THE UNIVERSITY OF
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Te Whare Wānanga o Waikato

Development of a High Protein Frozen Dessert

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Abstract

It was identified that there is a potential market for a low fat, low carbohydrate, high protein frozen dessert that has similar sensory attributes to ice cream. Such a product could be utilized by athletes, obesity sufferers and anyone seeking a healthy alternative to ice cream. Ingredients were sourced that could replace and replicate those found in traditional ice cream products.

A key challenge in producing the dessert was identifying suitable ingredients to control the freezing point depression (FPD). Fructose, erythritol, xylitol and polydextrose were identified as being suitable options and 18 prototype formulae were generated using Design-Expert® V8 software to try and find the best combination of these four ingredients. Ingredients used in fixed amounts were water, whey protein isolate, Simplesse® 100, vanilla flavour, Novagel GP 3282, carboxy methyl cellulose and mono/di-glycerides. The prototype desserts were prepared using a Breville Ice Cream Wizz. The hardness and viscosity of each prototype was measured, and the internal structures of selected prototypes were analysed using cryo-SEM. The results were compared to regular ice cream products, and then the formulation was optimized accordingly using the software.

The optimum prototype contained 11.6% protein, 14.3% carbohydrate and only 1.6% fat. It was estimated that if taken to market, the finished product could have a recommended retail price of $10.18 for 1L, placing it in the lower end of the premium ice cream products range. Using a 9-point hedonic scale, this optimised prototype received an overall appeal score of 7.18 ± 1.08 from a consumer panel, with a score of 7 corresponding to 'Like Moderately' and a score of 8 corresponding to 'Like Very Much'. However it received a lower score than the regular ice cream control (8.35 ± 0.77), and the difference was found to be statistically significantly ($p<0.05$). Despite this, due to its high protein and low fat contents, this unique product could fill a niche in the market, particularly if its consumer appeal could be further increased.

Future work should study the effect of increasing the air content in order to produce a softer product with a more favourable texture. Carbohydrate content should be lowered as product becomes softer and efforts should be made to correlate the relationship between FPD, hardness and overrun.

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1. Introduction

Tuatara Nutritional Technologies Ltd (TNT) is a New Zealand owned Sports Nutrition Company that focuses on developing natural nutritional supplements for athletes. Their customers include athletes of all abilities, from school level through to provincial, national and international representatives. Research carried out by TNT suggested that there is a market for an ice cream type product that is low in fat and carbohydrates whilst being high in protein, making it suitable for athletes, dieters and health-conscious individuals.

Ice cream, while a good source of calcium and energy, does not offer many other functional benefits. A product that contained more protein, with reduced sugar and fat levels could have many markets and applications. If 1 % of the current market for ice cream and related products could be captured for such a product, over 900,000 litres could be sold.

The aim of this work was to develop a new ice cream-like frozen dessert which is less than 3% fat and has a protein: carbohydrate ratio of at least 1:1; significantly higher than any commercial product currently available in New Zealand.

2. Literature Review

This review provides an overview of the ice cream market in New Zealand, a brief history of ice cream, the ingredients used in ice cream and the process used to manufacture ice cream. The potential benefits of high protein diets for athletes and obesity patients is discussed, leading to an investigation into ingredients that could be used to produce a low fat, low carbohydrate, high protein frozen dessert. Current frozen dessert options for health conscious individuals are covered, and a brief outline of food product development procedures is also included.

2.1 The Ice Cream Market in New Zealand

The New Zealand food industry is large and diverse. Products range from fresh produce like fruit, vegetables and meats to highly processed tinned foods, dairy products and instant meals. The food industry contributes over $15 billion in exports to the New Zealand economy each year (NZTE, 2010). Dairy product exports alone account for over $8 billion of that figure.

Frozen desserts are a favourite food product for many people. The frozen dessert of choice for many New Zealanders is ice cream, and Kiwis consume an average of 22 litres of ice cream and related products per person per annum (NZICMA, 2008). Vanilla is the most popular flavour, followed by Hokey Pokey and Chocolate (NZICMA, 2008). In 2008, the total New Zealand production of ice cream and related products was over 90 million litres, with exports totalling $37 million (NZICMA, 2008). The domestic market is much greater, with the moving annual total to August 14th 2011 of over $164 million for all ice cream sales (FMCG, 2011a).

Ice cream is a frozen emulsion consisting of air cells dispersed in an aqueous matrix (Marshall, Goff, & Hartel, 2003). Under Standard 2.5.6 of the Australia New Zealand Food Standards Code, ice cream is defined as the frozen product prepared from milk, cream or milk products consisting of not less than 10 % milk fat, and not less than 168 g/L of food solids (FSANZ, 2011b). Tip Top™ Vanilla flavoured Ice Cream contains 10.7 g of fat, 1.5 g of protein and 19.6 g of sugar per 100 g, and was awarded ‘Best in Category’ at the 2011 New Zealand Ice Cream Awards (FMCG, 2011b).

2.2 A History of Ice Cream

Despite many publications on the matter, it has been stated that much of the early history of ice cream remains unproven folklore (Goff, 1995). A timeline of the popular accounts include the following:

- Roman Emperor Nero Claudius Caesar (0037 – 0068) sent slaves to the mountains to bring snow and ice to cool and freeze fruit drinks (IAICM, 1978).
- Marco Polo (1254-1324) witnessed ice creams being made during a trip to China (Liddell & Weir, 1993).
- In the early 1600’s, King Charles 1 of England was hosting a state banquet. The King’s French chef served up a sweetened form of frozen cream for dessert, which was described as resembling “fresh fallen snow”. The chef, named DeMirco, was subsequently paid 500 pounds and ordered to promise that he would keep the recipe secret. He did not keep his promise (IAICM, 1978)!
- An early American record of ice cream comes from 1774, when confectioner Phillip Lenzi announced via a New York newspaper that he would be offering ice cream for sale (IAICM, 1978).
- In 1813, ice cream was served at U.S. President James Madison’s Inaugural Ball (IAICM, 1978).
- In 1846, American Nancy Johnson is credited with inventing a hand cranked ice cream freezer. By turning the freezer handle, a container of ice cream mix, sitting in a bed of salt and ice, was agitated until frozen (IAICM, 1978).
- Jacob Fussel is credited with beginning commercial production of ice cream in North America, when he began manufacturing ice cream in Baltimore in 1851 (IAICM, 1978).

It has been pointed out that the history of ice cream is closely associated with the development of refrigeration techniques. This can be traced in several stages (Clarke, 2004):

1. Cooling food and drink by mixing it with snow or ice.
2. The discovery that dissolving certain salts (such as potassium chloride) in water produces cooling.
3. The discovery that mixing salts and snow or ice lowers temperatures even further. This occurred around the mid to late 17th century. The inclusion of cream in the water-ice mixes also evolved around this time.
4. The invention of the ice cream maker in 1846.
5. The development of mechanical refrigeration, which led to the development of the modern ice cream industry.

New Zealand's largest ice cream manufacturer, Tip Top™, traces its beginnings to 1936, when two friends, Len and Albert, opened an ice cream parlour in Wellington. Described as being innovators, they began making their own ice cream. The business continued to grow until, in 1962, they built the iconic Tip Top™ factory on Auckland's Southern Motorway (Tip Top, 2010).

Today, the New Zealand Ice Cream Manufacturers Association (NZICMA) has 17 member companies who manufacture ice cream, along with 29 associate members who provide services to the industry (NZICMA, 2008). The author counted more than twenty different flavours at a local supermarket, ranging from plain vanilla to raspberry ripple to chocolate-chip cookie dough and everything in between!

2.3 Ice Cream Ingredients and Manufacture

2.3.1 Manufacturing Process

The basic steps in the ice cream manufacturing process are outlined in Figure 1.

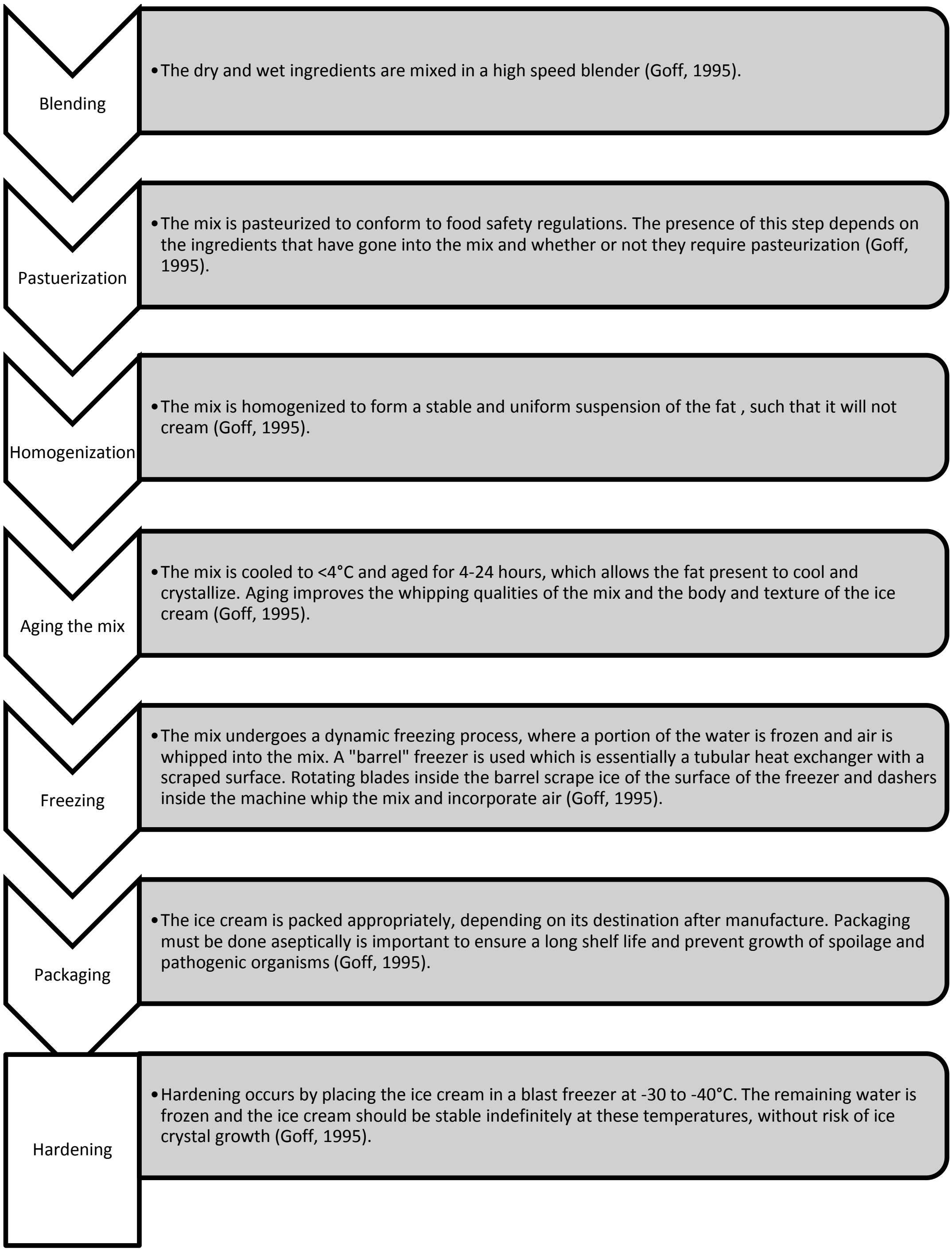

Figure 1: Flowchart outlining the basic steps used in the manufacture of ice cream.

2.3.2 Properties Attributed to Manufacturing Process

During ice cream manufacture, the whipping process incorporates air into the product in the form of tiny bubbles 50-80 µm in diameter. During freezing and aeration of the mix, the fat present undergoes partial coalescence, forming clusters that surround and stabilize the air bubbles (Goff, 2006).

The air content of ice cream is expressed in terms of 'overrun'. Overrun is defined as "the percentage increase in volume of ice cream greater than the amount of mix used to produce that ice cream" (Goff, 1995). In commercial manufacture, operators are often able to set their equipment to produce ice cream with an overrun of a desired value or range. This is done at the freezing stage of manufacture, with high dasher speeds ranging from 200-700 rpm used to whip and incorporate the air into the mixture (Drewett & Hartel, 2007; Goh, Ye, & Dale, 2006). Overrun can be up to 100% (Goff, 1995), and can be calculated using Equation 1:

Equation 1:

$$\%\, Overrun = \frac{(Vol.\ of\ ice\ cream - Vol.\ of\ mix\ used)}{Vol. of\ mix\ used}\, x\ 100\% \quad \text{(Goff, 1995)}$$

The size and volume fraction of air bubbles is influenced by the size of the fat globules. Smaller fat globules produce a greater surface area from the same amount of fat. In commercial preparation, a two stage homogenizer is normally used to break up fat clusters and reduce globule size. This is carried out at 14 – 17 MPa for the first stage and 3 – 7 MPa on the second stage (Goff, 1995). The size of the air bubbles present influences the texture of the product, with smaller air bubbles providing a smoother texture (Goff, 1995).

Overrun, along with ice crystal size, ice phase volume fraction, and extent of fat destabilization, also affects the hardness of ice cream (Muse & Hartel, 2004). The hardness of ice cream can be defined as "the measure of the resistance of the ice cream to deformation when an external force is applied" (Muse & Hartel, 2004). An inverse relationship exists between hardness and overrun (Goff, et al., 1995;

Tanaka, Pearson, & deMan, 1972; Wilbey, Cooke, & Dimos, 1998). It is unknown whether air bubble size influences the hardness of ice cream (Muse & Hartel, 2004). It has also been found that ice creams with large ice crystals are harder than those with smaller ice crystals, for the same ice phase volume (Sakurai, Kokubo, Hakamata, Tomita, & Yoshida, 1996). The hardness of ice cream is exponentially related to ice phase volume (Wilbey, et al., 1998).

The melting rate of ice cream is also affected by overrun. Ice creams with high overruns melt more slowly than those with low overrun. This is attributed to a reduced rate of heat transfer due to the larger air volume fraction (Sakurai, et al., 1996) which reduces its thermal diffusivity (Rahman, 2009).

2.3.3 Traditional Ingredients

The following ingredients are often found in ice cream: Skim milk, cream, sugar, milk solids, cocoa, egg yolk, locust bean gum, natural flavour. These ingredients all provide some functional purpose in the product, and can be classified under the following headings:

Milk fat: Milk fat is added to ice cream to provide body, texture and the desirable melting characteristics that ice cream is known for (Goff, 1995). It is added in the form of whole milk, cream or anhydrous milk fat.

Milk solids non-fat (MSNF): The major components of MSNF are milk proteins and lactose. The presence of milk proteins improves the texture of ice cream and the milk solids also provide body (Goff, 1995).

Emulsifier: Emulsifiers are compounds that have both a hydrophilic portion and a hydrophobic portion. This enables them to bind both fat and water, contributing to the formation of the appropriate fat structure which provides good textural and melting characteristics in the product (Goff, 1995).

Stabilizers: Stabilizers add viscosity and also extend the shelf life by limiting ice recrystallization during storage. Stabilizers also help prevent heat shock, which occurs when the ice present in ice cream partially melts then forms larger ice crystals as the product is re-frozen (Goff, 1995).

Sweeteners: Sweeteners not only contribute to the sweet taste desired by the consumer, but also contribute to freezing point depression (FPD). This means that the ice cream has some water which is unfrozen, without which the product would be too hard to scoop. Sweeteners are typically added at 12-16% by weight. The lactose present in the non-fat milk solids also contributes to FPD (Goff, 1995).

Flavours: Flavours and other ingredients for taste purposes are added as desired and required. Some flavour inclusions, such as fruit swirls and nut pieces, also contribute textural properties to ice cream (Goff, 1995).

2.3.4 Benefits of High Protein Diets

It is commonly accepted that the performance and recovery of athletes is enhanced by optimal nutrition (ADA, DOC, & ACSM, 2009). The protein needs of athletes must be met during times of high physical activity in order to maintain body weight and build and repair tissue (ADA, et al., 2009). High protein diets have consistently been shown to result in greater weight loss, greater fat loss, and greater preservation of lean mass as compared with lower protein diets (Phillips, 2006), and are useful for athletes wanting to maintain lean muscle mass while losing weight (Mettler, Mitchell, & Tipton, 2010). Protein is also an important macro nutrient for increasing strength and muscle bulk during resistance exercise training (Tarnopolsky, 2008).

According to consumer research from Tuatara Nutritional Technologies Ltd, many athletes consume their *pureMUSCLE Whey Protein Isolate (WPI)* product (30g) mixed with reduced fat milk (approximately 300ml). *pureMUSCLE WPI* retails for $109 for 1.5kg, which is 50 servings at a cost of $2.18 per serving. Typical consumption times are mid-morning, mid-afternoon, post-training and immediately before bed. Table 1 shows a breakdown of the nutritional information for *pureMUSCLE WPI*, reduced fat milk and per serve as consumed.

Athletes would be able to utilize a frozen dessert that is high in protein as part of their diet, as it would provide a change from more commonly used protein sources such as meat, fish and whey or soy protein supplements. By finding suitable ingredients, it may be possible to develop a frozen dessert which is high in protein, whilst being low in fat and carbohydrates, whilst still maintaining the sensory attributes of ice cream.

Table 1: Nutritional and cost information for pureMUSCLE WPI, reduced fat milk and per serve as consumed.

Nutritional Content Per 100g				
		Per 30g pureMUSCLE WPI (Chocolate flavour)	Per 300ml Reduced Fat Milk	Per Serve as Consumed (30g WPI mixed in 300ml Reduced Fat Milk)
Energy (kJ)		443	600	1043
Protein (g)		26.1	11.0	37.1
Fat	Total (g)	0.3	5.0	5.3
	Saturated (g)	0.2	3.0	3.2
Carbohydrates	Total (g)	1.2	15.0	16.2
	Sugar (g)	0.1	15.0	15.1
Sodium (mg)		48	132	180
Cost/serve		$2.18	$0.57	$2.75

High protein diets also have applications in countering the growing obesity epidemic. Obesity is a significant problem in the modern world, and it is attributed to an energy imbalance. The energy imbalance is being generated by greater food (calorie) intake and/or sedentary lifestyles (ADA, 2005). High calorie foods rich in sugars and fat, when consumed in excess, can contribute to the energy imbalance of obesity sufferers. It has been shown that high protein, low fat, low carbohydrate diets are useful for managing body weight and composition and reducing risk of cardio-vascular disease in overweight and obese patients (Clifton, Bastiaans, & Keogh, 2009; Torbay, et al., 2002). A high protein, low fat, low carbohydrate dessert may be useful for weight management of obesity patients.

2.3.5 Ingredient Search

Source of solids

Traditional ice cream contains milk solids, usually added in the form of milk, cream or a milk powder. Other options for solids include milk and whey proteins, with WPI showing favourable results. Using WPI in a frozen dessert lowers the levels of gelling agents required when compared with milk-based desserts without unfavourable changes to texture properties (Mleko, 1997). WPI is typically greater than 90% protein, with minimal fat and carbohydrate levels.

Fat substitute

According to Food Standards Australia New Zealand, ice cream must contain at least 10% milk fat. The milk fat contributes to the favorable texture and melting properties of ice cream. In recent times, researchers have begun looking at alternatives to milk fat in a bid to reduce the total calories in frozen desserts.

Okra gum has been shown to be an acceptable milk fat substitute in a frozen dairy dessert (Romanchik-Cerpovicz, Costantino, & Gunn, 2006). Consumers rated the characteristics of products containing different levels of milk fat replacement with okra gum. All ratings were similar, except for the aftertaste rating for 100% milk fat replacement with okra gum. This scored significantly lower than the control of 0% milk fat replacement. Replacing milk fats with okra gum was shown to decrease the melting rate ,and thus increase stability, of frozen desserts (Romanchik-Cerpovicz, et al., 2006).

Tapioca dextrin and potato maltodextrin have been used in studies to replace milk fat in a reduced-calorie frozen dessert. It was found that replacement of milk fat with either of these substances increased the coarseness and wateriness, while decreasing the creaminess of the dessert relative to a full milk fat control (Specter & Setser, 1994). A chalky texture was also noted, the perception of which was greater for increased tapioca dextrin than with increased potato maltodextrin.

A micro-particulated whey protein concentrate (WPC), commercially sold as Simplesse®, has also been used as a fat substitute in frozen desserts (Widhalm, Stargel, Burns, & Tschanz, 1994). It is claimed by the manufacturer that Simplesse® micro particles, in suspension, behave like a creamy fluid (CPKelco, 2010). Simplesse® can be used to enhance the quality of low-fat foods, as its particle size allows it to behave almost identically to fat globules (CPKelco, 2010). As it is a form of WPC, Simplesse® is also a natural ingredient and would increase the protein content of products in which it is used.

Sweeteners

When developing a sweetening system in ice cream, three factors must be considered; desired sweetness and taste, freezing point depression (FPD) and contribution to total solids (Güven & Karaca, 2002; Rothwell, 1985; Stampanoni Koeferli, Piccinali, & Sigrist, 1996). Previous development carried out by the author determined that the FPD plays a crucial role in developing an acceptable product (Nixon & Carson, 2010). It has also been recognized that there are two types of sweetening alternatives to sugar; natural/plant derived sweeteners and artificial/synthetic sweeteners (Sardesai & Waldshan, 1991).

Goff (1995) describes the FPD of a solution as:

"*A colligative property associated with the number of dissolved molecules. The lower the molecular weight, the greater the ability of a molecule to depress the freezing point for any given concentration. In ice cream manufacturing, monosaccharide's such as fructose or glucose produce a much softer ice cream than disaccharides such as sucrose, if the concentration of both is the same".*

By substituting sucrose for lower molecular weight carbohydrates, it is possible to achieve the same hardness with less sugar/carbohydrate content.

There are a range of different ingredient groups that can be used to provide the functions of conventional sweeteners in ice cream, including: sugar alcohols, bulking agents, milk solids non-fat (MSNF), stabilizer/emulsifier systems and high intensity sweeteners (Tharp, 2010). Tharp (2010) published Figure 2 which summarizes the role of some ingredients used to replace sweetener functionality in frozen dessert products.

It is noteworthy that the sugar alcohols do not provide water immobilization properties, so if any of these compounds were to be used, other ingredients would need to be added to serve this purpose. Table 2 summarizes properties of sugar alcohols and carbohydrates that can be used in frozen dessert formulations.

Xylitol has been used to depress the freezing point and hence replace sucrose in frozen desserts (Mitchell, 2008), however a combination of compounds such as those listed in Table 2 and Figure 2 may be the best method of achieving suitable FPD and water immobilization whilst producing an acceptable product. Using a higher molecular weight, low nutritive carbohydrate like polydextrose in conjunction with a low molecular weight sugar alcohol will enable easy modification of hardness (Mitchell, 2008). Factors such as laxation threshold, solubility in the mix and any texture imparted to the product also have to be considered.

Several studies have used sugar alcohols or high molecular weight carbohydrates in frozen dessert formulations. Specter & Setser (1994) created a frozen dessert by replacing sucrose with polydextrose-aspartame and milk fat with tapioca dextrin or potato maltodextrin. Ice cream sweetened with combinations of xylitol and sucrose have been shown to have characteristics similar to ice cream sweetened with sucrose alone (Marco & Pearson, 1982). Ice creams sweetened with maltitol have been shown to be preferred over ice cream sweetened with sorbitol by diabetic patients (Ozdemir, Dagdemir, Celik, & Ozdemir, 2003). Maltitol sweetened ice cream has also been shown to have overall preference over a regular 12% fat ice cream by a large consumer panel (Bordi, Cranage, Stokols, Palchak, & Powell, 2004).

	SWEETNESS	BULKING	WATER IMMOBILISATION	FREEZING-POINT INFLUENCE
Polyols				
Sorbitol[1]	Yes	Yes	No	Yes
Lactitol[1]	Yes	Yes	No	Yes
Maltitol[1]	Yes	Yes	No	Yes
Erythritol[1]	Yes	Yes	No	Yes
Glycerine[1,2]	Minor	Minor	No	Yes
Bulking Agents				
Polyglycitol[2,3,6]	Yes	Yes	Yes	Yes
Polydextrose[1,2,3]	No	Yes	Minor	Yes
Maltodextrin	No	Yes	Yes	Minor
Other Ingredients				
Milk protein concentrates[2,4]	No	Minor	Yes	Yes
Stabiliser/emulsifier systems[3,4,5]	No	No	Yes	No

Notes:
[1] Limited by laxative effects
[2] Limited by flavour contribution
[3] Effect variable with type and source
[4] Limited by potential viscosity effect
[5] Limited by over-stabilisation effect
[6] Polyglycitol is an acceptable term in the USA for hydrogenated starch hydrolysates, but is not acceptable in Europe.

