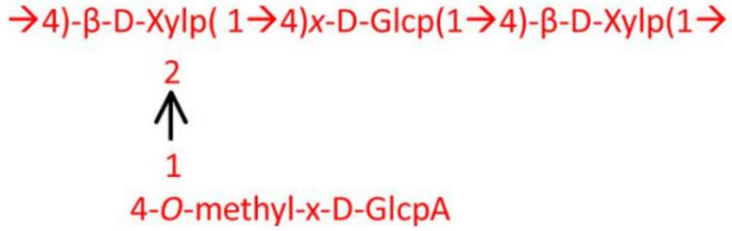


Figure 2.15 Chemical structure of Chia seed gel (Samateh et al., 2018)

2.7.3 Chemical composition of chia seed gel

The chemical composition of dried chia seed gel was determined by Timilsena et al. (2016), including moisture, lipids, protein and carbohydrate content. Table 2.5 shows that the carbohydrate content of CSG was 93.8±0.5% (w/w) with a small amount of protein (2.6± 0.2%, w/w) and traces of lipids (0.6±0.1%, w/w). Similarly, Goh et al. (2016) also found that freeze-dried chia seed gel consisted of 95% non-starch polysaccharides. Of the polysaccharides, 35% (w/w) was the soluble fraction and 65% (w/w) was insoluble fraction. The monosaccharide composition of chia seed gel polysaccharides consisted of glucose, xylose, galactose, mannose, and arabinose (Goh et al., 2016). Timilsena et al. (2015) and Lin et al. (1994) also found those monosaccharide categories in chia seed gel polysaccharides. However, the ratios of the presence of each monosaccharide were different due to the different soil and climate conditions when growing the crops as well as different chia seed gel extraction methods used (Goh et al., 2016).

Table 2.6 Chemical composition of dried chia seed gel (Timilsena et al., 2016)

Constituents	**Quantity (%, w/w)**
Moisture	3.9±0.3%
Total protein	2.6±0.2%
Total ash	0.8±0.1%
Crude fat	0.6±0.1%
Total carbohydrate	93.8±0.5%

±= SD; All measurements are on dry weight basis except the moisture.

2.7.4 Rheological properties of chia seed gel dispersions

Rheology, the study of dispersions, as well as of emulsions, studies the mechanical response of a fluid when stress is applied to it and the flow behaviour and viscoelastic properties of the material (Salva et al., 2022). Fluids that do not present a deformation rate proportional to the shear stress applied on them, also do not have constant viscosity, are called non-Newtonian fluids. The rheological behaviour of non-Newtonian fluids can be expressed by the Ostwald de Waele model (Equation 1). Here τ is the shear stress (Pa); γ is the shear rate (s^{-1}); k is the consistency index ($Pa.s^n$), and n is the flow behaviour index (dimensionless). The fluid is characterised as Newtonian if n = 1, pseudo-plastic if n < 1, and dilatant if n > 1:

$$\tau = k \cdot \gamma^n \qquad (1)$$

Chia seed gel dispersions exhibited non-Newtonian and shear thinning flow patterns at concentrations from 0.05% (w/w) to 0.8% (w/w), at shear rates from 10 to 1000 s^{-1} (Goh et al., 2016), shown in Figure 2.16. These findings partially agree with Capitai et al. (2015) who did not show data at the low concentration of 0.05% (w/w). By studying the reasons of such behaviour of chia seed gel, the polysaccharide dispersion of chia seed gel was unlike typical polysaccharide colloidal dispersions such as guar gum. Instead, the polysaccharide sample of chia seed gel contained a dispersion of micro-gel particles. The strong pseudo-plastic behaviour could then be caused by the presence of these soft micro-gel particles which were highly sensitive to shear rate and rapidly orientate in the direction of the flow even at very low shear rate and concentration (Capitani et al., 2015; Goh et al., 2016 and Timilsena et al., 2015).

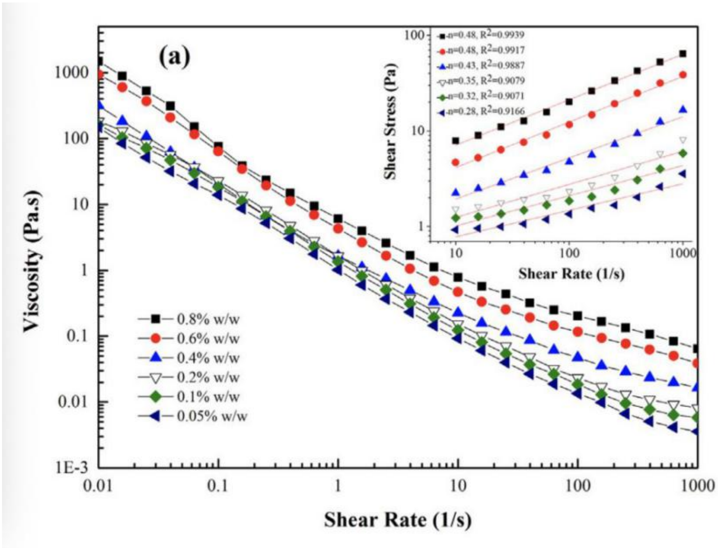


Figure 2.16 Viscosity curves of chia seed gel under different concentrations (Goh et al., 2016)

Except high pseudo-plastic property of chia seed gel, a 'weak gel' structure of chia seed gel polysaccharides was also observed (Goh et al., 2016). The behaviour was caused by the elasticity of the swollen micro-gel particles dispersed in a soluble polysaccharides fraction, thus forming a weak gel network (Timilsena et al., 2015). The gelling behaviour of chia seed gel has been reported in a previous study (Samateh et al., 2018). A hypothesis was elucidated and corroborated by Samateh et al. (2018) that the gelling behaviour of chia seed gel resulted from a nanoscale 3D-network formation, compared to conventional notion that gel formation is due to "coagulation" or "swelling" (Figure 2.17). Samateh et al. (2018) adopted the scanning electron microscope (SEM) imaging and found that an extensive network of nanoscale fibres extended from proximate seeds into all directions at about 4400X magnification (Figure 2.18 i).

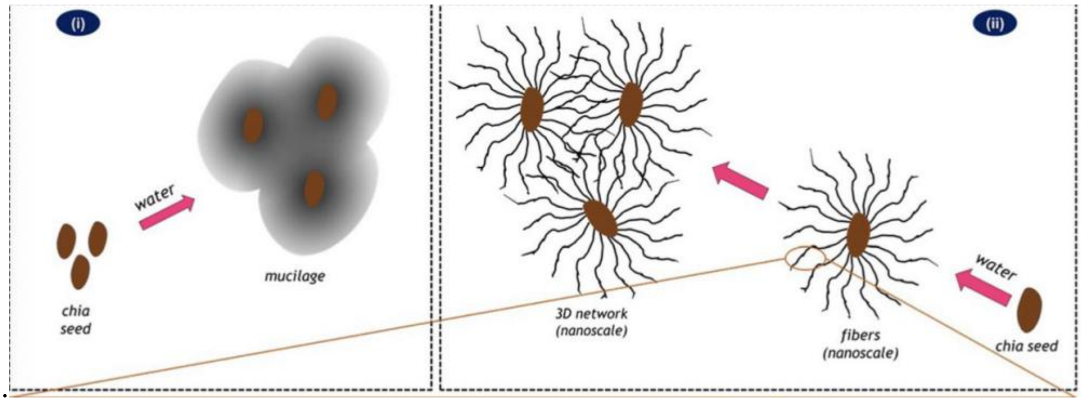


Figure 2.17 Illustration of gelation based on the current notion and hypothesis
(i) Conventional notion: gel formation is merely due to the seeds gel swelling in or coagulating water; (ii) Hypothesis: gel of chia contains nanoscale fibres that extend in water to form 3D network, entrapping and congealing water to form a gel (Samateh et al., 2018)

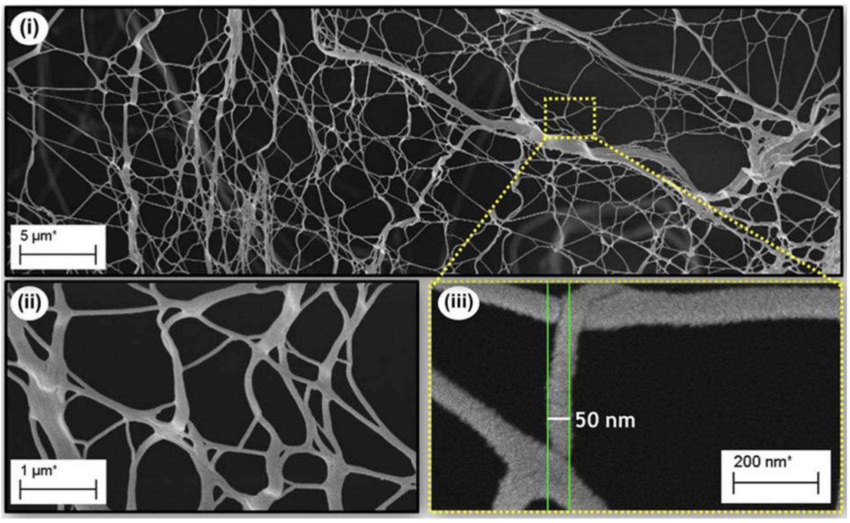


Figure 2.18 SEM micro-graph of gold-coated chia seed fibres

(i) 4,400X magnification, (ii) 30,000X magnification, and (iii) 150,000X magnification (Samateh et al., 2018)

Although the study on the rheological properties of chia seed gel was limited, the study on the rheological properties of basil seed gum was abundant. The dynamic viscoelastic study on the gelation of basil seed gum obtained by Rafe and Razavi (2013) showed similar flow and viscoelastic properties as chia seed polysaccharide. Basil seed gum also swells like chia seed polysaccharide when soaked in water, forming a gel layer surrounding the seeds. Furthermore, Naji-Tabasi and Razavi (2017) reported that basil seed gum could be used as an emulsifying, foaming, thickening, gelling, binding, fat replacing, binding and stabilising agent in food and pharmaceutical industries. It indicates that chia seed gel may have the same functions in food industries.

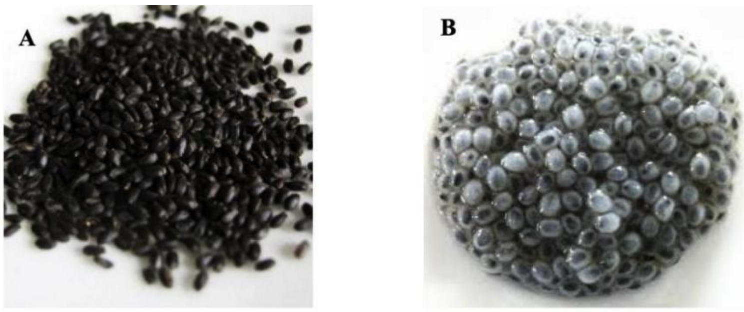


Figure 2.19 Basil seed before (A) and after (B) hydration (Naji-Tabasi and Razavi, 2017)

2.7.5 Applications of chia seed gel in food industry

Chia seed gel has abundant applications in food industries. Timilsena et al. (2015) studied the rheological properties of chia seed gel and found its unique physicochemical characteristics-retaining water and forming hydrogels, which gives its potential use as gelling and thickening agents. Chia seed gel can also be used as texture modifiers, emulsifiers and stabilisers in many food products including ice cream, frozen milk, and even cake (Campos et al.,2016; Felisberto et al., 2015). Silva et al. (2022) also reported that the addition of chia seed gel can increase the overrun and decrease the melting down rate of ice cream (1-4g/1kg chia seed gel). Additionally, Punia and Dhull (2019) found that chia seed gel can be used as fat re-placer in cookies development. Figure 2.20 summarizes some key properties of chia seed gel: food emulsions, technological properties and functional properties. These properties give chia seed gel the potential use in many food products including bakery, ice cream, mayonnaise and meat products.

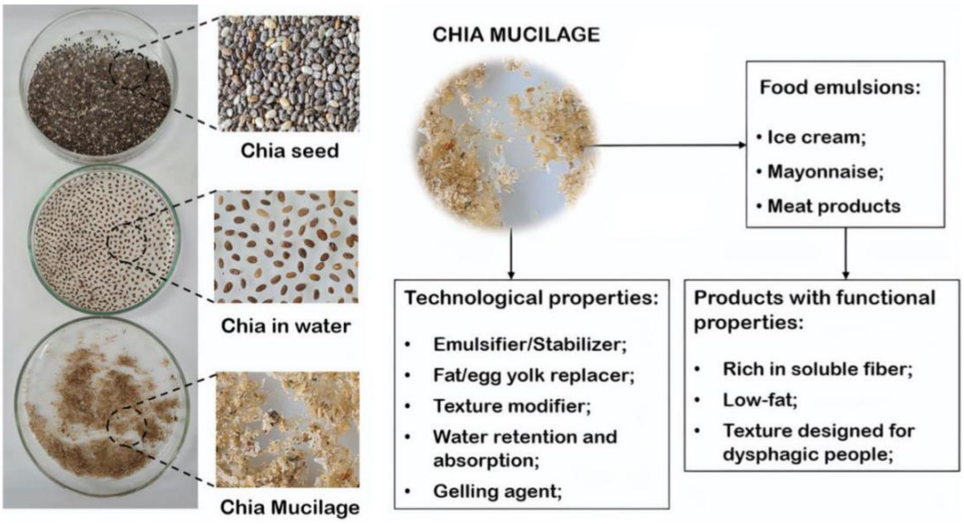


Figure 2.20 Application of chia seed gel/mucilage in food products (Silva et al., 2022)

The stabilising property of chia seed gel in ice cream has been reported in previous studies (Arnak and Tarakci, 2021; Campos, 2016; Feizi et al., 2021; Chavan et al., 2017). Campos (2016) optimised the condition for the extraction of chia seed gel and confirmed the possibility of replacing commercial stabiliser in ice cream by using the chia seed mucilage as the stabiliser and emulsifier in 1-2% (w/w). Chavan et al. (2017) studied the effect of different concentrations of chia seed gel on the physicochemical properties of ice cream and reported that the best concentration was 0.3% chia seed mucilage compared to 0.1%, 0.2%, and 0.4% (w/w). Feizi et al. (2021) also investigated the potential of chia seeds mucilage being used as stabiliser in ice cream and reported that the optimum concentration of chia seed gel in ice cream was 0.2% (w/w). Furthermore, in another study by Arnak and Tarakci (2021), the concentration of chia seed gel should be no more than 0.4% (w/w) if the quality of ice cream wants to be maintained.

Chapter 3 MATERIALS AND METHODS

3.1 Overview of experimental design

The study investigated the potential of using freshly extracted hydrated chia seed gel as stabiliser in ice cream to replace the conventional commercial stabilisers (guar gum and carrageenan). The experiment commenced with the extraction of chia seed gel in stage one. The (extracted) chia seed gel was characterised in stage two, followed by testing the performance of different concentrations of the chia seed gel as ice cream stabilisers. The most promising concentration of chia seed gel to stabilise ice cream was then used to optimise the formulation of ice cream. All the experiments were replicated twice.

The extraction of chia seed gel was based on previous studies (Campos et al., 2016; Feizi et al., 2021; Timilsena et al., 2015) and details of experiments are described in section 3.3.1. After the extraction of the chia seed gel under different conditions, the yield and apparent viscosity of the gel were determined. The yield (%) of the extracted chia seed gel was determined by dividing the weight of dried chia seed gel to chia seed according to previous studies (Campos et al., 2016; Feizi et al., 2021; Timilsena et al., 2015). The apparent viscosity (Pa·s) of chia seed gel was the shear stress applied to it by the shear rate (Campos et al., 2016; Timilsena et al., 2015). To make better comparisons between different samples, the optimum shear stress under shear rate 0.1 S^{-1} of all CSG samples was recorded and analysed in this experiment. Table 3.1 shows the experimental design of the extraction of chia seed gel.

Table 3.1 Optimisation of chia seed gel extraction

Experiment #	Experiment Code	Ratio of CS:water	CS soaking temperature (°C)
1	R_1S_1	1:10	80
2	R_1S_2	1:10	40
3	R_1S_3	1:10	20
4	R_2S_1	1:20	80
5	R_2S_2	1:20	40
6	R_2S_3	1:20	20
7	R_3S_1	1:30	80
8	R_3S_2	1:30	40
9	R_3S_3	1:30	20

R_1S_1-R_3S_3 = Samples of chia seed gel; CS = Chia seed; R = Ratio; S = Soaking; Independent experiments were replicated twice.

Optimisation of ice cream formulation containing different concentrations of chia seed gel was conducted in phase II. The formulations (Table 3.2) and procedures of ice cream production were based on previous studies with some minor modifications (Goff, 1997). Parameters used to characterise ice cream included viscosity of ice cream mix, overrun of ice cream, texture of ice cream, melting down rate of ice cream, fat globule size of ice cream mix and ice cream melts, and sensory evaluation. Figure 3.1 shows the overview of two phases conducted in this study.

Table 3.2 Ingredients (%, w/w) used in ice cream formulation

Formulation #	SMP	Cream	Sugar	MDG	GG	Carrageenan	CSG	Water
C_1	11	27.54	15	0.15	0	0	0	46.31
C_2	11	27.54	15	0.15	0.20	0.15	0	46.11
CS_1	11	27.54	15	0.15	0	0	16.35	29.96
CS_2	11	27.54	15	0.15	0	0	27.25	19.06
CS_3	11	27.54	15	0.15	0	0	37.8	8.51

CSG = chia seed gel (hydrated); MDG = mono/diglycerides; SMP = skim milk powder; GG = guar gum.

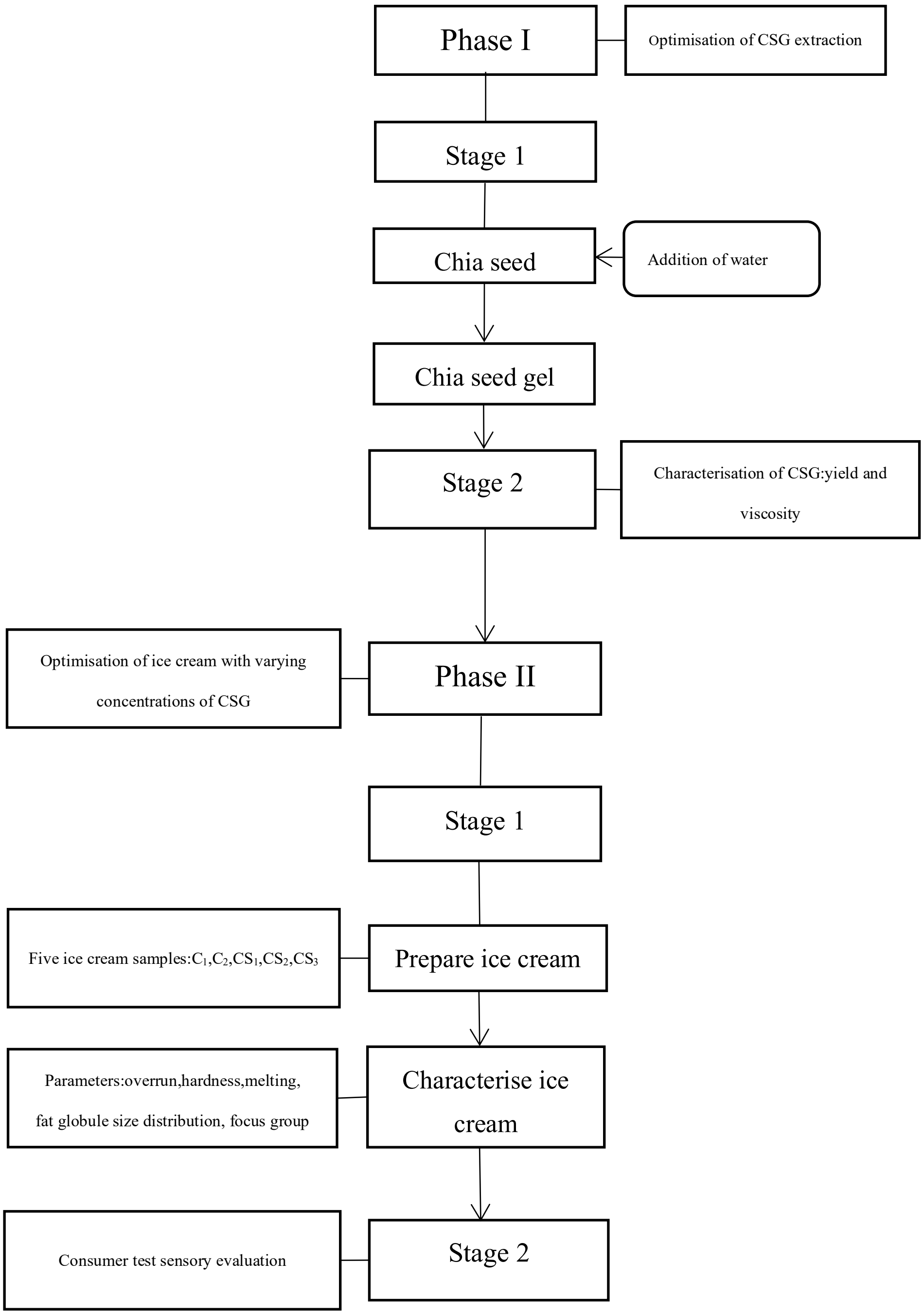


Figure 3.1 Overview of experimental design

CSG = chia seed gel

3.2 Raw Materials

Materials used in this study included skim milk powder (Anchor, Fonterra, New Zealand), pure cream (fat content 36.3%, Anchor, Fonterra, New Zealand), sugar (Pams, New Zealand), stabiliser (guar gum, carrageenan, Hawkins Watts, New Zealand), emulsifier (MDG 0069, Hawkins Watts, New Zealand) and chia seeds (Aotea Road, Auckland, NZ). To get a comparatively clean-label ice cream and to prevent any effects from flavours, other food additives were not added to the formulations**.**

3.3 Optimisation of the extraction of chia seed gel (Phase I)

3.3.1 Extraction of chia seed gel

The extraction of chia seed gel (CSG) was conducted based on previous studies with some modifications (Campos et al., 2016; Feizi et al., 2021). Chia seeds (Salvia hispanica L.) (50 g) were soaked (2 h) in distilled water at 80, 40 and 20 °C in 3-L glass beakers, with seed: water ratios of 1:10, 1:20 and 1:30, respectively. To facilitate the swelling of the seeds, an overhead stirrer (IKA Labortechnik, RW 20.n, Malaysia) was used to stir the mixture for 20 min at 680 rpm. A ceramic heating plate (IKA C-MAG, HS 7, Malaysia) at low setting was used to maintain the temperature during the seed soaking (seeds) and stirring process. The aqueous suspension was then centrifuged (Sigma 6-16 KS centrifuge) at 12,800 g/min at 20 °C to separate the seeds and the mucilage (gel). After being centrifuged for 40 min, the mucilage was separated from chia seed totally and collected manually. Samples of freshly extracted chia seed gel were immediately packed in 50-mL plastic containers and stored under cool (4 °C) and dry conditions until required for use. Figure 3.2 shows the steps and procedures used for the extraction of chia seed gel.

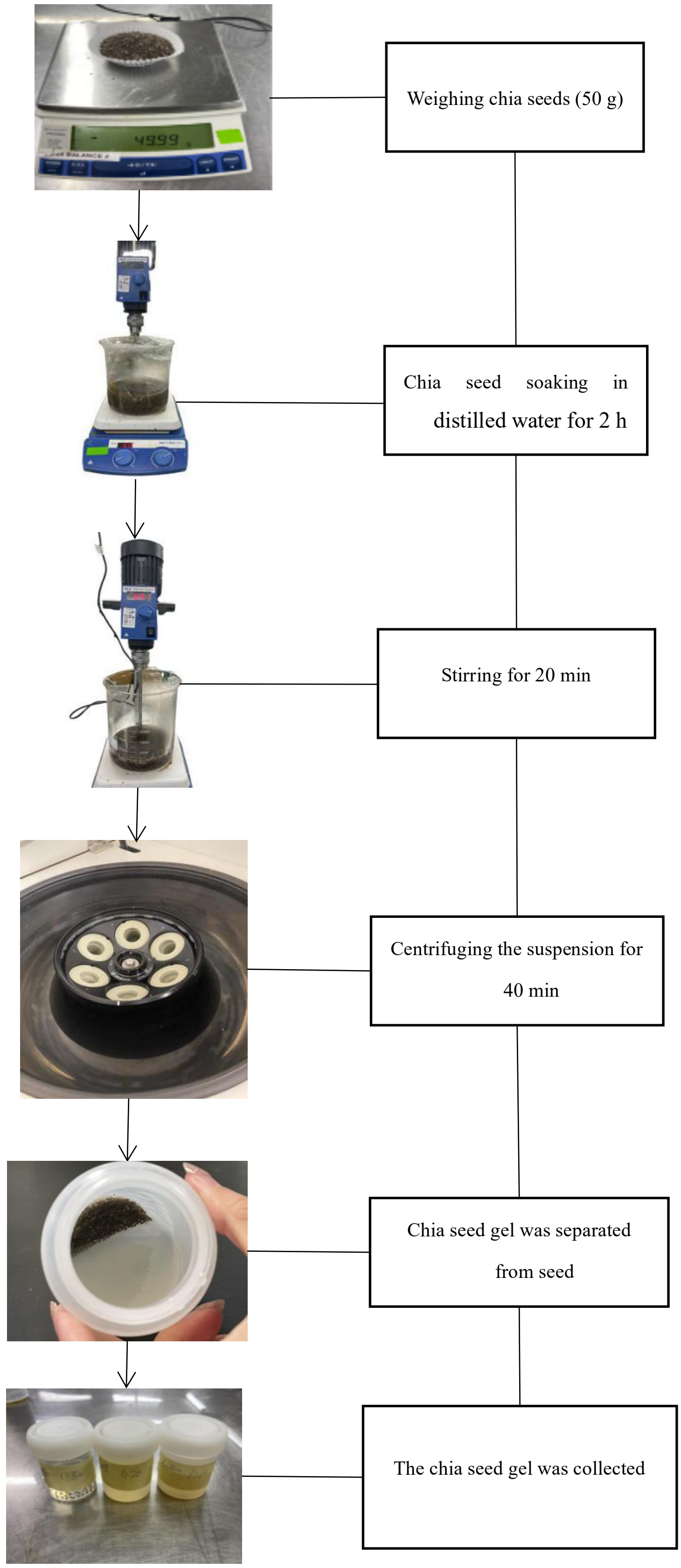


Figure 3.2 Extraction of chia seed gel
CSG = chia seed gel. Images captured by iPhone 11, Apple Inc., California, USA.

3.3.2 Characterisation of chia seed gel

3.3.2.1 Measurement of viscosity

Viscosity was measured according to Koocheki et al. (2009) using an AR-550 rheometer (TA, UK), equipped with a 2° cone and a 60-mm plate geometry at 5 ± 0.1°C. A cooling water bath (Julabo FT200) was also used to maintain the temperature of the rheometer. The settings of this experiment are shown in Table 3.3. The chia seed gel samples (10 ml) were loaded onto the lower plate of the rheometer, allowed to equilibrate for 2 min to ensure consistency of measurements. Samples (10 ml) were then subjected to pre-shear rate (1000 s^{-1} for 10 s^{-1}) to erase thixotropy by setting on the computer connected to rheometer ahead of the measurement (Campos et al., 2016). The data obtained from the Rheology Advantage program (TA Instruments Ltd) were plotted on a graph, with viscosity as a function of shear rate in the logarithmic scale. The viscosity was measured by rheometer AR-550 using Equation 1.

$$\sigma = K\gamma^{n} \quad \text{...} \quad (1)$$

σ = shear stress (Pa), K=consistency index (equal to viscosity when n = 1), n is a dimensionless number (Power Law Index) that indicates the closeness to Newtonian flow, γ. is the shear rate (s^{-1}).