Figure 2: Summary of roles of ingredients used to replace sweetener functionality in frozen dessert products (Tharp, 2010)

Table 2: Properties of sugar alcohols and carbohydrates that can be used in frozen dessert formulations (Carabin & Flamm, 1999; Dessert delight," 2003; DuBois, 2000; Foster-Powell, Holt, & Brand-Miller, 2002; Hill, 2010; Jenkins, et al., 1981; Marie, 1991; Marshall, et al., 2003; Nabours, 2001; Newsome, 1986; Noda, Nakayama, & Oku, 1994; Patil, Grimble, & Silk, 1987; M.-O. Portmann & Kilcast, 1996; M. O. Portmann & Birch, 1995; Whelan, Vega, Kerry, & Goff, 2008)

	Laxative threshold		**Glycemic index**	**Molecular weight**	**FPD**	**Sucrose equivalents (based on Mw)**	**Relative sweetness vs. Sucrose**	**Caloric value (kcal/g)**	**Solubility w/w % 25°C**
	(g/day)	**intestinal discomfort**							
Sucrose	None	None	59	342	1.00	100	100%	4.00	67/High
Lactose	Cases	Cases	56	342	1.00	14	40%	4.00	22/Low
Fructose	None	None	19	180	1.90	180-190	170%	3.70	High
Erythritol	>100	Low	0	122	2.80	53-70	70%	0.20	36/Med
Isomalt	35	High	17	344	0.99	35-60		2.00	Medium
Lactitol	Unknown	High	2	344	0.99	30-40	35%	2.00	High
Mannitol	20	High	0	182	1.88	50-60		1.60	Low
Maltitol	100	Low	55	344	0.99	85-90		3.00	60/High
Sorbitol	70	Medium	7	182	1.88	60	60%	2.60	72/High
Xylitol	50	Medium	7	152	2.25	87-100	100%	2.40	66/High
Tagatose	30	High	3	180	1.90	92		1.50	High
Trehalose	Unknown	Cases	Unknown	378	0.90	45		3.62	>45
Polydextrose	90	Low	6	182-5000	0.60	40	0%	1.00	High
10 DE Maltodextrin	None	None	80		0.21	5	0%	4.00	High

There are also high intensity, low-calorie alternatives to sugar that could be used to sweeten the frozen dessert. Such ingredients do not provide any contribution to FPD. Natural sweeteners include perillaldehyde, stevioside, rabaudioside, glycyrrhizin, osladin, thaumatins, and monellin (Sardesai & Waldshan, 1991).

Stevioside is an extract from the leaf of *Stevia rebaudiana Bertoni*, a shrub native to parts of South America. It is non-calorific and has a sweetness level approximately 300 times that of sucrose (Santini, Ferrara, Naviglio, Aragon, & Ritieni, 2008). The safety of stevia has been confirmed by various toxicity, mutagenicity and other studies (Panpatil & Polasa, 2008), and it has been approved for use as a food additive in New Zealand and Australia (Daniells, 2008). Due to its non-calorific properties, Stevia also has played an important role in medical research for treating diabetes, obesity, high blood pressure and tooth cavity and skin problems (Panpatil & Polasa, 2008). Studies have also indicated that *Stevia rebaudiana* is a source of natural antioxidants (Ghanta, Banerjee, Poddar, & Chattopadhyay, 2007).

Thaumatin is a low calorie protein sweetener, and is currently available as a commercial sweetener sold under the brand name Talin®. Like other naturally occurring sweet proteins, Thaumatin was discovered in a species of West African fruit (Gibbs, Alli, & Mulligan, 1996). It can also be produced by genetic modification of the yeast *Saccharomyces cerevisiae* (Gibbs, et al., 1996).

According to the manufacturer, Talin® is a suitable sweetener for dairy based desserts. It is claimed that Talin® provides a perceived increase in texture and flavour perception in low fat desserts (Naturex, 2009).

Stabilizer

Stabilizers are required to bind the ingredients together and improve the texture of the product. Locust bean gum is used in various products including dairy products such as ice cream. Typical dose rates are 0.1 to 1.0% (Absolute Ingredients Ltd, 2010).

Guar gum is the name given to the natural, cold water soluble stabilizer that is the milled endosperm of the legume *Cyamopsis tetragonolobus.* When used in ice cream, it can prevent ice crystals from forming and also adds a fat-like mouth feel (Absolute Ingredients Ltd, 2010). It can be mixed with locust bean gum to increase viscosity more than when either one is used alone, so lower doses can be used (Absolute Ingredients Ltd, 2010).

Other stabilizers that may be suitable for this application include lambda carrageenan and carboxy methyl cellulose (CMC) (Hawkins Watts Ltd, 2010). Both gums prevent ice crystal growth and control viscosity in frozen dessert applications.

Emulsifier

Egg yolk is the emulsifier traditionally used in ice cream. In modern recipes, mono and di-glycerides (derived from the partial hydrolysis of fats or oils) or Polysorbate-80 are more commonly used. Combined, stabilizers and emulsifiers make up less than 0.5 % w/w of ice cream (Goff, 1995).

Functional Ingredients

Polydextrose could be used to contribute to freezing point depression and mouth feel and would also be a source of fiber (Tharp, 2010). Products are continually being released with manufacturers making claims to fiber content, being high in fiber or having added fiber (Fuhrman, 2010), using the associated health benefits to aid sales. Fiber is said to prevent weight gain, disease, and also enhance cardiovascular and gastrointestinal function (Bales, 2010).

Flaxseed oil has been used to replace milk fat in ice cream without altering functionality, at a rate of 2% w/w in a 12% w/w fat ice cream (Goh, et al., 2006). Flaxseed oil is an excellent source of alpha-linolenic acids, which have been reported to help in the prevention and treatment of diseases such as diabetes, cancer, heart disease and autoimmune diseases (Larsson, Kumlin, Ingelman-Sundberg, & Wolk, 2004; Simopoulos, 1997). In modern western diets, there is a low intake of the healthy alpha-linolenic acids compared with linolenic acids

(James, 2000). Ice cream is considered to be an ideal food system for incorporating flaxseed oil due to its low storage temperature (Goh, et al., 2006).

2.3.6 Frozen Desserts for the Health Conscious Consumer

A review of products available in a local supermarket showed that there are several frozen desserts targeted toward the health conscious consumer wanting a reduced fat and/or reduced sugar option. The products, their nutritional properties and prices are summarized in Table 3.

It is observed that all of the products in Table 3 are low in protein, with Zilch!® Vanilla Bean Ice Cream having the most at 6.4%. This product also has the lowest carbohydrate content but has the highest fat levels. With 4.6% fat, it is labeled as a ‘reduced fat’ ice cream.

The Lite Licks® Dairy Free product has highest carbohydrate level and the lowest protein content. The two frozen yogurts are in between the other two products for protein, fat and carbohydrate content. A product which has more protein than carbohydrate (a ratio of 1:1 or greater), whilst being low in fat, could have a unique place in the market of frozen desserts. It would provide an attractive option for consumers looking to increase their protein intake and/or who could benefit from reducing carbohydrate and fat intake.

Table 3: Summary of frozen desserts targeted toward health conscious consumers.

Nutritional Content Per 100g		Zilch!® Vanilla Bean Ice Cream	Lite Licks® Dairy Free Vanilla Frozen Dessert	Zilch!® Passionfruit & Mango Frozen Yogurt	Bulla® Mango Frozen Yogurt
Energy (kJ)		620	640	490	587
Protein (g)		6.4	1.6	3.4	3.5
Fat	Total (g)	4.6	2.8	2.8	3
	Saturated (g)	3.2	2.1	2.3	1.8
Carbohydrates	Total (g)	8.4	28.7	19.5	25.7
	Sugar (g)	2.2	15.9	5.4	22.9
	Other [a] (g)	9.5		12.5	
Sodium (mg)		38	72	63	48
Price [b] /100g		$1.41	$1.57	$1.48	$0.70

[a] Refers to low nutritive carbohydrates added, including sugar alcohols and polydextrose, as listed on the Nutritional Information panel of the product.

[b] Prices taken from Pak 'n Save Clarence Street, Hamilton, on 11/04/11

2.3.7 Food Product Development Procedures

According to Earle & Earle (2001) there are four generic stages in food product development process:

1. Product strategy
2. Product design and process development
3. Product commercialisation
4. Product launch and post-launch evaluation

Figure 3 provides an outline of the product and process development steps used to take a product design specification (PDS) to a final product prototype.

Before experiments can begin, a base formula or recipe for the product must be produced. Five steps can be used to systematically develop a formula (Earle & Earle, 2001):

1. Set the required product qualities
2. Find the raw material compositions and costs
3. Determine the processing variables and any limits on the raw materials being used.
4. Use quantitative techniques such as linear programming, experimental designs and mixture designs to produce experimental formulations
5. Use technical tests to relate changes in formulation to changes in product qualities.

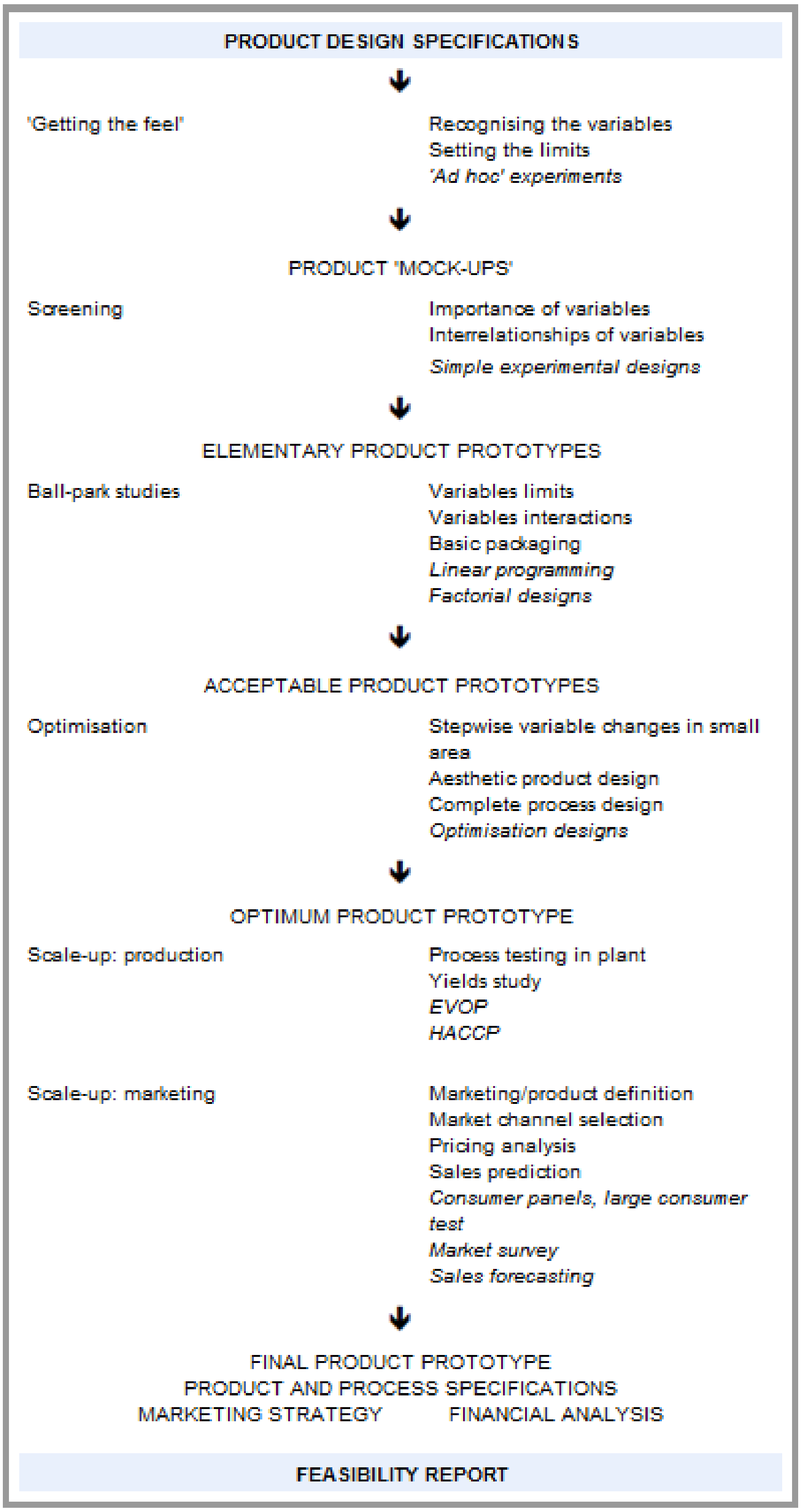

Figure 3: Activities in product design and process development (Earle & Earle, 2001).

2.4 Aims and Objectives

Since frozen desserts are so popular, the documented benefits of low fat, low carbohydrate, and high protein diets for certain segments of the population, combined with the general public's increasing awareness of the importance of a healthy diet, there is a clear incentive to produce a product which has similar sensory attributes to ice cream, but has better nutritional qualities. Therefore, the purpose of the study was to develop a new ice cream-like frozen dessert which is less than 3% fat and has a protein: carbohydrate ratio of at least 1:1; significantly higher than any commercial product currently available in New Zealand.

The study was to focus on Stage 2 of the product development procedure (as defined by Earle & Earle, 2001), the product design and process development. Stage one was carried out by Tuatara Nutritional Technologies Ltd. Stages three and four will be carried out by the company upon completion of Stage Two.The specific objectives of this project were to:

1. Carry out a literature search for possible ingredients to make the frozen dessert.
2. Develop prototypes of the frozen dessert that will be suitable for the target market.
3. Carry out instrumental measurements of the prototypes, compare them with a control sample and then optimize the formulation to achieve the desired physical properties.
4. Carry out consumer trials using volunteers from the target markets to determine acceptability of the product.

In addition to the product containing less than 3% fat and having a protein: carbohydrate ratio of at least 1:1, the following guidelines were also to be met:

- Product should have a similar sensory attributes to ice cream.
- Product should be composed of natural, naturally derived and nature identical ingredients only.
- All ingredients should be approved for use in food products.
- An attempt should be made to source ingredients locally so that the product can be labeled "New Zealand Made".

3. Product Design Specification

A Product Design Specification (PDS), following the outline published by Earle & Earle (2001), was produced in conjunction with Tuatara Nutritional Technologies:

3.1.1 Product Concept

The product will be a frozen dessert, similar to ice cream with respect to texture, hardness and flavour, but higher in protein and lower in fat and carbohydrates. The product will be packed in similar packaging to regular ice cream, and stored under the same conditions. It will be targeted at athletes, obesity sufferers, diabetics and health conscious individuals on carbohydrate-controlled diets, but will also be suitable for the general population. It will incorporate dairy proteins, flavours, sweeteners, emulsifiers and stabilizers as a frozen emulsion with similar overrun and solids-content to regular ice cream.

3.1.2 Product qualities

Table 4 outlines the desired qualities that the high protein frozen dessert should have.

3.1.3 Target consumers

The target consumers are athletes, obesity sufferers, diabetics as well as health conscious individuals. The product should also appeal to the general public.

3.1.4 Production design specifications

Raw materials/ingredients:

- Dairy proteins to provide a source of protein and solids.
- Freezing point depressor to control the freezing point of the product.
- High intensity sweetener, if required, to enhance the sweetness of the product in addition to the freezing point depressor.
- Emulsifier, to aid in the formation of the water/air/fat emulsion.
- Stabilizer, to prevent formation of ice crystals and provide viscosity.
- Flavours to provide appropriate flavour to the product.

- Additional 'functional' ingredients, which contribute to both the sensory attributes of the product and to the health and wellbeing of the consumer.

Table 4: Desired qualities of different attributes for a high protein frozen dessert.

Attribute	**Desired qualities**
Nutritional	Protein: carbohydrate ration of 1:1 or greater, less than 3% fat and low in sodium.
Sensory	Similar texture, hardness and flavour to regular ice cream. The colour of the product is dependent on the flavour.
Physical	A frozen emulsion with similar solids content and overrun to regular ice cream.
Chemical	Contains only naturally occurring or naturally derived ingredients approved for food use.
Microbiological	Microbiologically stable, free from Coliforms and Salmonella. Shelf life will be determined by the tendency of water in the product to crystallize and become "icy".
Processing	A similar process to that used in traditional ice cream manufacture will be used to form and freeze the emulsion.
Storage	Stable under storage conditions of regular ice cream for at least 6 months.
Packaging	Packaging will be confirmed at the completion of the product development stage.
Price	Not more than $1.50 per serve

Processing/formulation

- The product must be able to be made in an existing ice cream manufacturing plant with little or no modification.

Packaging

- Packaging size is to be confirmed.
- The packaging materials should be recyclable in NZ

Storage, transport

- The product must be stable under the storage and transport conditions of regular ice cream so that it can be stored in existing facilities, and transported similarly. It is envisaged that distribution will be via an existing distribution network with another company selling frozen dessert products, mainly to supermarkets.

3.1.5 Marketing design specifications

- **Packaging design:** Up-market branding that reflects target markets.
- **Promotion:** Directed to the target markets as well as the general population. Emphasis is directed to supermarkets, food outlets selling ice cream products and health food retailers in that order of priority.
- **Competition:** Major competition will come from regular ice cream products, which start at lower prices and come in a greater variety of flavours. Other competition will come from existing frozen desserts targeting the health conscious market, which are covered in Section 2.3.6.

4. Methodology

Using the work published by Earle & Earle, the following steps were produced and followed during the product design process (Earle & Earle, 2001):

Product Design Phase 1: Using a calculated base or theoretical formula, carry out 'ad hoc' experiments to recognise the variables.

Product Design Phase 2: Carry out simple experiments to test the variables and the relationships between different variables.

Product Design Phase 3: Use computer software to develop elementary product prototypes. Carry out instrumental testing of prototypes and compare with a control samples.

Product Design Phase 4: Optimise the product using stepwise variable changes.

Product Design Phase 5: Test the optimum product prototype for market acceptability by using a consumer panel of 30-50 people.

4.1 Ingredient Identification

Based on the literature search (Section 2.3), commercial ingredients were chosen which met criteria for suitability, availability and price. The selected ingredients are summarised in Table 5.

Table 5: Ingredients chosen for formulating a high protein frozen dessert.

Raw material	Description	Supplier
Whey Protein Isolate (WPI) 894	Instantized Whey Protein Isolate powder	Fonterra
Total Milk Protein (TMP) 1180	Milk protein powder isolated from skim milk	Fonterra
Stevia extract	Stevioside 90% extract	Hawkins Watts Ltd
Simplesse® 100	A micro-particulated whey protein concentrate	CP Kelco
Vanilla flavouring powder 443-00154-00	Nature identical Vanilla flavouring powder	Givauden / GS Hall Ltd
Cekol 4000	Carboxy methyl cellulose powder	Formula Foods Ltd
Novagel GP 3282	Powdered Microcrystalline Cellulose blend	Hawkins Watts Ltd
Mono/di-glycerides	Mono/di-glycerides from vegetable oil	Hawkins Watts Ltd
Fructose	100% Fructose powder	Hawkins Watts Ltd
Erythritol	100% Erythritol powder	Annie’s Marlborough Ltd
Xylitol	100% Xylitol powder	Annie’s Marlborough Ltd
Polydextrose	100% Polydextrose powder	Hawkins Watts Ltd
Flaxseed oil	100% Cold pressed Flaxseed oil	Healtheries NZ Ltd

4.2 Theoretical Formulation Development

Nutritional and cost information for the selected ingredients were combined into an MS Excel database. A spreadsheet was set up that could be used to calculate the following information for a particular high protein dessert recipe (see Appendix 3):

- Nutritional information
- FPD level
- Total solids content
- Soluble solids content
- Non-soluble solids content
- Cost of ingredients in each prototype

It was determined that the non-soluble solids content should be set at a maximum of 15%, while the FPD Factor (as calculated by Equation 2) should be in the range of 19-23.

Equation 2:

$$19 \leq x_1 a_1 + x_2 a_2 + \cdots + x_n a_n \leq 23$$

Where 'x_1' is the freezing point depression factor of ingredient '1' and 'a_1' is the percentage of ingredient '1' in the recipe. The level of soluble solids and hence total solids was dependent on the FPD ingredient(s) chosen and how much was required to meet the FPD range specification.

Both the non-soluble solids level and FPD Factor values were determined based on a combination of:

1. Values for commercial frozen dessert products
2. Observations made during ad-hoc experiments

The non-soluble solids level for commercial products was approximated by calculating the sum of the protein and fat, as listed in the nutritional information panel. The calculated values for the three commercial products used can be seen in Table 6.

Table 6: Values calculated for non-soluble solids content and FPD Factor of commercial products.

Ice Cream	Property	
	Approximate non-soluble solids	Approximate FPD Factor
Zilch!® Vanilla Bean Ice Cream	11%	15.5
Tip Top™ Vanilla Ice Cream	12%	20
Brent and Toby's Indulgent Chocolate Ice Cream	17%	23

Supplier recommendations were used to determine the levels of non-soluble ingredients; Simplesse® 100, Cekol 4000, Novagel GP 3282, Mono/di-glycerides and flavouring powder. The protein sources (WPI 894 and TMP 1180 – see Table 5) were used to make up the balance of the 15% allocated to non-soluble solids. Product formulas were created using the spreadsheet, then trialled in ad-hoc experiments. Due to the prohibitively large number of experiments that would be required to test the complete range of possible compositions of the frozen dessert, a trial and error approach was used to gain an understanding of the interactions between different ingredients and the effects that varying ingredient levels had on these interactions.

The nutritional information of the raw materials, which were supplied by the manufacturers, were used to carry out nutritional analyses of the prototypes. Nutritional information, as required under Standard 1.2.8 of the Australia New Zealand Food Standards Code, was calculated using Equation 3 for the components of energy, protein, total fat, saturated fat, total carbohydrate, sugar and sodium (FSANZ, 2011a).

Equation 3:

$$\text{Value} = \left(\frac{\text{M}_{\text{ingredient 1}}}{\text{M}_{\text{total}}}\right) \text{ x } \text{M}^{\frac{\text{value}}{\text{100g}}}_{\text{Ingredient 1}} + \cdots + \left(\frac{\text{M}_{\text{ingredient n}}}{\text{M}_{\text{total}}}\right) \text{ x } \text{M}^{\frac{\text{value}}{\text{100g}}}_{\text{ingredient n}}$$

Where “M” is the mass in grams of the ingredient, and “value” represents one component of the required nutritional information (e.g. protein, fat, carbohydrate etc).

The material cost for each prototype was calculated using Equation 4:

Equation 4:

$$Cost, \$ = \sum_{n}^{1} (Ingredient_1 \;\; Cost\, per\, kg\,) \times (\%\, of\, Ingredient_1\, in\, prototype)$$

4.3 Prototype preparation

After carrying out ad-hoc experiments, elementary product prototypes were developed with the aid of Design-Expert® Version 8 (V8) software, developed by Stat-Ease Inc.

Design-Expert® provides users with different statistical methods for designing experiments, including response surface, factorial, combined and mixture design structures. An *Optimal Mixture* design structure was used in this study as it is most suitable for carrying out food product formulations and allows for the greatest flexibility in the component ranges (Stat-Ease Inc, 2011)

The fundamental principle of mixture designs is the fact that the proportions must add up to one (Buyske & Trout, 2009) as shown by Equation 5:

Equation 5:

$$\sum_i x_i = 1$$

where $x \geq 0$, and is the proportion of component i the mixture. Equation 6 shows what a first order model would look like:

Equation 6:

$$E\ (y) = \beta_0 + \sum \beta_i x_i$$

Where $E\ (y)$ is the overall response and β_i represents the response to the linear blending of pure component i (Piepel, Szychowski, & Loeppky, 2002). Combining Equation 5 and Equation 6, for a mixture model the β_i terms will not be uniquely determined (Buyske & Trout, 2009). Rather than eliminate one of the x_i terms, Henry Scheffé developed his famous equations by multiplying β_0 by $1 = \sum x_i$ to get Equation 7:

Equation 7:

$$E\ (y) = \sum (\beta_0 + \beta_i)\, x_i$$

From this follows Scheffé's equations, Equation 8 and Equation 9, as used in mixture designs (Buyske & Trout, 2009; Stat-Ease Inc, 2011):

Equation 8: Linear

$$E\ (y) = \sum_{i=1}^{q} \beta_i\, x_i$$

Equation 9: Quadratic

$$E\ (y) = \sum_{i=1}^{q} \beta_i\, x_i + \sum_{i<j}^{q-1} \sum_{j}^{q} \beta_{ij} x_i x_j$$

where q is the number of products and β_{ij} represents the expected change in response due to the blending of components i and j (Piepel, et al., 2002).

Mixture designs in Design-Expert® V8 are based on models published by Scheffé. A D-Optimal Point Exchange design using a quadratic model was used for this study. D-Optimal Point Exchange designs search for the best design points whilst maximising information about the polynomial coefficients, allowing identification of the most vital variables (Stat-Ease Inc, 2011). A quadratic Scheffé model was used as, for this study, it produced a suitable number of 'runs' (prototype formulae) and provided a good fit. A summary of the design can be found in Appendix 6 and screen shots from the software can be viewed in Appendix 7.