Table 3.3 Rheometer settings

Setting	Parameter	Setting
Item	Geometry	60 mm 2° cone steel
	Gap setting	Zero Gap auto
	Pre shear rate	1000 s^{-1}
	Temperature	5 ℃
	Test type	Steady state flow
Test settings	Ramp	Shear rate (s^{-1})
	From	0.1-100
	Mode	Log
	Points per decade	10
	Temperature	5 °C
	Sample period	10 seconds
Steady state	Percentage tolerance	5
	Consecutive within tolerance	3
	Maximum point time	1 minute

Figure 3.3 Setup for measuring the viscosity of sample
Images captured by iPhone 11, Apple Inc., California, USA.

3.3.2.2 Determination of yield (%)

The yield (%) of the extracted chia seed gel was determined (Equation 2) by dividing the dehydrated weight of chia seed gel to the seeds using previous methods (Campos et al., 2016; Hussain et al., 2020) with minor modifications. Briefly, chia seed gel was extracted from 50 g chia seed by the methods in section 3.3.1. Chia seed gel was then dried by freeze-drying based on previous studies (Chavan et al., 2017; Feizi et al., 2021; Tavares et al., 2018). Specifically, the freshly extracted chia seed gel was transferred onto the stainless trays and covered with tinfoil. Then, covered trays were put in the freeze dryer (Labconco, free zone 6, USA) at 0.12 mBar with collector temperature of -50 ℃ and tray temperature of 25 ℃ for 72 h (Figure 3.4).

Figure 3.4 Covered chia seed gel in the freeze dryer

The weight of dehydrated chia seed gel was then recorded. The yield was calculated by using Equation 2.

$$Yield(\%) = \frac{Wdry - Wseed}{Wseed} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \text{(2)}$$

W_{dry} = weight of dried extracted chia seed gel; W_{seed} = weight of chia seed.

3.3.2.3 Measurement of total soluble solids (%) of chia seed gel

The total soluble solids (%) (TSS) of the extracted chia seed gel was determined by dividing the weight of dehydrated chia seed gel to the freshly hydrated extracted hydrated chia seed gel using previous methods (Campos et al., 2016; Hussain et al., 2020) with minor modifications. Briefly, 50 g of freshly extracted hydrated chia seed gel was put into oven under 50 ℃ for overnight. The constant weight of dried chia seed gel was recorded. Afterwards, the TSS was calculated by using Equation 3.

$$TSS\ (\%) = \frac{Wwet - Wdry}{Wwet} \times 100 \quad (3)$$

W_{wet} = weight of freshly extracted chia seed gel; W_{dry} = weight of dried chia seed gel.

3.3.2.4 Tyndall effect test of extracted chia seed gel

To determine whether chia seed gel was a colloid or not, Tyndall effect test was performed according to previous study (Tyndall, 1861). Briefly, a beam of light pointed at chia seed gel and water directly (Figure 3.5) and pictures were taken to show the result.

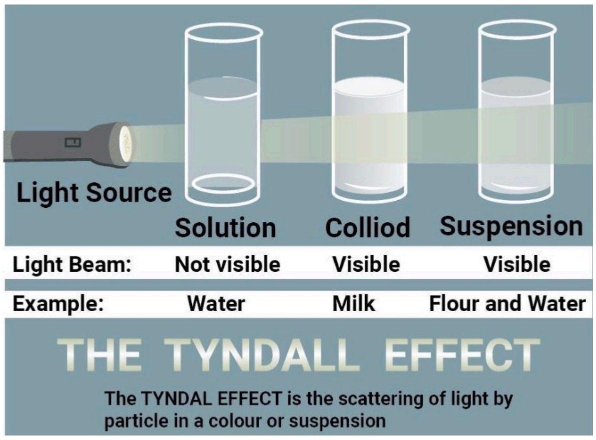


Figure 3.5 Illustration of Tyndall effect test
Source:https://brainly.in/question/18717295

3.4 Optimisation of ice cream containing chia seed gel (Phase II)

3.4.1 Preparation of ice cream with varying concentrations of chia seed gel

Ice cream mixes and ice cream samples were prepared according to the method of Bahram Parvar and Goff (2013) with some modifications. Two main stages were involved in this process. The first stage was the preparation of ice cream mixes, and the second stage was the freezing of ice cream mixes. Briefly, three test ice cream formulations (CS_1-CS_3) were prepared using different levels of freshly extracted chia seed gel (16.35%, 27.25%, 37.8 %, w/w) to replace the commercial stabilisers (guar gum and carrageenan). Two control ice cream formulations (C_1 and C_2) comprising with and without commercial stabiliser (0.2% guar gum, w/w; 0.15% carrageenan, w/w) were also prepared. A commercial emulsifier (MDG 0069) was used in all ice cream samples. The concentrations of CSG used in the ice cream formulations were based on an earlier study conducted in this laboratory (Feizi et al., 2021), and other studies (Bahram Parvar and Goff, 2013; Chavan et al., 2017).

The ice cream mix was prepared according to the formulations listed in Table 3.2. Specifically, all the ingredients were accurately weighed using an electronic scale. Liquid and solid ingredients were premixed before being added together. Chia seed gel was dissolved in water (50 °C) and then other ingredients were added and mixed. After being mixed uniformly, the ice cream mix was then homogenized for 40 min by using a Silverson Mixer (L4RT High Shear Mixer, Chesham, England). A two-stage of homogenization was used, firstly with a lower speed around 2000 rpv firstly for 20 min and then followed by a higher speed around 4000 rpv for another 20 min. After being homogenized, the samples were then pasteurised by using a water bath (Grant Instruments, United Kingdom). During pasteurisation, the core temperature of ice cream mix should be maintained at 75°C for around 5 min. After pasteurisation, the ice cream mixes were cooled to below 20°C and aged overnight at 4 °C in a refrigerator.

After aging for overnight, ice cream mixes were transferred into a benchtop ice cream batch freezer (Model Magi Mix, Gelato Expert, Italy) and churned for about 30 min. The ice cream base was obtained and packaged in a 250-mL plastic container and then allowed to harden at -20 °C for at least 24 h.

All experiments were repeated twice. The flow chart of the ice cream production is shown in Figure 3.6.

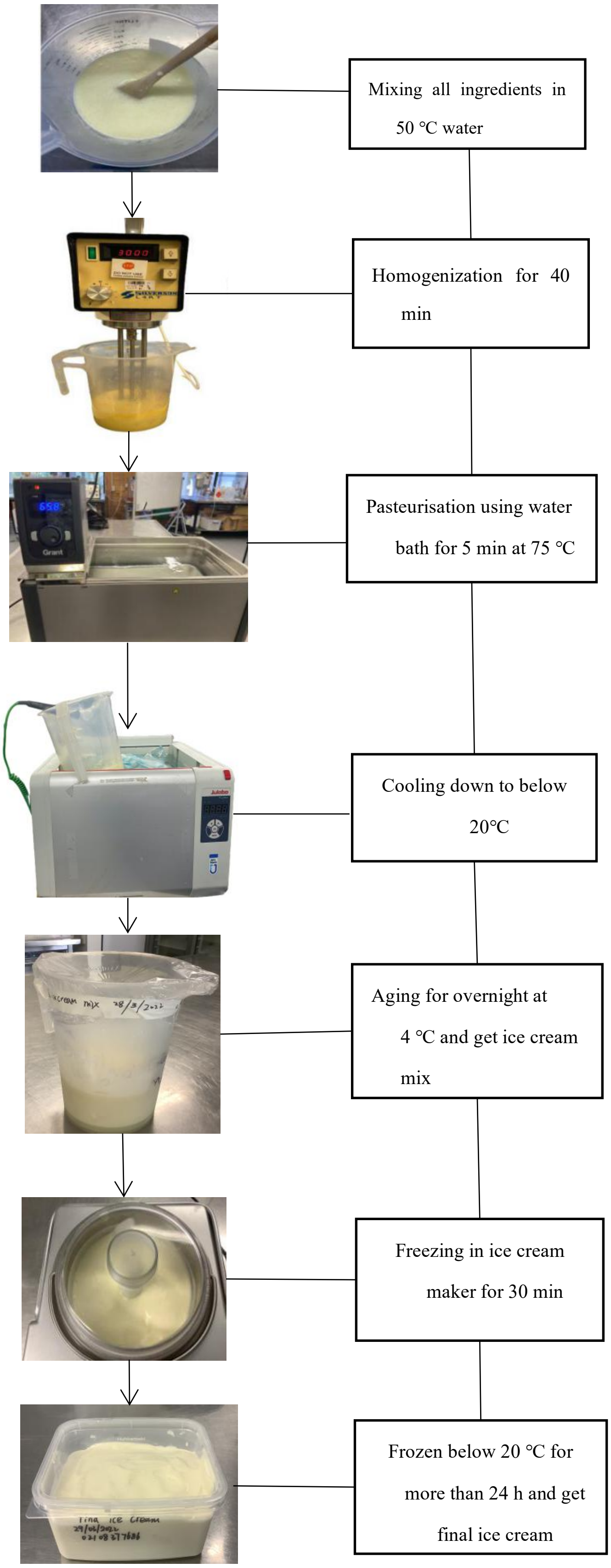


Figure 3.6 Laboratory production of ice cream

Images captured by iPhone 11, Apple Inc., California, USA.

3.4.2 Characterisation of ice cream containing freshly extracted chia seed gel

3.4.2.1 Analysis of overrun

Overrun is the percentage of air incorporated into ice cream during the freezing process. It is calculated by comparing the mass of unit volume of ice cream foam to ice cream mix (Goff, 1997). In this experiment, the weight of ice cream foam and ice cream mix were recorded by transferring ice cream mix and ice cream made from the same ice cream mix into the same volume cup (100 ml). Finally, overrun was calculated according to Equation 4.

$$Overrun\ (\%) = \frac{(Wmix - Wfoam)\ (g)}{Wfoam(g)} \times 100 \quad (4)$$

W_{mix} = weight of unit volume of ice cream mix; W_{foam} = weight of unit volume of ice cream foam.

3.4.2.2 Analysis of fat globule size distribution

Fat globule size distribution was measured by using a Malvern Mastersizer 2000 according to a previous study (Bahram Parvar and Goff, 2013). Each ice cream sample (≈10 g) was scooped out and transferred into a small (100ml) plastic beaker. The ice cream was allowed to melt at room temperature (22 °C) for 1-2 h. Before testing, the screen of the computer connected to Mastersizer should present a normal diagram to show the system is clean. After the system of Malvern Mastersizer 2000 was clean and stabilised, the pipetted sample was added dropwise into deionized water in the sink of the Mastersizer until laser obscuration values shown on the screen of the connected computer reached to over 10% (less than 20%) (Figure 3.6). When the value of laser obscuration was reached, the adding of sample should be stopped. The setup is shown in Figure 3.7. Consequently, the data was collected. In this experiment, the De Broukere mean diameter ($d_{4,3}$) was calculated as $\Sigma\ (N_i \times d_i^4)/\Sigma\ (N_i \times d_i^3)$, where N_i = number of mean fat globule with diameter d_i. It reflects the size of particles that constitute the bulk of the sample volume, and it is more sensitive to the presence of large particles in the size distribution (Hurtaud et al., 2020). The extent of partial coalescence was determined by comparing particle size distribution between aged ice cream mix and melted ice cream. All measurements of fat globule size distribution were conducted twice.

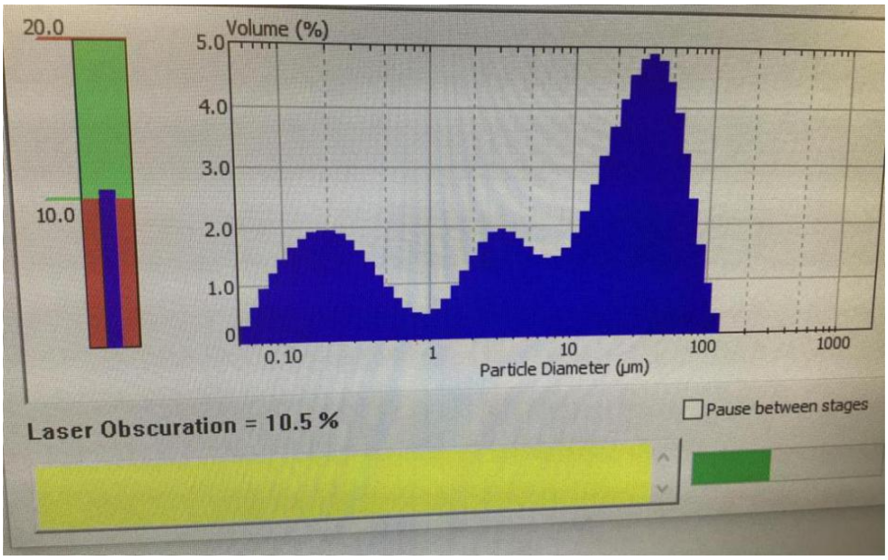


Figure 3.7 The laser obscuration value shown on the screen of computer connected to Mastersizer

Images captured by iPhone 11, Apple Inc., California, USA.

Figure 3.8 Setup for measuring the fat globule size distribution of ice cream mix and ice cream

Images captured by iPhone 11, Apple Inc., California, USA.

3.4.2.3 Analysis of apparent viscosity of the ice cream mix

The apparent viscosity of all aged ice cream mix samples was measured with the same method described in section 3.3.2.1 using an AR-550 rheometer (TA, UK). All experiments were conducted twice.

3.4.2.4 Texture analysis of ice cream

The texture of ice cream was determined by measuring its hardness as described by Feizi et al. (2021) using the TA-XT plus texture analyser (Alphatech Systems Ltd). Before conducting texture measurements, the instrument was set-up with the supplied 10-mm-diameter cylindrical probe and 50 kg loading cell. The original distance was set at 75 mm and the test speed was 0.5 mm s^{-1}. The rest of the settings used in this study is shown in Table 3.4. To conduct the measurements, each ice cream sample (50-mm thick) was transferred into a 90-mL plastic container as shown in Figure 3.8. The container was placed on the plate of the analyser. The probe was allowed to penetrate the sample to a depth of 25-mm at a room temperature (20.0 ± 0.5 °C). The samples should be measured quickly to minimize variability due to the melting of ice cream. Before conducting the test, the instrument should be calibrated for the force and height. After calibration, the measurement started. The probe was going down gradually to penetrate the sample until the maximum force was reached and the probe stopped. The maximum force used to penetrate the sample was recorded. The experiment set-up is shown in Figure 3.8. All experiments were conducted twice.

Table 3.4 Texture analyser settings

Item	**Setting**
Probe	10-mm-diameter cylindrical
Load cell	50 kg
T.A. Sequence	Return to start
Original probe distance	75 mm
Test mode	Hardness
Pre-test speed	5 mm/sec
Test speed	0.5 mm/sec
Post-speed	10 mm/sec
Target mode	Distance
Distance	25 mm
Trigger type	Auto by force
Tare mode	Auto
Break mode	Off

Figure 3.9 Setup for measuring the hardness of ice cream

Image captured by iPhone 11, Apple Inc., California, USA

The data was recorded by the Exponent programme connected to the Texture Analyser in gravitational force (g) and then converted to force (N) using Equation 5.

$$\text{Hardness (N)} = \frac{\text{Hardness (g)} \times 9.81}{1000} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

3.4.2.5 Meltdown test of ice cream

Meltdown rate of the ice cream samples was measured based on previous studies with some modifications (Bahram Parvar and Goff, 2013; Goh et al., 2008). Each ice cream sample (60 g) was scooped out from the container and placed on a mesh screen (Endecotts, Ltd, London, England) with 1-mm diameter square holes. A 100-mL glass beaker was placed underneath the mesh screen to collect the dripping of melted ice cream at ambient temperature (20.0 ± 0.5°C), as shown in Figure 3.9. The dripping weight of the melted samples was recorded every 10 minutes for 70 minutes. The weight loss of ice cream samples against time was plotted on a graph. The meltdown rate was calculated from the slope of each curve. All experiments were conducted twice.

Figure 3.10 Setup of meltdown test of ice cream

Images captured by iPhone 11, Apple Inc., California, USA

3.4.2.6 Focus group sensory evaluation of ice cream

The goal of the focus group sensory evaluation was to choose the most promising ice cream stabilised by chia seed gel. A focus group consisting of five experienced panellists evaluated the ice cream following the guidelines of Kemp et al. (2018). Four stages were involved in the focus group evaluation including introduction, rapport, in-depth and closure (Kemp et al., 2018). In this experiment, the introduction involved introducing myself and rules of this discussion; the rapport discussed the background and the main goal of the research; in-depth uncovered the attributes of each ice cream sample and what participants liked and disliked about each ice cream sample; closure reviewed what had been discussed and concluded by choosing the most promising ice cream formulation.

Before conducting the sensory evaluation, participants were asked to read the information sheet and signed the consent form. To conduct the evaluation, 10-g sample of ice cream transferred into a clean plastic sensory cup and then sealed with the lid. Before sensory evaluation, the sample was tempered for 5 min at 20 °C. All samples were coded by 3-digit random numbers. The samples were evaluated in the Product Development Laboratory at Massey University, Albany Campus. The panellists were asked to taste the ice cream samples and rinse their mouth with water between samples. The sensory test was conducted with the approval given by the Massey University Human Ethics Committee (Application ID: 4000026259).

The sensory attributes evaluated included appearance, creaminess, smoothness, firmness, meltdown in mouth, flavour, sweetness, mouth feel and overall acceptability of ice cream. The most promising ice cream was chosen by consensus of all participants.

3.4.3 Consumer sensory evaluation

The most liked ice cream by the focus group was subjected to consumer sensory evaluation with 60 panellists on a 9-point hedonic scale where 1 = dislike extremely, 2 = dislike very much, 3=dislike moderately, 4=dislike slightly, 5=neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely (Kemp et al., 2018). The main goal of the consumer sensory evaluation was to determine the overall acceptance of the selected ice cream with chia seed gel by consumer participants. Participants were invited to Sensory Laboratory at the New Innovation Centre Building through fliers, email messages and personal contacts. Each 10 g sample was scooped out and placed into a clean plastic cup. The cup with sample was presented to panellists through a booth in the sensory room. The samples were evaluated for appearance, creaminess, smoothness, firmness, meltdown in mouth, flavour, sweetness, mouth feel and overall acceptance. Participants were presented with the same documents used in section 3.4.2.6. The data were collected and analysed statistically.

3.4.4 Statistical analysis

Analysis of chia seed gel

The data on the yield and apparent viscosity of all chia seed gel samples were analysed by the SPSS Version 29 (IBM^{TM}, USA) using multivariate of General Linear Mode (GLM) analysis of variance. Data were analysed by descriptive statistics to determine the means and standard deviation. The data were tested for normality and homogeneity at 95% confidence level using Minitab 21 (Minitab Inc, Pennsylvania State University, USA). The data were also analysed by Minitab 21 to determine correlation coefficients and regression correlation to study the effect of each variable on the response. After data analysis, the data were plotted to generate the surface plots to illustrate the optimum condition. Tukey's multiple comparison test was used to separate significant differences ($p<0.05$) between the means of samples. The statistical outputs are shown in Appendix C.

Analysis of ice cream

The data on the viscosity of ice cream mix, overrun, hardness and melting rate of ice cream, fat globule size distribution of ice cream mix and ice cream melts were analysed by the SPSS Version 29 (IBM^{TM}, USA) using Univariate of General Linear Mode (GLM) analysis of variance. Data were tested for normality and homogeneity at 95% confidence level, then analysed by descriptive statistics to determine means and standard deviation. Tukey's multiple comparison test was used to separate significant differences ($p<0.05$) between the means of sample data.

The data on the consumer test sensory evaluation of ice cream were analysed by the SPSS Version 29 (IBM^{TM}, USA) using Frequencies of Descriptive Statistics.

The statistical outputs are shown in Appendix C.

Chapter 4 RESULTS AND DISCUSSIONS

4.1 Phase I Optimisation of extraction of chia seed gel

4.1.1 Effect of soaking temperature and seed: water ratio on the CSG extraction

4.1.1.1 Appearance of extracted chia seed gel

The extracted chia seed gel samples exhibited similar appearances. Figure 4.1 shows the appearance of one extracted chia seed gel sample after centrifugation for 40 min. The chia seed gel was transparent with a colloidal-like texture which was consistent with previous studies (Campos et al., 2016; Feizi et al., 2021; Munoz et al., 2012).

Figure 4.1 Chia seed gel following centrifugation of soaked chia seed

Images captured by iPhone 11, Apple Inc., California, USA.

4.1.1.2 Yield and viscosity of extracted CSG

The yield and viscosity of chia seed gel samples extracted under different conditions are shown in Table 4.1. Sample R_1S_1 had the highest yield (9.943 ± 0.75%) and the highest apparent viscosity (6.74 ± 0.24 Pa·s) of all the CSG samples. The yield and apparent viscosity of the gels of the remaining eight samples (R_1S_2, R_1S_3, R_2S_1, R_2S_2, R_2S_3, R_3S_1, R_3S_2 and R_3S_3) were lower ($p < 0.05$) than sample R_1S_1. The results show that the optimum temperature for the extraction of chia seed gel was 80 °C with a seed: water ratio of 1:10. The results were supported by linear regression analysis (section 4.4.1.3) which showed that the highest yield and highest apparent viscosity were obtained at high soaking temperature (80 °C) and seed: water ratio (1:10).

Table 4.1 Yield and viscosity of chia seed gel samples

Experiment #	Experiment Code	Ratio of seed: water	Soaking temperature (°C)	Yield (%)	Apparent viscosity (Pa·s)
1	R_1S_1	1:10	80	9.943±0.75	6.74±0.24
2	R_1S_2	1:10	40	8.356±0.06	2.54±0.38
3	R_1S_3	1:10	20	5.567±0.04	1.31±0.19
4	R_2S_1	1:20	80	7.458±0.03	3.55±0.66
5	R_2S_2	1:20	40	6.971±0.10	2.09±0.09
6	R_2S_3	1:20	20	4.853±0.09	1.15±0.02
7	R_3S_1	1:30	80	5.915±0.04	2.32±0.43
8	R_3S_2	1:30	40	5.427±0.00	1.68±0.22
9	R_3S_3	1:30	20	4.216±0.00	1.10±0.08

All chia seed samples were soaked for 2 h at the appropriate temperatures; R = Ratio; S = soaking; R_1S_1-R_3S_3 = Chia seed gel samples; ± = SD; Independent experiments were replicated twice.

4.1.1.3 The Linear Regression Modelling analysis of yield and viscosity of extracted chia seed gel

The linear regression modelling was used to estimate the effect of independent variables (soaking temperature and seed: water ratio) on the yield and viscosity of chia seed gel based on previous studies (Campos et al., 2016； Munoz et al., 2012). Two surface plots were generated from the Linear Regression Modelling to show the optimum conditions for the extraction of CSG (Figure 4.4). Before generating the surface plots, the residual plots (Figure 4.2 and Figure 4.3) for yield and apparent viscosity were conducted to examine the normality, homogeneity of variance and randomness of the data using the four-in-one graph generated by Minitab 21 (Minitab Inc., USA).

Data for the yield of CSG in the histogram shows a normally distributed shape (bell shape) (Figure 4.2). Also, most of the data points in the normal probability plot were aligned along the line of best fit, indicating the residuals of the data for the yield of CSG fitted the normal distribution.

Additionally, in the 'Versus fit' graph, the data points were evenly located on either side of the zero-line with two points located far away from the rest, thus, the two points were considered as influential points which may be attributed to the combined effect of high soaking temperature and high seed: water ratio (section 4.1.14). Lastly, in the 'Observation order' graph, there was no successive ascend or descend points, which indicates the observations were independent. Therefore, the model for yield was adopted.

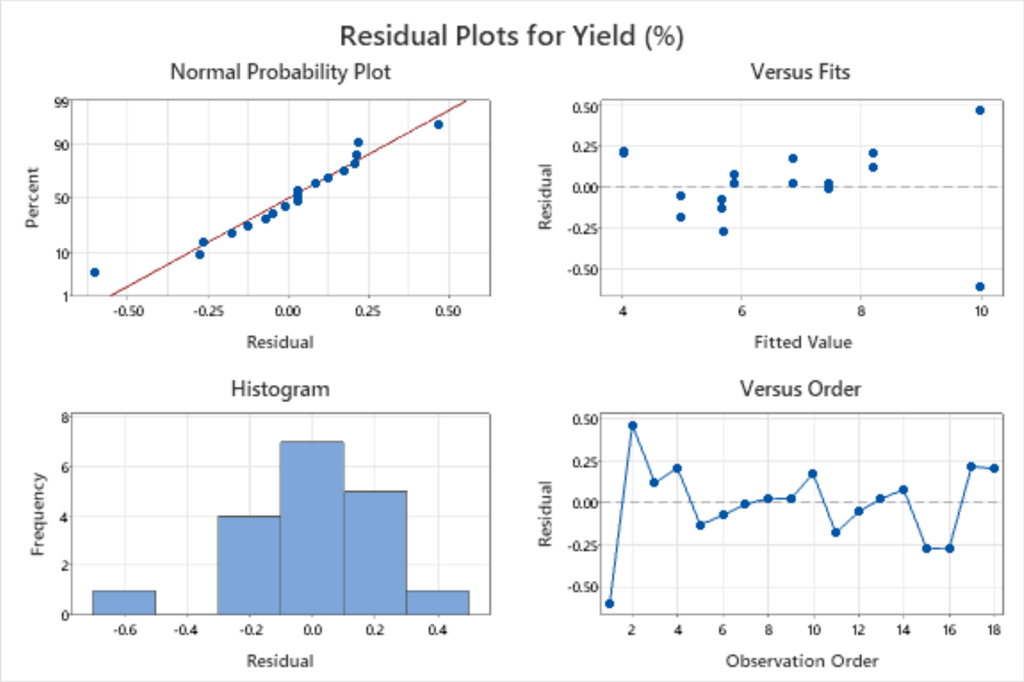


Figure 4.2 The output of the residual plots of yield of chia seed gel

The **normal probability** plot verifies the normal distribution of residuals of the data for the yield of CSG; The **Histogram** was used to show if there were any outliers or skewness of data for the yield of CSG; The **Versus fits** shows the homogeneity of variance of residual of the data; The **Versus order** was used to verify the independence of the observations of the data.

Data for the viscosity of the chia seed gel in the histogram was not perfectly normally distributed (Figure 4.3), but there was no apparent skewness. Most of the data points in the normal probability plot were aligned along the line of best fit, indicating the residuals fitted the normal distribution.

The ‘Versus fit graph’ showed that the variances of the data for the viscosity of CSG were not evenly distributed on either side of the zero-line, but there was neither a fanning effect nor a funnelling effect. Lastly, in the ‘Observation order’ graph, there was no successive ascend or descend points, which meant the observations were independent. Therefore, the model for viscosity was adopted.

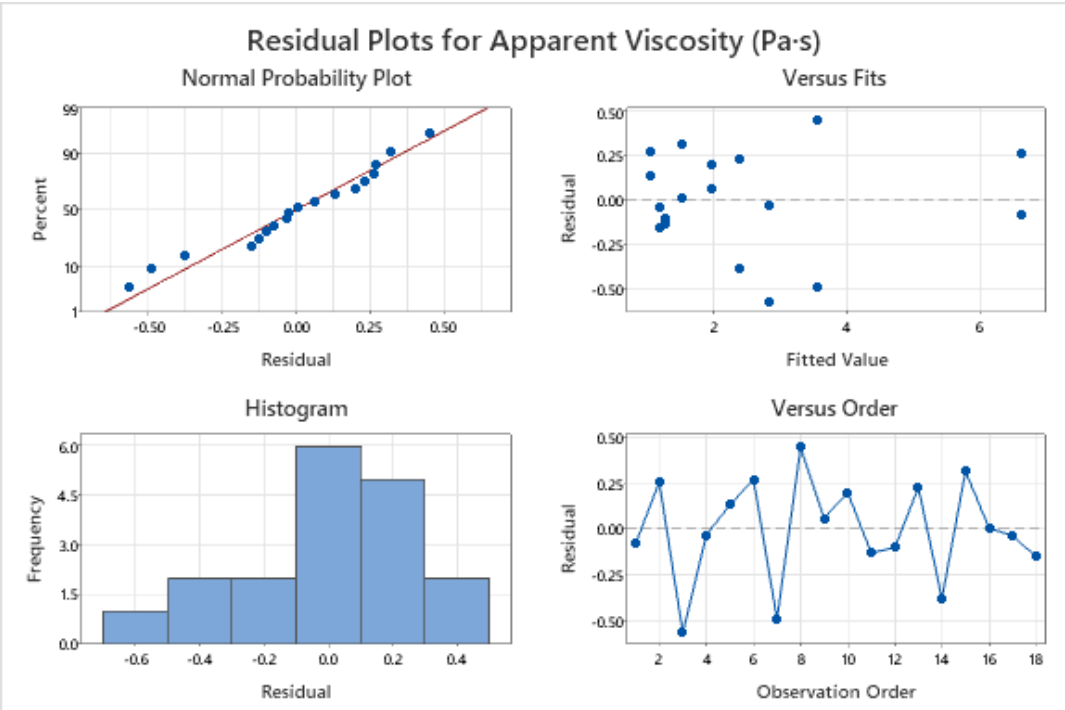


Figure 4.3 The output of the residual plots of viscosity of chia seed gel

The **normal probability** plot verifies the normal distribution of residuals of residuals of the data for the viscosity of CSG; The **Histogram** was used to show if there were any outliers or skewness of data for the viscosity of CSG; The **Versus fits** shows the homogeneity of variance of residual for the data; The **Versus order** was used to verify the independence of the observations for the data.

Consequently, two response surfaces were generated, expressed by two equations as follows:

Yield (%) = −1.381 + 100.4 SWR + 0.1446 ST (°C) − 659 SWR×SWR − 0.001344 ST (°C) ×ST (°C) + 0.6215 SWR×ST (°C) ……………………..(1)

R^2 = 98.19%

Apparent viscosity (Pa·s) = 1.289 − 6.3 SWR − 0.0256 ST (°C) −135 SWR×SWR + 0.000089 ST (°C) ×ST (°C) + 1.102 SWR×ST (°C) ……………………..............................(2)

R^2 = 97.43%

ST = Soaking Temperature; SWR = Seed: water Ratio

The coefficient of determination (R^2) for the equations of yield and apparent viscosity of chia seed gel were higher than 90%, indicating that the data for the yield and viscosity of extracted CSG in this experiment can be accepted. Two response surface graphs were generated based on the data. Figure 4.4 showed that the optimum point for yield of extracted CSG was located at higher soaking temperature (80 °C) and higher seed: water ratio (1:10), while the optimum point for apparent viscosity was also located at higher soaking temperature (80 °C) and higher seed: water ratio (1:10).

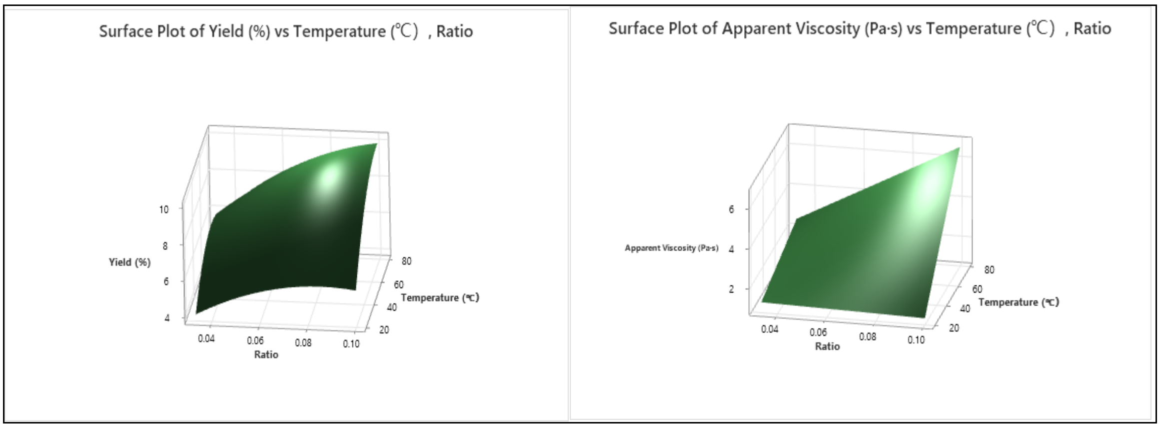


Figure 4.4 Response surface for the effect of soaking temperature and seed: water ratio on yield and viscosity of CSG

Ratio = Seed: water ratio; Temperature = Soaking temperature; CSG = chia seed gel

4.1.1.4 Effect of soaking temperature and seed: water ratio on the yield and viscosity of extracted CSG

The linear regression analysis coefficients for CSG (Table 4.2) showed that the soaking temperature had a significant effect on the yield of chia seed gel ($p < 0.05$) and the seed: water ratio also had a significant effect on the yield of chia seed gel ($p < 0.05$). Results also indicate that there was a combined effect between soaking temperature and seed: water ratio on the yield of CSG ($p < 0.05$). However, the effect of soaking temperature or seed: water alone on the apparent viscosity of CSG was not significant ($p > 0.05$). The apparent viscosity of CSG may be affected by the complementary interactions of soaking temperature and seed: water ratio ($p < 0.05$).

Table 4.2 Regression linear analysis coefficients for extraction of CSG

Parameter	Yield		Apparent viscosity	
	Coefficient	$P_{0.05}$	Coefficient	$P_{0.05}$
Constant	-1.381	NS	1.289	NS
SWR	100.4	0.002	-6.3	NS
ST	0.1446	0.000	-0.0256	NS
SWR*SWR	-659	0.003	-135	NS
ST*ST	-0.001344	0.000	0.000089	NS
ST*SWR	0.6215	0.000	1.102	0.000
R-Sq	98.19%		97.43%	
Lack of fit (P)	0.206		0.306	

A = Constant; ST = Soaking Temperature; SWR = Seed: Water Ratio; NS = Not significant, $P \leq 0.05$.

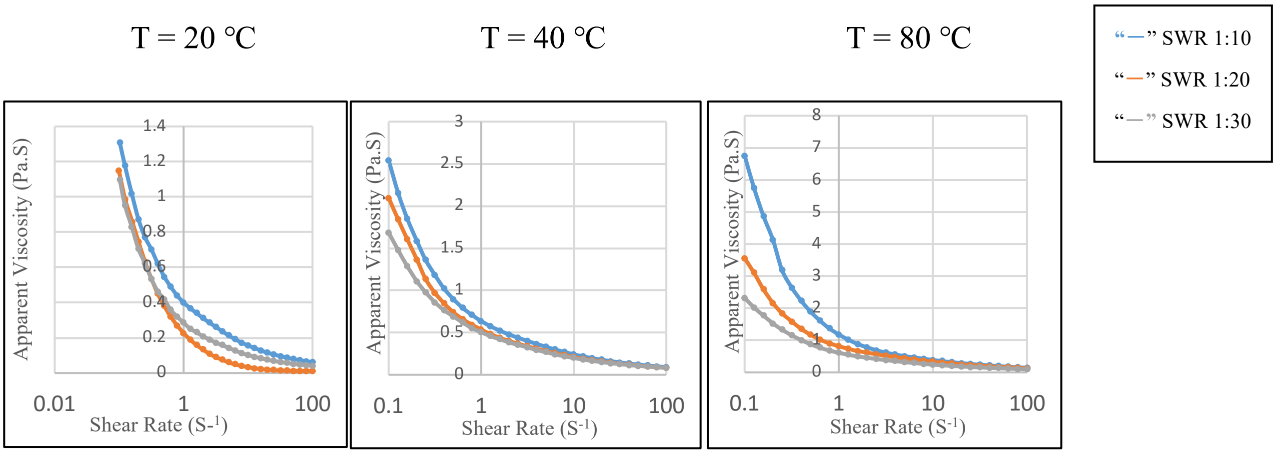
The best combination of soaking temperature and seed: water ratio was obtained at 80 °C and 1:10, respectively, which gave a yield of 9.943±0.75 % and apparent viscosity of 6.74±0.24 Pa·s. Increased soaking temperature may lead to high yield of CSG, which may be attributed to the high temperature of water that penetrates the solid matrix of seeds thereby causing the release of mucilage (Muñoz et al., 2012; Hussain et al., 2020). Increasing the seed: water ratio may also increase the yield, which is due to that the higher ratio of seed: water produced higher concentrations of aqueous chia seed suspension, thereby producing more chia seed gel.

Regarding the apparent viscosity of CSG, increase in soaking temperature and seed: water ratio increased the apparent viscosity of CSG. The increased viscosity may be attributed to the higher water retention and increased amount of inter-molecular bonds at a higher concentration (Tavares et al., 2018), which was due to the higher yield resulted from higher soaking temperature.

The results were consistent with a previous study by Campos (2016) who reported the highest yield of CSG at 70 °C and the highest apparent viscosity of CSG at 40 °C with a seed: water ratio of 1:14.

4.1.2 Characteristics of extracted chia seed gel

Figure 4.5 shows that all chia seed gel samples exhibited non-Newtonian shear-thinning behaviour. The rheograms show that the apparent viscosity of all the samples decreased with increasing shear rate ranging from 0.1-100 S^{-1}. The result was consistent with previous studies which reported that the rheology of chia seed polysaccharide solutions exhibited a pseudo-plastic shear-thinning behaviour as well as a gel-like structure when the concentration of solutions was higher than 0.06% at 25 °C (Feizi et al., 2021; Timilsena et al., 2018). The pseudo-plasticity or shear-thinning behaviour may be related to the increased alignment of constituent molecules of the system (Bahramparvar and Tehrani, 2011). The elastic properties of chia seed gel may contribute to the stabilisation of the micro-structure of ice cream mix, which indicates the potential of chia seed gel as a stabilising agent in ice cream (Feizi et al., 2021).



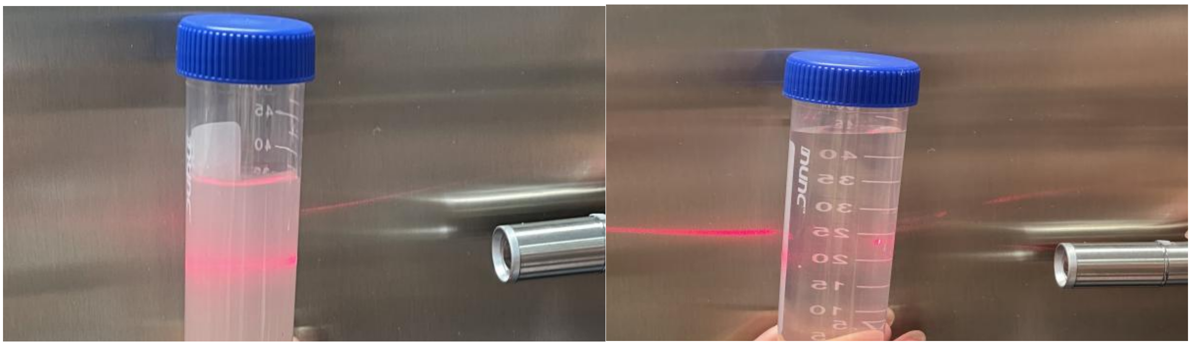
(a) (b) (c)

Figure 4.5 Viscosity of chia seed gel as a function of shear rate

Chia seed gels were extracted after soaking the seeds at (a) 20 °C; (b) 40 °C and (c) 80 °C

Tyndall effect

Chia seed gel is reported to be a colloid, which was confirmed by the Tyndall effect test (Figure 4.6) (Brax, 2019; Ogemdi, 2019). According to Ogemdi (2019), the particles in a colloid (dispersion phase) can stabilise in the dispersion medium because the constant pushing of the particles by the molecules of the dispersion medium has a stirring effect which does not permit the particles to settle. Figure 4.6 shows that chia seed gel scattered the beam of light indicating that the gel was a colloid, which explained the gelling properties and viscosity of chia seed gel. The result also confirmed the potential of chia seed gel used as a stabilising agent.



(a) (b)

Figure 4.6 Tyndall phenomenon of chia seed gel
(a) chia seed gel; (b) water

4.1.3 Total soluble solids (TSS) of chia seed gel

The total soluble solids of chia seed gel extracted under optimum conditions were determined by calculating the weight of dried chia seed gel to the weight of freshly extracted hydrated chia seed gel. The average content of total soluble solids of freshly extracted chia seed gel was 1.24 ± 0.00 %. There were no published comparative data for this part. However, total soluble solids of CSG are important for this experiment because it provides information on the concentration of freshly extracted chia seed gel used in the ice cream mix formulation. The concentration of chia seed gel in ice cream mix formulation was determined from previous studies (0.1%-0.3%, w/w) (Feizi et al., 2021; Goff, 1997; Syed et al., 2018). Therefore, the concentration of freshly extracted hydrated chia seed gel used in ice cream mix formulation in this experiment can be obtained by the calculation according to the ratio of total soluble solids (TSS) of freshly extracted chia seed gel, which is about 10%-30%.

4.1.4 Summary of phase I

Soaking temperature and seed: water ratio can affect the yield and apparent viscosity of chia seed gel ($p < 0.05$). The results showed that the optimum extraction conditions for chia seed gel were obtained under a soaking temperature of 80 °C with a seed: water ratio of 1:10.

4.2 Phase II Optimisation of ice cream formulation containing chia seed gel as stabiliser

4.2.1 Apparent viscosity of ice cream mix

The viscosity of ice cream mix is an important attribute of the intermediate product as it affects the body and texture of the finished product (Stanley et al., 1996). The results of apparent viscosity of the ice cream mix samples are shown in Figure 4.7. The highest apparent viscosity was recorded in sample C_2 (3.53 ± 0.18 Pa·s), followed by samples CS_3, CS_2 and CS_1 respectively. The control sample (C_1) had the lowest apparent viscosity (1.80 ± 0.11 Pa·s). When comparing samples CS_3, CS_2, CS_1 with the control sample (C_1) without stabiliser, results showed that the addition of chia seed gel increased the apparent viscosity of the ice cream mixes. Furthermore, sample CS_3 (3.39 ± 0.04 Pa·s) had similar viscosity to sample C_2 (3.53 ± 0.18 Pa·s) containing 0.2% (w/w) guar gum and 0.15% (w/w) carrageenan ($p > 0.05$). Results also showed a strong correlation ($R^2 = 0.915$) between the viscosity of the ice cream mixes and the concentration of CSG added into the formulations. The sample with the highest concentration of added CSG (CS_3) had the highest apparent viscosity than samples (CS_2 and CS_1) with lower concentrations of the gel ($p < 0.05$). The results obtained in this study were consistent with previous studies (BahramParvar, et al., 2012; Feizi et al.,2021; Javidi et al., 2016; Moeenfard and Tehrani, 2008). BahramParvar, et al., (2012) reported that the addition of BSG into ice cream mix formulation resulted in higher apparent viscosity of ice cream mixes than ice cream mixes containing guar gum at the same concentration. Feizi et al. (2021) also found that the addition of chia seed gel increased the viscosity of ice cream mix and as the concentration of chia seed gel increased, the viscosity of ice cream mix increased accordingly. In the study of Moeenfard and Tehrani (2008), the highest viscosity of ice cream mix was observed in a sample containing 0.25% stabiliser and the lowest viscosity was observed in the sample containing 0.14% stabiliser. Similarly, Javidi et al. (2016) reported that the viscosity of ice cream mix increased as the level of basil seed gum increased.

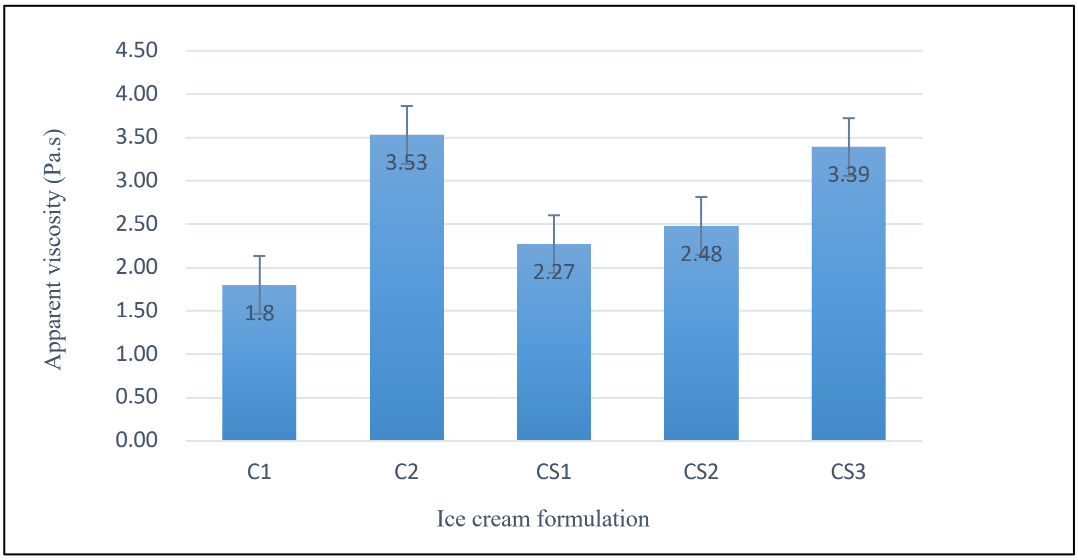


Figure 4.7 Apparent viscosity of ice cream mix samples

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; Error bars = ± SD; Independent experiments were replicated twice.

The viscosity of ice cream mix can be affected by the type and concentration of stabilisers (Moeenfard and Tehrani, 2008). Stabilisers have a high water-holding capacity and can affect the apparent viscosity of ice cream mixes (Moeenfard and Tehrani, 2008). Javidi et al. (2016) also investigated the effect of the concentration of basil seed gum on the thixotropic nature of ice cream mix and reported that increasing the content of basil seed gum increased the thixotropic effect of ice cream mix, which may be attributed to the physical interactions between the seed gum and milk proteins in the ice cream mix. Furthermore, Figure 4.8 shows that all ice cream mixes exhibited non-Newtonian pseudo-plastic flow behaviours, with decreasing apparent viscosity of ice cream mixes as the apparent shear rate increased from 0.1 s^{-1} to 100 s^{-1}. The apparent viscosity of chia seed gel has been investigated in section 4.1.2. Therefore, the effect of chia seed gel on the apparent viscosity of ice cream mix may be attributed to the elastic properties of CSG (Goh et al., 2016). The phenomenon was also reported by Feizi et al. (2021) who used chia seed gel to stabilise ice cream.

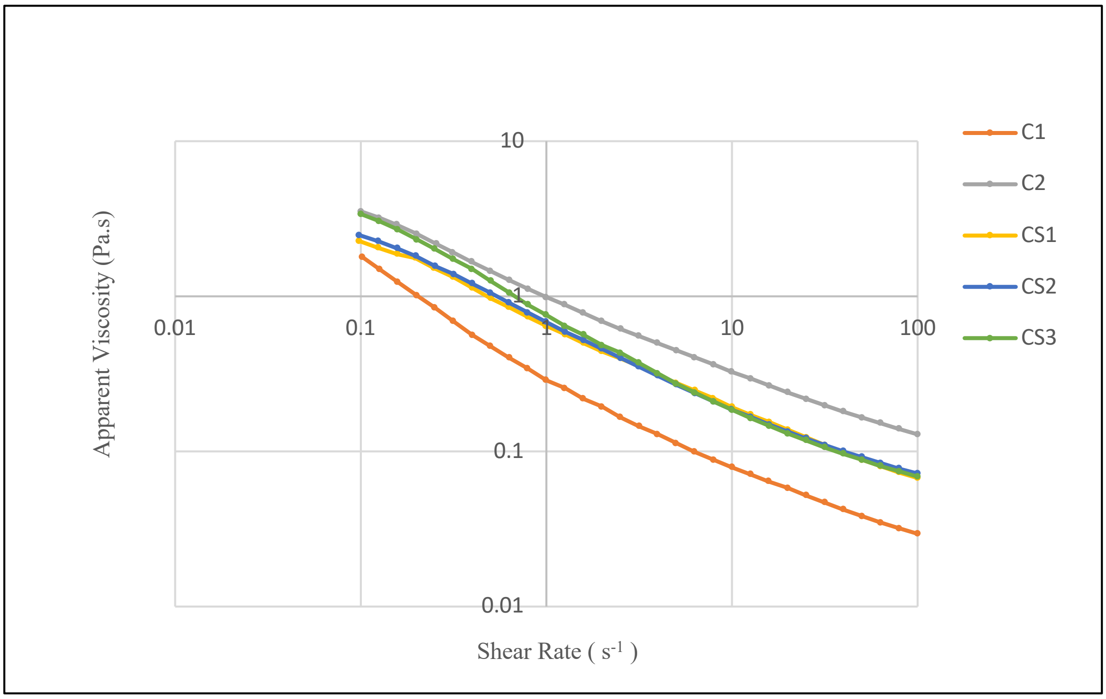


Figure 4.8 Apparent viscosity of ice cream mix samples as a function of shear rate

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; Independent experiments were replicated twice.

4.2.2 Overrun of ice cream

Air is an important component that contributes to the final texture of ice cream and is determined by overrun (Cottrel et al., 1979). The highest overrun (52.00 ± 0.10 %) and the lowest overrun (28.14 ± 0.61%) were obtained in samples CS_3 and C_1, respectively (Figure 4.9). The addition of CSG increased the overrun of ice cream in sample CS_1-CS_3 compared to the sample C_1 without CSG ($p < 0.05$). The overrun in sample C_2 with 0.2 guar gum (w/w) and 0.15 carrageenan (w/w) was higher than samples CS_1 and CS_2 ($p < 0.05$). However, there was no significant difference between the overruns from sample CS_3 and C_2. Furthermore, as the concentration of CSG increased (CS_1, CS_2, CS_3), the overrun of ice cream increased.

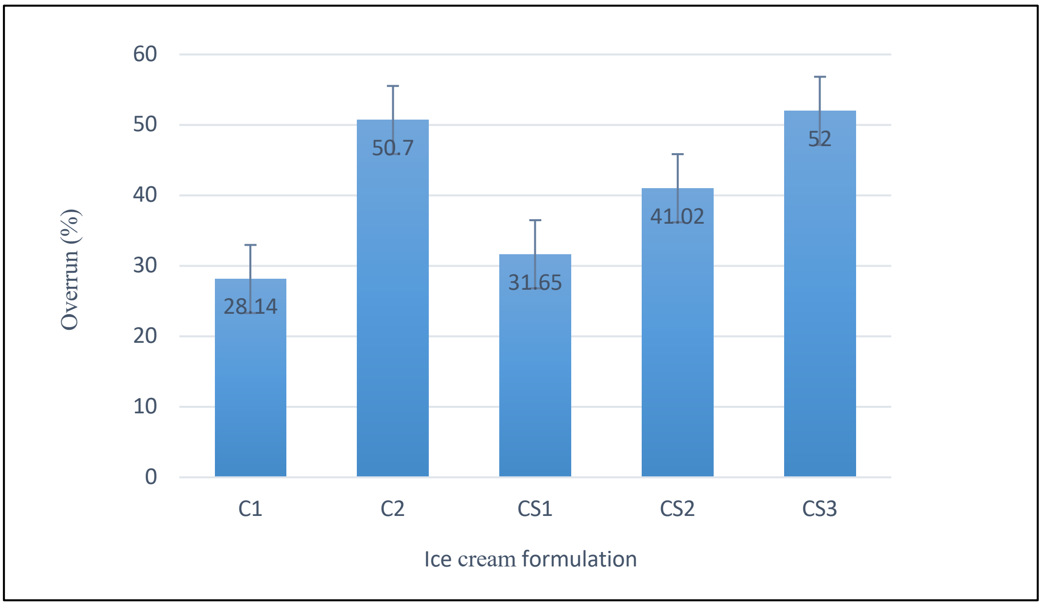


Figure 4.9 Overrun of ice cream samples

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; Error bars = ± SD; Independent experiments were replicated twice.

The results of this study were consistent with a study by Moeenfard and Tehrani (2008), in which increasing concentrations of stabiliser enhanced the overrun of ice cream. Increasing chia seed gel increased the apparent viscosity of ice cream mix, resulting in increased whipping rate and retention of air, thus increasing the overrun of ice cream (Frandsen and Arbuckle, 1961). According to Javidi et al. (2016), the viscosity of a liquid can influence the extent of air incorporation. A high viscous ice cream can trap a large volume of air in the barrel during churning. However, trapped air bubbles in a low viscous mix rapidly disappear due to the coalescence of the bubbles, resulting in a low overrun. In addition, high viscosity of mix can prevent vigorous agitation and incorporation of air (BahramParvar et al., 2013). Therefore, to produce the ideal texture of ice cream, a proper viscosity is important. According to Goff and Hartel, (2013), the ideal viscosity of ice cream ranges from 0.02 to 0.15 Pa·s at 100 s^{-1}.

Another reason for the increased overrun caused by the addition of stabiliser is that during freezing, many new air surfaces are formed (Sofjan and Hartel, 2004). Therefore, to stabilise the structure of ice cream and avoid coalescence, it is necessary to use stabilisers. The reason partially explained the increased overrun of the ice cream with added stabiliser. Additionally, the added stabiliser can reduce the size of air cells, thereby producing more air cells with smaller size (Bahramparvar and Mazaheri Tehrani, 2011. As a result, the total air surface and overrun increases accordingly.

Our results of the overrun of ice cream are contrast to Feizi et al. (2021) who reported low overrun whereas high overrun was observed in the current study when the concentration of chia seed gel was increased. Furthermore, the overrun in our study (30-60%) was lower than previous studies (Feizi et al., 2021; Goff, 1997). Overrun reported in previous studies ranged from 50-120%. The differences between the results of overrun may be attributed to different whipping methods used in the two studies. In the present study, whipping and freezing of the ice cream mix occurred at the same time in the freezer whereas in the previous study, the mix was whipped after freezing which affected post-freezing structural parameters such as overrun (BahramParvar and Goff, 2013).

4.2.3 Fat globule size distribution of ice cream mix and ice cream

Fat is a key component in the stabilisation of ice cream structure due to its contribution of partially coalesced fat in the stabilisation of the air bubbles and foam structure (Koxholt et al., 2001). Fat globule size distribution (FGSD) provides information on the degree of fat aggregation and/or its partial coalescence in ice cream. The average FGSD is commonly calculated by a volume-weighted mean size of all particle sizes (fat globule size, $d_{4,3}$) (Goff and Hartel, 2013). The fat globule sizes of the ice cream mix and melted ice cream samples are shown in Table 4.3. The fat globule sizes of the ice cream melt for all samples were higher than those of the ice cream mix as expected. The higher $d_{4,3}$ values of ice cream melts may be attributed to polysaccharide-protein interactions between the glucuronic acid in chia seed gel and the protein from milk ingredients during the manufacture of ice cream (Feizi et al., 2021). Samples of ice cream mix that contained higher levels of CSG (CS_2 and CS_3), had significantly higher fat globule size than the sample with lower concentration of CSG (CS_1) ($p < 0.05$). The results were consistent with BahramParvar and Goff (2013) who reported that ice cream mix with higher concentration of BSG had a higher fat globule size. An overall increase in fat globule size was observed with incremental addition of CSG. This trend was also consistent with a previous study by Feizi et al. (2021) who reported similar results. Further, among samples containing CSG, sample CS_3 (93.57 ± 0.00 μm) had similar fat globule size with sample C_2 (88.04 ± 1.02 μm) containing commercial stabilisers. The lowest $d_{4,3}$ values were observed in ice cream samples C1 without stabilisers.