The ad-hoc and simple experiments determined limits for four ingredients that were suitable for controlling the freezing point; fructose (A), erythritol (B), xylitol (C) and polydextrose (D). The combined freezing point depression calculated by Equation 10 was to be between 19 and 23. Flax seed oil (E) was also included in the design for its potential health benefits (James, 2000; Larsson, et al., 2004; Simopoulos, 1997). The mass sum of A, B, C, D and E was set to be 14%. This was for two reasons:

1. It would provide a total solids level of 29-32%, observed to be most suitable during ad-hoc experiments.
2. Using the product development spreadsheet, it was observed that 14% should allow for a protein: carbohydrate ratio in the vicinity of 1:1 to be achieved.

In summary, the following constraints were used:

$$A\% + B\% + C\% + D\% + \mathrm{E}\% = 14\%$$
$$0 \leq A\% \leq 8$$
$$0 \leq B\% \leq 6$$
$$0 \leq C\% \leq 8$$
$$3 \leq D\% \leq 6$$
$$0 \leq E\% \leq 2$$

Equation 10:

$$19 \leq 1.9A\% + 2.8B\% + 2.25C\% + 0.6D\% \leq 23$$

22 prototype composition formulae were generated. Of these, 18 were unique formulae with the remaining 4 being duplicates of 4 of the others. Only the 18 unique prototypes were manufactured; duplicate samples were not.

For each prototype, the calculated amounts of fructose (A), erythritol (B), xylitol (C) and polydextrose (D) were mixed with the calculated volume of water at 65°C until completely dissolved. WPI, Simplesse® 100, vanilla flavour and mono/di-glycerides were weighed and pre-mixed in a large beaker using a spatula. CMC and Novagel GP3282 were weighed and combined into a separate beaker, as was flax seed oil (E) for some of the prototypes. The sugar solution was added to a Zip Elegance Blender (Figure 4) along with the pre-mixed WPI, Simplesse® 100, vanilla flavour and mono/di-glycerides. The blender was ‘pulsed’ 4 times then left to run for 10 seconds. For prototypes containing flaxseed oil, this was added after 5 seconds with the blender still running. The CMC and Novagel GP3282 were then added and the blender was pulsed 4 times then left to run for 10 seconds. The solution was poured into a Breville Ice Cream Wizz (Figure 5, Figure 6), which was turned on and placed in a domestic freezer set at -16 ºC. After freezing, prototypes were transferred into 2 L polypropylene containers. Both the prototypes and the control products, described in Section 4.4, were stored at -16 °C for one week before analysis.

Figure 4: Blending the frozen dessert mix.

Figure 5: Pouring the frozen dessert mix into the Breville Ice Cream Wizz.

Figure 6: Breville Ice Cream Wizz

4.4 Property Testing

Prototypes were tested using instruments to measure hardness and viscosity, with micrographs being taken to analyze the internal structure. Two control samples were used;

1. Tip Top™ Vanilla flavoured Ice Cream (a regular, full fat ice cream).
2. Zilch!® Vanilla Bean Ice Cream (a reduced fat, low sugar ice cream deemed to be a competitor of the new product).

Results from the testing of frozen dessert prototypes were compared with data obtained from the control samples. The results were used to optimize the composition for the next design phase using Design-Expert®, such that the physical properties could be similar to the control samples.

4.4.1 Hardness Testing

Hardness was measured as the maximum force required to penetrate a prototype to a depth of 20mm (Goh, et al., 2006). This was carried out using an Instron 33R4204 Tensile Tester fitted with a stainless steel probe, 11mm in diameter and 40mm in length, moving at 0.5 mm/s (Figure 7, Figure 8). The probe dimensions and speed were the same as those used by Goh et al. (2006). Technical drawings of the probe used can be seen in Appendix 2.

Prototypes were stored in a freezer at -16°C for 1 week prior to testing. Once ready for testing, prototypes were removed from the freezer individually and placed in an insulated container filled with ice. A stainless steel cutter, 40x40x40mm (see Appendix 2), was used to extract a sub-sample, which was then tested under ambient conditions (18°C ± 3.5). Three sub-samples from each prototype were measured, following the timeframe as shown in Table 7:

Table 7: Timeframe used for hardness testing of frozen dessert prototypes.

Time (Minutes)	**Activity**
0-2	Remove prototype from freezer, transfer to insulated container and move to instrument room.
2-4	Prepare and test first sub-sample.
4-6	Prepare and test second sub-sample.
6-8	Prepare and test third sub-sample.

Figure 7: Instron 33R4204

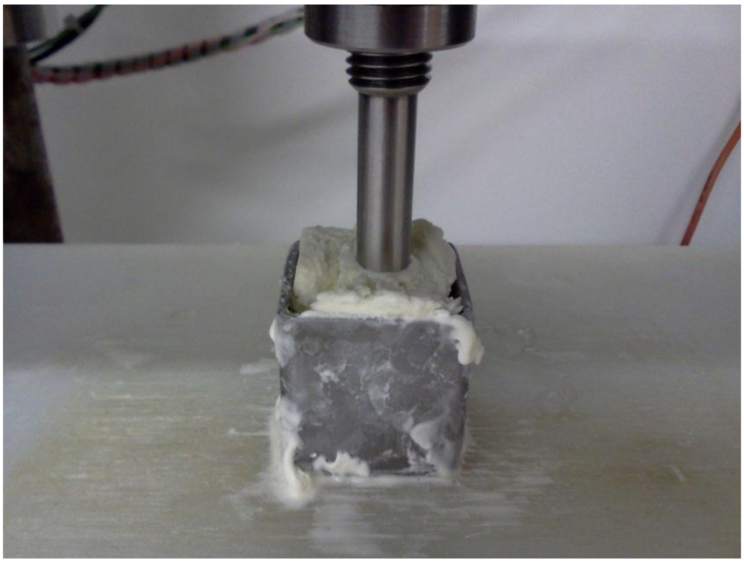

Figure 8: Probe penetrating frozen dessert sample, which is contained in a 40x40x40mm stainless steel cutter.

4.4.2 Viscosity Measurements

Prototypes were left in a refrigerator at 4°C overnight to soften slowly. 300 cm^3 of each melted prototype was transferred to an individual beaker. Viscosity was measured using a Brookfield Digital Viscometer DV-II (Figure 9). The LV Spindle #2 was used and the motor was set to 12 RPM. This combination of spindle and motor speed was used because it produced a viscosity reading between 10% and 100% torque, cited as being the requirement for selecting a spindle by the manufacturer (Brookfield Engineering Labororatories, 1985). Instructions provided by the manufacturer were followed for calibrating the viscometer before each use (Brookfield Engineering Labororatories, 1985).

Figure 9: Brookfield Viscometer

4.4.3 Scanning Electron Microscopy

Selected prototypes were analysed using a Hitachi S-4700 Scanning Electron Microscope (Figure 10). Two representative prototypes (Prototype 9 and Prototype 11) were chosen, based on the fact that they contained all five of the variable ingredients between them, and their microstructures were compared to a commercial sample.

1. Prototype 9: Contained fructose, xylitol, polydextrose.
2. Prototype 11: Contained fructose, erythritol, and polydextrose and flaxseed oil.
3. Tip Top™ Vanilla Ice Cream.

Sub-samples of the selected prototypes were taken and frozen using liquid nitrogen before being inserted into the charging chamber. The blade was used to fracture the surface of the sub-samples so that the undisturbed internal structure could be observed. Sub-samples were then coated with platinum (Figure 11) before being transferred to the electron chamber. The surfaces were then analysed on the computer monitor display and images taken.

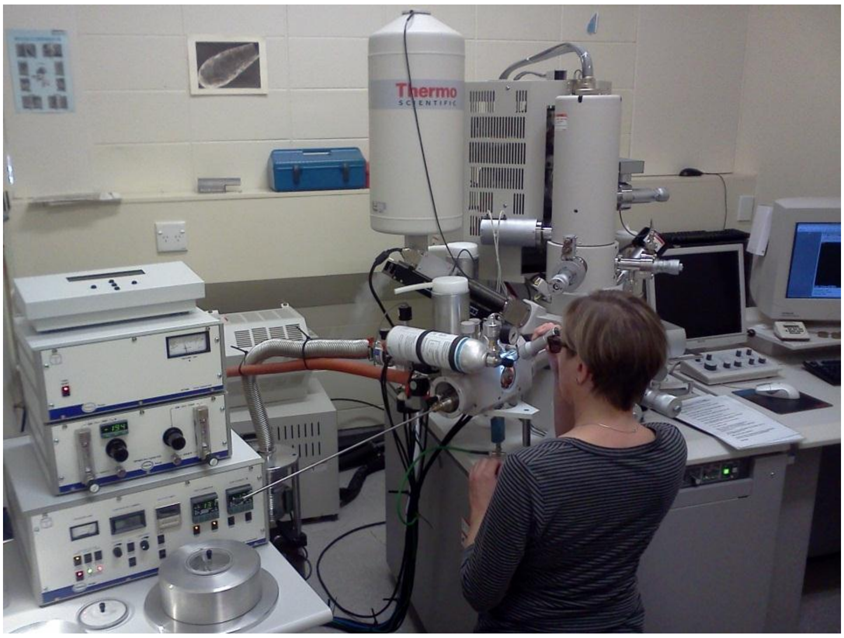

Figure 10: Hitachi S-4700 SEM being prepared for use.

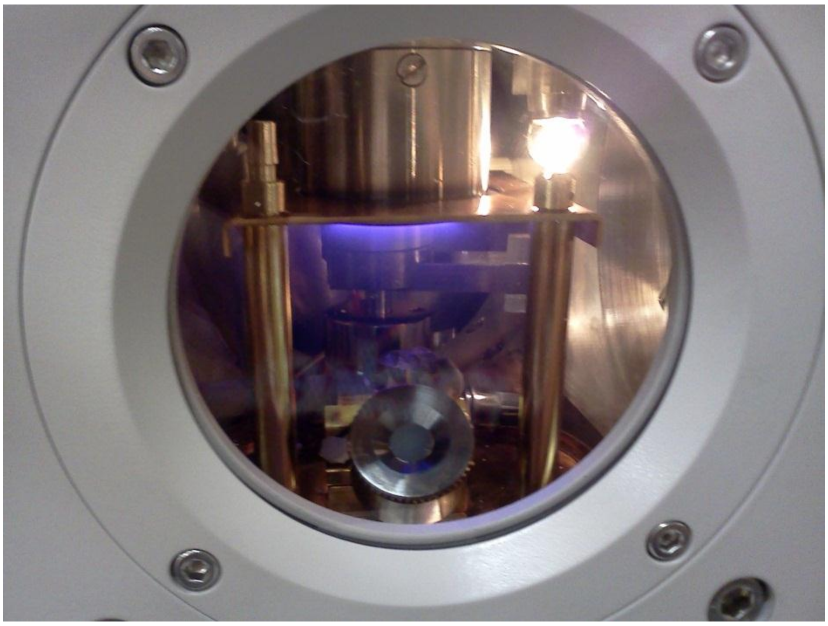

Figure 11: Cryogenically-frozen frozen dessert sample being coated with platinum in preparation for viewing under the SEM.

4.4.4 Optimization

Using the response data collected from the prototypes, optimum formulae were calculated using Design-Expert® V8 software. Criteria were selected such that the program generated sample formulations that would best replicate both the hardness and viscosity of the controls i.e. low hardness and high viscosity.

4.5 Consumer Panel Testing

Two different sets of consumer tests were carried out on the product prototypes. The first investigated the consumer's preferred prototype on the basis of sweetness. In the second, consumers tested the preferred prototype from the first test for other characteristics. Panellists were also asked to complete a short questionnaire to gain an understanding of their consumption of ice cream products and protein supplements (Figure 12).

All aspects of the consumer testing were approved by the Faculty of Science and Engineering Human Research Ethics Sub-committee (Appendix 8). Prior to participating, panellists were asked to read a covering letter, explaining the purpose of their participation, and asked to sign a consent form (Appendix 8).

4.5.1 Preference Ranking Test

The objective of this test was to determine which prototype, out of three, consumers preferred with regard to the attribute of sweetness. Three prototypes were prepared, with the only difference being the amount of stevia (high intensity natural sweetener) used. Prototypes contained 0%, 0.15% and 0.3% (mass basis) stevia.

20 consumers were recruited who were representative of the target market. Assessors were presented with 3 blind coded prototypes simultaneously. They were asked to assess the prototypes in the order provided and place them in order from most preferred to least preferred for the attribute of sweetness (Figure 13). Assessors cleansed their palate with water after each prototype (Kemp, Hollowood, & Hort, 2009).

Sensory Evaluation Questionnaire

For statistical purposes only:

Age:

Sex:

1. Are you a consumer of ice cream? (Circle one)

Yes/ No

2. How often do you consume ice cream products? (Circle one)

Daily / Weekly / Monthly / Never

3. Do you consume reduced-fat, low-fat, or fat-free desserts? How often?

Yes / No

Often / Occasionally / Rarely / Never

4. Do you partake in regular exercise?

Yes / No

5. Have you ever consumed whey or soy protein supplements as part of a diet and/or exercise routine? (Circle one)

Yes / No

Thank you for filling out this questionnaire. Please refer to the covering letter provided to you for information as to how this data will be used.

Figure 12: Questionnaire completed by panellists during sensory testing.

Preference ranking test for ice cream

Date________

Please taste the three ice cream samples in the following order. Use the water provided to cleanse your palate before tasting each sample:

348 268 921

Place the code numbers in the appropriate position below. One code only per line – no ties are allowed.

Most preferred ______

______

Least preferred ______

Comments:

Thank you for your participation.

Figure 13: Form consumers completed during Preference Ranking tests (modified from that presented in *Kemp, et al,* 2009)

4.5.2 Acceptance Test

The objective of this test was to provide an indication of the magnitude of consumer acceptability of the product (Kemp, et al., 2009), compared to Tip Top™ Vanilla Ice Cream, using a hedonic rating system.

40 consumers were recruited who were representative of the target market. For each prototype, subjects are asked to complete a form, indicating their level of liking on a nine point hedonic scale. The scale ranges from “dislike extremely” to “like extremely” (Figure 15). Assessors cleansed their palate with water after each prototype. Prototypes were presented to each consumer individually. As individuals are prone to scoring initial samples abnormally high (Kemp, et al., 2009), a ‘dummy’ prototype, similar to those in the sample set, was presented first to remove this source of bias. Its data was discarded. The remaining prototypes were then presented to each assessor according to a randomized design (Kemp, et al., 2009).

Data from consumer testing was analyzed using QI Macros Statistical Process Control Software, a statistics add-on package for MS Excel (Arthur, 2011).

Because the hedonic scale has problems related to un-equal scale intervals when used in consumer trials (Kemp, et al., 2009; Schutz & Cardello, 2001), the labelled affective magnitude (LAM) scale (Figure 14) published by Schutz & Cardello (2001) was be applied to the data before analysis for significance. Significance was set at p=0.05, in accordance with most sensory studies (Kemp, et al., 2009).

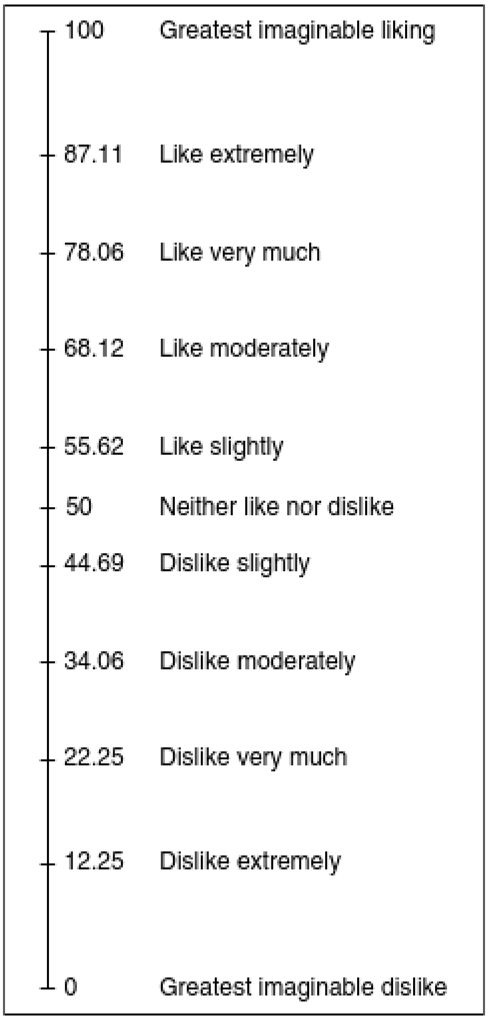

Figure 14: Labelled affective magnitude (LAM) scale, produced by Schutz & Cardello (2001) and taken from Kemp, et al.(2009).

Hedonic rating test for Ice Cream

Please taste ice cream samples in the following order. Use the water provided to cleanse your palate before tasting each sample:

348 268 921

Indicate how much you like each attribute of each sample by ticking the most appropriate phrase below:

	348					268					921				
	Sweetness	Flavour	Texture	Hard-ness	Overall Appeal	Sweetness	Flavour	Texture	Hard-ness	Overall Appeal	Sweetness	Flavour	Texture	Hard-ness	Overall Appeal
Like extremely															
Like very much															
Like moderately															
Like slightly															
Neither like nore dislike															
Dislike slightly															
Dislike moderately															
Dislike very mich															
Dislike extremely															

Comments:

Thank you for your participation.

Figure 15: Form completed by consumer panellists during Acceptance Testing of frozen dessert prototypes.

5. Results and Discussion

5.1 Observations made during Ad-Hoc Experiments

Samples made with TMP 1180 protein had a chewy, gum-like texture when compared with samples made with WPI 894. Samples with a 50/50 blend of TMP 1180 and WPI 894 also showed this trait. As a result, it was decided that only WPI 894 would be used as the protein source.

Samples made with erythritol appeared harder and had an icier texture than samples made with xylitol, for samples calculated to have the same overall freezing point depression factor. This was observed for a range of different samples. A full list of sample recipes and observations can be found in Appendix 4.

Reasonable sweetness and flavour intensity was being achieved without the aid of a high intensity sweetener. The sweetness provided by erythritol, xylitol and/or fructose was sufficient in most cases; therefore no stevia was included in the first stage of prototype formulation.

5.2 Formulation Generation

Table 8 presents the amounts of the non-variable ingredients used in the prototypes. Table 9 shows the amounts of the variable ingredients (Fructose, Erythritol, Xylitol, Polydextrose and Flax Seed Oil) used in each prototype, as calculated by Design-Expert®. A summary of the experiment design, produced by Design-Expert®, can be found in Appendix 6.

Table 8: Non-variable ingredients and amounts selected for use in frozen dessert prototypes.

Category	**Ingredient**	**Ingredient Amount %**
Protein source	WPI 894	9.79
Fat substitute	Simplesse® 100	5.00
Flavour	Vanilla	1.00
Stabilizers	CMC	0.40
	Novagel GP 3282	0.80
Emulsifier	Mono/di-glycerides	0.40
Water	Water	68.61

5.3 Hardness Testing

Table 10 shows the results from the hardness and viscosity testing of frozen dessert prototypes.

Table 9: Variable ingredient amounts generated for frozen dessert prototypes by Design-Expert® V8 software.

	Ingredient amount (%)					
Prototype Number*	A:Fructose	B:Erythritol	C:Xylitol	D:Polydextrose	E:Flax Seed Oil	Total FPD Factor
1	4.44	4.56	0.00	3.00	2.00	23.00
2	0.00	2.55	5.45	6.00	0.00	23.00
3	4.00	0.00	4.00	4.00	2.00	19.00
4	2.22	3.14	3.64	3.00	2.00	23.00
5	1.67	5.80	0.00	6.00	0.54	23.00
6	5.60	1.05	1.73	4.54	1.09	20.18
7	0.00	1.00	8.00	3.00	2.00	22.60
8	1.38	0.00	8.00	3.96	0.66	23.00
9	3.71	0.00	4.29	6.00	0.00	20.30
10	8.00	1.91	0.00	4.09	0.00	23.00
11	0.15	7.00	0.00	4.85	2.00	22.80
12	0.00	4.74	2.73	6.00	0.54	23.00
13	0.00	0.00	6.84	6.00	1.16	19.00
15	7.89	0.16	0.00	5.95	0.00	19.00
16	8.00	0.00	2.67	3.00	0.33	23.00
17	1.56	4.44	0.00	6.00	2.00	19.00
18	8.00	1.00	0.00	3.00	2.00	19.80
21	0.00	2.96	4.63	4.98	1.43	21.71
Optimised Prototype 1	6.43	0.00	1.75	4.75	1.07	19.00
Optimised Prototype 2	4.10	0.00	5.96	3.00	0.94	23.00

* Duplicate prototypes 14, 19, 20 and 22 have been excluded.

Table 10: Results from hardness and viscosity testing of frozen dessert prototypes.

Prototype #	Average Maximum Force Required to achieve 20mm Penetration Depth	% Error in Force Measurements	Viscosity (mPa.s)
1	3.3 ± 2.5	75%	835
2	1.6 ± 0.3	21%	539
3	8.3 ± 2.2	27%	755
4	3.7 ± 1.1	31%	643
5	13.4 ± 3.3	25%	646
6	2.7 ± 1.2	44%	765
7	4.5 ± 1.5	33%	611
8	4.0 ± 2.5	62%	621
9	4.0 ± 2.0	50%	559
10	3.5 ± 0.5	15%	468
11	55.7 ± 30.3	54%	772
12	3.2 ± 0.6	19%	646
13	15.4 ± 14.4	93%	501
15	4.0 ± 1.1	27%	686
16	2.8 ± 1.6	57%	635
17	21.4 ± 7.0	33%	650
18	10.3 ± 2.6	26%	586
21	20.6 ± 16.3	79%	518
Tip Top™ Vanilla Ice Cream	1.6 ± 0.4	23%	1240
Zilch!® Vanilla Bean Ice Cream	0.9 ± 0.1	15%	790
Measured Values			
Optimised Prototype 1	8.6 ± 3.0	35%	585
Optimised Prototype 2	4.2 ± 2.5	59%	651
Values Predicted by Design-Expert®			
Optimised Prototype 1	6.1		830
Optimised Prototype 2	2.4		779

The model values predicted for both Optimised prototypes fell within the error limits of the measured values. The percentage error in the hardness measurements ranged from 15% to 93%, with an average of 41%. Measuring the hardness of the frozen dessert prototypes in a consistent manner proved difficult. It is likely that melting rates of the ice creams and the prototype frozen desserts once exposed to room temperature, despite the short time involved, contributed more to inconsistent readings than hardness variability within the same batch.

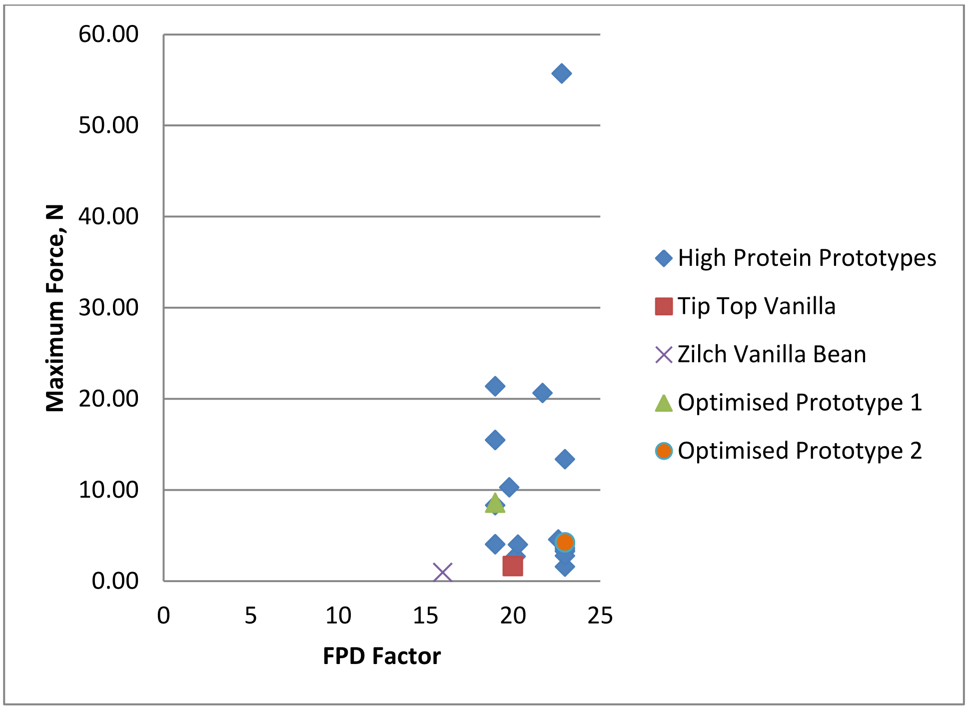

Figure 16: Plot of FPD Factor verses the Mean Maximum Force Required to Penetrate Frozen Dessert Prototypes 20mm using Instron 33R4204.

Figure 16 shows that no correlations could be drawn between calculated FPD factor and hardness in this study, when hardness is measured as described in Section 4.4.1. It is possible that the range of calculated FPD factors (19-23) is not large enough to produce noticeable trends relating to hardness, as despite one outlying point at (x,y) = (24,56), most values are in a relatively narrow range.

Optimised Prototypes 1 and 2 are harder than Tip Top™ Vanilla by 438% and 163% respectively, and harder than Zilch!® Vanilla Bean by 856% and 367% respectively. However, the 163% difference between Optimised Prototype 2 and Tip Top™ Vanilla is only 2.6 N. Using standard deviation, the upper limit for Tip

Top™ and the lower limit for Optimised Prototype 2 are in an overlapping range of 1.7-2 N, a positive result.

Both of the optimized prototypes were calculated to have an overrun of 35% using Equation 1. Overrun and hardness have an inverse relationship (Goff, et al., 1995; Tanaka, et al., 1972; Wilbey, et al., 1998), therefore an overrun value of 35%, significantly less than the 75% achieved by Goh et al. (2006), has probably been responsible for the prototype samples being harder than the two control products. It was not possible to control the overrun in this study due to limitations in the equipment being used. A table containing the overrun values for all prototype samples can be found in Appendix 1.

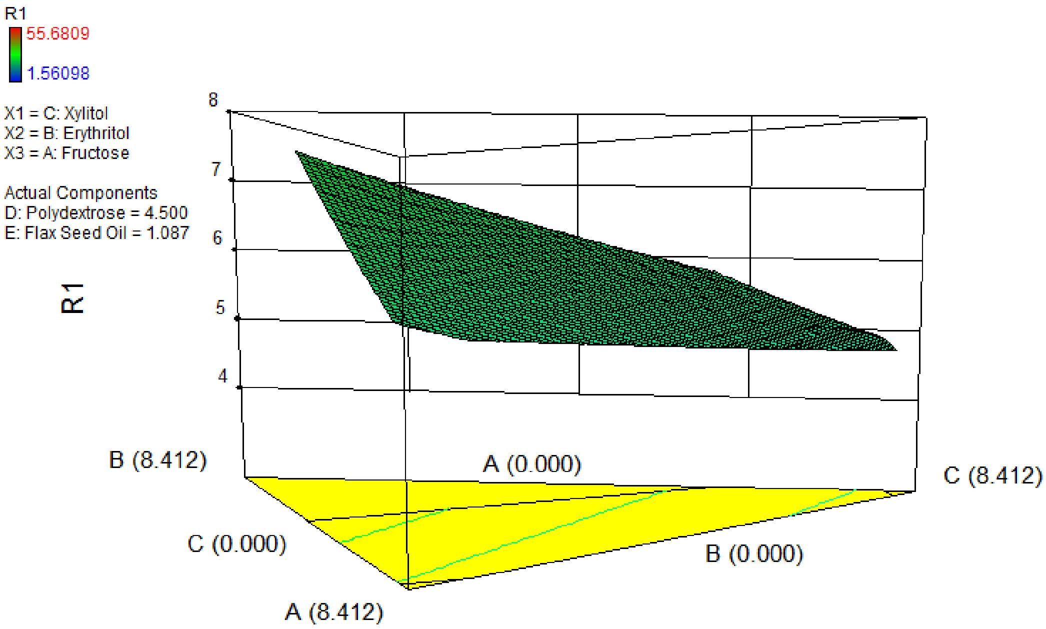

Figure 17: Response surface plot showing relationship between xylitol, erythritol and fructose on product hardness ('R1'), for a fixed amount of polydextrose and flax seed oil.

Figure 17 shows that increasing amounts of erythritol and decreasing amounts fructose and xylitol produced the hardest prototypes. This supports the observations made during ad-hoc experiments and therefore erythritol was deemed to be unsuitable for use in this high protein frozen dessert. Further observations made during the preparation of the high protein prototypes include:

- Prototypes that contained no or low amounts of fructose were found to be bland tasting and would need a high intensity sweetener to enhance sweetness and bring out the flavour.
- 8 of the 18 prototypes prepared were observed to have an icy texture to some degree.
- ‘Scooping hardness’, while not numerically measured during observations, was found to be acceptable when scooped with an ice cream scoop for most of the prototypes.

Specific observations for each individual prototype can be found in Appendix 5.

5.4 Viscosity Measurements

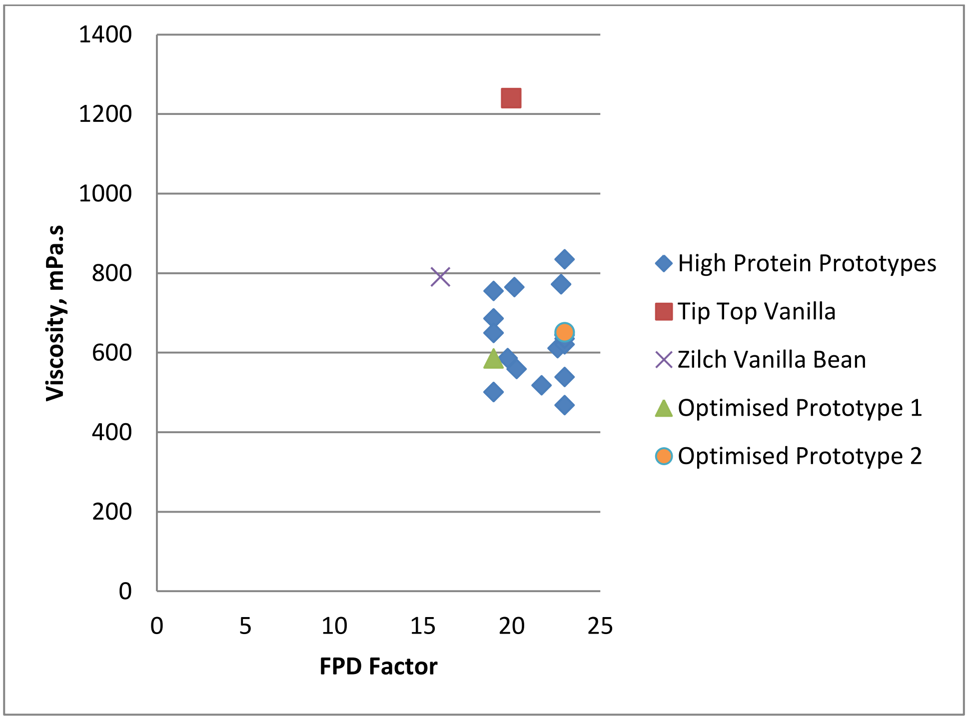

Figure 18: Plot of FPD Factor verses the Mean Viscosity for Ice Cream Prototypes.

Figure 18 shows a similar trend to Figure 16; no correlations can be drawn between calculated FPD Factor and viscosity. It is noted that the Tip Top™ Vanilla Ice Cream is softer and more viscous than most of the prototypes despite not having a high FPD Factor. The viscosity measurements for Optimised

Prototypes 1 and 2 show differences of 30% and 16% from the values predicted by Design-Expert® respectively (shown in Table 10).

Optimised Prototype 2 is only 16% or 139 mPa.s less viscous than Zilch!® Vanilla Bean. This places it in the vicinity of the control samples for both hardness and viscosity measurements. Because of this, Optimised Prototype 2 was determined to be the Optimum High Protein Prototype (OHPP). It was also softer and had a higher viscosity when compared to Optimised Prototype 1.

5.5 SEM Results

Figure 19 shows the fracture surface structure of Prototype 9. The round structures are air bubbles formed by the 3-D networks resulting from fat coalescence (Goff, 1995).

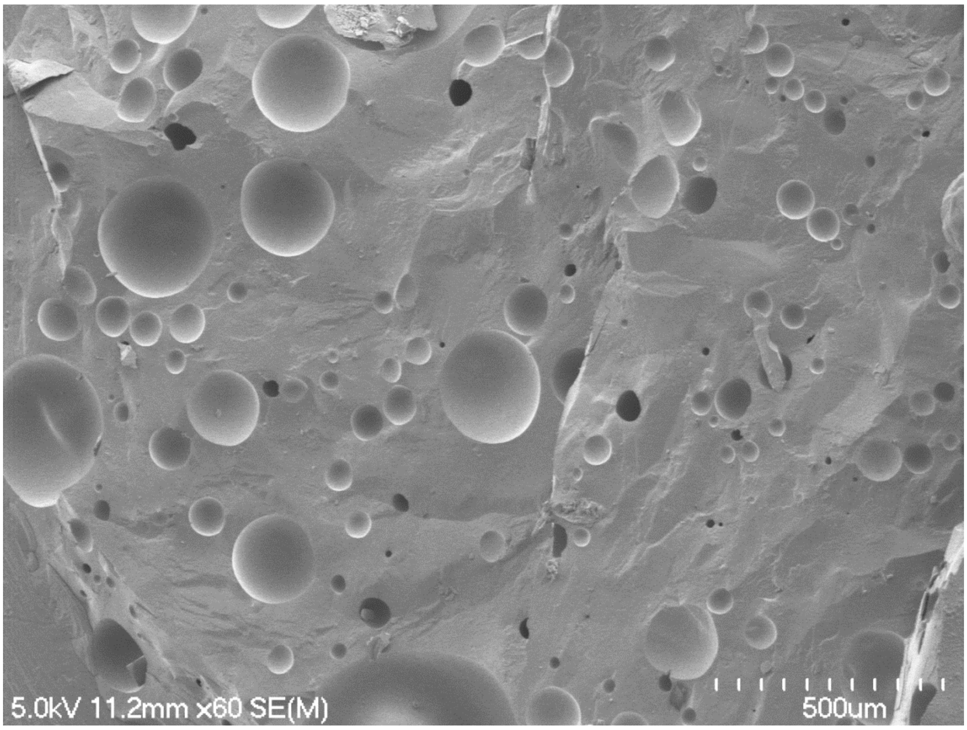

Figure 19: Micrograph of Frozen Dessert Prototype 9.

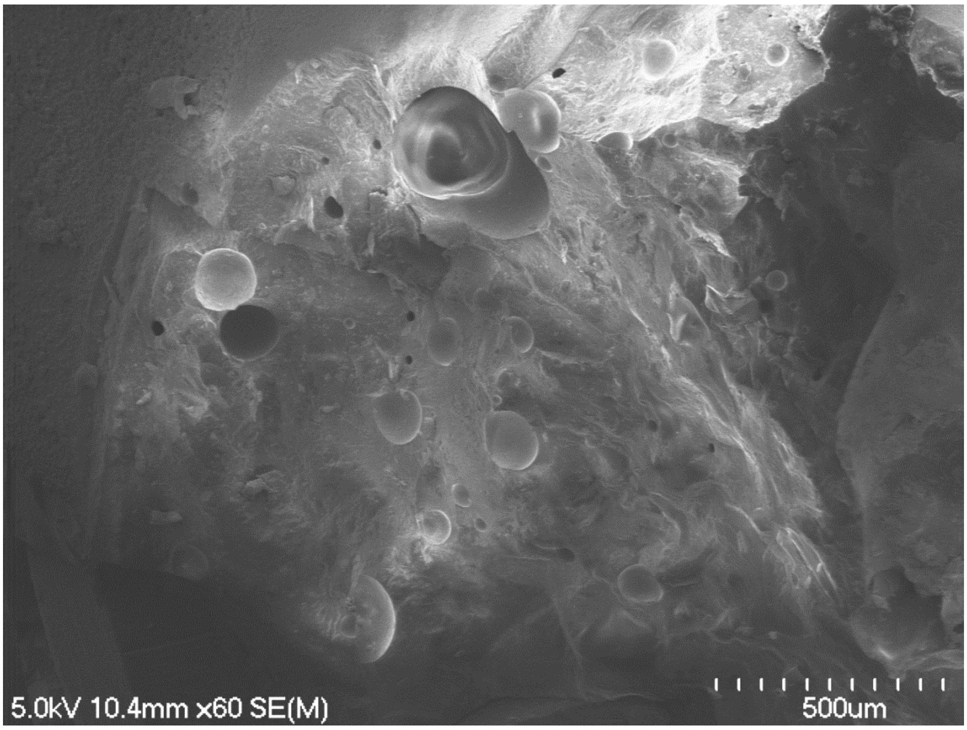

Figure 20: Micrograph of Frozen Dessert Prototype11.

Figure 20 shows a micrograph of Prototype 11. This prototype did not fracture as well as Prototype 9. Significant ‘charging’ on the surface also made viewing difficult. Charging occurs when there is an excessive build-up of electrons on the surface of the sample. This build up creates an electric field, which deflects the electron beam of the instrument, inhibiting its ability to generate detailed images (Rice, 2011). Figure 20 does however show that air bubbles, similar to those observed in Figure 19, were formed in the prototype and can be seen in the centre of the image.

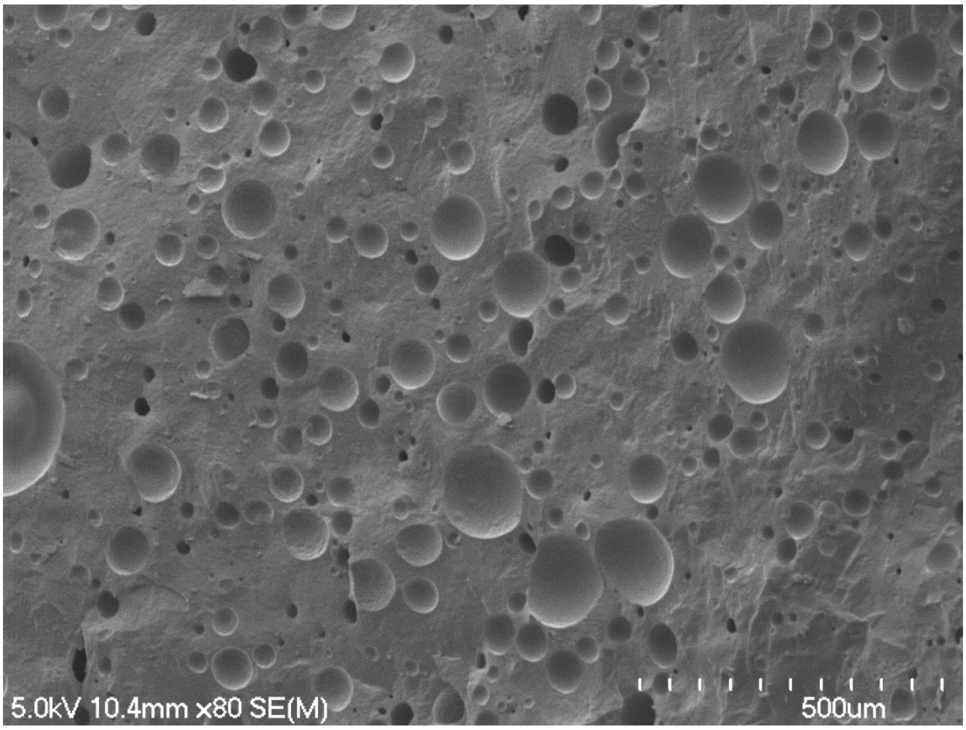

Figure 21: Micrograph taken of Tip Top™ Vanilla Ice Cream.

Figure 21 shows a significantly more air bubbles in the Tip Top™ sample than the prototype samples in Figure 19 and Figure 20. They range in size from less than 10µm, up to approximately 100 µm.

The dasher speed of the Breville Ice Cream Whiz used in this study was only 30 rpm. This has resulted in less air being incorporated into the product, resulting in a product which is harder and has greater density compared with Tip Top™ Vanilla Ice Cream. The low air content was also shown in the low overrun values calculated for the optimised prototypes (see Appendix 1). It is also observed that some of the air bubbles in Prototype 9 (Figure 19) are up to 100 µm, or 100%, larger than those seen in Figure 21. It is likely that the low dasher speed has influenced the air bubble size, as well as the total air content.

In the case of the high protein prototypes, the Simplesse® 100 was to take the place of the fat globules. It is stated by the manufacturer that Simplesse® 100 can be processed under standard homogenization pressures (CP Kelco, 2000). Using a homogenization process that mimics commercial procedures, it may be possible to better disperse the Simplesse® 100 particles. Combined with a higher dasher speed, it should be possible to incorporate more air into the product and with smaller air bubble size.

5.6 Nutritional and Cost Information

As well as being in the same range of hardness and viscosity values as the control samples, Optimised Prototype 2, the Optimum High Protein Prototype (OHPP) calculated using Design-Expert® V8 software, met most of the points in the design specification for nutritional information (Table 11). The OHPP has a protein to carbohydrate ration of 0.81:1 and less than 2% fat, meeting the PDS in this regard. It contains 82% more protein and 65% less fat than Zilch!® Vanilla Bean Ice Cream.

Table 11: Nutritional Information for the OHPP Compared with Commercial Products.

		Zilch!® Vanilla Bean Ice Cream	Tip Top™ Vanilla Ice Cream	OHPP
Nutritional Content Per 100g				
Energy (kJ)		620	853	477
Protein (g)		6.4	1.5	11.6
Fat	Total (g)	4.6	10.7	1.6
	Saturated (g)	3.2	6.3	0.4
Carbohydrates	Total (g)	8.4	25	14.3
	Sugar (g)	2.2	19.6	6.5
	Other [1] (g)	9.5		2.5
Sodium (mg)		38	36	14
Composition Information				
alpha-Linolenic acid (mg)		0	0	570

[1] Refers to low nutritive carbohydrates added, including sugar alcohols and polydextrose, as listed on the Nutritional Information panel of the product.

Cost factors were used to determine an approximate recommended retail price (RRP) from the cost of the ingredients for the OHPP (Table 12). According to Tharp & Young (2011), ingredients can be 55-60% of the final product cost, packaging is typically 15-20% and fixed and variable costs are usually 25%. Freight, warehousing and merchandising have been approximated by the author to add 20% to the total cost. A manufacturers margin of 20% (Tharp & Young, 2011) and a retail margin of 30% were also added.

Table 12: Calculation of RRP for OHPP.

	Cost / L	**Factor/margin**
Ingredients	$2.99	55% of Finished product
Finished Product	$5.44	
Distribution	$6.52	20%
Wholesale Price	$7.83	20%
RRP	$10.18	30%

Table 13: Comparison of unit prices between a selection of supermarket ice cream brands and the OHPP.

	Zilch!® Vanilla Bean Ice Cream	**Tip Top™ Vanilla Ice Cream**	**OHPP**	**Kapiti® Vanilla Bean Ice Cream**	**Kohu Road® Vanilla Ice Cream**
Pack Size (L)	0.946	2	1	1	1
RRP	$8.81[1]	$7.49[1]	$10.18	$11.49[1]	$19.41[1]
RRP/L	$9.31	$3.75	$10.18	11.49	19.41

[1] Price as at 29/11/11, taken from www.shop.countdown.co.nz

The OHPP would be 2.71 and 1.09 times more expensive than Tip Top™ Vanilla Ice Cream and Zilch!® Vanilla Bean Ice Cream respectively (Table 13). It would be 11% cheaper than Kapiti® Vanilla Bean Ice Cream and 48% cheaper than Kohu Road® Vanilla Ice Cream. This would place it in the middle of the market, at the lower-end of the premium branded products.

Table 14: Nutritional and cost comparisons between OHPP and pureMUSCLE WPI.

		Per Serve as Consumed (30g pureMUSCLE WPI mixed in 300ml Reduced Fat Milk)	**1 serve (100g) OHPP**	**2 serves (200g) OHPP**
Energy (kJ)		1043	477	954
Protein (g)		37	11.6	23.2
Fat	Total (g)	5	1.6	3.2
	Saturated (g)	3	0.4	0.8
Carbohydrates	Total (g)	16	14.3	28.6
	Sugar (g)	16	6.5	13
	Other[1](g)	0	2.5	5
Sodium (mg)		167	14	28
Cost/serve		$2.75	$1.02	$2.04

A single serve of OHPP delivers significantly less protein than a serve of pureMUSCLE WPI but with a similar amount of carbohydrate (Table 14). However, a double serve of OHPP delivers 63% of the protein at 74% of the cost and with 9% less calories. This would make the OHPP a viable option as an evening protein source for athletes if the additional carbohydrates are not an issue for the individual. The price of $1.02 per single serve is considerably less than the $1.50 maximum specified in the PDS.

It is possible that increasing the air content and reducing air bubble size would enable the carbohydrate content to be decreased. As mentioned previously, an inverse relationship exists between hardness and overrun so increasing air content will provide a softer product and reduce the amount of carbohydrate required to control FPD. Reducing the carbohydrate levels further would add to the nutritional appeal of this product compared with regular ice cream.

5.7 Consumer Panel Results

40 people took part in the acceptance test component of the consumer trials, 16 of whom were female and 24 were male. The results from the questionnaire in Figure 12 are presented in Table 15. Interestingly, only 2 respondents reported consuming reduced-fat, low-fat, or fat-free desserts often, yet most reported consuming regular ice cream products weekly. This could suggest that consumers prefer the regular ice cream products because of the sensory properties, the cost, the accessibility, or a combination of all three factors.

In the preference ranking test, in which only 20 consumers were asked to partake, 100% of the consumers ranked the 0% stevia prototype as their most preferred, followed by 0.15% and 0.3%. All consumers commented on experiencing a slightly bitter aftertaste for the prototypes containing stevia. The results from the acceptance test, which used the hedonic scale as shown in Figure 15, can be seen in Table 16.

Table 15: Results from consumer questionnaire.

Question		Response		
		Male	Female	Combined
Average Age:		21.2 ± 2.5	23.5 ± 3.3	22.2 ± 3.0
1. Are you a consumer of ice cream?	Yes	79%	81%	80%
	No	21%	19%	20%
2. How often do you consume ice cream products?	Daily	13%	13%	15%
	Weekly	38%	44%	40%
	Monthly	29%	25%	25%
	Never	21%	19%	20%
3. Do you consume reduced-fat, low-fat, or fat-free desserts? How often?	Yes	63%	63%	60%
	No	38%	38%	40%
	Often	4%	7%	5%
	Occasionally	25%	21%	20%
	Rarely	42%	43%	40%
	Never	29%	29%	35%
4. Do you partake in regular exercise?	Yes	100%	100%	100%
	No	0%	0%	0%
5. Have you ever consumed whey or soy protein products as part of a diet and/or exercise routine?	Yes	54%	56%	55%
	No	46%	44%	45%

Table 16: Results from consumer acceptance test of frozen dessert prototype and a control product.

Sensory characteristic*	OHPP			Tip Top® Vanilla Ice Cream		
	mean ± standard deviation					
Sweetness	7.00	±	1.13	8.13	±	1.04
Flavour	6.58	±	1.17	8.35	±	0.86
Texture	7.33	±	1.31	8.25	±	0.90
Hardness	6.75	±	1.45	8.40	±	0.71
Overall Appeal	7.18	±	1.08	8.35	±	0.77

*Characteristics were evaluated by consumers on a nine point hedonic scale

The level of consumer acceptance for the different sensory characteristics of the OHPP range from ‘like slightly’ to ‘like moderately’ on the 9 point hedonic scale. With an overall appeal of 7.18, or ‘like moderately’, this is a positive outcome. Panellists rated all characteristics for Tip Top® Vanilla Ice Cream in the ‘like very much’ category, giving it an overall appeal 1 point higher than the OHPP.

The average values for texture and overall appeal were the highest two scores for the OHPP. This suggests that the product seemed and looked like ice cream (see Figure 22, Figure 23 and Figure 24) and with some improvement to the flavour and sweetness combination, along with work on the hardness (as discussed in Section 5.5), a higher overall appeal and more acceptable product could be produced.

After applying the LAM scale, the full data set for each characteristic was checked for normality on MS Excel using the Anderson-Darling method (Stephens, 1974). The results are presented in Table 17.

Table 17: Results from Anderson-Darling Test for normality of consumer panel data.

Product Attribute	**A-Squared**	**p**	**Result**	**Distribution Type**
Sweetness	3.59	<0.001	$A^2 \geq p$	Non normal
Flavour	3.94	<0.001	$A^2 \geq p$	Non normal
Texture	4.46	<0.001	$A^2 \geq p$	Non normal
Hardness	4.11	<0.001	$A^2 \geq p$	Non normal
Overall Appeal	3.67	<0.001	$A^2 \geq p$	Non normal

According to Figure 3.3 in Kemp, et al. (2009), the appropriate test for 2 unrelated samples with non-normal data distribution is the Mann-Whitney U-test. The results of such analysis, presented in Table 18, showed that all attribute scores for the OHPP were significantly different from those obtained for Tip Top® Vanilla Ice Cream. The complete results obtained from the Mann-Whitney U-test can be found in Appendix 9.