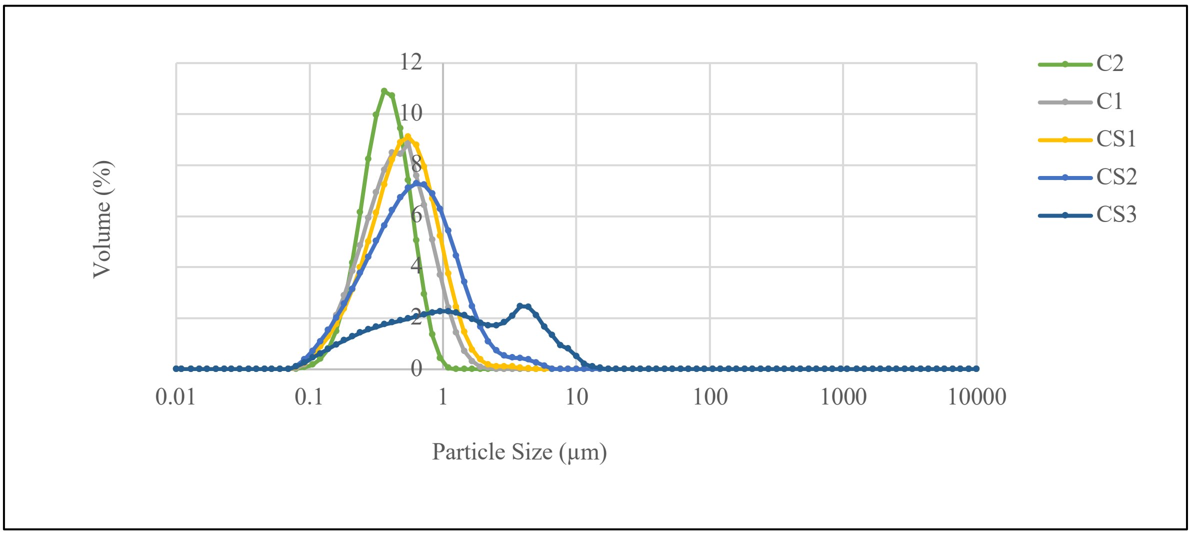
Table 4.3 Fat globule size distribution of ice cream mixes and melted ice cream

Ice cream formulation	Fat globule size ($d_{4,3}$) of ice cream mix (μm)	Fat globule size ($d_{4,3}$) of melted ice cream (μm)
C_1	1.02±0.00^a	2.62±0.06^a
C_2	0.58±0.00^a	88.04±1.02^b
CS_1	1.68±0.32^a	10.14±0.52^b
CS_2	3.28±0.61^b	94.46±2.69^b
CS_3	8.02±0.20^b	93.57±0.00^b

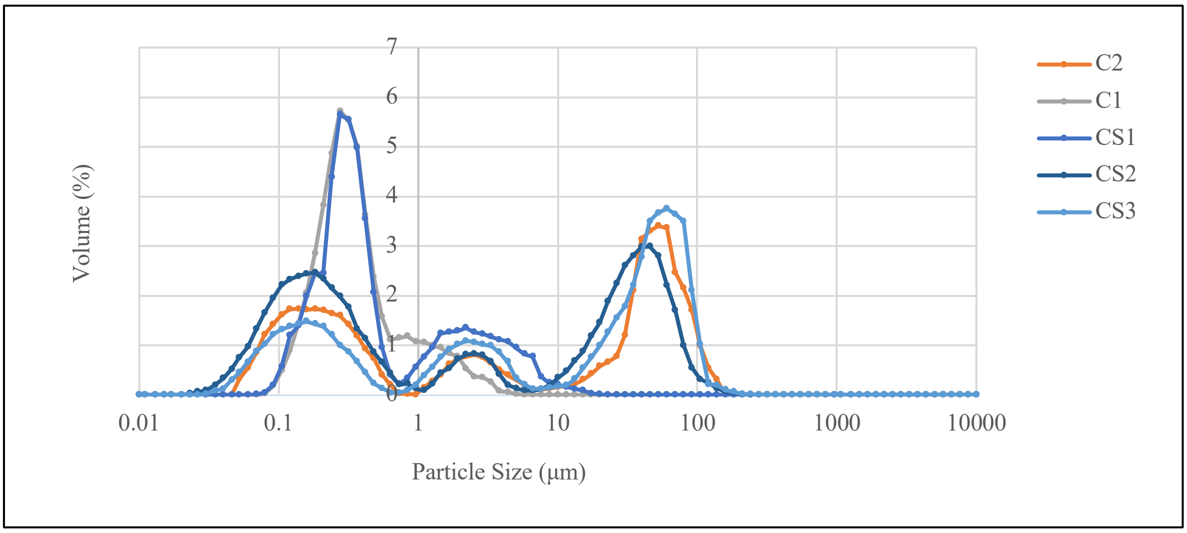
C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; ± = SD; Independent experiments were replicated twice; Means with identical superscript letters in a column are not significantly different at $P<0.05$.

Figure 4.10 shows that fat globule size distribution in the ice cream was broader than in the ice cream mix and the second peak indicates the percentage of fat agglomerates (Koxholt et al., 2001). Figure 4.10 (a) shows that the critical mean fat globule diameter in ice cream mix was slightly less than 1 μm and the maximum fat particle size of the distribution was around 2-3 μm in four samples (C_1, C_2, CS_1 and CS_2). However, in sample CS_3, the maximum fat particle size reached 8 μm, which may be caused by improper homogenization (Goff and Hartel, 2013).

Furthermore, the second peak of the particle size distribution of ice cream mix in sample CS_3 indicate that there were probably some fat agglomerates in the ice cream mix. The three-modal peaks of the particle size distribution of ice cream melts shown in Figure 4.10 (b) may be attributed to the fat droplet coalescence and/or fat droplet aggregation during whipping/ freezing as well as particles contributed by CSG aggregates (Feizi et al., 2021; Goff, 2003).



(a)



(b)

Figure 4.10 Particle size distribution of ice cream mix and ice cream melts

(a) Particle size distribution of ice cream mixes; and (b) Particle size distribution of ice cream melts measured by a laser light scattering technique.

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; Independent experiments were replicated twice.

The partial coalescence (PC) was calculated as the ratio of the volume of the third peak of ice cream melts to the volume of the initial emulsion (the second peak) of the mix (Goff, 1997). Partial coalescence of fat from each sample is shown in Table 4.4. Sample C_1 had the lowest PC (0.0 ± 0.0%) even though it contained a commercial emulsifier (MDG) ($p < 0.05$). The highest PC (62.0 ± 1.0%) was obtained in sample CS_3 which contained the highest level of CSG among the samples containing CSG ($p < 0.05$). By comparing the samples containing CSG with sample C_2 containing commercial stabilisers, sample CS_2 produced similar PC with sample C_2. The results were similar with previous studies, where the addition of CSG or other stabilisers increased the level of destabilized fat (Feizi et al., 2021; Wu et al., 2019). The increased level of PC caused by increased quantity of stabilisers may be attributed to the fact that stabilisers increased the shear stress during freezing by increasing apparent viscosity of ice cream mix, thereby enhancing shear interactions among fat globules.

Table 4.4 Fat partial coalescence of ice cream samples

Experiment #	Ice cream formulation	Partial coalescence %
1	C_1	$0.0±0.0^a$
2	C_2	$34.0±2.0^b$
3	CS_1	$1.0±0.0^a$
4	CS_2	$29.0±0.0^b$
5	CS_3	$62.0±1.0^b$

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; ± = SD; Independent experiments were replicated twice; Means with identical superscript letters in a column are not significantly different at $P<0.05$.

4.2.4 Meltdown of ice cream

The drip weight of ice cream during meltdown test was recorded and plotted against time, as shown in Figure 4.11. According to previous studies (Warren and Hartel, 2018; Wu et al., 2019), the melting of ice cream is complex due to the intricate nature of the micro-structure of ice cream. Three phases are involved in the process: the lag phase, the fast-melting phase and the stationary phase. Specifically, when heat penetrates the ice cream, the ice crystals start melting, thus diluting the suspensions which leads to the decrease of the viscosity. When melting ice cream reaches the fast-melting phase, it starts dripping through the mesh screen. Lastly, the stationary phase is reached when the meltdown gradually slows as the remaining air cells and fat globules form a three-dimensional network and reduce the speed of melting.

In this experiment, the three phases were observed in all ice cream samples (Figure 4.11). The lag phase took place in the first 20 min., followed by the fast-melting phase from about 20 min. to 50 min. and the stationary phase started around 50 min.. Figure 4.11 shows a delayed fast-melting phase and a prolonged stationary phase for the four samples (CS_1, CS_2, CS_3 and C_2), especially sample CS_3 which contained the highest level of chia seed gel recorded the longest melting time. On the other hand, ice cream sample (C_1) without chia seed gel recorded the shortest melting time. Thus, the results indicate that the addition of chia seed gel can stabilise the structure of ice cream and high concentrations of chia seed gel increase the melting resistance of ice cream. However, the mechanism of the stabilising property of chia seed gel in ice cream needs further study.

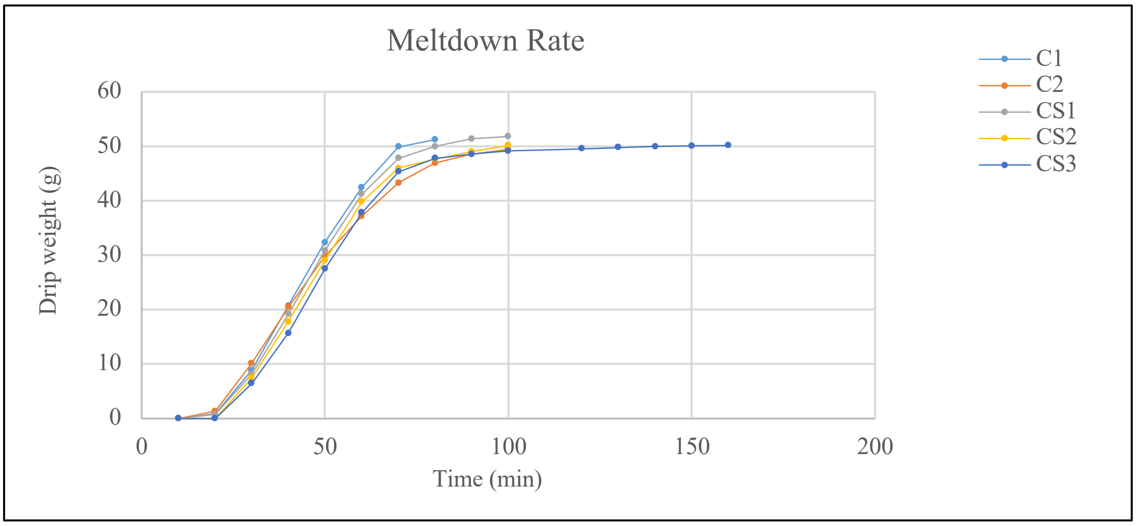
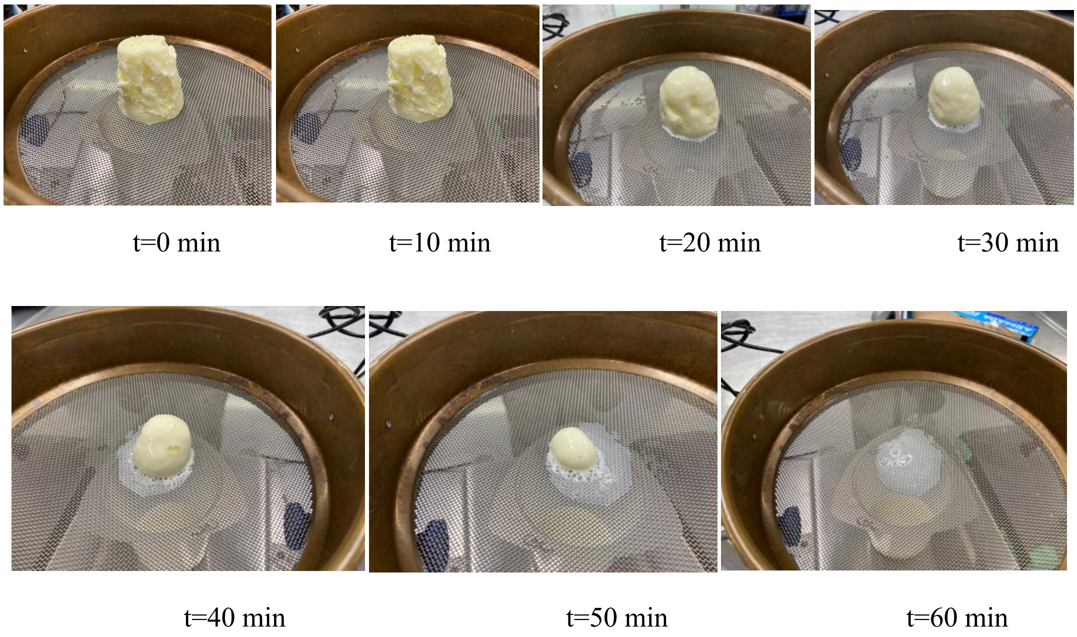


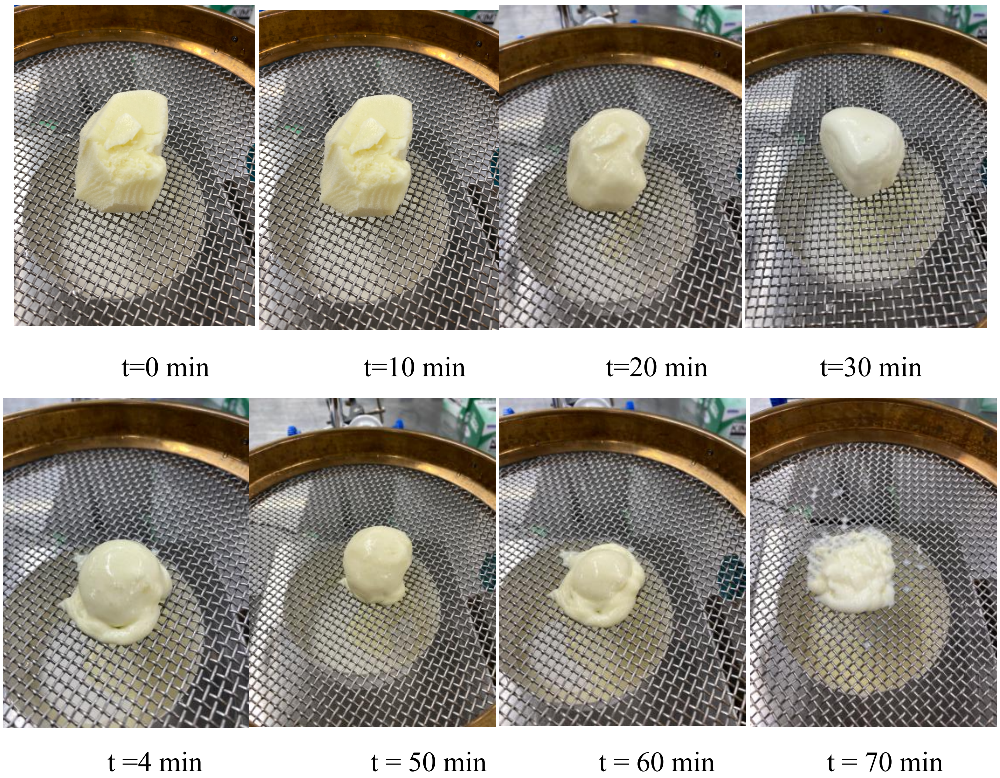
Figure 4.11 Drip weight of ice cream samples during meltdown for 60 min.

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; Independent experiments were replicated twice.

The dynamics of ice cream during meltdown depends on the composition of the formulation (Warren and Hartel, 2018). Ice cream without stabiliser in Figure 4.12 (a) was completely melted within an hour, while ice cream with 37.80% CSG (Figure 4.12 (b)) took a relatively longer time (1.5-2 h) to melt, which agreed with Wu et al. (2019). Results in present study indicate that the addition of CSG in ice cream increased the apparent viscosity of ice cream mix, thus extending the time of first drip through the mesh screen and lowering the drip-through rate. The remaining foam is a network of fat clusters and air cells (Wu et al., 2019). The remaining foam was also observed by Eisner et al. (2005) who reported that the cell structure of air and fat agglomeration contribute to the retention of the shape of ice cream during melting.



(a) Melting of ice cream sample C_1



(b) Melting of ice cream sample CS_3

Figure 4.12 Ice cream samples during meltdown test
Photos captured by iPhone 11, Apple Inc., California, USA.

The rate of the meltdown of ice cream was calculated from the slope of the meltdown curve using the regression equation. The pattern of meltdown rates in the present study was similar with a previous study (Bahram Parvar and Goff, 2013). In the present study, results show that the addition of CSG reduced the rate of meltdown compared with the control sample C_1 without stabilisers. Ice cream samples containing higher concentrations of CSG showed more resistance to melting (Table 4.5) with the lowest rate of meltdown (0.41 ± 0.0 g/min) being recorded for CS_3 compared with the other two samples containing CSG ($p < 0.05$). Moreover, among the samples containing CSG (CS_1, CS_2, CS_3), sample CS_1 had a similar meltdown rate with sample C_2 containing commercial stabilisers.

Results of our study agreed with previous studies (Bahram Parvar and Goff, 2013; Dogan et al., 2013; Feizi et al., 2021), where high concentrations of BSG or CSG resulted in high melting resistance. The correlation between concentration of stabilisers in the formulation and the melting resistance of ice cream resulted from increased viscosity of the ice cream mix with the addition of CSG or BSG as stabilisers. According to Wu et al. (2019), the presence of stabilisers in ice cream increases the viscosity of the liquid phase of the frozen dessert. Specifically, melting of ice crystals release water which dilutes the liquid phase. Thus, the melting of ice cream is governed by the gravitational force (Wu et al., 2019). When the liquid phase is viscous, the drainage process slows and leads to a reduced meltdown rate. As a result, high viscosity of the liquid phase may decrease the meltdown rate by slowing the drainage process (Wu et al., 2019).

Table 4.5 Melting rate (g/min) of ice cream samples

Experiment #	Ice cream formulation	Meltdown rate (g/min)
1	C_1	$0.78±0.08^a$
2	C_2	$0.46±0.02^b$
3	CS_1	$0.47±0.00^b$
4	CS_2	$0.44±0.01^b$
5	CS_3	$0.41±0.00^b$

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; ± = SD; Independent experiments were replicated twice; Means with identical superscript letters in a column are not significantly different at $P<0.05$.

In addition to the viscosity of ice cream mix, the meltdown down rate of ice cream is also affected by the overrun of ice cream (Feizi et al., 2021). A comparison between the overrun and meltdown rate of ice cream samples is shown in Table 4.6 which shows an inverse relationship between the two parameters. The inverse relationship of the overrun and meltdown rate of ice cream may be caused by reduced heat transfer caused by larger volume of air, thus reducing the rate of meltdown. Specifically, air is an insulator which can prevent heat penetration. As previously discussed, high amount of air in ice cream results in high overrun which contributes to the reduction of the heat of conduction and penetration thereby decreasing the meltdown rate of ice cream (Goff, 1997; Wu et al., 2019). Therefore, high overrun resulted in a reduced meltdown rate. However, high overrun with low meltdown rate was only observed in the samples without stabilisers (Wu et al., 2019).

Table 4.6 Comparison of overrun and meltdown rate of ice cream samples

Ice cream formulation	Overrun (%)	Meltdown rate (g/min)
C_1	$28.14±0.61^a$	$0.78±0.08^a$
C_2	$50.70±0.42^b$	$0.46±0.02^b$
CS_1	$31.65±0.51^a$	$0.47±0.00^b$
CS_2	$41.02±0.89^b$	$0.44±0.01^b$
CS_3	$52.00±0.10^b$	$0.41±0.00^b$

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel;

CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; ± = SD; Independent experiments were replicated twice; Means with identical superscript letters in a column are not significantly different at P<0.05.

The fat network also plays an important role in the meltdown rate of ice cream (Muse and Hartel, 2004). A high level of partially coalesced fat increases the fat network, thereby decreasing the meltdown rate of ice cream (Table 4.7). The result was consistent with previous studies (Liu et al., 2022; Warren and Hartel, 2018; Wu et al., 2019). High partial coalescence of fat in ice cream produces a high yield stress, resulting in increased resistance of water to flow against gravitational force (Wu et al., 2019). According to Liu et al. (2022), the degree of partial coalescence of fat in ice cream can significantly affect the melting properties of ice cream. The influence of fat on the meltdown rate of ice cream may be attributed to the formation of a thick and viscoelastic membrane at the oil/water interface caused by fat aggregates formed during the freezing of ice cream (Liu et al., 2022).

Table 4.7 Partial coalescence and meltdown rate of ice cream samples

Experiment #	Ice cream formulation	Partial coalescence of fat in ice cream (%)	Meltdown rate (g/min)
1	C_1	$0.0±0.0^a$	$0.78±0.08^a$
2	C_2	$34.0±2.0^b$	$0.46±0.02^b$
3	CS_1	$1.0±0.0^a$	$0.47±0.00^b$
4	CS_2	$29.0±0.0^b$	$0.44±0.01^b$
5	CS_3	$62.0±1.0^b$	$0.41±0.00^b$

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; ± = SD; Independent experiments were replicated twice; Means with identical superscript letters in a column are not significantly different at P<0.05.

4.2.5 Texture of ice cream

The textural properties of ice cream mainly include the stability of the foam and melting behaviour (Trgo and Danone, 2003). Any factor affecting these two parameters can affect the texture of ice cream. In this study, the hardness of ice cream was measured to determine the texture of ice cream. Table 4.8 shows the results of hardness (N) of ice cream samples. The lowest hardness (74.07 ±14.79 N) was obtained in the control sample C_1 without stabiliser. The addition of CSG increased the hardness of ice cream (Figure 4.13) which agreed with Feizi et al. (2021). Among all the ice cream samples that contained CSG (CS_1, CS_2, CS_3), the highest level of hardness was recorded in sample CS_3 (186.17 ± 5.06 N). The hardness between samples CS_3 and C_2 was not different ($p > 0.05$).

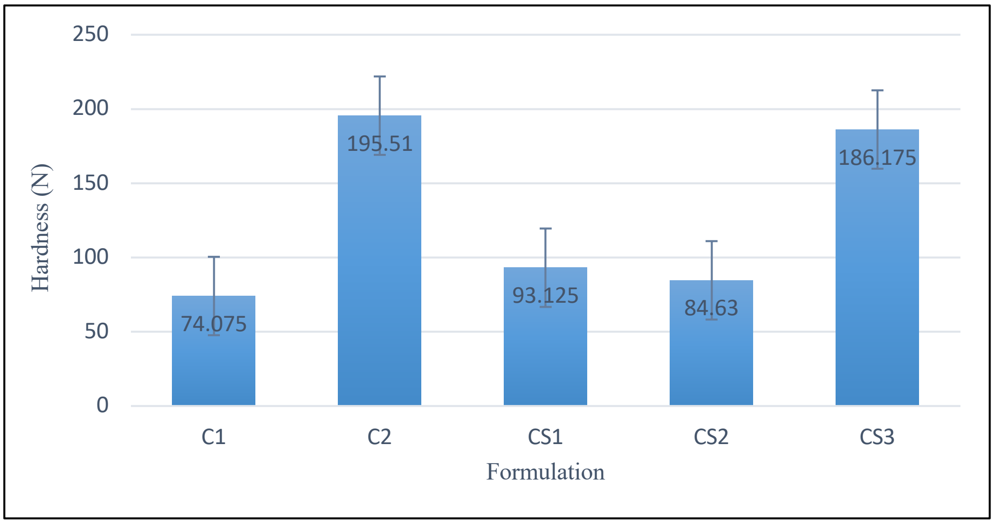


Figure 4.13 Hardness of all ice cream samples

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; Error bars = ± SD; Independent experiments were replicated twice.

The hardness of ice cream can be affected by several factors including apparent viscosity of ice cream mix, overrun, the extent of partial coalescence of fat globules, volume of the ice phase and ice crystal size of the frozen dessert (Muse and Hartel, 2004).

The apparent viscosity of the ice cream mix has the largest effect on the hardness of ice cream (Muse and Hartel, 2004). The hardness of ice cream samples increased as the apparent viscosity of ice cream mix increased (Table 4.8). As discussed earlier (section 4.2.1), results showed that the addition of chia seed gel increased the apparent viscosity of ice cream mix, resulting in increased resistance to penetration by the texture analyser probe (Muse and Hartel, 2004).

Table 4.8 Apparent viscosity of ice cream mix samples and hardness of ice cream

Experiment #	Ice cream formulation	Apparent viscosity of mix (Pa·s)	Hardness (N)
1	C1	1.80±0.11[a]	74.07±14.79[a]
2	C2	3.53±0.18[b]	195.51±1.37[b]
3	CS1	2.27±0.42[b]	93.13±4.30[b]
4	CS2	2.48±0.04[b]	84.63±6.14[b]
5	CS3	3.39±0.04[b]	186.17±5.06[b]

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; ± = SD; Independent experiments were replicated twice; Means with identical superscript letters in a column are not significantly different at $P<0.05$.

Overrun can also affect the hardness of ice cream. Table 4.9 shows that there is a positive correlation between the overrun and hardness of ice cream. As the overrun increased, the hardness of ice cream increased. In contrast, ice cream samples in previous experiments did not follow the same trend of high hardness despite having high overrun. According to previous studies ice cream samples with high overrun were softer (Muse and Hartel, 2004; Wilbey et al.,1998). The high volume of a compressible dispersed phase leads to reduced resistance to an applied force. Javidi et al. (2016) also reported that a decrease in overrun enhances the hardness of ice cream. The differences in results of hardness of ice cream of the present study and previous work may be caused by the inability of guar gum or chia seed gel to reduce the rate of ice crystal growth (Feizi et al., 2021).

Table 4.9 Overrun, partial coalescence (PC) and hardness of ice cream samples

Formulation	Overrun (%)	PC (%)	Hardness (N)
C_1	28.14±0.61^a	0.0±0.0^a	74.07±14.79^a
C_2	50.70±0.42^b	34.0±2.0^b	195.51±1.37^b
CS_1	31.65±0.51^b	1.0±0.0^a	93.13±4.30^b
CS_2	41.02±0.89^b	29.0±0.0^b	84.63±6.14^b
CS_3	52.00±0.10^b	62.0±1.0^b	186.17±5.06^b

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; ± = SD; Independent experiments were replicated twice; Means with identical superscript letters in a column are not significantly different at $P<0.05$.

The extent of fat partial coalescence can also affect the hardness of ice cream (Muse and Hartel, 2004). In this study, there was a positive correlation between fat partial coalescence and hardness of ice cream, with high (ice cream) hardness recorded in the sample with high partial coalescence (Table 4.9). The increased hardness of ice cream caused by high partial coalescence of fat was also reported in previous studies (Muse and Hartel, 2004; Tharp et al. 1998). Partially coalesced fat forms a network among the air cells in the ice cream, thus enhancing the hardness of ice cream. In the previous study, the hardest ice cream was reported in samples with high levels of polysorbate 80 which is presumed to have contributed to high destabilized fat index (Tharp et al. 1998).

The crystal size and volume of ice phase also affect the hardness of ice cream. According to Goral et al. (2018), ice cream with a high number of large ice crystals can lead to high hardness. The hardness of ice cream is exponentially related to the ice phase volume (Wilbey et al., 1998; Hartel et al., 2004). The presence of increased ice in the ice cream can reduce the depth of penetration by the penetrometer which therefore indicates the level of hardness of the ice cream sample. The high level of hardness of ice cream obtained in this study was likely caused by the high concentrations of CSG added to the formulations. The presence of high CSG in the ice cream possibly inhibited the ability of the chia seed gel to reduce the rate of ice crystal growth.

However, ice crystal size and ice volume of ice cream in this experiment were not measured, therefore, future data on this part would be useful.

4.2.6 Focus group sensory evaluation

Based on the results of the focus group sensory evaluation, the appearance of all the ice cream samples were described as creamy white with a tinge of yellowness (Figure 4.14). The yellowness may result from the added skim milk powder in the ice cream mix formulation (Goff, 1997). Furthermore, the results of perceived melting and texture characteristics shown in Table 4.7 and Table 4.9 supported the experimental results of this study (sections 4.2.4 and 4.2.5). The addition of stabilisers contributed to the stabilisation of foam structure and creaminess of ice cream. Further, in section 4.2.5, the addition of chia seed gel affected the texture (hardness and firmness) of ice cream. Therefore, chia seed gel possibly contributed to the sensory attributes of sample CS_2.