Table 18: Results from Mann-Whitney U-test on sensory data for different product attributes.

Product Attribute Compared	**p**	**Result**
Sweetness	<0.001	Reject Null Hypothesis at $p = 0.05$
Flavour	<0.001	Reject Null Hypothesis at $p = 0.05$
Texture	<0.001	Reject Null Hypothesis at $p = 0.05$
Hardness	<0.001	Reject Null Hypothesis at $p = 0.05$
Overall Appeal	<0.001	Reject Null Hypothesis at $p = 0.05$

Figure 22: Photo of OHPP.

Figure 23: Close-up photo of OHPP.

Figure 24: Clockwise from top: OHPP, Tip Top™ Vanilla Ice Cream and Zilch!® Vanilla Bean Ice Cream

6. Conclusions and Recommendations

High-protein frozen dessert prototypes were produced that met the design criteria for nutritional composition. The prototypes were generally harder and had lower overrun than both commercial samples tested. No correlations could be observed between FPD factor, hardness and viscosity within the range of compositions tested.

Three ingredients, fructose, xylitol and polydextrose, were found to be suitable for controlling the freezing point of high protein frozen desserts. Erythritol was found to produce harder samples for same overall FPD factor, and was thus deemed unsuitable for use in such products.

Optimised Prototype 2 (containing 68.61% water, 9.79% WPI, 5.96% xylitol, 5% Simplesse® 100, 4.1 % fructose, 3% polydextrose, 1% vanilla flavour, 0.94% flax seed oil, 0.8% Novagel GP 3282, 0.4% CMC, 0.4% mono/di-glycerides), the Optimum High Protein Prototype (OHPP), was found to have hardness and viscosity values of a similar order of magnitude to the control samples. It also met the design criteria for nutritional composition. With an estimated recommended retail price of $1.02 per serve, the OHPP would feature at the lower end of the premium ice-cream range in the market. During consumer trials, the OHPP received an overall appeal of 7.18 ± 1.08, slightly lower than that given to Tip Top® Vanilla Ice Cream of 8.35 ± 0.77. Differences in scores for all attributes between the two products were found to be statistically significantly ($p<0.05$).

Future development work should focus on lowering the hardness by increasing overrun. Carbohydrate and hence sugar content should be lowered as product becomes softer and further efforts should be made to correlate the relationship between FPD factors, hardness and overrun. Once hardness and texture have been perfected, the flavour and sweetness combination should be optimised and large scale consumer panels used to evaluate the final product.

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8. Appendices

8.1 Appendix 1: Overrun Values for Frozen Dessert Prototypes

Table A1: List of overrun values for frozen dessert prototypes.

Prototype #	Overrun (%)
1	32
2	42
3	32
4	30
5	30
6	42
7	38
8	40
9	41
10	37
11	41
12	42
13	34
14	32
15	41
16	35
17	32
18	41
19	31
20	35
21	33
22	37
Optimized Prototype 1	35
Optimized Prototype 2	35

8.2 Appendix 2: CAD Drawings for Hardness Probe Attachment, Fastener and Cutter

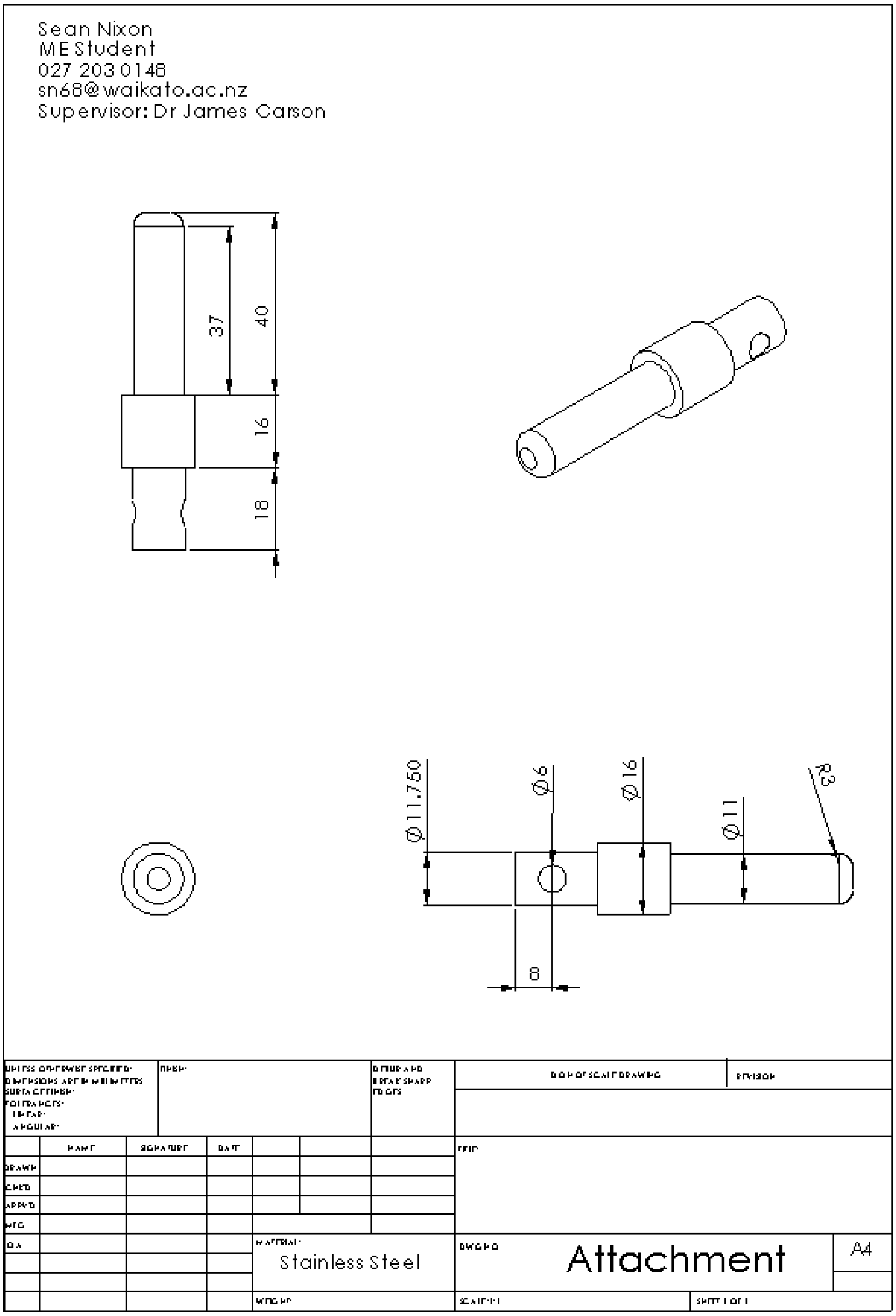


Figure A1: CAD drawing for probe attachment used to measure hardness of frozen dessert prototypes.

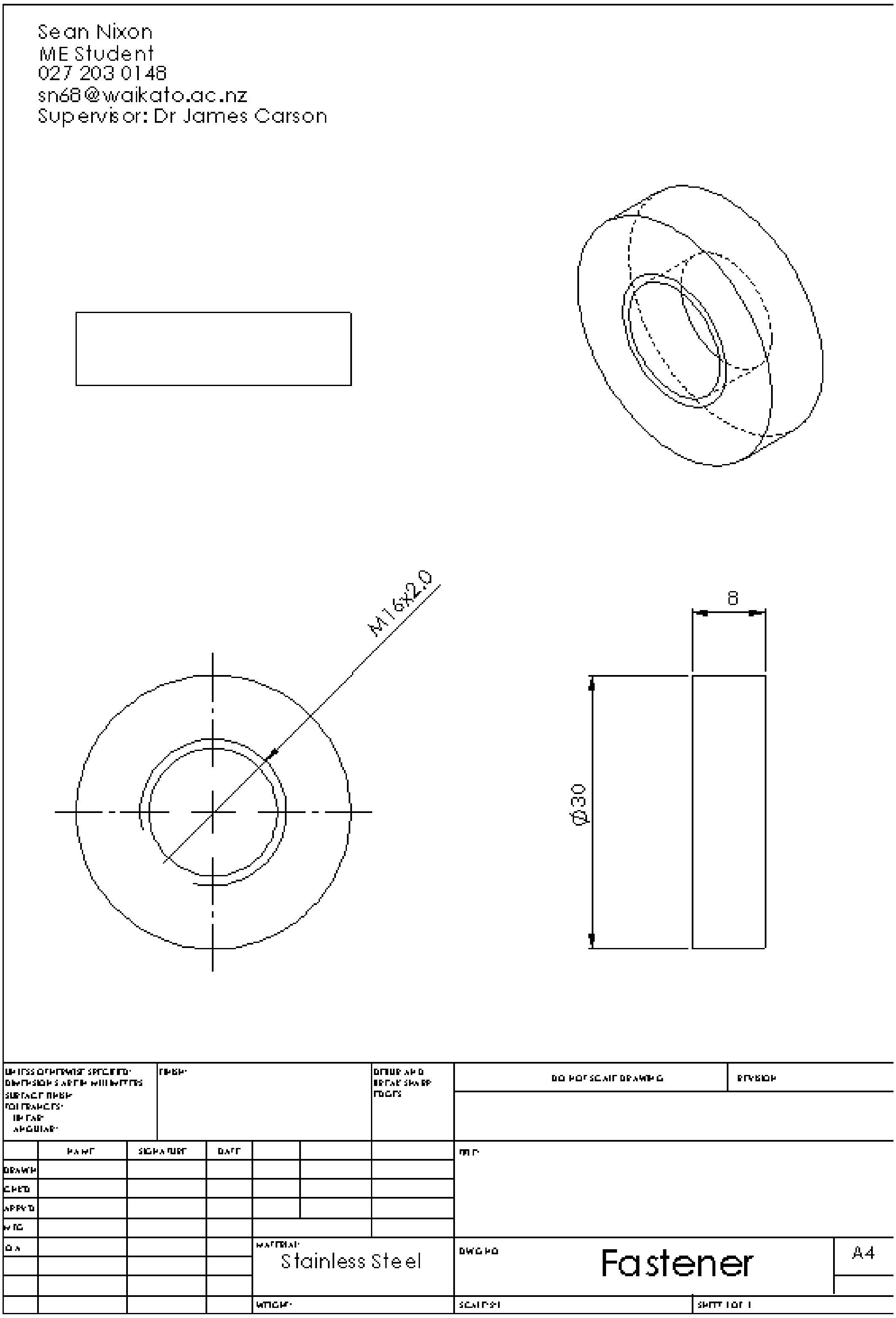


Figure A2: CAD drawing for fastener used to attach probe to Instron 33R4204 during hardness testing of frozen dessert prototypes.

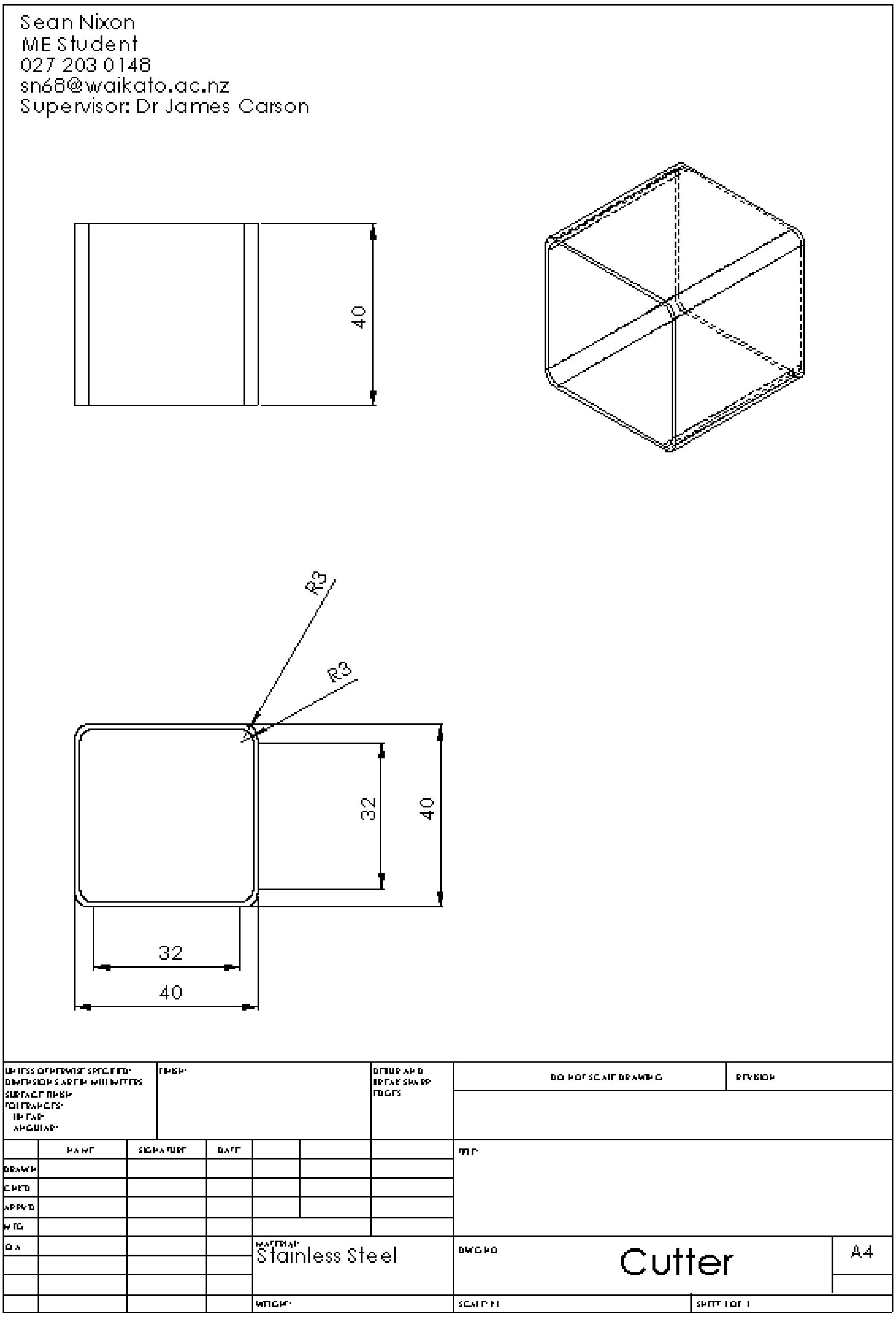


Figure A3: CAD drawing for cutter used to prepare frozen dessert prototypes for hardness testing.

8.3 Appendix 3: Example of Product Development Spreadsheet Template

Table A2: Spreadsheet layout used during product development of high protein frozen dessert samples.

FIXED FACTORS	Target	Actual
Total Solids:	32%	31%
Non soluble solids (g/100g):	15.0	13.2
FPD	22	23.00%
Protein:Carb	1	0.81

Serve size (g): 100

Category	**Ingredient**	**Ratio (g)**	**Per 100g**	**Per serve**	**%**	**kg / kg product**	**ingredient cost /kg**	**cost /kg product**	**Amount / 600g batch**
Protein source	WPI 894	9.79	9.79	9.79	9.79%	0.0979	$ 18.50	$ 1.81	58.76
Fat substitute	Simplesse	5.00	5.00	5.00	5.00%	0.0500	$ 17.00	$ 0.85	30.00
Flavour	Vanilla	1.00	1.00	1.00	1.00%	0.0100	$ 81.70	$ 0.82	6.00
									0.00
Stabilizer	CMC	0.40	0.40	0.40	0.40%	0.0040	$ 10.00	$ 0.04	2.40
	Novagel GP 3282	0.80	0.80	0.80	0.80%	0.0080	$ 10.00	$ 0.08	4.80
Emulsifier	Mono/di-glycerides	0.40	0.40	0.40	0.40%	0.0040	$ 50.00	$ 0.20	2.40
Freezing Point Depressor	Fructose	4.10	4.10	4.10	4.10%	0.0410	$ 6.50	$ 0.27	24.62
	Erythritol	0.00	0.00	0.00	0.00%	0.0000	$ 11.00	$ -	0.00
	Xylitol	5.96	5.96	5.96	5.96%	0.0596	$ 8.50	$ 0.51	35.75
	Polydextrose	3.00	3.00	3.00	3.00%	0.0300	$ 6.90	$ 0.21	18.00

Functional Ingredients	Flax seed oil	0.94	0.94	0.94	0.94%	0.0094	$ 22.00	$ 0.21	5.64
	Water	68.61	68.61	68.61	68.61%	0.6861	$ -	$ -	411.63
	TOTALS (g):	**100.00**	**100.00**	**100.00**	**100.00%**	**1**		**$ 4.99**	

Ingredient	FPD Factor	Laxation Threshold (g/day)	Solubility g/100g water at 25°C	Glycemic index	% in mixture	% FPD Contribution
Fructose	1.9	1000	100	19	4%	7.80%
Erythritol	2.8	100	36	0	0%	0.00%
Xylitol	2.25	50	66	7	6%	13.41%
Polydextrose	0.6	90	70	6	3%	1.80%

		Per 100g		Per Serve	
Energy		476.9	kJ	476.9	kJ
Protein		11.6	g	11.6	g
Fat	Total	1.6	g	1.6	g
	Saturated	0.4	g	0.4	g
Carbohydrates	Total	14.3	g	14.3	g
	Sugars	6.5	g	6.5	g
	Dietary Fiber	2.5	g	2.5	g
Sodium		13.9	mg	13.9	mg
Alpha Linolenic Acid (Omega-3)		61.00	g	61.00	g

8.4 Appendix 4: Formulae and Observations used in Ad-Hoc Experiments

27th May 2011

Table A3: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	32.50
Sweetener	Stevia	0.50	0.25
Fat substitute	Simplesse	25.00	12.50
Flavour	Chocolate	6.00	3.00
	Cocoa	6.00	3.00
Stabilizer	CMC	0.80	0.40
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	1.00
Freezing point depressor	Fructose	0.00	0.00
	Erythritol	27.00	13.50
	Xylitol	0.00	0.00
	Polydextrose	100.00	50.00
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	348.40	174.23
	TOTALS (g):	**580.70**	**290.38**

Method:

Added water to dry ingredients (except CMC). 5 x pulse, then blend for 5 sec. Add CMC, 2 x pulse, blend for 3 secs. Add mixture to ice cream machine and freeze for 40mins before transferring to ice cream container and freezing over night.

Observations:

Not aerated enough (over run to low). Too hard; not enough freezing point depression.

30th May 2011

Table A4: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	9.79
		0.00	0.00
Sweetener	Stevia	0.50	0.08
Fat substitute	Simplesse	25.00	3.77
Flavour	Chocolate	6.00	0.90
	Cocoa	6.00	0.90
Stabilizer	CMC	0.80	0.12
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.30
Freezing point depressor	Fructose	0.00	0.00
	Erythritol	27.00	4.07
	Xylitol	0.00	0.00
	Polydextrose	100.00	15.07
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	431.40	65.00
	TOTALS (g):	**663.70**	**100.00**

Method:

Dissolve erythritol and PD in water. Add solution to dry ingredients (except CMC). 5 x pulse, then blend for 5 sec. Add CMC, 2 x pulse, blend for 3 secs. Add mixture to ice cream machine and leave in freezer until frozen.

Observations:

Small batch, only took 15mins until blade in ice cream machine couldn't rotate any more. Turned machine off and left in freezer for a further 45mins. Was softer than the previous batch. Although not measured, the overrun appeared to still be small.

30th May 2011

Table A5: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	9.28
		0.00	0.00
Sweetener	Stevia	0.30	0.04
Fat substitute	Simplesse	25.00	3.57
Flavour	Chocolate	12.00	0.86
	Cocoa	0.00	0.86
Stabilizer	CMC	0.80	0.11
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.29
Freezing point depressor	Fructose	0.00	0.00
	Erythritol	40.00	5.71
	Xylitol	0.00	0.00
	Polydextrose	100.00	14.28
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	455.20	65.00
	TOTALS (g):	**700.30**	**100.00**

Method:

Dissolve erythritol and PD in water. Mix in solution in blender for 10 seconds to ensure sugars are fully dissolved. Add dry ingredients (except CMC) to solution. 5 x pulse, then blend for 5 sec. Add CMC, 2 x pulse, blend for 3 secs. Add mixture to ice cream machine and leave in freezer until frozen. Transferred from machine to ice cream container after 55mins

Observations:

Hardness favourable and appearance is like regular ice cream. Not creamy enough and feels watery as it melts. Taste pretty good with just Cocoa as flavouring. Needs improved creaminess and melting characteristics.

1st June 2011

Table A6: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	9.10
	TMP 1180	0.00	
Sweetener	Stevia	0.30	0.04
Fat substitute	Simplesse	25.00	3.50
Flavour	Chocolate	4.00	0.56
	Cocoa	8.00	1.12
Stabilizer	CMC	0.80	0.11
	Novagel GP 3282	5.00	0.70
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.28
Freezing point depressor	Fructose	0.00	0.00
	Erythritol	40.00	5.60
	Xylitol	0.00	0.00
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	464.50	65.00
	TOTALS (g):	**714.60**	**100.00**

Method:

Dissolve erythritol and PD in water. Mix in solution in blender for 10 seconds to ensure sugars are fully dissolved. Add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer until frozen.

Observations:

Product was ‘crunchy’. A little hard, not smooth and creamy. Taste not as good as with pure cocoa.

3rd June 2011

Table A7: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	0.00	0.00
	TMP 1180	65.00	
Sweetener	Stevia	0.30	0.04
Fat substitute	Simplesse	25.00	3.50
Flavour	Chocolate	0.00	0.00
	Cocoa	12.00	1.68
Stabilizer	CMC	0.80	0.11
	Novagel GP 3282	5.00	0.70
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.28
Freezing point depressor	Fructose	0.00	0.00
	Erythritol	40.00	5.60
	Xylitol	0.00	0.00
	Polydextrose	100.00	13.99
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	464.50	74.10
	TOTALS (g):	**714.60**	**100.00**

Method:

Dissolve erythritol and PD in warm water. Mix in solution in blender for 10 seconds to ensure sugars are fully dissolved. Add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer until frozen.

Observations:

Ice cream was gummy and reasonably hard (freezer too cold? Need thermometer). Mixture was thick before freezing, think this was reflected in the texture. Need to measure overrun as this may need to be increased. May need to reduce solids to 30% for next batch and ensure sugars are fully dissolved before adding remaining ingredients.

16th June 2011

Table A8: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65	7.09
	TMP 1180	0	
Sweetener	Stevia	0.3	0.03
Fat substitute	Simplesse	30	3.27
Flavour	Chocolate	4	0.44
	Cocoa	8	0.87
Stabilizer	CMC	0.8	0.09
	Novagel GP 3282	5	0.55
Emulsifier	Egg Yolk Powder	0	0
	Mono/di-glycerides	2	0.22
Freezing point depressor	Fructose	0	0
	Erythritol	60	6.54
	Xylitol	0	0
	Polydextrose	100	10.91
Functional Ingredients	Flax Seed oil:	0	0
	Water	641.9	70
	TOTALS (g):	**917**	**100**

Method:

Dissolve erythritol and PD in 70deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer until frozen.

Observations:

30% solids. Still very hard. Think the PD and erythritol may not be dissolving properly. Should try fructose instead of PD? Taste good with just Cocoa. Need to get some ice cream flavours from D S Hall and bring some fructose from home.

21st June 2011

Table A9: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	6.58
	TMP 1180	0.00	
Sweetener	Stevia	0.30	0.03
Fat substitute	Simplesse	30.00	3.04
Flavour	Chocolate	0.00	0.00
	Cocoa	12.00	1.21
Stabilizer	CMC	2.00	0.20
	Novagel GP 3282	5.00	0.51
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.20
Freezing point depressor	Fructose	0.00	0.00
	Erythritol	0.00	0.00
	Xylitol	80.00	8.10
	Polydextrose	100.00	10.12
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	691.40	70.00
	TOTALS (g):	**987.70**	**100.00**

Method:

Dissolve xylitol and PD in 70deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer until frozen (1hr 30mins).

Observations:

30% solids. On day after manufacture, sample is reasonably soft (scoop able). Could be the xylitol? Further samples will see. Texture ok, a little icy. Some small ice crystal growth. Product is still too dense and needs to have a greater overrun. 5/07/11: Ice crystal formation on type. Hardness and texture (apart from ice crystals) still pretty good.

22nd June 2011

Table A10: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	32.50	3.29
	TMP 1180	32.50	3.29
Sweetener	Stevia	0.30	0.03
Fat substitute	Simplesse	30.00	3.04
Flavour	Chocolate	0.00	0.00
	Cocoa	12.00	1.21
Stabilizer	CMC	2.00	0.20
	Novagel GP 3282	5.00	0.51
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.20
Freezing point depressor	Fructose	0.00	0.00
	Erythritol	0.00	0.00
	Xylitol	80.00	8.10
	Polydextrose	100.00	10.12
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	691.40	70.00
	TOTALS (g):	**987.70**	**100.00**

Method:

Dissolve xylitol and PD in 70deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer until frozen (left in for 2hours). Sample was refrigerated overnight, re blended for 10sec, then frozen as above.