Figure 4.14 Appearance of ice cream

Photos captured by iPhone 11, Apple Inc., California, USA.

Among the samples with added CSG, the highest meltdown resistance and hardness was sample CS_3 which contained the highest level of CSG; however, the sample was described as chew-able and undesirable with large ice crystals. Samples C_1 and CS_1 were described as slightly gritty and fast melting with a weak body and texture. Sample C_2 was overall acceptable, however, the presence of commercial stabilisers in this sample were not favourable among the focus group panellists.

Based on the focus group sensory evaluation (Figure 4.15), sample C_2 with guar gum and carrageenan had better firmness than sample C_1 without stabiliser. Sample CS_2 was the most liked formulation among the samples that contained added CSG. Based on the sensory attributes (appearance, creaminess, meltdown, smoothness, firmness, mouth-feel, sweetness, flavour, overall acceptance), sample CS_2 received the highest scores, and it had high melting resistance with a firm texture. The sweetness and creaminess of sample CS_2 was liked by the panellists. Sample CS_2 had comparable flavour, overall acceptance, better appearance, creaminess, and meltdown to the control sample (C_2) containing guar gum and carrageenan, which indicated the potential of using chia seed gel as stabiliser. Therefore, this sample (CS_2) was subjected to consumer sensory evaluation (section 4.3). The selected sample (CS_2) contained 27.25% of CSG in the ice cream formulation.

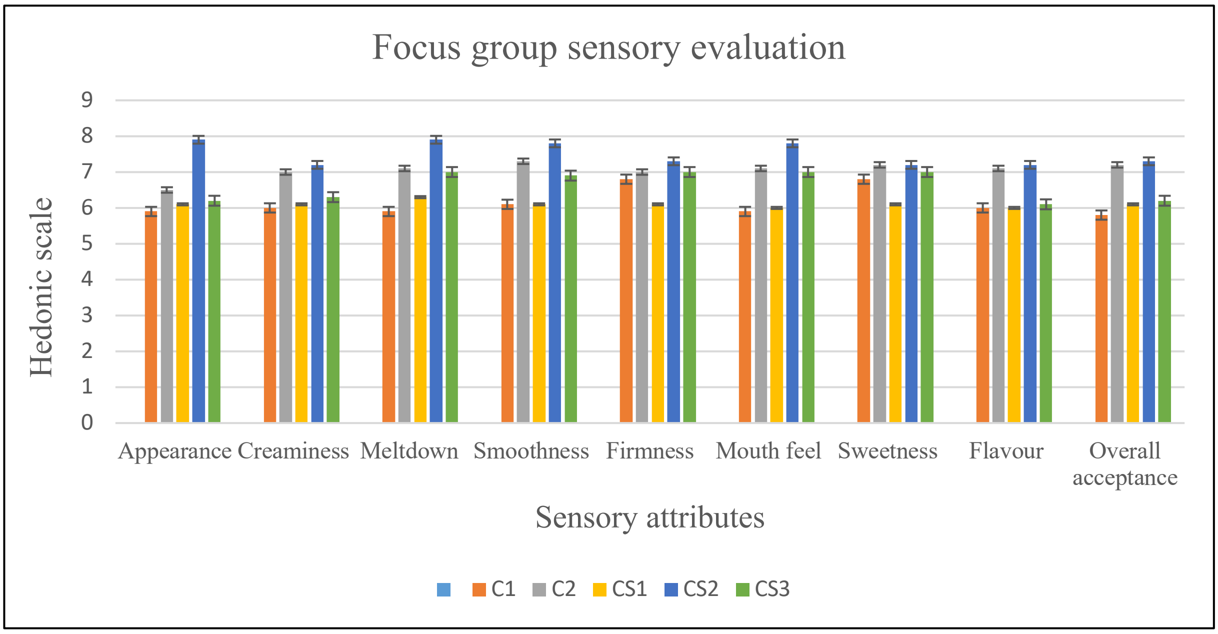


Figure 4.15 The results of focus group sensory evaluation

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; Error bars = ± SD; Independent experiments were replicated twice.

The results of focus group were consistent with previous studies (BahramParvar and Goff, 2013; Feizi et al., 2021). BahramParvar and Goff (2013) studied the micro-structure of ice cream containing BSG and reported high viscosity of ice cream mix with high level of added BSG might lead to relatively small air cells and smaller ice crystals in the ice cream, which could bring about creamier ice cream and more stable of the foam structure. Therefore, CSG which has similar properties with BSG could possibly contribute to the desirable sensory attributes of CS_2 when added in its formulation.

4.3 Consumer sensory evaluation

Consumer sensory panellists (n=60) evaluated sample CS_2 ice cream using the 9-point hedonic scale (Figure 4.16). The sample was evaluated for appearance, meltdown, creaminess, smoothness, firmness, mouth feel, sweetness, flavour and overall acceptance. Figure 4.16 shows that most of the attributes related to the sample ice cream obtained an average score over 7.0 excluding the smoothness. The slightly coarseness of the ice cream may result from some minor ice crystals existing in the ice cream, which may be caused by inefficient homogenization or temperature fluctuation during the consumer test. According to Clarke (2015), the fluctuation of temperature during consumer evaluation or consumption can cause the recrystallization of ice cream, thus affecting the smoothness of ice cream. The appearance, firmness, sweetness and flavour of the sample all received high sensory evaluation scores (7.50 ± 0.04, 7.17 ± 0.04, 7.26 ± 0.14 and 7.32 ± 0.26, respectively). Creaminess received the highest score (7.6 ± 0.09) compared with the other attributes. The average score for the overall acceptance of sample CS_2 was 7.40 ± 0.02 which indicated that the ice cream was liked moderately by consumers according to the 9-point hedonic scale.

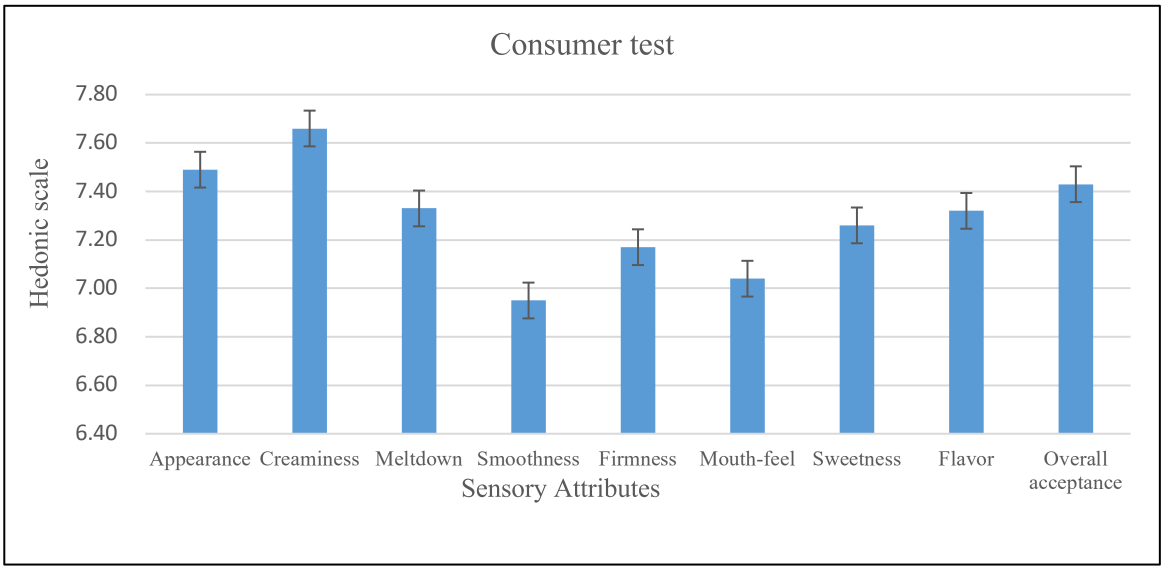


Figure 4.16 Mean consumer sensory evaluation scores of ice cream sample CS_2

Error bars= ± SD; Independent experiments were replicated twice.

4.4 Summary of phase II

Results showed that the addition of chia seed gel as well as the concentration of chia seed gel significantly affected the texture, melting properties and sensory attributes of ice cream ($p < 0.05$). The optimum concentration of CSG in ice cream mix formulation was 27.25% (w/w) based on the overrun, hardness, fat globule size distribution, melting properties and focus group sensory evaluation of ice cream. The ice cream with 27.25% (w/w) chia seed gel was also well-liked by the consumer sensory evaluation panellists.

Chapter 5 OVERALL CONCLUSIONS

The present study investigated the potential of chia seed gel replacing the conventional commercial stabilisers in ice cream. Five ice cream samples were studied with three levels (16.35%, 27.25%, 37.80%, w/w) of freshly extracted chia seed gel added in the ice cream mixes to replace commercial stabilisers (0.2% guar gum and 0.15% carrageenan). The addition of 27.25% (w/w) freshly extracted chia seed gel as stabiliser in the ice cream samples produced a creamier structure with superior sensory and physical characteristics compared with other samples. The ice cream sample was well-accepted by both the focus group and consumer sensory evaluations. Meltdown rate decreased with increasing concentrations of CSG in the ice cream formulations. Conversely, overrun, hardness and fat globule size distribution increased. The relatively high overrun, meltdown resistance, high fat globule size, as well as acceptable sensory properties, showed the potential of CSG as a replacement stabiliser for the conventional commercial stabilisers.

Chapter 6 RECOMMENDATIONS

In the present study, the chemical and nutritional components such as crude fibre, unsaturated fats, proteins, and vitamins of extracted chia seed gel were not analysed. Information on these components would be useful for developing food products containing freshly extracted chia seed gel.

The comparison of micro-structures of freshly extracted chia seed gel and freeze-dried chia seed gel using scanning electron microscope (SEM) was not determined in this study. Therefore, information on this part would be valuable for characterising ice cream containing chia seed gel.

Drying methods (freeze-drying and oven drying) can affect the yield and micro-structure of chia seed gel. Information on different drying methods for chia seed gel would be useful.

The crystal size of ice cream samples during heat-shock was not measured. Changes in crystal size of ice cream can affect the texture.

Chia seed gels should be characterized by oscillatory rheology which better describes elasticity and pseudo-plasticity.

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Chapter 8 APPENDICES

Appendices A. Sensory evaluation questionnaire, participant information sheet and consent form, and flyer form

QUESTIONNAIRE

Hello, my name is yuting yu and I am a master student of Food Technology of Massey University. My experiment is about ice cream but my ice cream formulation is different from conventional ones. I used a familiar ingredient- chia seed gel to replace commercial stabiliser like guar gum in ice cream. Here, we are going to discuss some questions regarding five ice cream formulations. The meeting will last for 1-2 hours and will take place at the University. Can I start by asking you a few questions?

1. Do you like ice cream?

2. What kind of flavour do you prefer? Vanilla, Chocolate or No flavor?

3. Have you heard of guar gum?

4. Have you heard of chia seed?

5. Do you prefer softer or harder ice cream?

6. Do you prefer low sugar or high sugar ice cream?

7. Now we have five ice cream samples with different formulations, please taste them and rate them with the following form.

INFORMATION SHEET

Project Title: Ice cream stabilised by chia seed gel

Introduction

I am Yuting Yu, a Master of Food Technology student at School of Food and Advanced Technology (SF&AT), Auckland, Massey University. The aim of the study is to produce ice cream containing natural, functional and wholesome ingredients which are typically found in domestic kitchens. In this project, conventional stabilisers and emulsifiers use in ice cream are replaced by chia seed gum. Conventional stabilizers and emulsifiers are labelled with E-numbers on nutrition panels of food products. E-numbers are negatively perceived by consumers as some of them are complex chemical compounds or are associated with public health concerns. Further, consumers are concerned about long list and complex names of ingredients on food labels.

The objective of the sensory evaluation is to evaluate the level of acceptance of the ice cream by consumer sensory panellists .

Participant involvement

This study involves tasting and evaluating ice cream samples and it may take 5 minutes. The ice cream that you will taste may contain all or some of following ingredients: **skim milk powder, sugar, cream, MDG, Guar gum or chia seed gel.**

You should not participate if you are allergic or may be affected by the consumption of any of the listed ingredients. In the unlikely event of any adverse reaction, medical assistance will be provided. You may advise one of the researchers of any potentially relevant cultural, religious or ethical beliefs which may prevent you from consuming the food under consideration. The information collected in this study will not be linked to any individual's identity and will be used to complete my postgraduate degree research project. In case you wish to receive a summary of the findings once data analysis has been completed, please provide your email address.

You are under no obligation to accept this invitation. If you decided to participate, you have the right to:

- Decline to answer any particular questions;
- Withdraw from the study (at any time);
- Ask any questions about the study at any time during participation;
- Provide information on the understanding that your name will not be used unless you give permission to the researchers.

Project contacts

- Yuting Yu: yuyuting19870527@gmail.com
- Dr. Tony Mutukumira (Supervisor) - a.n.mutukumira@massey.ac.nz

This project has been evaluated by peer review and judged to be low risk (Application No.4000026259). Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Research Ethics, telephone 06 350 5249, email humanethics@massey.ac.nz.

Panelist Number:

Date

Please evaluate the ice cream samples given to you by selecting (√) the attribute that best describes your feelings about the respective property of the ice cream. Please rinse your mouth with water before tasting each ice cream sample.

Sample									
Attribute	Dislike extremely 1	Dislike very much 2	Dislike moderately 3	Dislike slightly 4	Neither like nor dislike 5	Like slightly 6	Like moderately 7	Like very much 8	Like extremely 9
Appearance									
Creaminess									
Meltdown									
Smoothness									
Firmness									
Mouth-feel									
Sweetness									
Flavor									
Overall acceptance									
Purchase willing									

Comment on the specific features of the ice cream that you liked:

………………………………………………………………………………………

PARTICIPANT CONSENT FORM

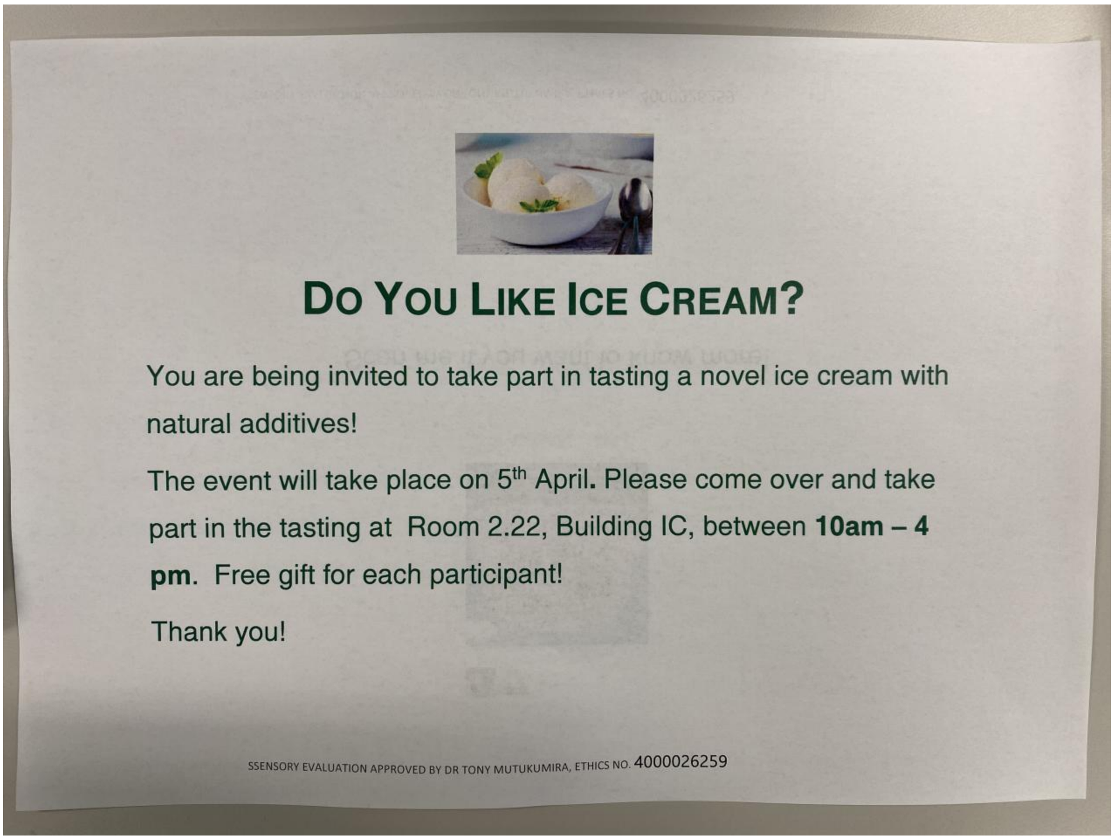
Ice cream stabilised by chia seed gel

- I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.
- I understand that I have the right to withdraw from the study at any time and decline my answers.
- I agree to voluntarily participate in this study under the condition set out the Information Sheet.
- I have discussed and advised the researchers of any potentially relevant cultural, religious or ethical beliefs that may prevent me from consuming this product under consideration.

Signature: ____________________ **Date: ________________________**

Full Name (Printed): _________________________

FLYER


DO YOU LIKE ICE CREAM?
You are being invited to take part in tasting a novel ice cream with natural additives!
The event will take place on 5th April. Please come over and take part in the tasting at Room 2.22, Building IC, between 10am – 4 pm. Free gift for each participant!
Thank you!
SSENSORY EVALUATION APPROVED BY DR TONY MUTUKUMIRA, ETHICS NO. 4000026259

Appendices B. Raw data

B.1 Raw data of yield of chia seed gel

Experiment #	Experiment Code	Ratio of seed: water	Soaking temperature (℃)	Yield Replication 1	Yield Replication 2
1	R_1S_1	1:10	80	9.407	10.479
2	R_1S_2	1:10	40	8.312	8.400
3	R_1S_3	1:10	20	5.539	5.595
4	R_2S_1	1:20	80	7.439	7.477
5	R_2S_2	1:20	40	6.897	7.045
6	R_2S_3	1:20	20	4.789	4.917
7	R_3S_1	1:30	80	5.887	5.943
8	R_3S_2	1:30	40	5.431	5.423
9	R_3S_3	1:30	20	4.222	4.210

B.2 Raw data of Viscosity of chia seed gel

The viscosity CSG extracted under soaking temperature 20℃ with a seed: water ratio of 1：10

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.104	1.169	0.101	1.446
0.124	1.082	0.122	1.273
0.157	0.954	0.157	1.083
0.201	0.822	0.198	0.924
0.254	0.712	0.250	0.830
0.319	0.662	0.314	0.742
0.398	0.574	0.398	0.666
0.501	0.501	0.503	0.591
0.628	0.448	0.632	0.532
0.795	0.400	0.793	0.480
0.995	0.364	0.998	0.436
1.260	0.335	1.262	0.402
1.583	0.310	1.588	0.371
1.994	0.284	1.994	0.340
2.508	0.257	2.513	0.316
3.161	0.232	3.165	0.291
3.982	0.209	3.977	0.265
5.007	0.186	5.005	0.240
6.310	0.166	6.311	0.217
7.938	0.150	7.943	0.195
9.998	0.135	9.993	0.178
12.590	0.122	12.580	0.162
15.850	0.111	15.850	0.145
19.950	0.101	19.950	0.130
25.120	0.093	25.120	0.119
31.620	0.085	31.620	0.108
39.800	0.078	39.810	0.097
50.120	0.071	50.120	0.088
63.100	0.066	63.100	0.080
79.430	0.061	79.440	0.073
100.000	0.057	100.000	0.066

The viscosity CSG extracted under soaking temperature 20℃ with a seed: water ratio of 1：20

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.101	1.134	0.097	1.163
0.123	1.007	0.126	0.959
0.158	0.884	0.161	0.835
0.201	0.758	0.198	0.735
0.252	0.636	0.249	0.633
0.318	0.543	0.317	0.527
0.398	0.453	0.394	0.449
0.501	0.383	0.500	0.379
0.635	0.322	0.630	0.316
0.795	0.270	0.793	0.271
0.997	0.227	0.998	0.228
1.262	0.189	1.263	0.192
1.590	0.155	1.581	0.162
1.999	0.131	1.997	0.136
2.512	0.107	2.512	0.111
3.159	0.088	3.163	0.093
3.985	0.072	3.977	0.078
5.016	0.058	5.021	0.063
6.303	0.047	6.310	0.052
7.951	0.038	7.945	0.043
10.010	0.030	9.994	0.036
12.590	0.025	12.590	0.030
15.850	0.021	15.850	0.025
19.950	0.017	19.950	0.021
25.120	0.015	25.120	0.018
31.620	0.013	31.620	0.016
39.810	0.012	39.810	0.015
50.120	0.011	50.120	0.014
63.090	0.011	63.100	0.013
79.430	0.011	79.420	0.014
100.000	0.011	99.980	0.014

The viscosity CSG extracted under soaking temperature 20℃ with a seed: water ratio of 1：30

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.101	1.154	0.100	1.039
0.130	0.940	0.125	0.965
0.159	0.828	0.156	0.833
0.201	0.696	0.199	0.713
0.251	0.606	0.253	0.640
0.312	0.519	0.321	0.550
0.401	0.438	0.400	0.488
0.497	0.395	0.503	0.441
0.631	0.333	0.634	0.384
0.792	0.289	0.797	0.352
0.997	0.253	1.003	0.319
1.265	0.220	1.262	0.284
1.601	0.203	1.587	0.259
1.989	0.183	1.992	0.235
2.514	0.170	2.512	0.212
3.164	0.153	3.165	0.192
3.978	0.142	3.980	0.175
5.004	0.128	5.011	0.158
6.310	0.114	6.303	0.142
7.944	0.100	7.945	0.127
10.000	0.090	9.994	0.114
12.590	0.083	12.590	0.103
15.860	0.075	15.850	0.092
19.960	0.068	19.950	0.083
25.120	0.062	25.120	0.075
31.620	0.058	31.630	0.068
39.810	0.053	39.810	0.062
50.120	0.049	50.110	0.057
63.100	0.046	63.100	0.051
79.440	0.043	79.430	0.047
100.000	0.040	100.000	0.044

The viscosity CSG extracted under soaking temperature 40°C with a seed: water ratio of 1：10

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.099	2.267	0.102	2.805
0.126	1.932	0.127	2.370
0.158	1.698	0.159	2.006
0.204	1.491	0.202	1.672
0.252	1.308	0.249	1.414
0.315	1.162	0.318	1.200
0.397	1.022	0.400	1.016
0.500	0.918	0.503	0.873
0.632	0.826	0.631	0.758
0.793	0.750	0.795	0.669
1.002	0.682	0.997	0.592
1.258	0.626	1.261	0.523
1.587	0.574	1.591	0.472
1.992	0.529	1.993	0.428
2.517	0.482	2.518	0.394
3.157	0.442	3.158	0.361
3.979	0.400	3.976	0.331
5.011	0.361	5.018	0.302
6.302	0.326	6.319	0.272
7.945	0.295	7.943	0.246
10.000	0.263	9.999	0.220
12.600	0.238	12.590	0.199
15.850	0.214	15.850	0.179
19.950	0.195	19.950	0.161
25.120	0.177	25.120	0.146
31.620	0.160	31.620	0.132
39.810	0.145	39.800	0.120
50.120	0.131	50.120	0.109
63.100	0.120	63.100	0.099
79.430	0.109	79.430	0.090
100.000	0.099	100.000	0.082

The viscosity CSG extracted under soaking temperature 40℃ with a seed: water ratio of 1：20

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.097	2.022	0.102	2.162
0.126	1.732	0.126	1.947
0.159	1.540	0.158	1.676
0.203	1.275	0.196	1.448
0.250	1.022	0.252	1.247
0.316	0.858	0.315	1.084
0.403	0.732	0.397	0.957
0.503	0.637	0.502	0.842
0.635	0.563	0.631	0.755
0.792	0.498	0.791	0.689
0.995	0.444	0.995	0.629
1.262	0.389	1.256	0.574
1.581	0.352	1.585	0.525
1.991	0.318	1.986	0.486
2.516	0.289	2.515	0.445
3.164	0.266	3.163	0.410
3.976	0.242	3.976	0.376
5.010	0.221	5.011	0.342
6.308	0.199	6.308	0.312
7.941	0.181	7.948	0.284
10.000	0.162	10.000	0.258
12.600	0.144	12.600	0.236
15.850	0.130	15.850	0.216
19.950	0.116	19.950	0.198
25.120	0.105	25.120	0.181
31.620	0.095	31.620	0.165
39.810	0.085	39.810	0.151
50.110	0.078	50.120	0.138
63.090	0.070	63.090	0.126
79.430	0.064	79.430	0.116
100.000	0.058	100.000	0.106

The viscosity CSG extracted under soaking temperature 40°C with a seed: water ratio of 1：30

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.100	1.837	0.099	1.527
0.128	1.635	0.126	1.315
0.157	1.434	0.156	1.142
0.199	1.249	0.199	0.961
0.247	1.131	0.250	0.824
0.319	0.992	0.317	0.725
0.397	0.900	0.399	0.638
0.501	0.801	0.498	0.581
0.632	0.726	0.631	0.512
0.796	0.655	0.798	0.450
1.003	0.604	0.994	0.406
1.262	0.548	1.259	0.366
1.584	0.510	1.592	0.333
1.993	0.467	1.985	0.302
2.515	0.430	2.512	0.278
3.165	0.396	3.158	0.254
3.981	0.358	3.984	0.230
5.009	0.326	5.011	0.210
6.310	0.295	6.316	0.189
7.944	0.268	7.947	0.172
9.993	0.241	10.000	0.158
12.590	0.218	12.580	0.144
15.840	0.199	15.850	0.132
19.950	0.180	19.950	0.122
25.120	0.165	25.120	0.112
31.630	0.150	31.630	0.103
39.810	0.136	39.810	0.095
50.120	0.125	50.120	0.088
63.100	0.113	63.090	0.083
79.430	0.103	79.430	0.076
100.000	0.093	100.000	0.071

The viscosity CSG extracted under soaking temperature 80℃ with a seed: water ratio of 1：10

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.101	6.569	0.101	6.907
0.126	5.409	0.126	6.098
0.159	4.459	0.159	5.281
0.200	3.681	0.200	4.571
0.250	3.111	0.249	3.268
0.320	2.565	0.315	2.710
0.403	2.160	0.398	2.294
0.499	1.838	0.497	1.966
0.631	1.550	0.630	1.675
0.793	1.309	0.798	1.424
1.000	1.125	1.001	1.237
1.258	0.964	1.254	1.077
1.585	0.836	1.584	0.933
1.996	0.733	1.990	0.829
2.508	0.642	2.515	0.733
3.162	0.570	3.156	0.660
3.979	0.510	3.976	0.601
5.007	0.461	5.001	0.548
6.305	0.421	6.318	0.504
7.939	0.387	7.935	0.462
9.997	0.351	10.000	0.417
12.590	0.320	12.590	0.378
15.860	0.290	15.850	0.341
19.940	0.264	19.950	0.310
25.120	0.242	25.120	0.282
31.630	0.220	31.630	0.255
39.800	0.198	39.810	0.231
50.120	0.181	50.120	0.208
63.090	0.162	63.100	0.187
79.430	0.145	79.440	0.167
100.000	0.129	100.000	0.150

The viscosity CSG extracted under soaking temperature 80°C with a seed: water ratio of 1：20