Observations:

Quite chewy, this has been observed previously with samples containing TMP. Hardness was good – again could be the xylitol. Texture ok apart from the chewiness. 5/07/11: ice crystal formation on surface. Other factors still pretty good.

23rd June 2011

Table A11: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	10.36
	TMP 1180	0.00	0.00
Sweetener	Stevia	0.30	0.05
Fat substitute	Simplesse	30.00	4.78
Flavour	Chocolate	0.00	0.00
	Cocoa	12.00	1.91
Stabilizer	CMC	2.00	0.32
	Novagel GP 3282	5.00	0.80
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.32
Freezing point depressor	Fructose	30.00	4.78
	Erythritol	0.00	0.00
	Xylitol	42.00	6.69
	Polydextrose	0.00	0.00
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	439.40	70.00
	TOTALS (g):	**627.70**	**100.00**

Method:

Dissolve xylitol and FR in 70deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer until frozen (was left for 45mins).

Observations:

Hardness is very good – conclude that the xylitol is much better than the erythritol for this. Will try a fructose-erythritol combination to confirm. Texture is pretty good. Flavour is strong as percentage levels were higher than samples with PD. Not much ice crystal formation. 5/07/11: ice crystal formation on surface. Other factors still pretty good.

24th June 2011

Table A12: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	11.06
	TMP 1180	0.00	0.00
Sweetener	Stevia	0.30	0.05
Fat substitute	Simplesse	30.00	5.10
Flavour	Chocolate	0.00	0.00
	Cocoa	12.00	2.04
Stabilizer	CMC	2.00	0.34
	Novagel GP 3282	5.00	0.85
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.34
Freezing point depressor	Fructose	30.00	5.10
	Erythritol	30.00	5.10
	Xylitol	0.00	0.00
	Polydextrose	0.00	0.00
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	411.40	70.00
	TOTALS (g):	**587.70**	**100.00**

Method:

Dissolve erythritol and FR in 70deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer until frozen (was left for 50mins). Then frozen overnight.

Observations:

Hardness is very good – possible that fructose helping more than PD. Texture is pretty good. Flavour is strong as percentage levels were higher than samples with PD. Not much ice crystal formation. 5/07/11: ice crystal formation on surface. Other factors still pretty good.

27th June 2011

Table A13: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	11.32
	TMP 1180	0.00	0.00
Sweetener	Stevia	0.00	0.00
Fat substitute	Simplesse	30.00	5.22
Flavour	Vanilla 443-00154-00	6.00	1.04
		0.00	0.00
Stabilizer	CMC	2.00	0.35
	Novagel GP 3282	5.00	0.87
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.35
Freezing point depressor	Fructose	30.00	5.22
	Erythritol	0.00	0.00
	Xylitol	32.00	5.57
	Polydextrose	0.00	0.00
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	402.00	70.00
	TOTALS (g):	**574.00**	**100.00**

Method:

Dissolve xylitol and FR in 65 deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer (at -16deg) until frozen (was left for 50mins). Then frozen overnight.

Observations:

Flavour is great – even at 1%. Hardness seems good. Texture looks good and is ok but a little icy on the tongue. Will try adding more stabilizers. Will also try a combination of CMC and Guar – using two might help more than adding more!
21/07/11: Minimal ice crystal growth. Hardness, texture and taste still pretty good.

4th July 2011

Table A14: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	11.75
	TMP 1180	0.00	0.00
Sweetener	Stevia	0.00	0.00
Fat substitute	Simplesse	30.00	5.42
Flavour	Vanilla 443-00154-00	6.00	1.08
		0.00	0.00
Stabilizer	CMC	4.00	0.72
	Novagel GP 3282	5.00	0.90
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.36
Freezing point depressor	Fructose	30.00	5.42
	Erythritol	0.00	0.00
	Xylitol	24.00	4.34
	Polydextrose	0.00	0.00
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	387.00	70.00
	TOTALS (g):	**553.00**	**100.00**

Method:

Dissolve xylitol and FR in 65 deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer (at -16deg) until frozen (was left for 75mins). Then frozen overnight. USED 150ml WATER.

Observations:

Ice cream was harder than previous batch – FPD to low. Strawberry flavour not as good as the vanilla. Ice crystal growth seems to be minimal but hard to tell when product is hard. 21/07/11: Medium amount of ice crystal growth. Hardness ok? Strawberry taste ok, but needs colour added to make more appealing.

5th July 2011

Table A15: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	11.37
	TMP 1180	0.00	0.00
Sweetener	Stevia	0.00	0.00
Fat substitute	Simplesse	30.00	5.25
Flavour	Van DC10139	6.00	1.05
		0.00	0.00
Stabilizer	CMC	5.00	0.87
	Novagel GP 3282	5.00	0.87
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	2.00	0.35
Freezing Point Depressor	Fructose	0.00	0.00
	Erythritol	10.00	1.75
	Xylitol	48.55	8.49
	Polydextrose	0.00	0.00
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	400.00	70.00
	TOTALS (g):	**572.00**	**100.00**

Method:

Dissolve xylitol and erythritol in 65 deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer (at -16deg) until frozen (was left for 45mins). Then frozen overnight.

Observations:

Taste is bad. A little hard. No ice crystal growth yet (7/07/11). Still no IC growth (21/07/11). Texture ok. Possible that combination of this vanilla and the vanilla used in the batch on 27/06/11 will produce a nice flavour.

5th July 2011

Table A16: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	5.69
	TMP 1180	0.00	0.00
Sweetener	Stevia	0.00	0.00
Fat substitute	Simplesse	55.00	4.81
Flavour	Caramel 610184A	10.00	0.96
	Cocoa (for colour)	1.00	0.10
Stabilizer	CMC	7.00	0.61
	Novagel GP 3282	7.00	0.61
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	5.00	0.44
Freezing Point Depressor	Fructose	0.00	0.00
	Erythritol	10.00	0.88
	Xylitol	82.76	7.24
	Polydextrose	100.00	8.75
Functional Ingredients	Flax Seed oil:	0.00	0.00
	Water	**800.00**	70.00
	TOTALS (g):	**1143.00**	**100.00**

Method:

Dissolve xylitol, PD and erythritol in 65 deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 5 x pulse, then blend for 15 sec. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer (at -16deg) until frozen (was left for 65mins). Then frozen overnight.

Observations:

Taste is bad. A little hard. No ice crystal growth yet (7/07/11). Still no IC growth (21/07/11). Wasn't left in ice cream machine long enough. Sample is course and icy.

26th July 2011

Table A17: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	9.97
	TMP 1180	0.00	0.00
Sweetener	Stevia	0.00	0.00
Fat substitute	Simplesse	28.00	4.29
Flavour	Van DC10139	5.60	0.86
		0.00	0.00
Stabilizer	CMC	4.00	0.61
	Novagel GP 3282	4.00	0.61
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	4.00	0.61
Freezing Point Depressor	Fructose	35.00	5.37
	Erythritol	0.00	0.00
	Xylitol	35.00	5.37
	Polydextrose	0.00	0.00
Functional Ingredients	Flax seed oil	15.00	2.30
	Water	456.40	70.00
	TOTALS (g):	**652.00**	**100.00**

Method:

Dissolve xylitol and fructose in 65 deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 3 x pulse, then blend for 5 sec. Add flaxseed oil, 3 x pulse, blend for 10 secs. Add stabilizers, 2 x pulse, blend for 10 secs. Add mixture to ice cream machine and leave in freezer (at -16deg) until frozen (was left for 35mins). Then frozen overnight.

Observations:

Hardness ok. Texture pretty good – less icy and nice smooth feeling on tongue. Flavour great (using the nice vanilla). Update 18/08/11: One of the best samples so far. Texture and appearance still good. Taste still great

27th July 2011

Table A18: Formulation used to produce high protein frozen dessert sample on given date.

Category	Ingredient	Ratio (g)	Per 100g Wet
Protein source	WPI 894	65.00	12.70
	TMP 1180	0.00	0.00
Sweetener	Stevia	0.00	0.00
Fat substitute	Simplesse	25.59	5.00
Flavour	Dark Choc flavour	5.12	1.00
	Cocoa	5.12	1.00
Stabilizer	CMC	2.05	0.40
	Novagel GP 3282	4.61	0.90
Emulsifier	Egg Yolk Powder	0.00	0.00
	Mono/di-glycerides	4.61	0.90
Freezing Point Depressor	Fructose	27.13	5.30
	Erythritol	0.00	0.00
	Xylitol	27.13	5.30
	Polydextrose	0.00	0.00
Functional Ingredients	Flax seed oil	12.80	2.50
	Water	332.67	65.00
	TOTALS (g):	**511.80**	**100.00**

Method:

Dissolve xylitol and fructose in 65 deg water. Ensure sugars are fully dissolved. Blend then add dry ingredients (except stabilizers, CMC and Novagel) to solution. 3 x pulse, then blend for 5 sec. Continue blending, adding flaxseed oil, blend for 5 secs. Continue blending, add stabilizers, and blend for 10 secs. Add mixture to ice cream machine and leave in freezer (at -16deg) until frozen (was left for 2 hours). Then frozen overnight. Took a long time to freeze!

Observations:

Taste average. Texture and harness pretty good. Not too icy.

8.5 Appendix 5: Observations Made During Prototype Production

11th August 2011

Recipe: Run 1, with TMP

Method: As described in Methodology section.

Observations: Initial observations: product too chewy with TMP – will try same recipe with WPI for a comparison. Looks like I will drop the idea of using TMP and stick with WPI.

12th August 2011

Recipe: Run 1, with WPI

Method: As described in Methodology section.

Observations: Initial observations: product still chewy, but far less than TMP sample. I will compare both once hardening is complete. After hardening, prototype is much better than TMP prototype. As this is in line with previous observations, I will change all formulas to use WPI instead of TMP.

15th August 2011

Recipe: Run 2, WPI

Method: As described in Methodology section.

Observations: Product reasonably hard, but acceptably. Not very creamy, taste ok. Appearance good.

17th August 2011

Recipe: Run 3, WPI

Method: As described in Methodology section.

Observations: Very hard, expected with only FPD of 19. Taste and appearance good.

18th August 2011

Recipe: Run 4, WPI

Method: As described in Methodology section.

Observations: Hardness pretty good. Texture, appearance and taste also good.

19th August 2011

Recipe: Run 5, WPI

Method: As described in Methodology section.

Observations: Prototype not really distinguishable from other previous 4 prototypes. Texture, hardness and taste all pretty good.

22nd August 2011

Recipe: Run 6, WPI

Method: As described in Methodology section.

Observations: Product quite hard. Taste and texture very good (no ice crystals noticeable).

23rd August 2011

Recipe: Run 7, WPI

Method: As described in Methodology section.

Observations: Hardness and appearance both good. Texture is a little icy. Taste is quite bland; needs something to 'bring it out'.

24th August 2011

Recipe: Run 8, WPI

Method: As described in Methodology section.

Observations: Taste, texture and harness all pretty good.

25th August 2011

Recipe: Run 9, WPI

Method: As described in Methodology section.

Observations: Some ice crystal growth. Taste texture and appearance otherwise all good. Meltdown feels good, although a slight icy texture can be felt.

26th August 2011

Recipe: Run 10, WPI

Method: As described in Methodology section.

Observations: Hardness very good. Texture a little icy, appearance very good.

29th August 2011

Recipe: Run 11, WPI

Method: As described in Methodology section.

Observations: Taste a little bland – would need some stevia added to bring out flavour. Texture seems nice and creamy.

30th August 2011

Recipe: Run 15, WPI

Method: As described in Methodology section.

Observations: Some ice crystal growth on surface. Taste texture and appearance otherwise all good. Meltdown feels good. Product slightly too hard.

31st August 2011

Recipe: Run 12, WPI

Method: As described in Methodology section.

Observations: Soft and weak tasting – will need stevia to bring out flavour. Appearance good. Texture a little icy on the tongue.

1st September 2011

Recipe: Run 13, WPI

Method: As described in Methodology section.

Observations: Taste a little weak – needs stevia to enhance flavour. Hardness is good. Texture is a little icy but to bad – melt down feels good in mouth.

2nd September 2011

Recipe: Run 16, WPI

Method: As described in Methodology section.

Observations: Taste, texture and harness all pretty good.

12th September 2011

Recipe: Run 17, WPI

Method: As described in Methodology section.

Observations: Took ages to freeze. Taste quite bland. Texture a little icy. Hardness pretty good.

13th September 2011

Recipe: Run 18, WPI

Method: As described in Methodology section.

Observations: Took ages to freeze. Taste ok. Texture a little icy. Hardness pretty good.

14th September 2011

Recipe: Run 21, WPI

Method: As described in Methodology section.

Observations: Freezing time normal. Taste is good but is quite hard and has an icy texture. Appearance ok.

8.6 Appendix 6: Design Summary Table Produced During Frozen Dessert Prototype Formulation

Table A19: Design summary table produced by Design-Expert® V8.

Design Summary									
File Version	8.0.6.1								
Study Type	Mixture		Runs	22					
Design Type	D-optimal	Point Exchange	Blocks	No Blocks					
Design Model	Quadratic		Build Time (ms)	1640.346397					
Component	Name	Units	Type	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Fructose	%	Mixture	0	8	0.000=0.000	0.727=8.000	3.010088682	3.108065176
B	Erythritol	%	Mixture	0	7	0.000=0.000	0.636=7.000	2.358915453	2.372212273
C	Xylitol	%	Mixture	0	8	0.000=0.000	0.727=8.000	2.673869623	2.86647463
D	Polydextrose	%	Mixture	3	6	0.000=3.000	0.273=6.000	4.825821149	1.212073044
E	Flax Seed Oil	%	Mixture	0	2	0.000=0.000	0.182=2.000	1.131305094	0.821648101
				Total =	14	L_Pseudo Coding			

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
Y1	R1	N	0	Polynomial	No Data	No Data	No Data	No Data	N/A	None	No model chosen
Y2	R2	mPa	0	Polynomial	No Data	No Data	No Data	No Data	N/A	None	No model chosen

Point Exchange searches a set of candidates for the best design points. The candidates can be generated by the program, or read in from a file.

D-optimal designs maximize information about the polynomial coefficients. D-optimality is desirable for factorial and screening designs where you want to identify the most vital variables. The algorithm picks points that minimize the volume of the confidence ellipsoid for the coefficients (i.e. it minimizes the determinant of the X'X inverse matrix).

8.7 Appendix 7: Screenshots taken from Design-Expert ® V8 Software during Formulation Development

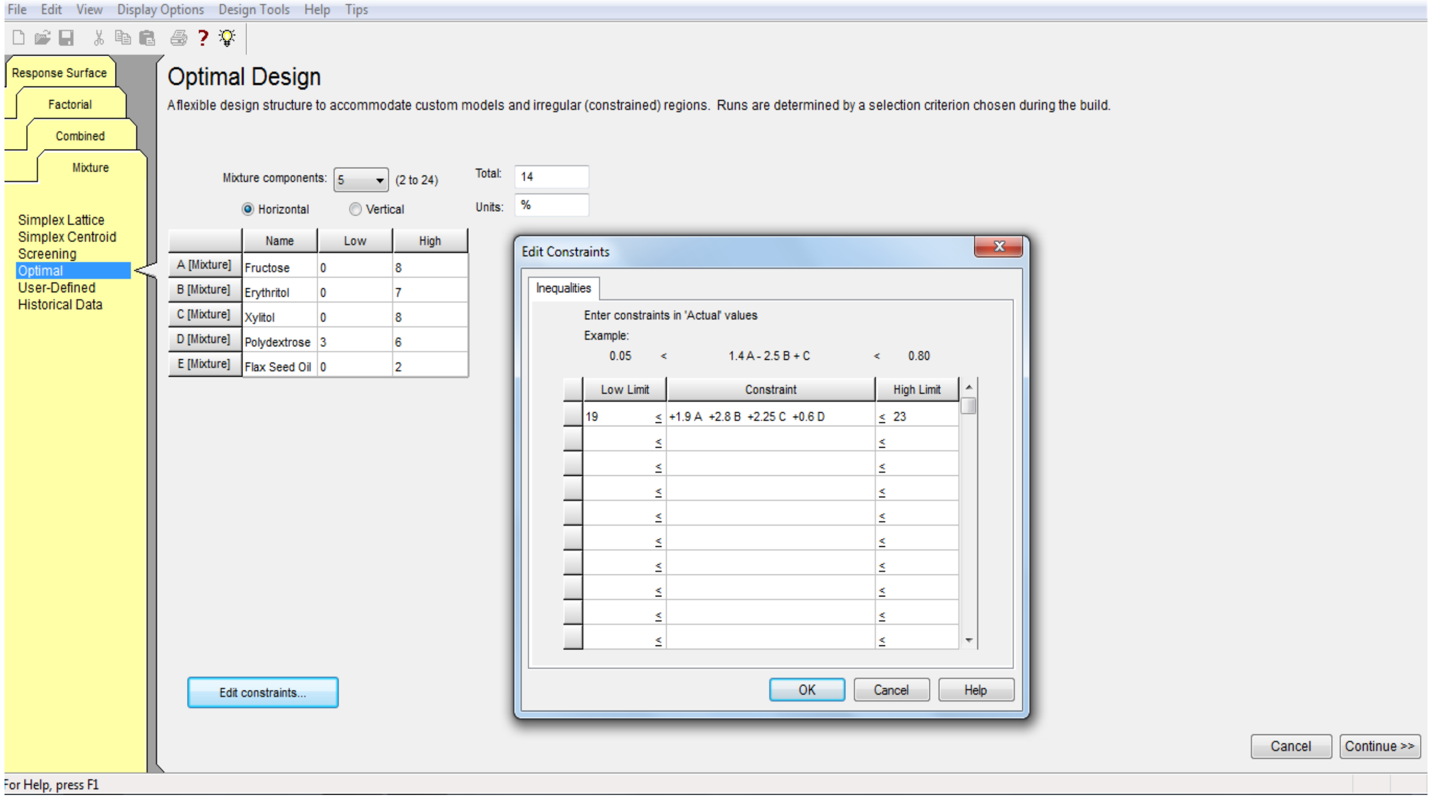


Figure A4: Entering the design constraints into Design-Expert® V8 software.

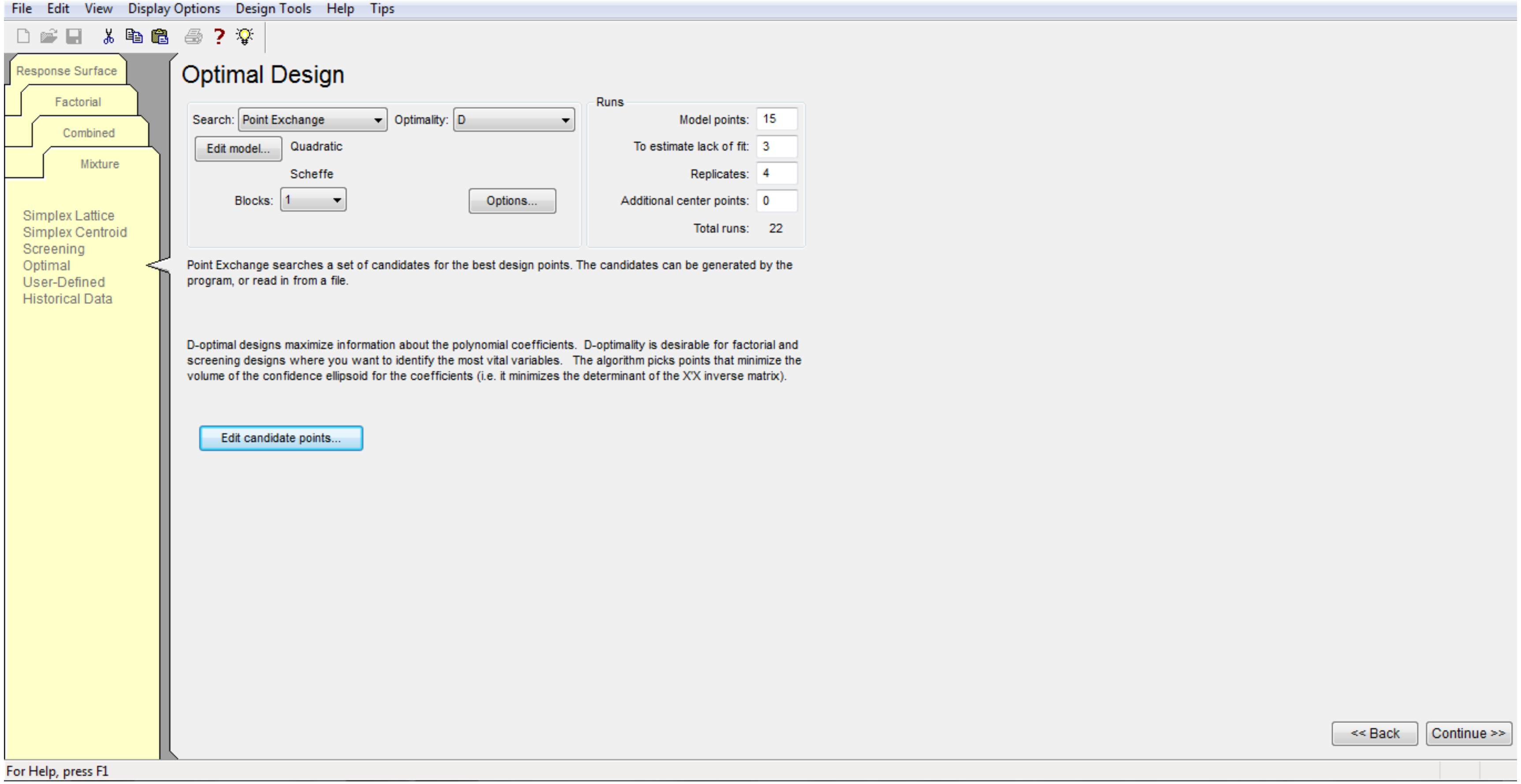


Figure A5: Choosing the mixture model type in Design-Expert® V8 software.