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.098	3.079	0.104	4.018
0.122	2.606	0.122	3.605
0.157	2.176	0.157	2.996
0.201	1.822	0.202	2.497
0.249	1.570	0.252	2.113
0.315	1.347	0.315	1.820
0.402	1.138	0.397	1.568
0.498	0.990	0.498	1.365
0.635	0.858	0.633	1.187
0.797	0.760	0.790	1.052
0.998	0.683	0.993	0.950
1.257	0.608	1.261	0.861
1.584	0.547	1.587	0.784
1.993	0.506	1.993	0.727
2.505	0.462	2.517	0.666
3.165	0.422	3.162	0.615
3.982	0.390	3.981	0.563
5.014	0.358	5.012	0.515
6.310	0.328	6.307	0.471
7.939	0.297	7.940	0.429
9.993	0.270	9.996	0.391
12.590	0.244	12.590	0.356
15.850	0.222	15.840	0.323
19.950	0.203	19.960	0.293
25.110	0.185	25.120	0.266
31.630	0.168	31.620	0.242
39.810	0.153	39.810	0.220
50.120	0.138	50.120	0.199
63.100	0.126	63.090	0.180
79.420	0.114	79.430	0.162
100.000	0.103	100.000	0.147

The viscosity CSG extracted under soaking temperature 80℃ with a seed: water ratio of 1：30

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.101	2.623	0.102	2.014
0.129	2.239	0.125	1.807
0.160	1.962	0.156	1.578
0.203	1.684	0.199	1.366
0.250	1.471	0.252	1.189
0.315	1.256	0.316	1.048
0.398	1.090	0.399	0.920
0.499	0.942	0.496	0.823
0.637	0.814	0.632	0.724
0.794	0.723	0.796	0.641
0.999	0.645	0.997	0.576
1.264	0.578	1.260	0.524
1.583	0.521	1.591	0.476
1.992	0.478	1.995	0.437
2.516	0.435	2.512	0.398
3.164	0.401	3.164	0.364
3.974	0.369	3.973	0.332
5.005	0.339	5.011	0.303
6.305	0.308	6.314	0.275
7.949	0.280	7.942	0.251
9.998	0.256	10.000	0.229
12.590	0.234	12.590	0.209
15.840	0.212	15.850	0.191
19.950	0.194	19.960	0.175
25.120	0.176	25.120	0.161
31.630	0.161	31.620	0.147
39.810	0.147	39.810	0.134
50.110	0.135	50.120	0.123
63.090	0.122	63.100	0.113
79.440	0.112	79.420	0.104
100.000	0.101	100.000	0.096

B.3 Raw data of overrun of ice cream samples

C1					
Replication 1			Replication 2		
Mix weight (g)	Ice cream weight (g)	Overrun (%)	Mix weight (g)	Ice cream weight (g)	Overrun (%)
78.09	56.23	27.71	77.81	55.58	28.57
C2					
Replication 1			Replication 2		
Mix weight (g)	Ice cream weight (g)	Overrun (%)	Mix weight (g)	Ice cream weight (g)	Overrun (%)
76.66	38.34	50.40	76.68	37.58	50.99
CS1					
Replication 1			Replication 2		
Mix weight (g)	Ice cream weight (g)	Overrun (%)	Mix weight (g)	Ice cream weight (g)	Overrun (%)
76.94	52.31	32.01	77.56	53.29	31.29
CS2					
Replication 1			Replication 2		
Mix weight (g)	Ice cream weight (g)	Overrun (%)	Mix weight (g)	Ice cream weight (g)	Overrun (%)
78.43	46.75	40.39	78.22	45.64	41.65
CS3					
Replication 1			Replication 2		
Mix weight (g)	Ice cream weight (g)	Overrun (%)	Mix weight (g)	Ice cream weight (g)	Overrun (%)
77.64	37.32	51.93	77.95	37.36	52.07

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.8 chia seed gel;

B.4 Raw data of apparent viscosity of ice cream mixes

The viscosity of ice cream mix of sample C1

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.101	1.694	0.103	1.898
0.128	1.381	0.126	1.595
0.160	1.139	0.155	1.336
0.200	0.923	0.201	1.101
0.251	0.778	0.250	0.912
0.317	0.666	0.315	0.712
0.398	0.552	0.401	0.571
0.502	0.473	0.500	0.479
0.634	0.396	0.633	0.407
0.796	0.349	0.787	0.339
0.997	0.283	1.003	0.294
1.255	0.251	1.261	0.260
1.585	0.223	1.580	0.214
1.991	0.203	1.997	0.186
2.511	0.168	2.508	0.164
3.161	0.146	3.165	0.145
3.977	0.128	3.979	0.131
5.004	0.111	5.008	0.115
6.308	0.096	6.305	0.103
7.940	0.084	7.942	0.092
9.998	0.075	10.010	0.083
12.580	0.067	12.590	0.075
15.580	0.061	15.850	0.067
19.950	0.055	19.950	0.061
25.110	0.050	25.120	0.055
31.620	0.044	31.630	0.050
39.810	0.040	39.800	0.045
50.120	0.036	50.110	0.041
63.090	0.033	63.090	0.037
79.430	0.030	79.430	0.034
100.000	0.028	100.000	0.031

The viscosity of ice cream mix of sample C2

Replication 1		Replication 2	
Shear Rate (s-1)	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.101	3.649	0.101	3.401
0.126	3.358	0.126	3.053
0.156	3.048	0.156	2.751
0.200	2.657	0.200	2.385
0.256	2.293	0.256	2.073
0.314	2.045	0.314	1.789
0.397	1.763	0.397	1.581
0.499	1.532	0.499	1.382
0.634	1.307	0.634	1.226
0.797	1.147	0.797	1.084
0.997	1.026	0.997	0.949
1.258	0.916	1.258	0.849
1.585	0.807	1.585	0.756
1.993	0.705	1.993	0.677
2.514	0.626	2.514	0.606
3.162	0.562	3.162	0.547
3.976	0.504	3.976	0.498
5.013	0.448	5.013	0.450
6.300	0.402	6.300	0.407
7.944	0.361	7.944	0.368
9.995	0.322	9.995	0.330
12.590	0.293	12.590	0.298
15.850	0.262	15.850	0.269
19.950	0.236	19.950	0.245
25.120	0.213	25.120	0.222
31.620	0.194	31.620	0.202
39.810	0.177	39.810	0.186
50.120	0.161	50.120	0.170
63.100	0.148	63.100	0.156
79.420	0.136	79.420	0.144
100.000	0.125	100.000	0.132

The viscosity of ice cream mix of sample CS1

Replication 1		Replication 2	
Shear rate (s-1)	Viscosity (Pa.s)	Shear rate (s-1)	Viscosity (Pa.s)
0.100	1.849	0.097	2.688
0.125	1.711	0.124	2.401
0.157	1.611	0.158	2.142
0.195	1.511	0.199	2.031
0.248	1.315	0.251	1.716
0.314	1.144	0.319	1.512
0.398	0.994	0.403	1.272
0.502	0.858	0.503	1.090
0.631	0.749	0.628	0.956
0.799	0.648	0.797	0.829
0.997	0.570	0.999	0.718
1.261	0.496	1.266	0.638
1.586	0.441	1.591	0.561
1.998	0.383	1.992	0.500
2.516	0.355	2.514	0.441
3.162	0.326	3.162	0.385
3.981	0.285	3.976	0.337
5.005	0.259	5.009	0.293
6.313	0.236	6.305	0.258
7.940	0.213	7.940	0.227
10.000	0.191	9.996	0.196
12.580	0.172	12.590	0.173
15.840	0.155	15.850	0.154
19.960	0.140	19.950	0.136
25.110	0.125	25.120	0.122
31.630	0.111	31.620	0.109
39.810	0.099	39.810	0.097
50.120	0.089	50.120	0.088
63.100	0.081	63.100	0.079
79.430	0.074	79.430	0.072
100.000	0.069	100.000	0.066

The viscosity of ice cream mix of sample CS2

Replication 1		Replication 2	
Shear rate (s-1)	Viscosity (Pa.s)	Shear rate (s-1)	Viscosity (Pa.s)
0.100	2.515	0.097	2.444
0.124	2.295	0.126	2.224
0.160	2.048	0.156	2.034
0.199	1.837	0.198	1.804
0.252	1.601	0.253	1.532
0.318	1.404	0.317	1.367
0.400	1.226	0.398	1.190
0.502	1.068	0.494	1.041
0.629	0.919	0.629	0.895
0.795	0.794	0.793	0.773
1.000	0.684	0.998	0.681
1.260	0.595	1.268	0.589
1.586	0.518	1.587	0.524
1.989	0.451	1.991	0.466
2.514	0.392	2.513	0.407
3.160	0.344	3.163	0.359
3.980	0.301	3.982	0.315
5.011	0.264	5.012	0.276
6.314	0.231	6.304	0.243
7.938	0.204	7.944	0.215
9.993	0.182	9.998	0.191
12.590	0.163	12.580	0.170
15.850	0.146	15.860	0.152
19.960	0.132	19.960	0.136
25.120	0.120	25.120	0.123
31.630	0.109	31.630	0.111
39.810	0.100	39.800	0.101
50.120	0.092	50.120	0.092
63.090	0.084	63.100	0.084
79.430	0.078	79.430	0.078
100.000	0.073	100.000	0.072

The viscosity of ice cream mix of sample CS3

Replication 1		Replication 2	
Shear rate (s^{-1})	Viscosity (Pa.s)	Shear rate (s^{-1})	Viscosity (Pa.s)
0.100	3.433	0.101	3.344
0.124	3.078	0.126	3.026
0.157	2.697	0.158	2.694
0.200	2.288	0.201	2.344
0.251	1.967	0.251	2.078
0.315	1.697	0.317	1.779
0.400	1.450	0.396	1.551
0.502	1.216	0.502	1.292
0.631	1.017	0.632	1.093
0.794	0.847	0.797	0.924
0.991	0.725	1.003	0.793
1.258	0.599	1.260	0.687
1.588	0.533	1.589	0.596
1.996	0.437	1.992	0.530
2.517	0.411	2.507	0.453
3.165	0.351	3.159	0.393
3.974	0.294	3.980	0.341
5.003	0.252	5.006	0.295
6.307	0.219	6.308	0.259
7.947	0.195	7.947	0.225
9.997	0.174	9.999	0.195
12.590	0.154	12.590	0.173
15.840	0.139	15.850	0.153
19.960	0.125	19.950	0.136
25.120	0.113	25.120	0.122
31.620	0.102	31.620	0.110
39.810	0.094	39.810	0.100
50.120	0.085	50.120	0.091
63.100	0.079	63.090	0.083
79.430	0.073	79.430	0.076
100.000	0.067	100.000	0.070

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.8 chia seed gel;

B.5 Raw data of meltdown test

B.5.1 The weight of dripped ice cream in all ice cream samples

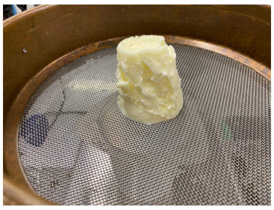
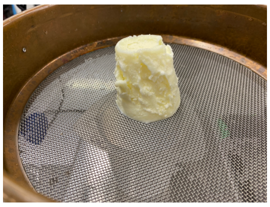
C1 Replication 1	Time (min)	Weight (g)	C2 Replication 1	Time (min)	Weight (g)
	10	0		10	0
	20	1.32		20	0.71
	30	10.16		30	3.85
	40	20.44		40	10.76
	50	29.78		50	17.11
	60	37.17		60	23.35
	70	43.25		70	27.97
C1Replication 2	Time (min)	Weight (g)	C2 Replication 2	Time (min)	Weight (g)
	10	0		10	0
	20	1.43		20	0.83
	30	8.87		30	8.87
	40	20.70		40	15.84
	50	32.31		50	22.18
	60	42.46		60	24.80
	70	49.91		70	26.59

CS1 Replication 1	Time (min)	Weight (g)	CS2 Replication 1	Time (min)	Weight (g)	CS3 Replication 1	Time (min)	Weight (g)
	10	0		10	0		10	0
	20	0.76		20	0		20	0
	30	7.13		30	3.25		30	1.22
	40	10.11		40	10.25		40	8.15
	50	18.81		50	16.55		50	16.10
	60	21.23		60	21.90		60	20.89
	70	27.78		70	25.62		70	24.87
CS1 Replication 2	Time (min)	Weight (g)	CS2 Replication 2	Time (min)	Weight (g)	CS3 Replication 2	Time (min)	Weight (g)
	10	0		10	0		10	0
	20	0.71		20	0		20	0
	30	3.85		30	3.85		30	1.32
	40	10.76		40	10.76		40	9.24
	50	17.11		50	17.11		50	17.42
	60	23.35		60	23.35		60	20.54
	70	27.97		70	26.97		70	24.80

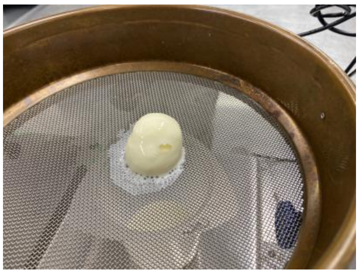
C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.8 chia seed gel;

B.5.2 Melting down of some ice cream sample at 10 min intervals in 60 min

C1

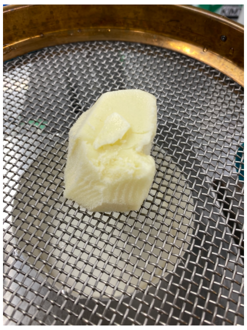
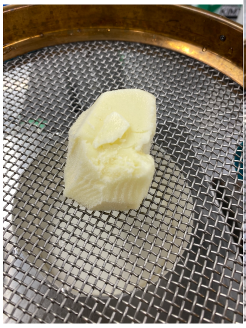
   

t=0min t=10min t=20min t=30min

t=40min **t=50min** **t=60min**

CS3

t=0min t=10min t=20min t=30min

t=4min t=50min t=60min t=70min

B.6 Raw data of hardness of ice cream samples

C1							
Replication 1				Replication 2			
Force (g)	Distance (mm)	Time (s)	Force (N)	Force (g)	Distance (mm)	Time (s)	Force (N)
5498.000	1.624	3.250	84.530	4137.600	1.624	3.250	63.620
C2							
Replication 1				Replication 2			
Force (g)	Distance (mm)	Time (s)	Force (N)	Force (g)	Distance (mm)	Time (s)	Force (N)
12779.200	1.624	3.250	196.480	12653.200	1.624	3.250	194.540
CS1							
Replication 1				Replication 2			
Force (g)	Distance (mm)	Time (s)	Force (N)	Force (g)	Distance (mm)	Time (s)	Force (N)
5859.100	1.624	3.250	90.080	6254.900	1.624	3.250	96.170
CS2							
Replication 1				Replication 2			
Force (g)	Distance (mm)	Time (s)	Force (N)	Force (g)	Distance (mm)	Time (s)	Force (N)
5222.100	1.624	3.250	80.290	5786.400	1.624	3.250	88.970
CS3							
Replication 1				Replication 2			
Force (g)	Distance (mm)	Time (s)	Force (N)	Force (g)	Distance (mm)	Time (s)	Force (N)
11876.100	1.624	3.250	182.590	12341.800	1.624	3.250	189.760

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.8 chia seed gel;

B.7 Raw data of fat globule size distribution of ice cream mixes and melted ice cream

B.7.1 Fat globule size distribution of ice cream mixes

Fat globule size distribution of ice cream mix of sample C1

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	0.27	0.37	239.883	0	0
0.013	0	0	1.905	0.08	0.09	275.423	0	0
0.015	0	0	2.188	0.06	0.05	316.228	0	0
0.017	0	0	2.512	0.02	0.01	363.078	0	0
0.020	0	0	2.884	0	0	416.869	0	0
0.023	0	0	3.311	0	0	478.630	0	0
0.026	0	0	3.802	0	0	549.541	0	0
0.030	0	0	4.365	0	0	630.957	0	0
0.035	0	0	5.012	0	0	724.436	0	0
0.040	0	0	5.754	0	0	831.764	0	0
0.046	0	0	6.607	0	0	954.994	0	0
0.052	0	0	7.586	0	0	1069.478	0	0
0.060	0	0	8.710	0	0	1258.925	0	0
0.069	0	0	10.000	0	0	1445.44	0	0
0.079	0.03	0.03	11.482	0	0	1659.587	0	0
0.091	0.19	0.19	13.183	0	0	1905.461	0	0
0.105	0.50	0.50	15.136	0	0	2187.762	0	0
0.120	0.90	0.91	17.378	0	0	2511.886	0	0
0.138	1.43	1.44	19.953	0	0	2884.032	0	0
0.158	2.10	2.11	22.909	0	0	3311.311	0	0
0.182	2.90	2.90	26.303	0	0	3801.894	0	0
0.209	3.84	3.83	30.200	0	0	4365.158	0	0
0.240	4.88	4.84	34.674	0	0	5011.872	0	0
0.275	5.95	5.89	39.811	0	0	5754.399	0	0
0.316	6.98	6.90	45.709	0	0	6606.934	0	0
0.363	7.86	7.78	52.481	0	0	7585.776	0	0
0.417	8.51	8.46	60.256	0	0	8709.636	0	0
0.479	8.37	8.49	69.183	0	0	10000	0	0
0.550	8.84	8.86	79.433	0	0			
0.631	7.53	7.64	91.201	0	0			
0.724	6.38	6.49	104.713	0	0			
0.832	5.02	5.12	120.226	0	0			
0.955	3.65	3.73	138.038	0	0			
1.096	2.39	2.46	158.489	0	0			
1.259	1.39	1.46	181.970	0	0			
1.445	0.68	0.76	208.930	0	0			

Fat globule size distribution of ice cream mix of sample C2

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	0	0	239.883	0	0
0.013	0	0	1.905	0	0	275.423	0	0
0.015	0	0	2.188	0	0	316.228	0	0
0.017	0	0	2.512	0	0	363.078	0	0
0.020	0	0	2.884	0	0	416.869	0	0
0.023	0	0	3.311	0	0	478.630	0	0
0.026	0	0	3.802	0	0	549.541	0	0
0.030	0	0	4.365	0	0	630.957	0	0
0.035	0	0	5.012	0	0	724.436	0	0
0.040	0	0	5.754	0	0	831.764	0	0
0.046	0	0	6.607	0	0	954.994	0	0
0.052	0	0	7.586	0	0	1069.478	0	0
0.060	0	0	8.710	0	0	1258.925	0	0
0.069	0	0	10.000	0	0	1445.440	0	0
0.079	0.01	0.01	11.482	0	0	1659.587	0	0
0.091	0.08	0.07	13.183	0	0	1905.461	0	0
0.105	0.18	0.17	15.136	0	0	2187.762	0	0
0.120	0.42	0.39	17.378	0	0	2511.886	0	0
0.138	0.82	0.78	19.953	0	0	2884.032	0	0
0.158	1.53	1.46	22.909	0	0	3311.311	0	0
0.182	2.67	2.55	26.303	0	0	3801.894	0	0
0.209	4.27	4.09	30.200	0	0	4365.158	0	0
0.240	6.28	6.03	34.674	0	0	5011.872	0	0
0.275	8.38	8.07	39.811	0	0	5754.399	0	0
0.316	10.14	9.78	45.709	0	0	6606.934	0	0
0.363	11.08	10.71	52.481	0	0	7585.776	0	0
0.417	10.89	10.54	60.256	0	0	8709.636	0	0
0.479	9.6	9.29	69.183	0	0	10000	0	0
0.550	7.52	7.27	79.433	0	0			
0.631	5.15	4.95	91.201	0	0			
0.724	3.01	2.87	104.713	0	0			
0.832	1.41	1.3	120.226	0	0			
0.955	0.48	0.39	138.038	0	0			
1.096	0.07	0.03	158.489	0	0			
1.259	0	0	181.970	0	0			
1.445	0	0	208.930	0	0			

Fat globule size distribution of ice cream mix of sample CS1

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	0.29	1.25	239.883	0	0
0.013	0	0	1.905	0.09	0.66	275.423	0	0
0.015	0	0	2.188	0.02	0.34	316.228	0	0
0.017	0	0	2.512	0.02	0.21	363.078	0	0
0.020	0	0	2.884	0.01	0.21	416.869	0	0
0.023	0	0	3.311	0.08	0.13	478.630	0	0
0.026	0	0	3.802	0.04	0.07	549.541	0	0
0.030	0	0	4.365	0.01	0.04	630.957	0	0
0.035	0	0	5.012	0	0.01	724.436	0	0
0.040	0	0	5.754	0	0	831.764	0	0
0.046	0	0	6.607	0	0	954.994	0	0
0.052	0	0	7.586	0	0	1069.478	0	0
0.060	0	0	8.710	0	0	1258.925	0	0
0.069	0	0	10.000	0	0	1445.440	0	0
0.079	0.12	0.02	11.482	0	0	1659.587	0	0
0.091	0.3	0.19	13.183	0	0	1905.461	0	0
0.105	0.62	0.49	15.136	0	0	2187.762	0	0
0.120	0.96	0.79	17.378	0	0	2511.886	0	0
0.138	1.41	1.16	19.953	0	0	2884.032	0	0
0.158	1.96	1.59	22.909	0	0	3311.311	0	0
0.182	2.66	2.09	26.303	0	0	3801.894	0	0
0.209	3.52	2.69	30.200	0	0	4365.158	0	0
0.240	4.57	3.4	34.674	0	0	5011.872	0	0
0.275	5.78	4.24	39.811	0	0	5754.399	0	0
0.316	7.07	5.17	45.709	0	0	6606.934	0	0
0.363	8.32	6.16	52.481	0	0	7585.776	0	0
0.417	9.32	7.11	60.256	0	0	8709.636	0	0
0.479	9.88	7.9	69.183	0	0	10000	0	0
0.550	9.82	8.39	79.433	0	0			
0.631	9.1	8.46	91.201	0	0			
0.724	7.82	8.06	104.713	0	0			
0.832	6.15	7.21	120.226	0	0			
0.955	4.41	6.02	138.038	0	0			
1.096	2.82	4.67	158.489	0	0			
1.259	1.59	3.31	181.970	0	0			
1.445	0.75	2.15	208.930	0	0			

Fat globule size distribution of ice cream mix of sample CS2

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	2.84	2.09	239.883	0	0
0.013	0	0	1.905	1.87	1.48	275.423	0	0
0.015	0	0	2.188	1.11	1.07	316.228	0	0
0.017	0	0	2.512	0.61	0.84	363.078	0	0
0.020	0	0	2.884	0.32	0.74	416.869	0	0
0.023	0	0	3.311	0.21	0.70	478.630	0	0
0.026	0	0	3.802	0.19	0.68	549.541	0	0
0.030	0	0	4.365	0.15	0.60	630.957	0	0
0.035	0	0	5.012	0.07	0.46	724.436	0	0
0.040	0	0	5.754	0.05	0.22	831.764	0	0
0.046	0	0	6.607	0.02	0	954.994	0	0
0.052	0	0	7.586	0.01	0	1069.478	0	0
0.060	0	0	8.710	0	0	1258.925	0	0
0.069	0	0	10.000	0	0	1445.440	0	0
0.079	0.06	0.17	11.482	0	0	1659.587	0	0
0.091	0.27	0.48	13.183	0	0	1905.461	0	0
0.105	0.61	0.81	15.136	0	0	2187.762	0	0
0.120	0.97	1.22	17.378	0	0	2511.886	0	0
0.138	1.39	1.68	19.953	0	0	2884.032	0	0
0.158	1.85	2.20	22.909	0	0	3311.311	0	0
0.182	2.34	2.79	26.303	0	0	3801.894	0	0
0.209	2.88	3.42	30.200	0	0	4365.158	0	0
0.240	3.44	4.09	34.674	0	0	5011.872	0	0
0.275	4.03	4.75	39.811	0	0	5754.399	0	0
0.316	4.64	5.4	45.709	0	0	6606.934	0	0
0.363	5.27	6.00	52.481	0	0	7585.776	0	0
0.417	5.91	6.53	60.256	0	0	8709.636	0	0
0.479	6.52	6.93	69.183	0	0	10000	0	0
0.550	7.05	7.15	79.433	0	0			
0.631	7.41	7.15	91.201	0	0			
0.724	7.55	6.90	104.713	0	0			
0.832	7.38	6.38	120.226	0	0			
0.955	6.89	5.65	138.038	0	0			
1.096	6.10	4.75	158.489	0	0			
1.259	5.08	3.80	181.970	0	0			
1.445	3.95	2.87	208.930	0	0			

Fat globule size distribution of ice cream mix of sample CS3

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	1.91	2.02	239.883	0	0
0.013	0	0	1.905	1.77	1.87	275.423	0	0
0.015	0	0	2.188	1.67	1.77	316.228	0	0
0.017	0	0	2.512	1.66	1.77	363.078	0	0
0.020	0	0	2.884	1.78	1.88	416.869	0	0
0.023	0	0	3.311	2.05	2.14	478.630	0	0
0.026	0	0	3.802	2.44	2.50	549.541	0	0
0.030	0	0	4.365	2.578	2.31	630.957	0	0
0.035	0	0	5.012	2.566	1.68	724.436	0	0
0.040	0	0	5.754	2.36	0.99	831.764	0	0
0.046	0	0	6.607	1.81	0.86	954.994	0	0
0.052	0	0	7.586	1.07	0.81	1069.478	0	0
0.060	0	0	8.710	0.89	0.72	1258.925	0	0
0.069	0	0	10.000	0.52	0.52	1445.440	0	0
0.079	0.09	0.11	11.482	0.31	0.12	1659.587	0	0
0.091	0.24	0.27	13.183	0.12	0.07	1905.461	0	0
0.105	0.42	0.48	15.136	0.06	0.03	2187.762	0	0
0.120	0.58	0.65	17.378	0	0	2511.886	0	0
0.138	0.75	0.84	19.953	0	0	2884.032	0	0
0.158	0.91	1.02	22.909	0	0	3311.311	0	0
0.182	1.06	1.19	26.303	0	0	3801.894	0	0
0.209	1.21	1.35	30.200	0	0	4365.158	0	0
0.240	1.34	1.51	34.674	0	0	5011.872	0	0
0.275	1.46	1.64	39.811	0	0	5754.399	0	0
0.316	1.57	1.75	45.709	0	0	6606.934	0	0
0.363	1.66	1.85	52.481	0	0	7585.776	0	0
0.417	1.74	1.93	60.256	0	0	8709.636	0	0
0.479	1.81	2.00	69.183	0	0	10000	0	0
0.550	1.89	2.08	79.433	0	0			
0.631	1.98	2.16	91.201	0	0			
0.724	2.06	2.24	104.713	0	0			
0.832	2.13	2.31	120.226	0	0			
0.955	2.18	2.35	138.038	0	0			
1.096	2.19	2.34	158.489	0	0			
1.259	2.14	2.28	181.970	0	0			
1.445	2.05	2.16	208.930	0	0			

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.8 chia seed gel;

B.7.2 Fat globule size distribution of melted ice cream

Fat globule size distribution of melted ice cream of sample C_1

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	0.85	0.82	239.883	0	0
0.013	0	0	1.905	0.79	0.77	275.423	0	0
0.015	0	0	2.188	0.54	0.52	316.228	0	0
0.017	0	0	2.512	0.39	0.34	363.078	0	0
0.020	0	0	2.884	0.39	0.32	416.869	0	0
0.023	0	0	3.311	0.27	0.26	478.630	0	0
0.026	0	0	3.802	0.08	0.07	549.541	0	0
0.030	0	0	4.365	0.06	0.05	630.957	0	0
0.035	0	0	5.012	0.02	0.01	724.436	0	0
0.040	0	0	5.754	0	0	831.764	0	0
0.046	0	0	6.607	0	0	954.994	0	0
0.052	0	0	7.586	0	0	1069.478	0	0
0.060	0	0	8.710	0	0	1258.925	0	0
0.069	0	0	10.000	0	0	1445.440	0	0
0.079	0.03	0.02	11.482	0	0	1659.587	0	0
0.091	0.19	0.17	13.183	0	0	1905.461	0	0
0.105	0.50	0.48	15.136	0	0	2187.762	0	0
0.120	0.90	0.88	17.378	0	0	2511.886	0	0
0.138	1.43	1.42	19.953	0	0	2884.032	0	0
0.158	2.10	2.00	22.909	0	0	3311.311	0	0
0.182	2.90	2.80	26.303	0	0	3801.894	0	0
0.209	3.84	3.80	30.200	0	0	4365.158	0	0
0.240	4.88	4.84	34.674	0	0	5011.872	0	0
0.275	5.73	5.71	39.811	0	0	5754.399	0	0
0.316	5.55	5.53	45.709	0	0	6606.934	0	0
0.363	5.02	5.00	52.481	0	0	7585.776	0	0
0.417	3.65	3.61	60.256	0	0	8709.636	0	0
0.479	2.39	2.37	69.183	0	0	10000	0	0
0.550	1.58	1.56	79.433	0	0			
0.631	1.12	1.11	91.201	0	0			
0.724	1.15	1.14	104.713	0	0			
0.832	1.19	1.18	120.226	0	0			
0.955	1.09	1.06	138.038	0	0			
1.096	1.06	1.06	158.489	0	0			
1.259	1.00	1.00	181.970	0	0			
1.445	0.96	0.95	208.930	0	0			