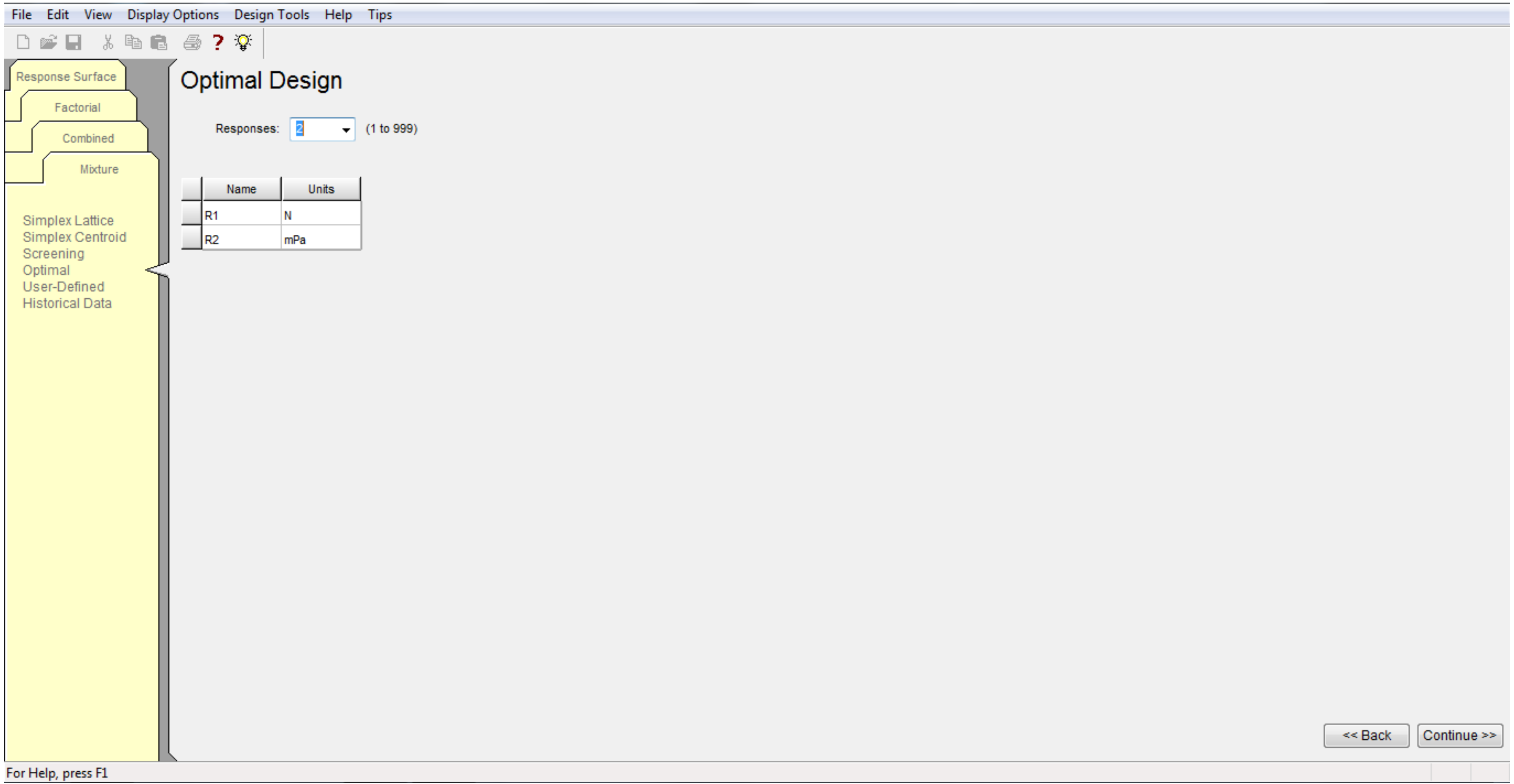
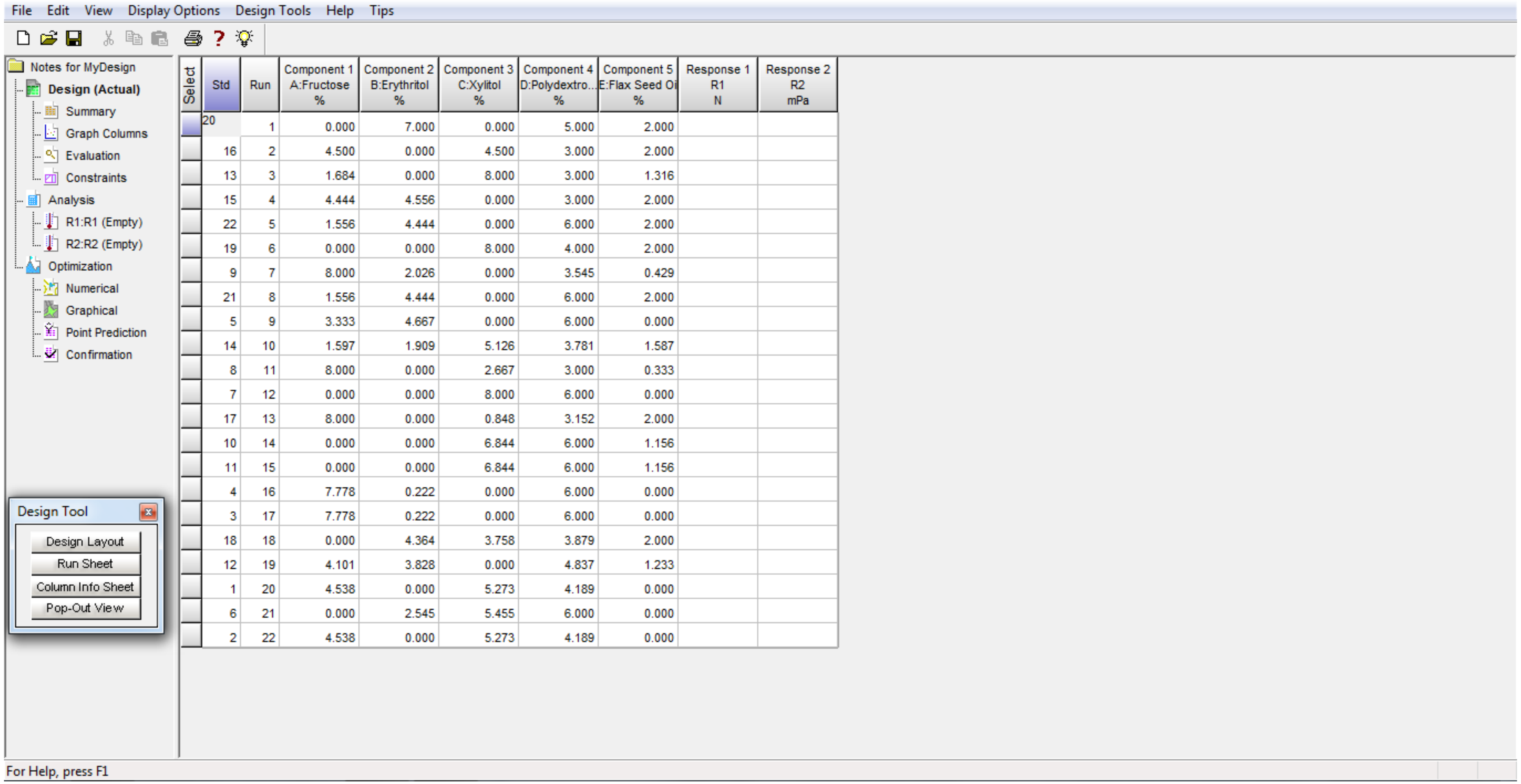


Figure A6: Entering the experiment responses (force, N, and viscosity, mPa.s, the variables being tested) into Design-Expert® V8 software.



Select	Std	Run	Component 1 A:Fructose %	Component 2 B:Erythritol %	Component 3 C:Xylitol %	Component 4 D:Polydextro... %	Component 5 E:Flax Seed Oi %	Response 1 R1 N	Response 2 R2 mPa
	20	1	0.000	7.000	0.000	5.000	2.000		
	16	2	4.500	0.000	4.500	3.000	2.000		
	13	3	1.684	0.000	8.000	3.000	1.316		
	15	4	4.444	4.556	0.000	3.000	2.000		
	22	5	1.556	4.444	0.000	6.000	2.000		
	19	6	0.000	0.000	8.000	4.000	2.000		
	9	7	8.000	2.026	0.000	3.545	0.429		
	21	8	1.556	4.444	0.000	6.000	2.000		
	5	9	3.333	4.667	0.000	6.000	0.000		
	14	10	1.597	1.909	5.126	3.781	1.587		
	8	11	8.000	0.000	2.667	3.000	0.333		
	7	12	0.000	0.000	8.000	6.000	0.000		
	17	13	8.000	0.000	0.848	3.152	2.000		
	10	14	0.000	0.000	6.844	6.000	1.156		
	11	15	0.000	0.000	6.844	6.000	1.156		
	4	16	7.778	0.222	0.000	6.000	0.000		
	3	17	7.778	0.222	0.000	6.000	0.000		
	18	18	0.000	4.364	3.758	3.879	2.000		
	12	19	4.101	3.828	0.000	4.837	1.233		
	1	20	4.538	0.000	5.273	4.189	0.000		
	6	21	0.000	2.545	5.455	6.000	0.000		
	2	22	4.538	0.000	5.273	4.189	0.000		

Figure A7: Prototype formulae generated by Design-Expert® V8 software.

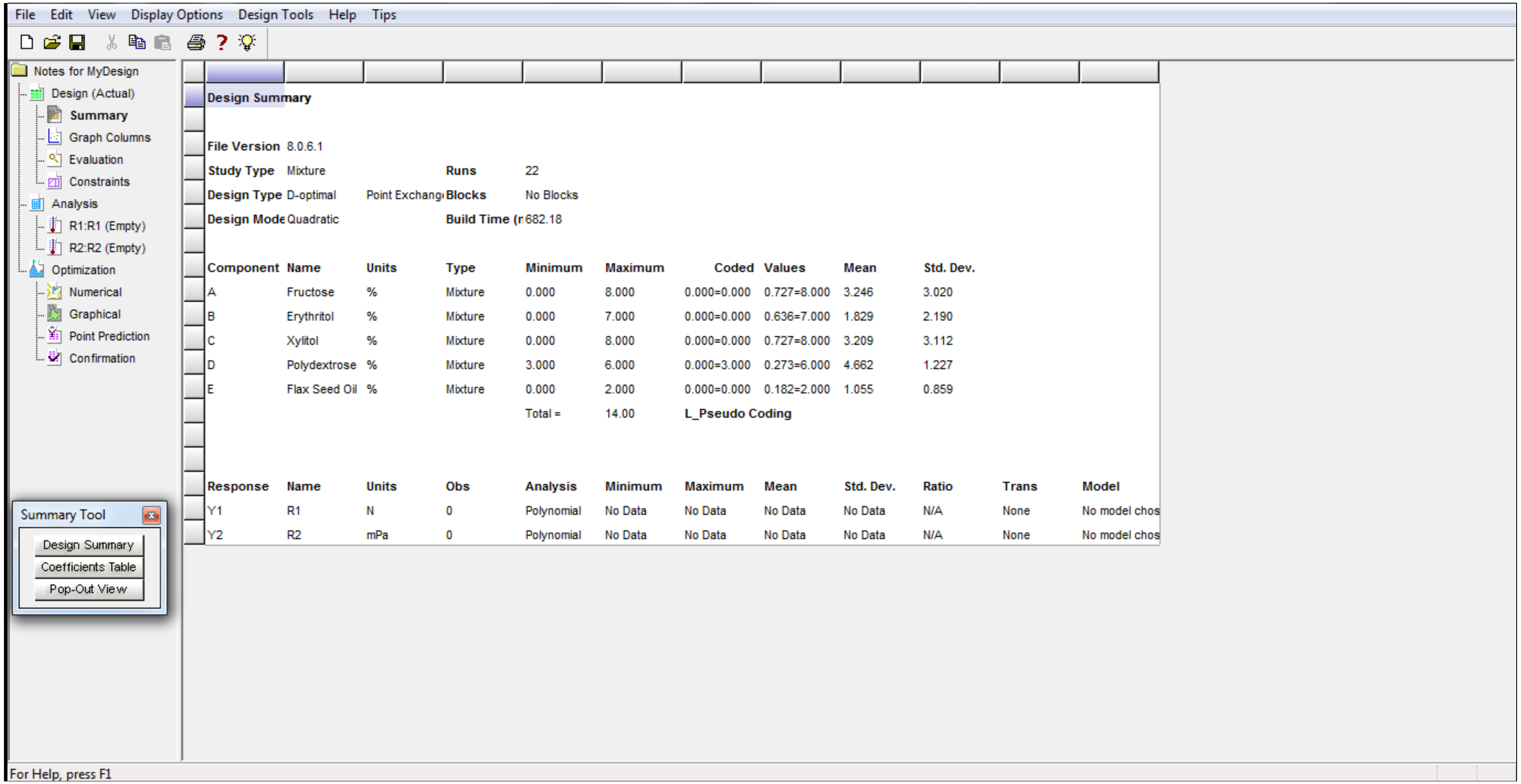


Figure A8: Design summary produced by Design-Expert® V8 software.

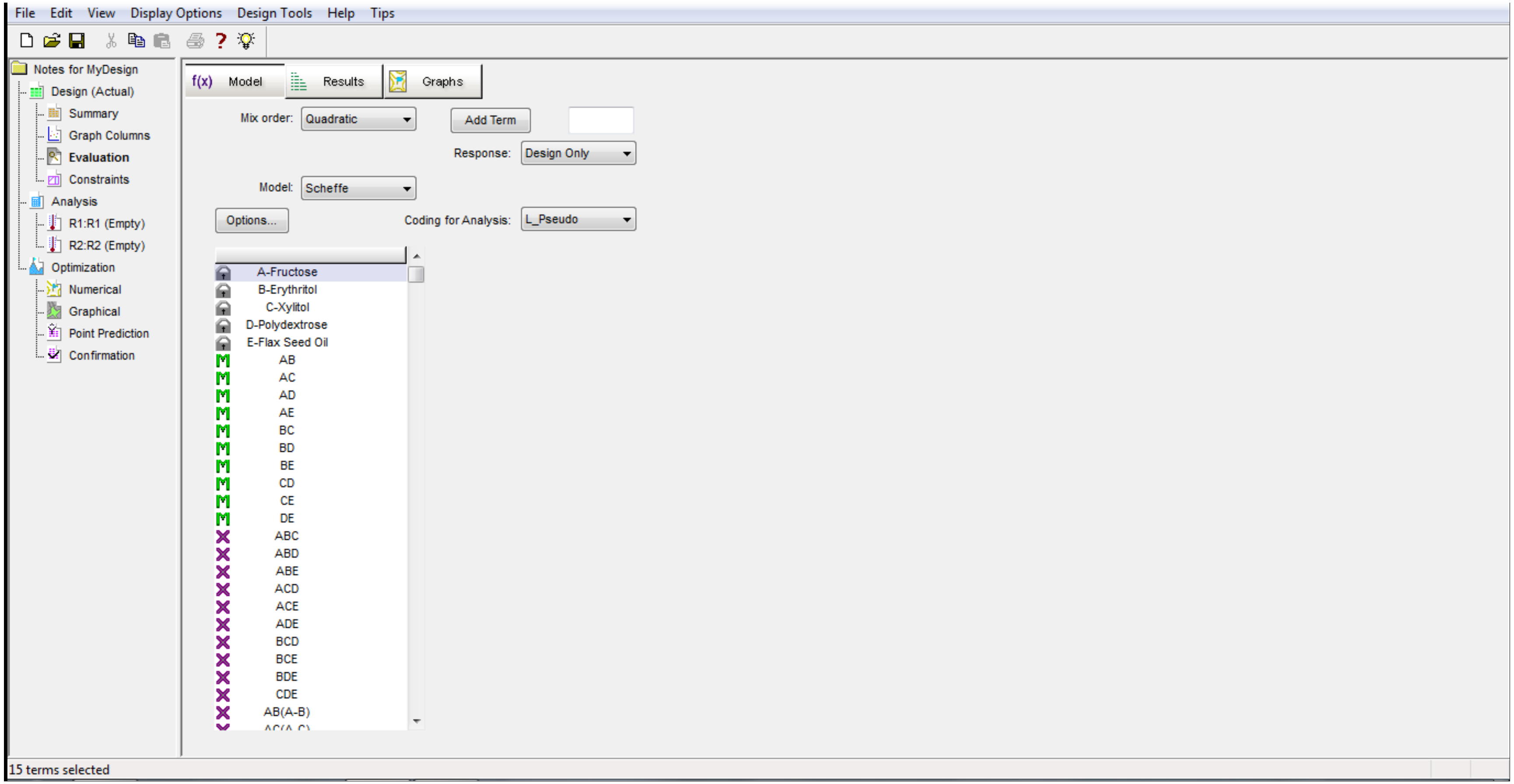


Figure A9: Preparing to evaluate the model using Design-Expert® V8 software.

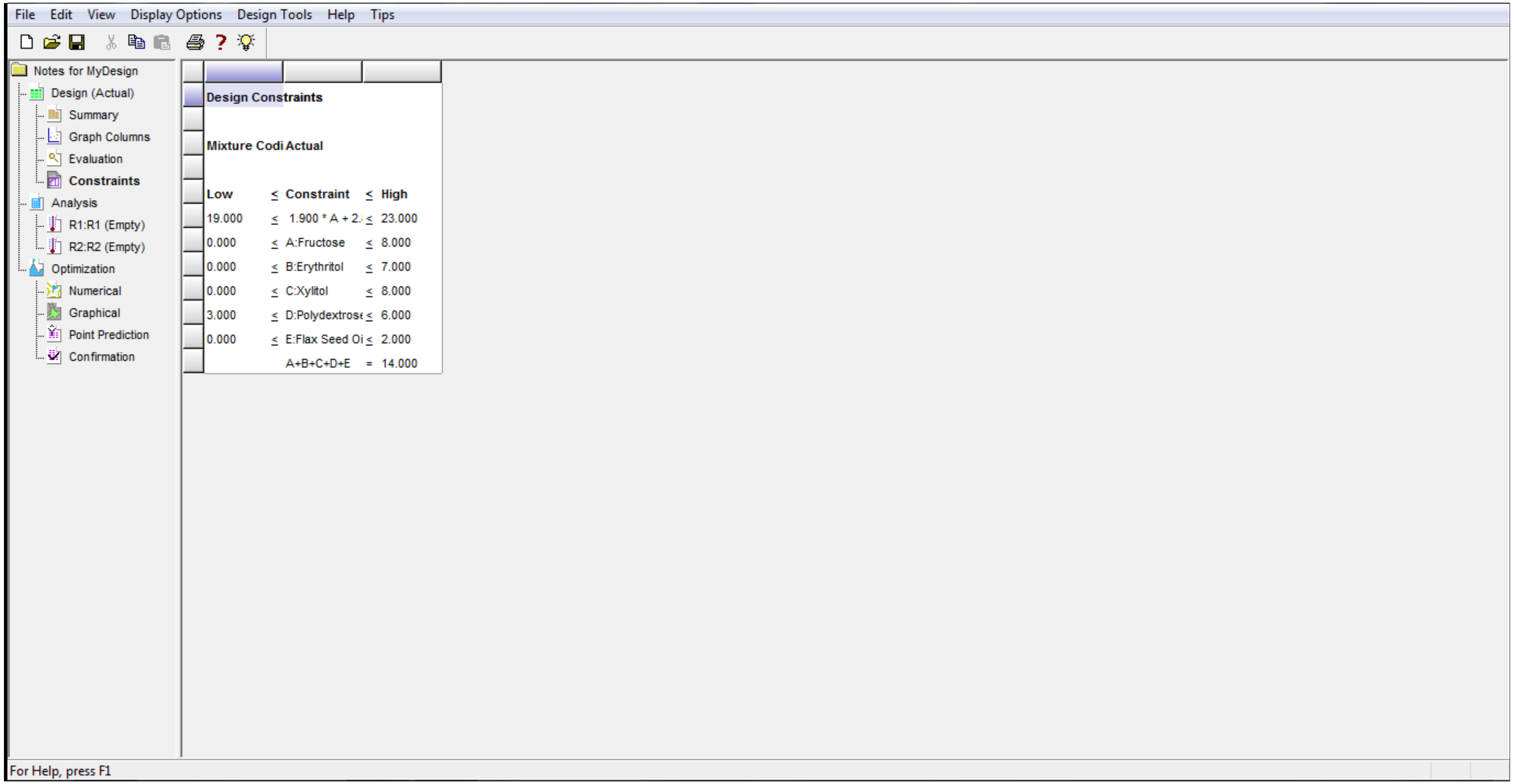
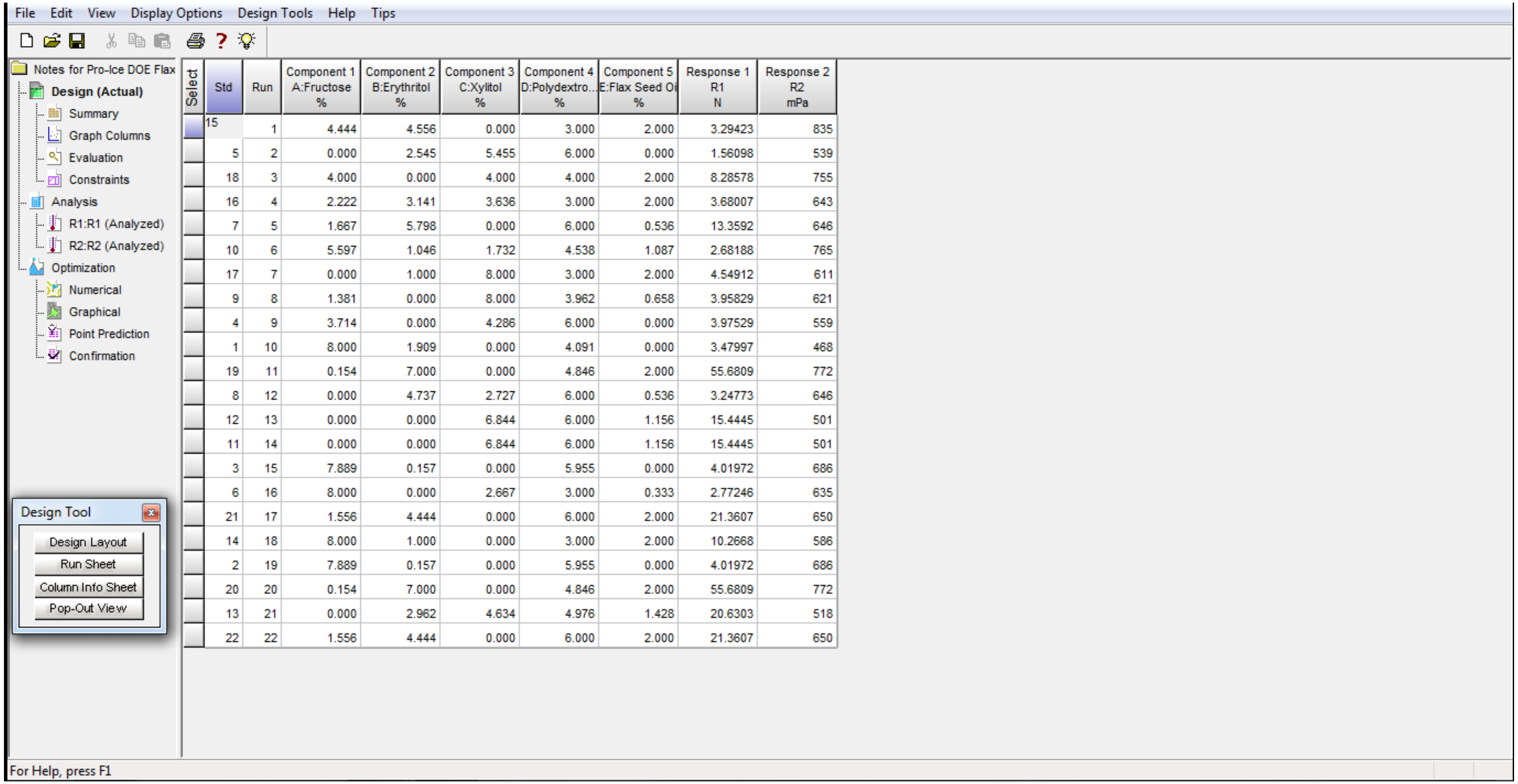


Figure A10: A summary of the experiment constraints provided by Design-Expert® V8 software.



Std	Run	Component 1 A:Fructose %	Component 2 B:Erythritol %	Component 3 C:Xylitol %	Component 4 D:Polydextro... %	Component 5 E:Flax Seed Oi %	Response 1 R1 N	Response 2 R2 mPa
15	1	4.444	4.556	0.000	3.000	2.000	3.29423	835
5	2	0.000	2.545	5.455	6.000	0.000	1.56098	539
18	3	4.000	0.000	4.000	4.000	2.000	8.28578	755
16	4	2.222	3.141	3.636	3.000	2.000	3.68007	643
7	5	1.667	5.798	0.000	6.000	0.536	13.3592	646
10	6	5.597	1.046	1.732	4.538	1.087	2.68188	765
17	7	0.000	1.000	8.000	3.000	2.000	4.54912	611
9	8	1.381	0.000	8.000	3.962	0.658	3.95829	621
4	9	3.714	0.000	4.286	6.000	0.000	3.97529	559
1	10	8.000	1.909	0.000	4.091	0.000	3.47997	468
19	11	0.154	7.000	0.000	4.846	2.000	55.6809	772
8	12	0.000	4.737	2.727	6.000	0.536	3.24773	646
12	13	0.000	0.000	6.844	6.000	1.156	15.4445	501
11	14	0.000	0.000	6.844	6.000	1.156	15.4445	501
3	15	7.889	0.157	0.000	5.955	0.000	4.01972	686
6	16	8.000	0.000	2.667	3.000	0.333	2.77246	635
21	17	1.556	4.444	0.000	6.000	2.000	21.3607	650
14	18	8.000	1.000	0.000	3.000	2.000	10.2668	586
2	19	7.889	0.157	0.000	5.955	0.000	4.01972	686
20	20	0.154	7.000	0.000	4.846	2.000	55.6809	772
13	21	0.000	2.962	4.634	4.976	1.428	20.6303	518
22	22	1.556	4.444	0.000	6.000	2.000	21.3607	650

Figure A11: Entering the response data (force, N, and viscosity, mPa.s, the variables being tested) into Design-Expert® V8 software.