Fat globule size distribution of melted ice cream of sample C2

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	0.67	0.57	239.883	0	0
0.013	0	0	1.905	0.78	0.67	275.423	0	0
0.015	0	0	2.188	0.81	0.73	316.228	0	0
0.017	0	0	2.512	0.83	0.79	363.078	0	0
0.020	0	0	2.884	0.8	0.72	416.869	0	0
0.023	0	0	3.311	0.68	0.60	478.630	0	0
0.026	0	0	3.802	0.53	0.49	549.541	0	0
0.030	0	0	4.365	0.42	0.38	630.957	0	0
0.035	0	0	5.012	0.33	0.28	724.436	0	0
0.040	0	0	5.754	0.21	0.18	831.764	0	0
0.046	0	0	6.607	0.12	0.09	954.994	0	0
0.052	0.35	0.29	7.586	0.12	0.09	1069.478	0	0
0.060	0.57	0.51	8.710	0.14	0.11	1258.925	0	0
0.069	0.87	0.84	10.000	0.17	0.15	1445.440	0	0
0.079	1.23	1.19	11.482	0.19	0.17	1659.587	0	0
0.091	1.46	1.39	13.183	0.25	0.19	1905.461	0	0
0.105	1.64	1.59	15.136	0.35	0.27	2187.762	0	0
0.120	1.75	1.70	17.378	0.47	0.38	2511.886	0	0
0.138	1.78	1.69	19.953	0.6	0.56	2884.032	0	0
0.158	1.77	1.66	22.909	0.71	0.62	3311.311	0	0
0.182	1.75	1.71	26.303	0.8	0.74	3801.894	0	0
0.209	1.72	1.69	30.200	1.26	1.14	4365.158	0	0
0.240	1.67	1.62	34.674	2.24	1.97	5011.872	0	0
0.275	1.62	1.57	39.811	3.30	2.98	5754.399	0	0
0.316	1.43	1.40	45.709	3.50	3.10	6606.934	0	0
0.363	1.21	1.17	52.481	3.58	3.23	7585.776	0	0
0.417	0.98	0.87	60.256	3.50	3.23	8709.636	0	0
0.479	0.76	0.72	69.183	2.80	2.14	10000	0	0
0.550	0.43	0.38	79.433	2.20	2.11			
0.631	0.21	0.2	91.201	1.71	1.71			
0.724	0.04	0.01	104.713	1.00	1.00			
0.832	0.03	0	120.226	0.54	0.54			
0.955	0.01	0	138.038	0.31	0.31			
1.096	0.19	0.09	158.489	0	0			
1.259	0.34	0.21	181.970	0	0			
1.445	0.45	0.36	208.930	0	0			

Fat globule size distribution of melted ice cream of sample CS1

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	1.26	1.28	239.883	0	0
0.013	0	0	1.905	1.29	1.29	275.423	0	0
0.015	0	0	2.188	1.34	1.36	316.228	0	0
0.017	0	0	2.512	1.27	1.26	363.078	0	0
0.020	0	0	2.884	1.23	1.23	416.869	0	0
0.023	0	0	3.311	1.18	1.17	478.63	0	0
0.026	0	0	3.802	1.12	1.11	549.541	0	0
0.030	0	0	4.365	1.09	1.06	630.957	0	0
0.035	0	0	5.012	0.94	0.96	724.436	0	0
0.040	0	0	5.754	0.83	0.82	831.764	0	0
0.046	0	0	6.607	0.78	0.77	954.994	0	0
0.052	0	0	7.586	0.38	0.35	1069.478	0	0
0.060	0	0	8.710	0.24	0.24	1258.925	0	0
0.069	0.02	0	10.000	0.21	0.20	1445.440	0	0
0.079	0.04	0.05	11.482	0.17	0.15	1659.587	0	0
0.091	0.20	0.20	13.183	0.12	0.12	1905.461	0	0
0.105	0.90	0.25	15.136	0.09	0.09	2187.762	0	0
0.120	1.20	1.20	17.378	0.03	0.03	2511.886	0	0
0.138	1.58	1.20	19.953	0.01	0.01	2884.032	0	0
0.158	1.97	2.00	22.909	0	0	3311.311	0	0
0.182	2.20	2.70	26.303	0	0	3801.894	0	0
0.209	2.10	2.80	30.200	0	0	4365.158	0	0
0.240	4.20	4.58	34.674	0	0	5011.872	0	0
0.275	5.64	5.66	39.811	0	0	5754.399	0	0
0.316	5.42	5.67	45.709	0	0	6606.934	0	0
0.363	4.86	5.10	52.481	0	0	7585.776	0	0
0.417	3.45	3.64	60.256	0	0	8709.636	0	0
0.479	2.00	2.13	69.183	0	0	10000	0	0
0.550	0.95	0.95	79.433	0	0			
0.631	0.34	0.45	91.201	0	0			
0.724	0.23	0.21	104.713	0	0			
0.832	0.32	0.34	120.226	0	0			
0.955	0.58	0.54	138.038	0	0			
1.096	0.75	0.78	158.489	0	0			
1.259	0.97	0.94	181.970	0	0			
1.445	1.24	1.23	208.930	0	0			

Fat globule size distribution of melted ice cream of sample CS2

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	0.54	0.53	239.883	0	0.01
0.013	0	0	1.905	0.72	0.72	275.423	0	0
0.015	0	0	2.188	0.81	0.81	316.228	0	0
0.017	0	0	2.512	0.83	0.83	363.078	0	0
0.020	0	0	2.884	0.80	0.80	416.869	0	0
0.023	0.03	0.02	3.311	0.68	0.67	478.630	0	0
0.026	0.06	0.07	3.802	0.41	0.42	549.541	0	0
0.030	0.09	0.09	4.365	0.20	0.20	630.957	0	0
0.035	0.19	0.21	5.012	0.13	0.14	724.436	0	0
0.040	0.34	0.33	5.754	0.08	0.09	831.764	0	0
0.046	0.52	0.52	6.607	0.09	0.09	954.994	0	0
0.052	0.75	0.76	7.586	0.12	0.11	1069.478	0	0
0.060	0.96	0.97	8.710	0.19	0.18	1258.925	0	0
0.069	1.32	1.34	10.000	0.34	0.35	1445.440	0	0
0.079	1.64	1.66	11.482	0.47	0.48	1659.587	0	0
0.091	1.95	1.95	13.183	0.68	0.69	1905.461	0	0
0.105	2.20	2.23	15.136	0.87	0.88	2187.762	0	0
0.120	2.31	2.34	17.378	1.19	1.19	2511.886	0	0
0.138	2.39	2.39	19.953	1.46	1.45	2884.032	0	0
0.158	2.45	2.44	22.909	1.88	1.89	3311.311	0	0
0.182	2.47	2.45	26.303	2.24	2.24	3801.894	0	0
0.209	2.34	2.34	30.200	2.61	2.60	4365.158	0	0
0.240	2.15	2.15	34.674	2.81	2.80	5011.872	0	0
0.275	1.98	1.99	39.811	2.97	2.98	5754.399	0	0
0.316	1.76	1.77	45.709	2.99	2.99	6606.934	0	0
0.363	1.34	1.33	52.481	2.80	2.81	7585.776	0	0
0.417	1.13	1.13	60.256	2.20	2.22	8709.636	0	0
0.479	0.86	0.86	69.183	1.71	1.70	10000	0	0
0.550	0.66	0.65	79.433	1.00	1.00			
0.631	0.44	0.43	91.201	0.54	0.55			
0.724	0.20	0.21	104.713	0.31	0.32			
0.832	0.23	0.23	120.226	0.24	0.25			
0.955	0.13	0.12	138.038	0.13	0.14			
1.096	0.08	0.09	158.489	0.07	0.06			
1.259	0.22	0.21	181.970	0.04	0.04			
1.445	0.45	0.44	208.930	0.02	0.02			

Fat globule size distribution of melted ice cream of sample CS3

	Replication 1	Replication 2	Continued on the previous columns			Continued on the previous columns		
Size (um)	Volume %	Volume %		Replication 1	Replication 2		Replication 1	Replication 2
0.010	0	0	Size (um)	Volume %	Volume %	Size (um)	Volume %	Volume %
0.011	0	0	1.660	0.92	0.92	239.883	0.01	0.01
0.013	0	0	1.905	1.02	1.02	275.423	0	0
0.015	0	0	2.188	1.09	1.09	316.228	0	0
0.017	0	0	2.512	1.06	1.06	363.078	0	0
0.020	0	0	2.884	1.02	1.02	416.869	0	0
0.023	0	0	3.311	0.99	0.99	478.630	0	0
0.026	0	0	3.802	0.86	0.86	549.541	0	0
0.030	0.02	0.02	4.365	0.67	0.67	630.957	0	0
0.035	0.08	0.08	5.012	0.33	0.33	724.436	0	0
0.040	0.12	0.12	5.754	0.21	0.21	831.764	0	0
0.046	0.30	0.30	6.607	0.12	0.12	954.994	0	0
0.052	0.45	0.45	7.586	0.12	0.12	1069.478	0	0
0.060	0.66	0.66	8.710	0.14	0.14	1258.925	0	0
0.069	0.88	0.88	10.000	0.17	0.17	1445.440	0	0
0.079	1.02	1.02	11.482	0.19	0.19	1659.587	0	0
0.091	1.22	1.22	13.183	0.32	0.32	1905.461	0	0
0.105	1.32	1.32	15.136	0.54	0.54	2187.762	0	0
0.120	1.38	1.38	17.378	0.76	0.76	2511.886	0	0
0.138	1.43	1.43	19.953	0.99	0.99	2884.032	0	0
0.158	1.48	1.48	22.909	1.26	1.26	3311.311	0	0
0.182	1.43	1.43	26.303	1.55	1.55	3801.894	0	0
0.209	1.38	1.38	30.200	1.78	1.78	4365.158	0	0
0.240	1.21	1.21	34.674	2.21	2.21	5011.872	0	0
0.275	1.00	1.00	39.811	2.78	2.78	5754.399	0	0
0.316	0.87	0.87	45.709	3.50	3.50	6606.934	0	0
0.363	0.67	0.67	52.481	3.67	3.67	7585.776	0	0
0.417	0.45	0.45	60.256	3.75	3.75	8709.636	0	0
0.479	0.23	0.23	69.183	3.64	3.64	10000	0	0
0.550	0.13	0.13	79.433	3.50	3.50			
0.631	0.04	0.04	91.201	2.10	2.10			
0.724	0.04	0.04	104.713	1.02	1.02			
0.832	0.09	0.09	120.226	0.21	0.21			
0.955	0.20	0.20	138.038	0.20	0.20			
1.096	0.39	0.39	158.489	0.10	0.10			
1.259	0.56	0.56	181.970	0.06	0.06			
1.445	0.76	0.76	208.930	0.02	0.02			

Fat globule size ($d_{4,3}$) of ice cream mix (μm)

Ice cream formulation	Replication 1	Replication 2
C_1	1.015	1.019
C_2	0.587	0.580
CS_1	1.454	1.900
CS_2	2.844	3.707
CS_3	8.158	7.876

Fat globule size ($d_{4,3}$) of ice cream melts (μm)

Ice cream formulation	Replication 1	Replication 2
C_1	2.664	2.575
C_2	88.786	87.338
CS_1	10.139	10.873
CS_2	92.526	96.336
CS_3	93.571	93.572

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.80 chia seed gel; ± = SD; Independent experiments were replicated twice.

B.8 Outcomes of sensory evaluation from focus group (n=5)

Replication 1

Panelist	sample	Appearance	Creaminess	Meltdown	Smoothness	Firmness	Mouth feel	Sweetness	Flavour	Overall acceptance
1	C1	6	6	6	6	7	6	7	6	6
	C2	6	7	7	7	7	7	7	7	7
	CS1	6	6	7	6	6	6	6	6	6
	CS2	8	7	8	7	7	8	7	7	7
	CS3	6	7	8	7	7	7	7	6	6
2	C1	6	5	6	7	6	6	7	6	6
	C2	6	7	7	7	7	7	7	7	7
	CS1	6	6	6	6	6	6	6	6	6
	CS2	8	7	8	8	7	8	7	7	7
	CS3	6	6	7	7	7	7	7	6	6
3	C1	6	6	6	6	6	6	6	6	5
	C2	6	7	7	7	7	7	7	7	7
	CS1	6	6	6	6	6	6	6	6	6
	CS2	8	7	8	8	7	8	7	7	7
	CS3	6	6	6	6	7	7	7	6	6
4	C1	6	6	6	6	7	6	7	6	6
	C2	6	7	7	8	7	7	8	7	7
	CS1	6	6	6	5	6	5	6	6	6
	CS2	8	7	8	8	7	8	7	7	7
	CS3	6	6	7	7	7	7	7	6	6
5	C1	6	6	6	6	7	6	7	6	6
	C2	8	7	7	8	7	7	7	7	7
	CS1	6	6	6	6	6	6	6	6	6
	CS2	8	7	8	9	7	8	7	7	7
	CS3	6	6	7	7	7	7	7	6	6

Replication 2

Panelist	sample	Appearance	Creaminess	Meltdown	Smoothness	Firmness	Mouth-feel	Sweetness	Flavour	Overall acceptance
1	C1	6	7	6	6	7	6	6	6	6
	C2	7	7	8	7	7	7	8	8	8
	CS1	7	7	8	8	7	7	7	6	7
	CS2	8	8	8	7	8	7	8	8	8
	CS3	7	7	7	7	8	7	7	7	7
2	C1	6	6	6	6	7	6	7	6	6
	C2	6	7	7	7	7	7	7	7	7
	CS1	6	6	6	6	6	6	6	6	6
	CS2	8	7	8	8	7	8	7	7	7
	CS3	6	6	7	7	7	7	7	6	6
3	C1	6	6	6	6	7	6	7	6	6
	C2	7	7	7	8	8	8	7	7	8
	CS1	6	6	6	6	6	6	6	6	6
	CS2	8	8	8	8	8	8	8	8	8
	CS3	7	6	7	7	7	7	7	6	7
4	C1	5	6	5	6	7	5	7	6	5
	C2	6	7	7	7	6	7	7	7	7
	CS1	6	6	6	6	6	6	6	6	6
	CS2	7	7	7	7	7	7	7	7	7
	CS3	6	6	7	7	6	7	7	6	6
5	C1	6	6	6	6	7	6	7	6	6
	C2	7	7	7	7	7	7	7	7	7
	CS1	6	6	6	6	6	6	6	6	6
	CS2	8	7	8	8	8	8	7	7	8
	CS3	6	7	7	7	7	7	7	6	6

C_1, C_2, CS_1, CS_2, CS_3 = prototype ice cream formulations (%, w/w); C_1: 0 Guar gum; 0 Carrageenan; 0 chia seed gel; C_2: 0.20 Guar gum; 0.15 Carrageenan; 0 chia seed gel; CS_1: 0 Guar gum; 0 Carrageenan; 16.35 chia seed gel; CS_2: 0 Guar gum; 0 Carrageenan; 27.25 chia seed gel; CS_3: 0 Guar gum; 0 Carrageenan; 37.8 chia seed gel;

B.9 Outcome of consumer test

Consumer test of selected ice cream (n= 60)

Replication 1

Panelist	Appearance	Creaminess	Meltdown	Smoothness	Firmness	Mouth feel	Sweetness	Flavour	Overall acceptance
1	8	8	7	8	7	8	8	8	8
2	8	7	7	7	8	8	5	4	6
3	7	7	6	8	8	6	8	7	7
4	8	7	7	8	7	9	8	8	8
5	7	8	9	9	6	7	7	6	8
6	7	7	6	7	8	7	7	7	7
7	7	7	8	8	7	8	7	8	7
8	9	9	6	8	6	8	7	8	8
9	7	6	6	5	7	6	8	7	7
10	6	6	5	7	5	7	6	6	6
11	7	8	8	7	8	7	8	7	8
12	6	7	4	8	6	6	3	5	6
13	7	7	8	8	6	7	7	7	7
14	7	8	5	7	7	5	8	6	7
15	7	8	8	7	6	7	3	4	7
16	9	8	9	9	9	9	9	9	9
17	7	8	7	8	4	8	4	7	8
18	8	9	8	9	7	9	8	7	9
19	5	5	6	4	7	5	6	7	6
20	9	9	9	9	9	9	9	9	9
21	8	5	5	5	7	4	7	3	4
22	7	8	5	7	8	5	7	8	8
23	7	8	8	7	8	8	5	5	8
24	8	8	8	8	8	8	8	8	8
25	8	9	8	7	9	9	9	8	9
26	9	9	9	9	9	9	9	9	9
27	7	8	8	9	8	7	8	8	8
28	7	7	8	7	7	7	7	7	7
29	8	7	8	7	7	8	8	8	8
30	8	8	6	7	8	7	8	8	7

Replication 2

Panelist	Appearance	Creaminess	Meltdown	Smoothness	Firmness	Mouth feel	Sweetness	Flavour	Overall acceptance
1	7	7	7	7	7	7	7	6	7
2	7	9	9	9	9	9	6	9	8
3	5	7	6	7	6	6	6	6	6
4	7	6	7	5	7	5	7	6	6
5	8	8	7	7	6	7	6	8	7
6	8	9	9	9	9	9	9	9	9
7	9	8	7	7	6	6	8	7	8
8	7	8	7	7	7	7	6	7	7
9	7	5	9	9	7	5	6	9	7
10	9	9	9	9	9	9	9	9	9
11	4	7	7	5	6	6	6	6	6
12	8	9	8	8	8	8	7	7	8
13	9	9	9	9	8	8	7	7	8
14	8	7	8	9	8	8	6	8	8
15	8	9	8	6	8	9	7	9	9
16	6	7	5	6	5	6	7	7	6
17	7	8	8	8	6	7	8	7	8
18	7	4	6	5	7	6	8	8	7
19	7	8	7	5	6	4	6	6	7
20	9	9	9	8	9	8	9	9	8
21	7	8	8	6	8	8	9	9	9
22	8	8	7	7	9	8	8	8	8
23	9	9	8	6	8	8	8	7	8
24	9	9	7	9	8	8	9	8	8
25	7	8	7	5	7	5	8	7	6
26	8	9	7	8	6	8	8	7	8
27	8	6	7	5	7	7	6	5	7
28	8	8	6	7	7	8	9	8	8
29	6	4	3	3	3	3	3	2	4
30	8	8	8	7	8	8	9	9	8

Appendices C. Statistical output

C.1 Correlation coefficients and regression correlation: Yield and Viscosity of chia seed gel using Minitab

Regression Analysis: Yield (%) versus Seed: water Ratio, Soaking Temperature (°C)

Regression Equation

Yield (%)	=	-1.381 + 100.4 Ratio + 0.1446 Temperature (°C) - 659 Ratio*Ratio - 0.001344 Temperature (°C) *Temperature (°C) + 0.6215 Ratio*Temperature (°C)

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-1.381	0.846	-1.63	0.129	
Ratio	100.4	24.9	4.02	0.002	110.51
Temperature (°C)	0.1446	0.0197	7.33	0.000	53.65
Ratio*Ratio	-659	178	-3.70	0.003	107.01
Temperature (°C) *Temperature (°C)	-0.001344	0.000182	-7.40	0.000	49.00
Ratio*Temperature (°C)	0.6215	0.0951	6.53	0.000	9.15

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.285178	98.19%	97.44%	94.72%

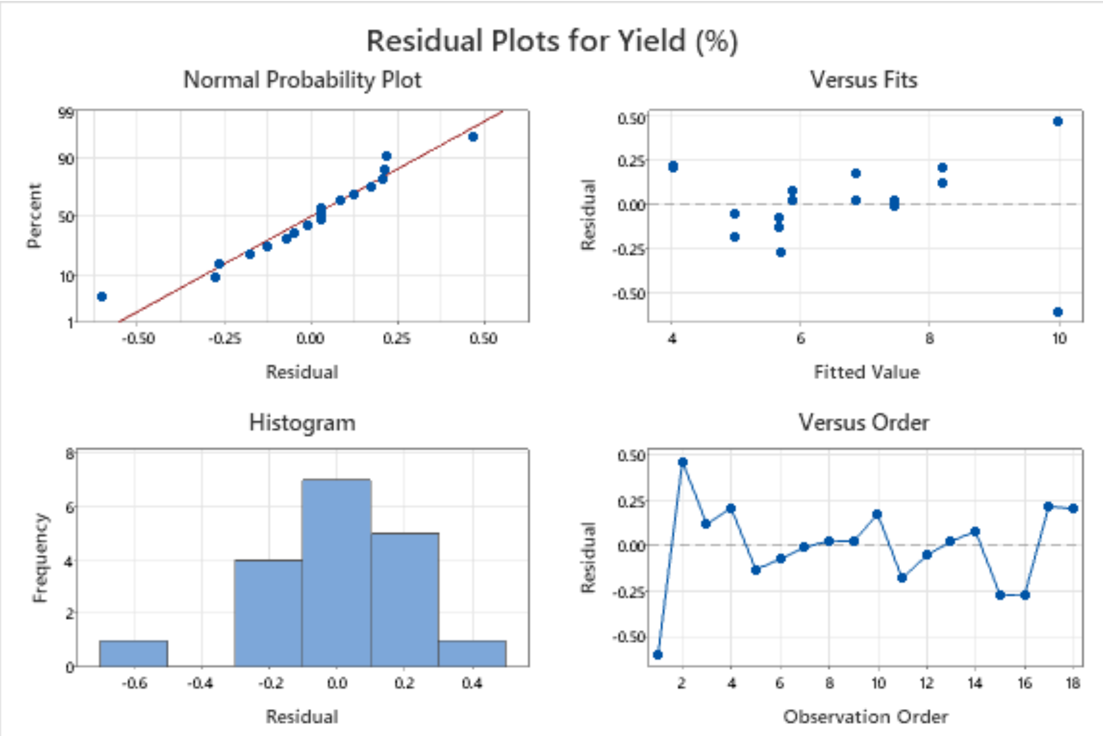
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	53.0800	10.6160	130.54	0.000
Ratio	1	1.3170	1.3170	16.19	0.002
Temperature (°C)	1	4.3650	4.3650	53.67	0.000
Ratio*Ratio	1	1.1129	1.1129	13.68	0.003
Temperature (°C) *Temperature (°C)	1	4.4565	4.4565	54.80	0.000
Ratio*Temperature (°C)	1	3.4711	3.4711	42.68	0.000
Error	12	0.9759	0.0813		
Lack-of-Fit	3	0.3743	0.1248	1.87	0.206
Pure Error	9	0.6016	0.0668		
Total	17	54.0559			

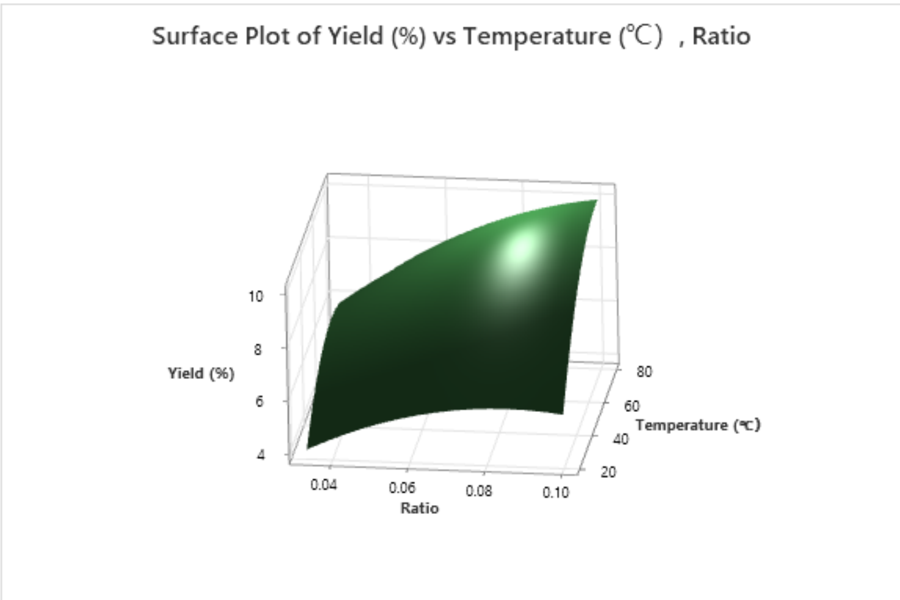
Fits and Diagnostics for Unusual Observations

Obs	Yield (%)	Fit	Resid	Std Resid	
1	9.407	10.010	-0.603	-2.89	R
2	10.479	10.010	0.469	2.25	R

R Large residual



Surface Plot of Yield (%) vs Temperature (°C) , Ratio



Regression Analysis: Apparent Viscosity (Pa·s) versus Ratio, Temperature (℃)

Regression Equation

Apparent Viscosity (Pa·s)	=	1.289 - 6.3 Ratio - 0.0256 Temperature (℃) - 135 Ratio*Ratio + 0.000089 Temperature (℃) *Temperature (℃) + 1.102 Ratio*Temperature (℃)

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1.289	0.985	1.31	0.215	
Ratio	-6.3	29.0	-0.22	0.832	110.51
Temperature (℃)	-0.0256	0.0230	-1.11	0.288	53.65
Ratio*Ratio	-135	207	-0.65	0.526	107.01
Temperature (℃) *Temperature (℃)	0.000089	0.000211	0.42	0.681	49.00
Ratio*Temperature (℃)	1.102	0.111	9.95	0.000	9.15

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.332022	97.43%	96.36%	94.34%

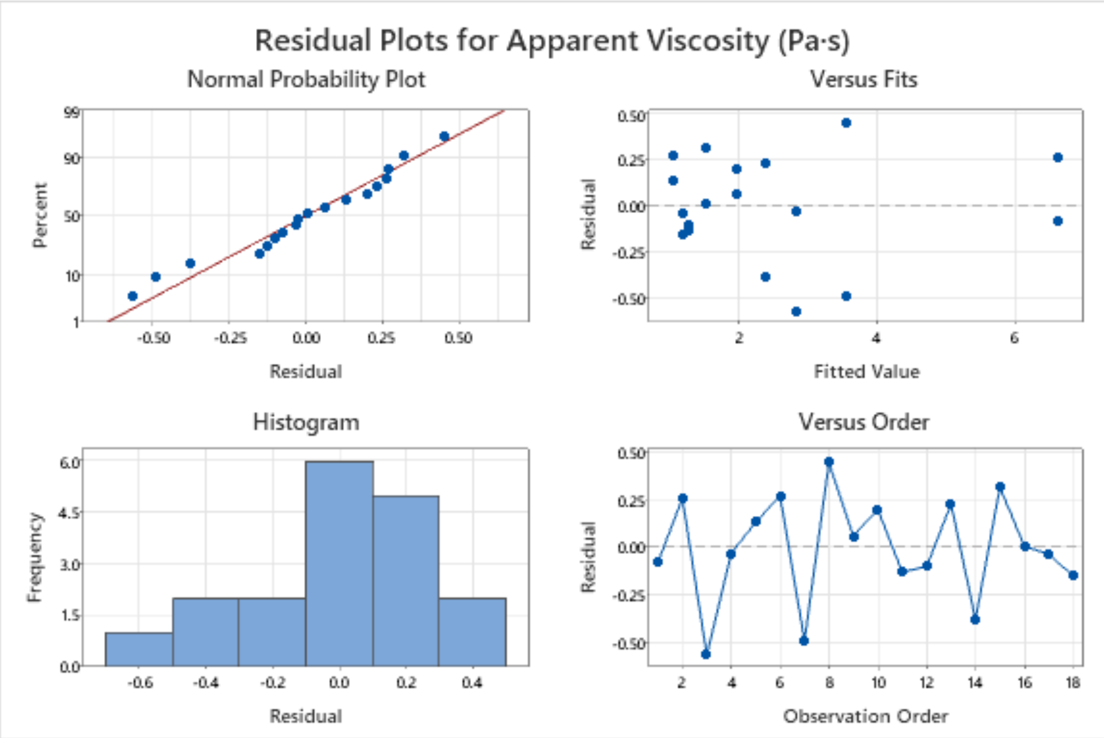
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	50.2139	10.0428	91.10	0.000
Ratio	1	0.0052	0.0052	0.05	0.832
Temperature (℃)	1	0.1364	0.1364	1.24	0.288
Ratio*Ratio	1	0.0469	0.0469	0.43	0.526
Temperature (℃) *Temperature (℃)	1	0.0196	0.0196	0.18	0.681
Ratio*Temperature (℃)	1	10.9085	10.9085	98.95	0.000
Error	12	1.3229	0.1102		
Lack-of-Fit	3	0.4202	0.1401	1.40	0.306
Pure Error	9	0.9026	0.1003		
Total	17	51.5367			

Fits and Diagnostics for Unusual Observations

Obs	Apparent Viscosity (Pa·s)	Fit	Resid	Std Resid	
3	2.267	2.833	-0.566	-2.02	R

R Large residual



Regression Analysis: Apparent Viscosity (Pa·s) versus Ratio, Temperature (℃)

Regression Equation

Apparent Viscosity (Pa·s)	=	1.631 - 24.86 Ratio - 0.01639 Temperature (℃) + 1.102 Ratio*Temperature (℃)

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1.631	0.375	4.35	0.001	
Ratio	-24.86	5.56	-4.47	0.001	4.50
Temperature (℃)	-0.01639	0.00708	-2.32	0.036	5.65
Ratio*Temperature (℃)	1.102	0.105	10.48	0.000	9.15

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.315026	97.30%	96.73%	95.41%

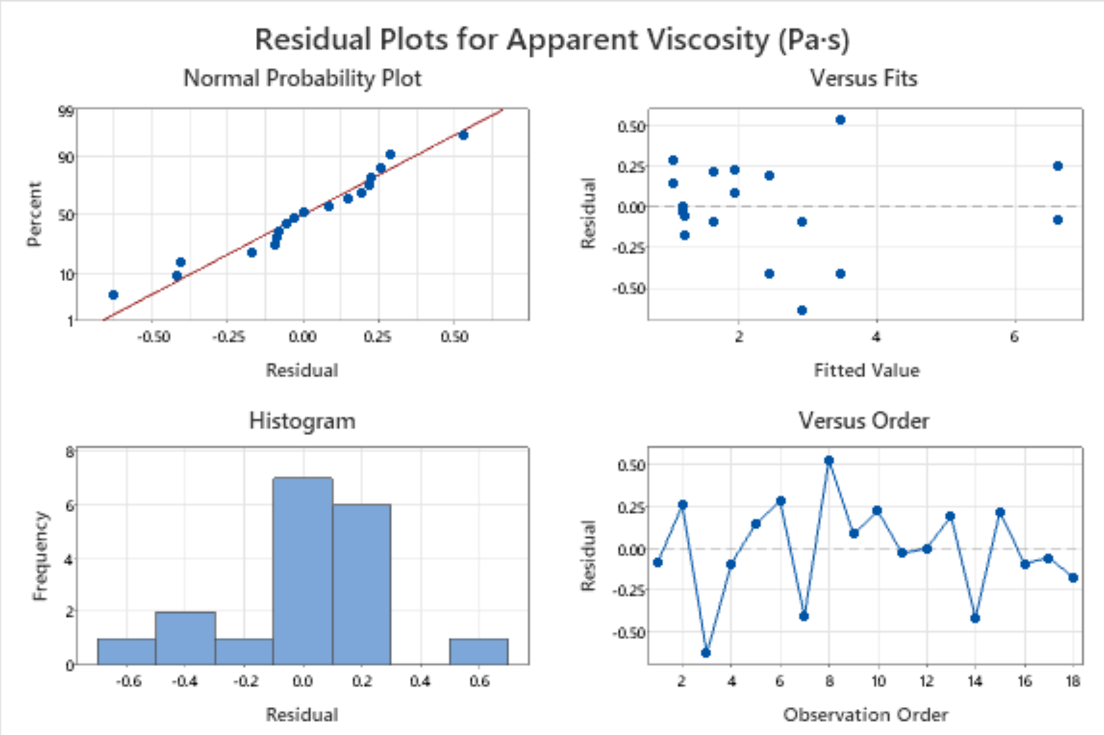
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	50.1473	16.7158	168.44	0.000
Ratio	1	1.9832	1.9832	19.98	0.001
Temperature (℃)	1	0.5324	0.5324	5.37	0.036
Ratio*Temperature (℃)	1	10.9085	10.9085	109.92	0.000
Error	14	1.3894	0.0992		
Lack-of-Fit	5	0.4868	0.0974	0.97	0.484
Pure Error	9	0.9026	0.1003		
Total	17	51.5367			

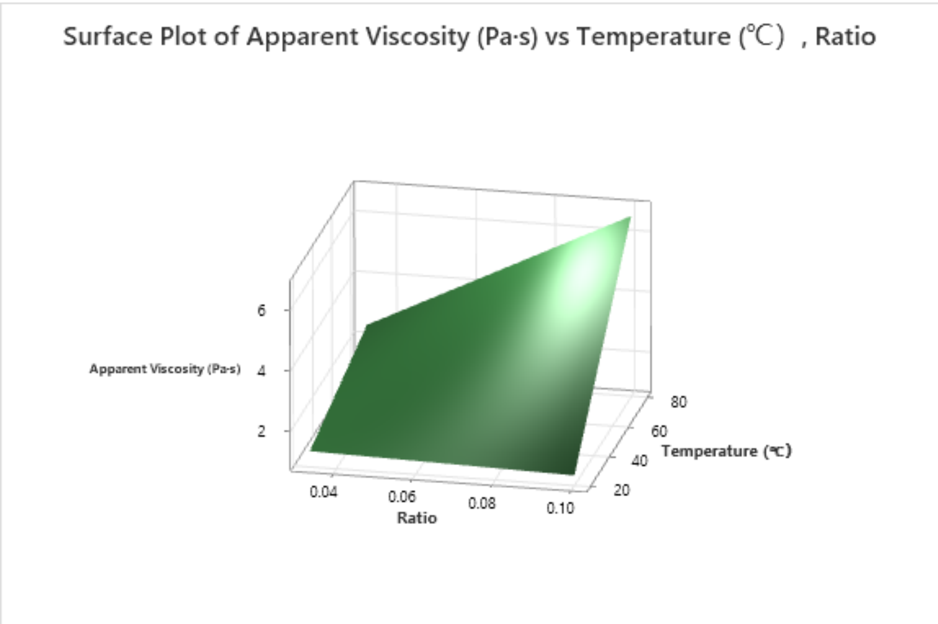
Fits and Diagnostics for Unusual Observations

Obs	Apparent Viscosity (Pa·s)	Fit	Resid	Std Resid	
3	2.267	2.896	-0.629	-2.19	R

R Large residual



Surface Plot of Apparent Viscosity (Pa·s) vs Temperature (℃), Ratio



Response Optimization: Apparent Viscosity (Pa·s), Yield (%)

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Apparent Viscosity (Pa·s)	Minimum		1.039	6.907	1	1
Yield (%)	Maximum	4.21	10.479		1	1

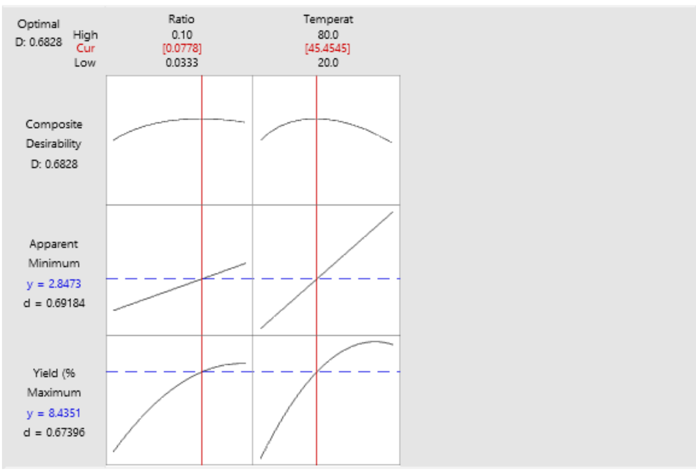
Solution

Solution	Ratio	Temperature(°C)	Apparent Viscosity (Pa·s) Fit	Yield (%) Fit	Composite Desirability
1	0.0777778	45.4545	2.84730	8.43508	0.682841

Multiple Response Prediction

Variable	Setting
Ratio	0.0777778
Temperature (°C)	45.4545

Response	Fit	SE Fit	95% CI	95% PI
Apparent Viscosity (Pa·s)	2.8473	0.0863	(2.6623, 3.0323)	(2.1468, 3.5478)
Yield (%)	8.435	0.193	(8.014, 8.856)	(7.685, 9.186)



C.2 One-way ANOVA and Tukey test: Yield and viscosity of chia seed gel using SPSS

C.2.1 One-way ANOVA and Tukey test: Yield of chia seed gel

Descriptive Statistics

Dependent Variable: Yield

Ratio	SoakingTemperature	Mean	Std. Deviation	N
1	20	5.5670	.03960	2
	40	8.3560	.06223	2
	80	9.9430	.75802	2
	Total	7.9553	2.01052	6
2	20	4.8530	.09051	2
	40	6.9710	.10465	2
	80	7.4580	.02687	2
	Total	6.4273	1.24037	6
3	20	4.2160	.00849	2
	40	5.4270	.00566	2
	80	5.9150	.03960	2
	Total	5.1860	.78263	6
Total	20	4.8787	.60614	6
	40	6.9180	1.31166	6
	80	7.7720	1.84919	6
	Total	6.5229	1.78319	18

Post Hoc Tests

Ratio

Multiple Comparisons

Dependent Variable: Yield

Tukey HSD

(I) Ratio	(J) Ratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	1.5280*	.14927	<.001	1.1112	1.9448
	3	2.7693*	.14927	<.001	2.3526	3.1861
2	1	-1.5280*	.14927	<.001	-1.9448	-1.1112
	3	1.2413*	.14927	<.001	.8246	1.6581
3	1	-2.7693*	.14927	<.001	-3.1861	-2.3526
	2	-1.2413*	.14927	<.001	-1.6581	-.8246

Based on observed means.

The error term is Mean Square(Error) = .067.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Yield

Tukey HSD[a,b]

Ratio	N	Subset 1	2	3
3	6	5.1860		
2	6		6.4273	
1	6			7.9553
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .067.

a. Uses Harmonic Mean Sample Size = 6.000.

b. Alpha = .05.

Soaking Temperature

Multiple Comparisons

Dependent Variable: Yield

Tukey HSD

(I) Soaking Temperature	(J) Soaking Temperature	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound
20	40	-2.0393*	.14927	<.001	-2.4561
	80	-2.8933*	.14927	<.001	-3.3101
40	20	2.0393*	.14927	<.001	1.6226
	80	-.8540*	.14927	<.001	-1.2708
80	20	2.8933*	.14927	<.001	2.4766
	40	.8540*	.14927	<.001	.4372

Based on observed means.

The error term is Mean Square(Error) = .067.

*. The mean difference is significant at the .05 level.

C.2.2 One-way ANOVA and Tukey test: Viscosity of chia seed gel

Descriptive Statistics

Dependent Variable: Viscosity

Soaking Temperature	Ratio	Mean	Std. Deviation	N
20	1	1.2383	.09793	2
	2	1.1485	.02051	2
	3	1.0965	.08132	2
	Total	1.1611	.08625	6
40	1	2.5360	.38042	2
	2	2.0920	.09899	2
	3	1.6820	.21920	2
	Total	2.1033	.43180	6
80	1	6.7380	.23900	2
	2	3.5485	.66397	2
	3	2.3185	.43063	2
	Total	4.2017	2.07342	6
Total	1	3.5041	2.57954	6
	2	2.2630	1.12239	6
	3	1.6990	.58894	6
	Total	2.4887	1.74114	18

Post Hoc Tests

Soaking Temperature

Multiple Comparisons

Dependent Variable: Viscosity

Tukey HSD

(I) Soaking Temperature	(J) Soaking Temperature	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound
20	40	-.9422*	.18284	.002	-1.4527
	80	-3.0406*	.18284	<.001	-3.5511
40	20	.9422*	.18284	.002	.4318
	80	-2.0983*	.18284	<.001	-2.6088
80	20	3.0406*	.18284	<.001	2.5301
	40	2.0983*	.18284	<.001	1.5878

Multiple Comparisons

Dependent Variable: Viscosity

Tukey HSD

(I) Soaking Temperature	(J) Soaking Temperature	95% Confidence Interval Upper Bound
20	40	-.4318
	80	-2.5301
40	20	1.4527
	80	-1.5878
80	20	3.5511
	40	2.6088

Based on observed means.

The error term is Mean Square(Error) = .100.

*. The mean difference is significant at the .05 level.

Ratio

Multiple Comparisons

Dependent Variable: Viscosity

Tukey HSD

(I) Ratio	(J) Ratio	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	1.2411*	.18284	<.001	.7306	1.7516
	3	1.8051*	.18284	<.001	1.2946	2.3156
2	1	-1.2411*	.18284	<.001	-1.7516	-.7306
	3	.5640*	.18284	.032	.0535	1.0745
3	1	-1.8051*	.18284	<.001	-2.3156	-1.2946
	2	-.5640*	.18284	.032	-1.0745	-.0535

Based on observed means.

The error term is Mean Square(Error) = .100.

*. The mean difference is significant at the .05 level.

C.3 One-way ANOVA and Tukey test: Viscosity of ice cream mix samples

Descriptives

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	2	3.53	0.175	0.124	1.95	5.10	3	4
2	2	1.80	0.144	0.102	0.50	3.09	2	2
3	2	2.27	0.593	0.420	-3.06	7.60	2	3
4	2	2.48	0.050	0.036	2.03	2.93	2	3
5	2	3.39	0.063	0.044	2.82	3.95	3	3
Total	10	2.69	0.732	0.231	2.17	3.22	2	4

Test of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
viscosity	Based on Mean	1011389453729452200000000000000.000	4	5	0.000
	Based on Median	1011389453729452200000000000000.000	4	5	0.000
	Based on Median and with adjusted df	1011389453729452200000000000000.000	4	2.941	0.000
	Based on trimmed mean	202277890745890400000000000000.000	4	5	0.000

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.413	4	1.103	13.453	0.007
Within Groups	0.410	5	0.082		
Total	4.823	9			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: viscosity

Tukey HSD

(I) samples	(J) samples	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	1.729*	0.286	0.009	0.58	2.88
	3	1.257*	0.286	0.035	0.11	2.41
	4	1.046	0.286	0.070	-0.10	2.19
	5	0.137	0.286	0.986	-1.01	1.29
2	1	-1.729*	0.286	0.009	-2.88	-0.58
	3	-0.473	0.286	0.530	-1.62	0.68
	4	-0.683	0.286	0.256	-1.83	0.47
	5	-1.592*	0.286	0.013	-2.74	-0.44
3	1	-1.256*	0.286	0.035	-2.41	-0.11
	2	0.473	0.286	0.530	-0.68	1.62
	4	-0.211	0.286	0.938	-1.36	0.94
	5	-1.120	0.286	0.055	-2.27	0.03
4	1	-1.045	0.286	0.070	-2.19	0.10
	2	0.684	0.286	0.256	-0.47	1.83
	3	0.211	0.286	0.938	-0.94	1.36
	5	-0.909	0.286	0.113	-2.06	0.24
5	1	-0.137	0.286	0.986	-1.29	1.01
	2	1.592*	0.286	0.013	0.44	2.74
	3	1.120	0.286	0.055	-0.03	2.27
	4	0.909	0.286	0.113	-0.24	2.06

*. The mean difference is significant at the 0.05 level.

Tukey HSD[a]

samples	N	Subset for alpha = 0.05		
		1	2	3
2	2	1.80		
3	2	2.27	2.27	
4	2	2.48	2.48	2.48
5	2		3.39	3.39
1	2			3.53
Sig.		0.256	0.055	0.070

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

C.4 One-way ANOVA and Tukey test: Overrun of ice cream samples

Descriptive Statistics

Dependent Variable: Overrun

Sample	Mean	Std. Deviation	N
1	28.1400	.60811	2
2	50.6950	.41719	2
3	31.6500	.50912	2
4	41.0200	.89095	2
5	52.0000	.09899	2
Total	40.7010	10.19969	10

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Overrun
Tukey HSD

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-22.5550*	.56686	<.001	-24.8290	-20.2810
	3	-3.5100*	.56686	.008	-5.7840	-1.2360
	4	-12.8800*	.56686	<.001	-15.1540	-10.6060
	5	-23.8600*	.56686	<.001	-26.1340	-21.5860
2	1	22.5550*	.56686	<.001	20.2810	24.8290
	3	19.0450*	.56686	<.001	16.7710	21.3190
	4	9.6750*	.56686	<.001	7.4010	11.9490
	5	-1.3050	.56686	.280	-3.5790	.9690
3	1	3.5100*	.56686	.008	1.2360	5.7840
	2	-19.0450*	.56686	<.001	-21.3190	-16.7710
	4	-9.3700*	.56686	<.001	-11.6440	-7.0960
	5	-20.3500*	.56686	<.001	-22.6240	-18.0760
4	1	12.8800*	.56686	<.001	10.6060	15.1540
	2	-9.6750*	.56686	<.001	-11.9490	-7.4010
	3	9.3700*	.56686	<.001	7.0960	11.6440
	5	-10.9800*	.56686	<.001	-13.2540	-8.7060
5	1	23.8600*	.56686	<.001	21.5860	26.1340
	2	1.3050	.56686	.280	-.9690	3.5790
	3	20.3500*	.56686	<.001	18.0760	22.6240
	4	10.9800*	.56686	<.001	8.7060	13.2540

Based on observed means.

The error term is Mean Square(Error) = .321.

*. The mean difference is significant at the .05 level.

Tukey HSD[a,b]

Sample	N	Subset			
		1	2	3	4
1	2	28.1400			
3	2		31.6500		
4	2			41.0200	
2	2				50.6950
5	2				52.0000
Sig.		1.000	1.000	1.000	.280

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .321.

a. Uses Harmonic Mean Sample Size = 2.000.

b. Alpha = .05.

C.5 One-way ANOVA and Tukey test: Fat partial coalescence (PC) of ice cream samples

Descriptive Statistics

Dependent Variable: PC

Sample	Mean	Std. Deviation	N
1	.00	.000	2
2	34.02	1.584	2
3	.64	.000	2
4	29.90	.078	2
5	61.78	.184	2
Total	25.27	24.392	10

Post Hoc Tests

Multiple Comparisons

Dependent Variable: PC

Tukey HSD

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-34.02*	.714	<.001	-36.88	-31.16
	3	-.64	.714	.887	-3.50	2.22
	4	-29.89*	.714	<.001	-32.76	-27.03
	5	-61.78*	.714	<.001	-64.64	-58.92
2	1	34.02*	.714	<.001	31.16	36.88
	3	33.38*	.714	<.001	30.52	36.24
	4	4.12*	.714	.011	1.26	6.99
	5	-27.76*	.714	<.001	-30.62	-24.90
3	1	.64	.714	.887	-2.22	3.50
	2	-33.38*	.714	<.001	-36.24	-30.52
	4	-29.25*	.714	<.001	-32.12	-26.39
	5	-61.14*	.714	<.001	-64.00	-58.28
4	1	29.90*	.714	<.001	27.03	32.76
	2	-4.12*	.714	.011	-6.99	-1.26
	3	29.26*	.714	<.001	26.39	32.12
	5	-31.88*	.714	<.001	-34.75	-29.02
5	1	61.78*	.714	<.001	58.92	64.64
	2	27.76*	.714	<.001	24.90	30.62
	3	61.14*	.714	<.001	58.28	64.00
	4	31.89*	.714	<.001	29.02	34.75

Based on observed means;The error term is Mean Square(Error) = .510. *. The mean difference is significant at the .05 level.

Homogeneous Subsets

Tukey HSD[a,b]

1	N	Subset 1	2	3	4
3	2	.00			
4	2	.64			
2	2		29.90		
5	2			34.02	
Sig.	2				61.78

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .510.

a. Uses Harmonic Mean Sample Size = 2.000.

b. Alpha = .05.

C.6 One-way ANOVA and Tukey test: Hardness of ice cream samples

Descriptive Statistics

Dependent Variable: Hardness

Sample	Mean	Std. Deviation	N
1	74.08	14.786	2
2	195.51	1.372	2
3	93.13	4.306	2
4	84.63	6.138	2
5	186.18	5.070	2
Total	126.70	55.956	10

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Hardness

Tukey HSD

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	-121.43*	7.777	<.001	-152.63	-90.24
	3	-19.05	7.777	.240	-50.25	12.15
	4	-10.55	7.777	.675	-41.75	20.64
	5	-112.10*	7.777	<.001	-143.30	-80.90
2	1	121.43*	7.777	<.001	90.24	152.63
	3	102.39*	7.777	<.001	71.19	133.58
	4	110.88*	7.777	<.001	79.68	142.08
	5	9.33	7.777	.753	-21.86	40.53
3	1	19.05	7.777	.240	-12.15	50.25
	2	-102.38*	7.777	<.001	-133.58	-71.19
	4	8.50	7.777	.805	-22.70	39.69
	5	-93.05*	7.777	<.001	-124.25	-61.85
4	1	10.55	7.777	.675	-20.64	41.75
	2	-110.88*	7.777	<.001	-142.08	-79.68
	3	-8.50	7.777	.805	-39.69	22.70
	5	-101.55*	7.777	<.001	-132.74	-70.35
5	1	112.10*	7.777	<.001	80.90	143.30
	2	-9.33	7.777	.753	-40.53	21.86
	3	93.05*	7.777	<.001	61.85	124.25
	4	101.55*	7.777	<.001	70.35	132.74

Based on observed means; The error term is Mean Square(Error) = 60.483.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Tukey HSD[a,b]

Sample	N	Subset 1	Subset 2
1	2	74.08	
4	2	84.63	
3	2	93.13	
5	2		186.18
2	2		195.51
Sig.		.240	.753

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = 60.483.

a. Uses Harmonic Mean Sample Size = 2.000.

b. Alpha = .05.

C.7 One-way ANOVA and Tukey test: Melting Rate of ice cream samples

Descriptive Statistics

Dependent Variable: MeltingRate

Sample	Mean	Std. Deviation	N
1	.7750	.07778	2
2	.4550	.02121	2
3	.4650	.00707	2
4	.4400	.01414	2
5	.4100	.00000	2
Total	.5090	.14418	10

Post Hoc Tests

Multiple Comparisons

Dependent Variable: MeltingRate

Tukey HSD

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	.3200*	.03674	.002	.1726	.4674
	3	.3100*	.03674	.002	.1626	.4574
	4	.3350*	.03674	.001	.1876	.4824
	5	.3650*	.03674	<.001	.2176	.5124
2	1	-.3200*	.03674	.002	-.4674	-.1726
	3	-.0100	.03674	.998	-.1574	.1374
	4	.0150	.03674	.992	-.1324	.1624
	5	.0450	.03674	.741	-.1024	.1924
3	1	-.3100*	.03674	.002	-.4574	-.1626
	2	.0100	.03674	.998	-.1374	.1574
	4	.0250	.03674	.953	-.1224	.1724
	5	.0550	.03674	.604	-.0924	.2024
4	1	-.3350*	.03674	.001	-.4824	-.1876
	2	-.0150	.03674	.992	-.1624	.1324
	3	-.0250	.03674	.953	-.1724	.1224
	5	.0300	.03674	.915	-.1174	.1774
5	1	-.3650*	.03674	<.001	-.5124	-.2176
	2	-.0450	.03674	.741	-.1924	.1024
	3	-.0550	.03674	.604	-.2024	.0924
	4	-.0300	.03674	.915	-.1774	.1174

Based on observed means; The error term is Mean Square(Error) = .001. *. The mean difference is significant at the .05 level.

Homogeneous Subsets

Tukey HSD[a,b]

Sample	N	Subset 1	Subset 2
5	2	.4100	
4	2	.4400	
2	2	.4550	
3	2	.4650	
1	2		.7750
Sig.		.604	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .001.

a. Uses Harmonic Mean Sample Size = 2.000.

b. Alpha = .05.

C.8 Frequencies analysis of the data from consumer test

Overall Acceptance

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	2	3.4	3.4	3.4
	6	9	15.3	15.3	18.6
	7	16	27.1	27.1	45.8
	8	23	39.0	39.0	84.7
	9	9	15.3	15.3	100.0
	Total	59	100.0	100.0	

Appearance

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	1	1.7	1.7	1.7
	5	2	3.4	3.4	5.1
	6	4	6.8	6.8	11.9
	7	24	40.7	40.7	52.5
	8	18	30.5	30.5	83.1
	9	10	16.9	16.9	100.0
	Total	59	100.0	100.0	

Creaminess

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	2	3.4	3.4	3.4
	5	3	5.1	5.1	8.5
	6	4	6.8	6.8	15.3
	7	14	23.7	23.7	39.0
	8	21	35.6	35.6	74.6
	9	15	25.4	25.4	100.0
	Total	59	100.0	100.0	

Meltdown

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	1.7	1.7	1.7
	4	1	1.7	1.7	3.4
	5	5	8.5	8.5	11.9
	6	9	15.3	15.3	27.1
	7	15	25.4	25.4	52.5
	8	18	30.5	30.5	83.1
	9	10	16.9	16.9	100.0
	Total	59	100.0	100.0	

Smoothness

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	1.7	1.7	1.7
	4	1	1.7	1.7	3.4
	5	8	13.6	13.6	16.9
	6	4	6.8	6.8	23.7
	7	20	33.9	33.9	57.6
	8	12	20.3	20.3	78.0
	9	13	22.0	22.0	100.0
	Total	59	100.0	100.0	

Firmness

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	1.7	1.7	1.7
	4	1	1.7	1.7	3.4
	5	2	3.4	3.4	6.8
	6	12	20.3	20.3	27.1
	7	17	28.8	28.8	55.9
	8	17	28.8	28.8	84.7
	9	9	15.3	15.3	100.0
	Total	59	100.0	100.0	

Mouthfeel

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	1.7	1.7	1.7
	4	2	3.4	3.4	5.1
	5	6	10.2	10.2	15.3
	6	8	13.6	13.6	28.8
	7	14	23.7	23.7	52.5
	8	18	30.5	30.5	83.1
	9	10	16.9	16.9	100.0
	Total	59	100.0	100.0	

Sweetness

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	3	5.1	5.1	5.1
	4	1	1.7	1.7	6.8
	5	2	3.4	3.4	10.2
	6	11	18.6	18.6	28.8
	7	14	23.7	23.7	52.5
	8	17	28.8	28.8	81.4
	9	11	18.6	18.6	100.0
	Total	59	100.0	100.0	

Flavour

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	1.7	1.7	1.7
	3	1	1.7	1.7	3.4
	4	2	3.4	3.4	6.8
	5	3	5.1	5.1	11.9
	6	8	13.6	13.6	25.4
	7	18	30.5	30.5	55.9
	8	15	25.4	25.4	81.4
	9	11	18.6	18.6	100.0
	Total	59	100.0	100.0	