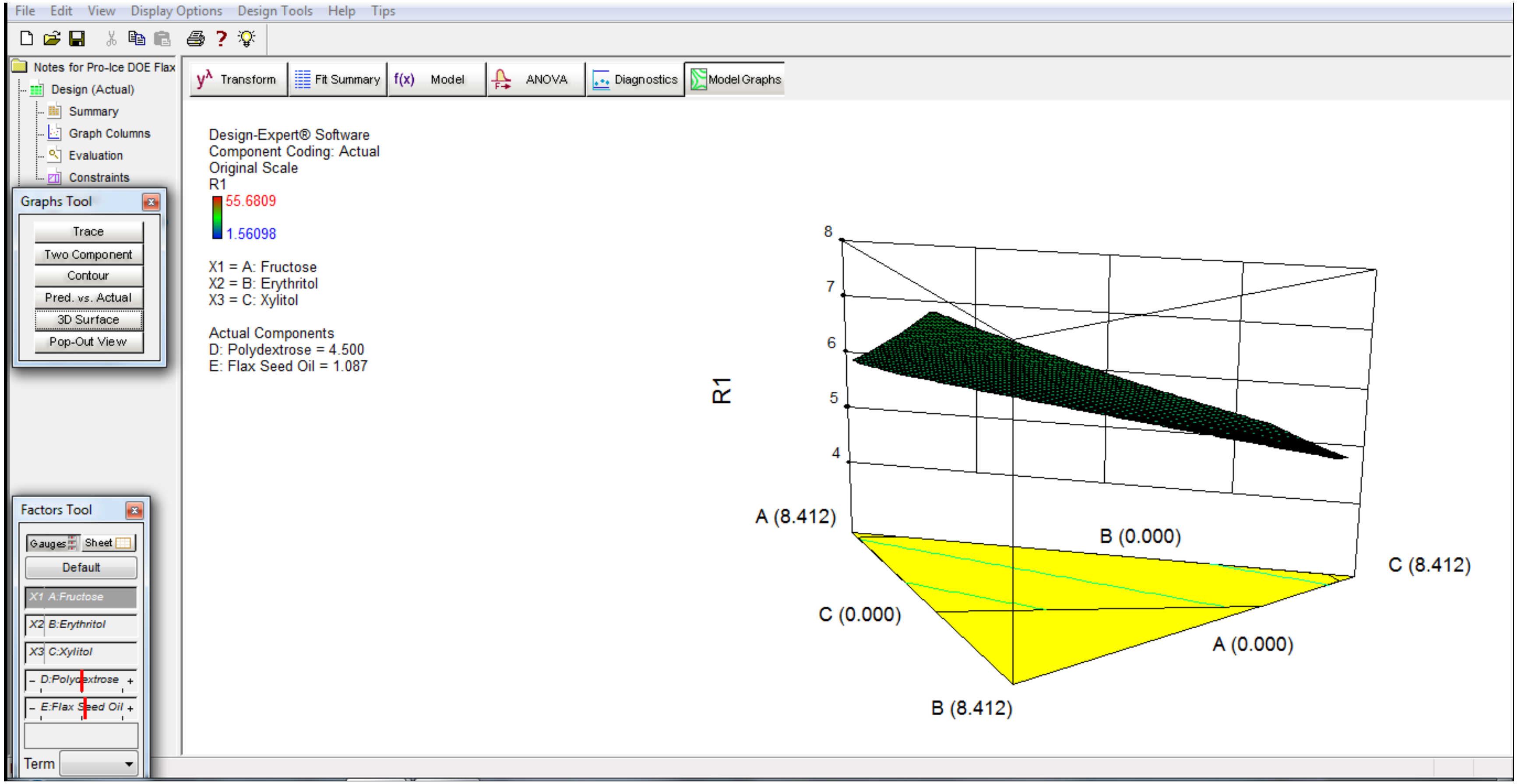


Figure A12: Viewing response surface plots for hardness testing results in Design-Expert® V8 software.

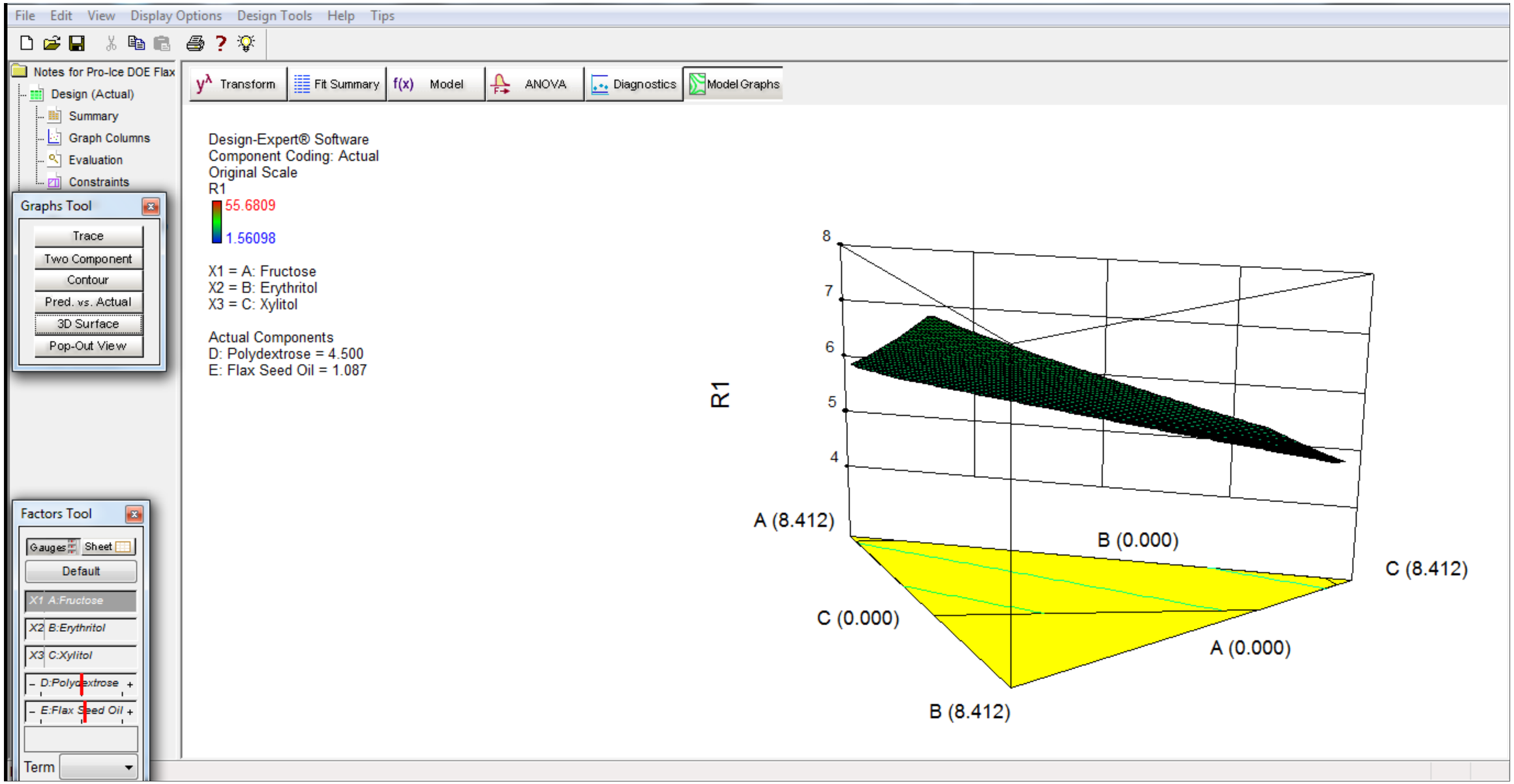


Figure A13: Viewing response surface plots for viscosity testing results in Design-Expert® V8 software.

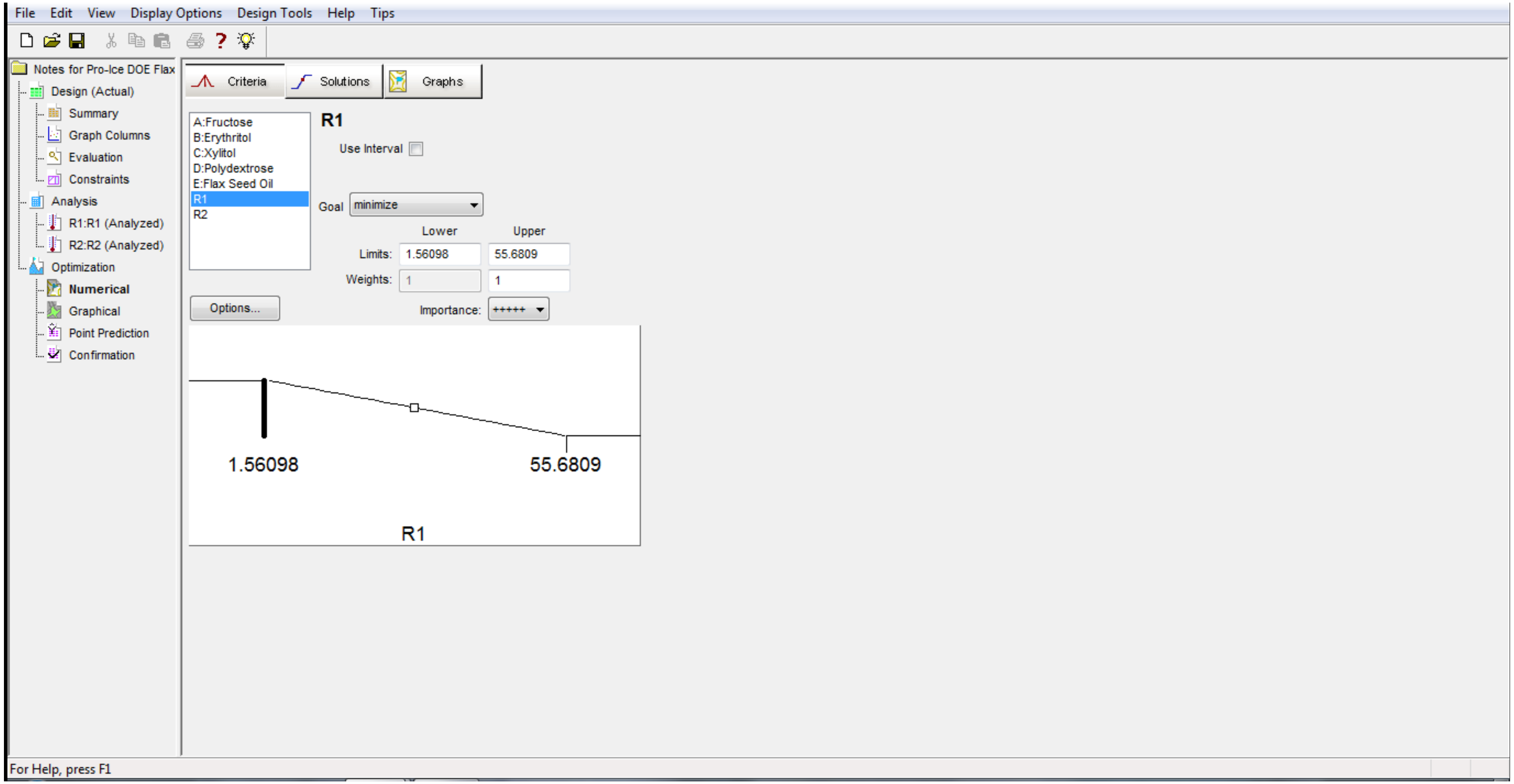


Figure A14: Optimizing the product formulation for the attribute of hardness, based on testing results, using Design-Expert® V8 software.

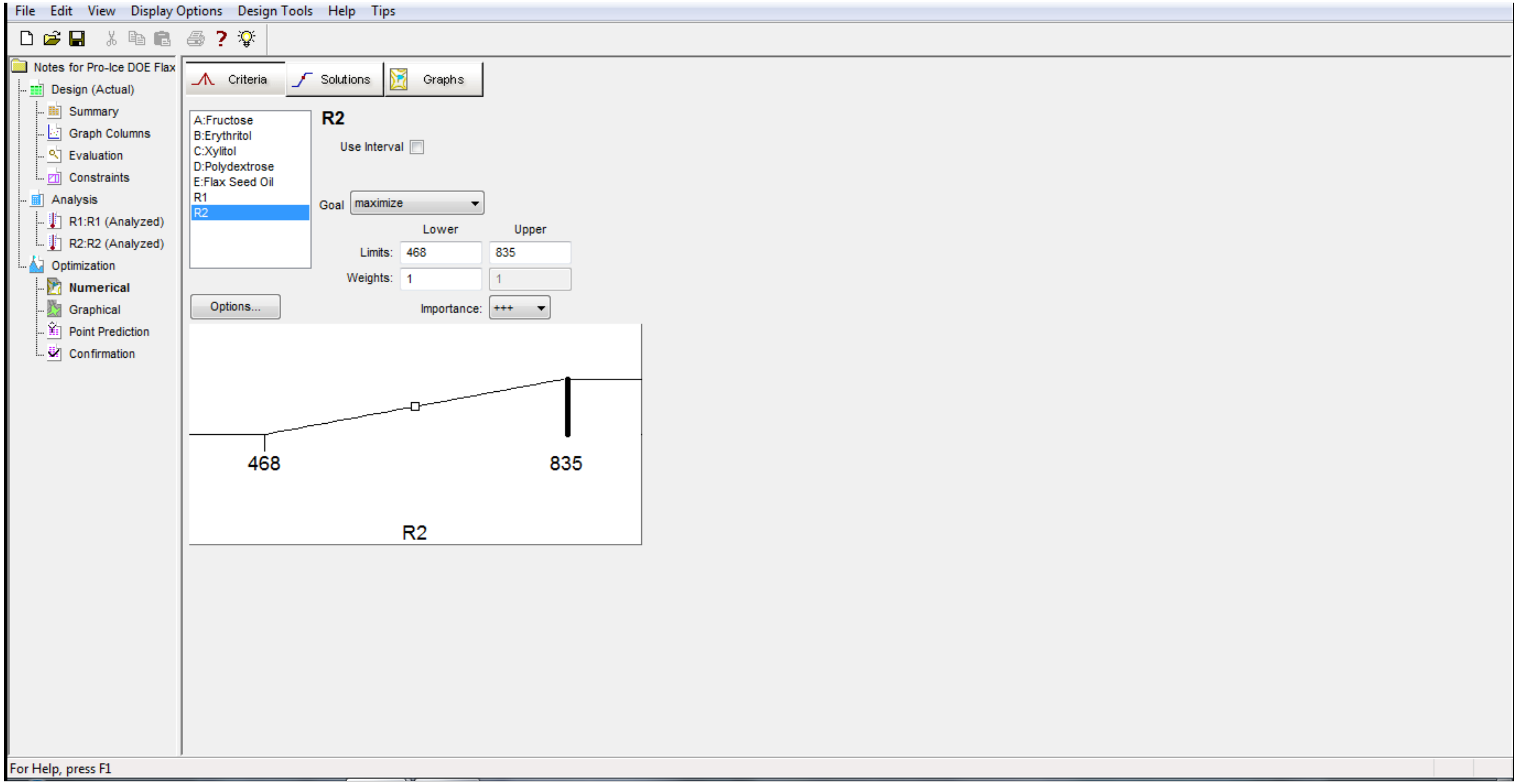


Figure A15: Optimizing the product formulation for the attribute of viscosity, based on testing results, using Design-Expert® V8 software.

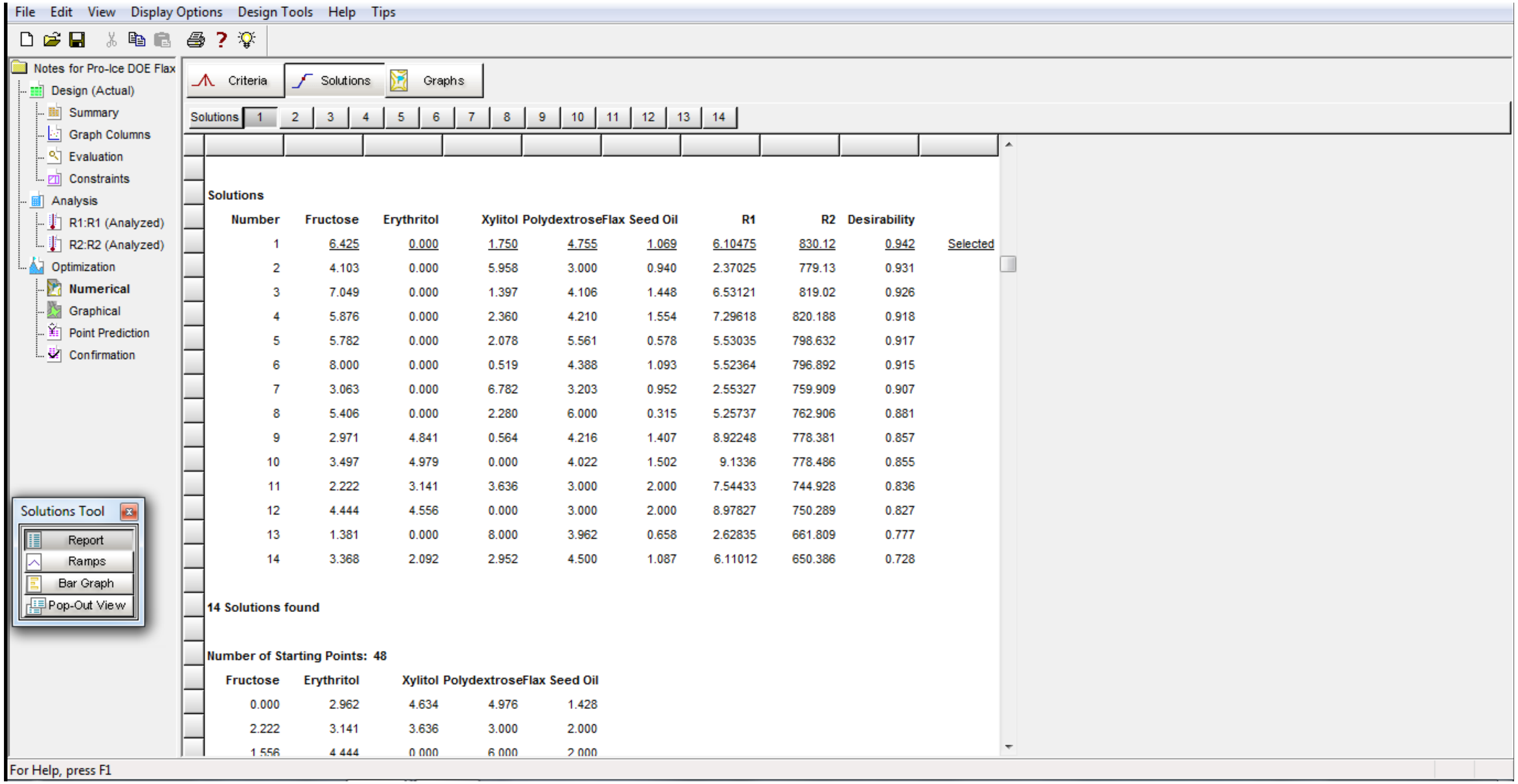


Figure A16: The top 14 solutions provided during the optimization process, generated by Design-Expert® V8 software.

8.8 Appendix 8: Application for Ethics Approval, Participants Covering Letter and Consent From

The University of Waikato

Application for Ethics Approval

By FSEN Students

Faculty of Science and Engineering
Human Research Ethics Sub-committee

1 Title of Project

Development of a High Protein Ice Cream

2 Researcher(s) and Contact Details

a Name of applicant

Sean Nixon

b Department/Centre/Unit

School of Engineering

c Qualifications

BE (Hons) Biochemical

d Other personnel

Supervisor: Dr James Carson

A. 3. Research Design Proposal

The committee needs to see some detail about your research design so it can judge if you have thought through all the ethical issues in your research. Describe your research design in points 3a-c below.

a. Research Objectives

There are two objectives to this research:

1. To carry out a preference ranking test, where participants will determine if a difference exists between three samples with regard to the attribute of sweetness, and then rank the samples in their preferred order.
2. To carry out acceptance tests using the most preferred sample, as indicated in the first set of tests. A hedonic rating will be used to compare the level of liking of attributes of the sample to those of a similar product that is on the market.

b. Research Methodology

Preference ranking test objective: To determine which sample, out of three, consumers prefer with regard to the attribute of sweetness.
Experimental design: 10-20 consumers will be recruited who are representative of the target market. Samples will be presented to each consumer simultaneously.
Procedure: Assessors are presented with several blind coded samples. They are asked to assess the samples in the order provided and place them in order from most preferred to least preferred for the specified attribute. Appropriate palate cleansers will be used after each sample.

Acceptance tests objective: To determine the level of liking of the product, compared to the market leader, using a hedonic rating system.
Experimental design: 20-40 consumers will be recruited who are representative of the target market. Samples will be presented to each consumer individually. As individuals are prone to scoring initial samples abnormally high, a 'dummy' sample, similar to those in the sample set, will be presented first to remove this source of bias. Its data will be discarded. The remaining samples are then presented to each assessor according to a randomized design.
Procedure: For each product, subjects are asked to indicate their level of liking on a hedonic scale. The scale ranges from "dislike extremely" to "like extremely". Appropriate palate cleansers will be used after each sample.

This methodology has been adapted from that published by Kemp, Hollowood and Hort in *Sensory Evaluation : A Practical Handbook* (2009).

c. Significance of Research Project

This research is the culmination of 8 months work developing a high protein ice cream formula for my Master of Engineering thesis. It is a vital step in the food product development process that the product is tested by consumers, which is what this step of my research entails.

Timetable of Events

07/11/11 Gain ethics approval

07/11/11 – 18/11/11 Gather research data

18/11/11 – 25/11/11 Analyse data

4 Research Procedures

a Procedure for recruitment of participants

Participants will be recruited from University sports teams (athletes are one of the target markets) and from Sir Edmund Hillary Scholars. Participants will be contacted via a combination of email, face to face contact and text message. It is hoped that between 10 and 20 participants can be recruited for the first part and 20-40 participants for the second part of the research.

b Procedures in which research participants will be involved

Participants will be asked to taste ice cream samples and rank / rate them, depending on the test being undertaken (please refer to part 3b). Participants will also be asked to fill out a short questionnaire relating to their use and consumption of ice cream:

Each part of the research would only take an individual participant 5-10 minutes to complete.

c Procedures for handling information and materials produced in the course of the research

Hard data, in the form of paper questionnaires, will be kept in a locked filing cabinet. Electronic files used to record and analyze the data will be stored on a password protected USB storage device. Data will be kept for five years after collection before being destroyed, as required by national law.

5 Ethical Concerns

a Access to participants

Sir Edmund Hillary program staff will be consulted before Scholars are recruited via the scholar email database (as a Sir Edmund Hillary Scholar, I have access to the database). Members of the University Rugby Club, of which I am a member, will be consulted directly on a face to face or via text message.

b Informed consent

Participants will be asked to read a covering letter, providing background to the project, and then sign a consent form. All participants will be over 16 years of age.

c Confidentiality

No personal details will be collected other than the participants name and signature on the consent forms. This information will not be used for data analysis purposes. Signed consent forms will be kept locked in a filing cabinet for five years after collection before being destroyed, as required by national law.

d Potential harm to participants

As the research involves consuming a food product, the food product will be produced and served in accordance with NZFSA regulations to ensure its safety. Allergy information for the product will be provided to participants in the background information sheet.

e Participants right to decline

Participants will be advised that they have the right to decline to be involved in the study and that they have the right to withdraw at any time, without stating any reason.

f Arrangements for participants to receive information

A summary of the study's findings will be sent via email to all participants.

g Use of information

The collected data will be published in my Master of Engineering thesis. Data obtained from the information gathered may be published in a journal article.

h Conflicts of interest

Not applicable.

i Cultural sensitivity

Participants will be informed that samples do not meet any religious/cultural standards (Halal, Kosher etc).

j Compensation for participation

Participants will not be compensated for their participation.

k Procedure for resolution of disputes

Participants will be advised, in the covering letter, that disputes can be brought to the attention of the researcher, in the first instance, or the supervisor should they not be resolved.

6 Ethical Statement

The project will follow the University of Waikato Human Research Ethics Regulations 2008 and the ethical guidelines of the NZARE and include the following. Informed consent of participants will be obtained, without coercion. Exploitation (or perception of exploitation) of researcher-participant relationship will be prevented. Privacy and confidentiality will be respected. The participant will own the raw material collected, and their requests regarding the material will be honored. Participation in the research will not impact academically on the participants.

7 Legal Issues

a Copyright

No intellectual property rights will be infringed during the course of this research.

b Ownership of materials produced

Researcher's notes and interpretation of those notes will remain the property of the researchers. Participants will be advised that they own their own raw data and, in the event of a withdrawal by the participant, any data obtained from them will be returned and not used in the study, where possible.

c Any other legal issues relevant to the research

None.

8 Place in which the research will be conducted

The research will be conducted on the University of Waikato campus.

9 Has this application in whole or part previously been declined or approved by another ethics committee?

No.

10 For research to be undertaken at other facilities under the control of another ethics committee, has an application also been made to that committee?

Not applicable.

11 Further conditions

In the event of this application being approved, the undersigned agrees to request approval from the FSEN Human Research Ethics sub-committee for any change subsequently proposed.

12 Applicant Request for Approval of Ethics Application

For the study described, I agree to follow the conditions as specified in this application

Signed

Date **2/11/11**

As the applicant's research supervisor:
I am aware of this study and the conditions under which it is proposed to be undertaken

Signed

Date 2/11/11

The ethics application is approved

Signed on behalf of the Committee

(Chairperson of the Committee or their nominee)

Date 4/11/11

Participants' covering letter:

The purpose of the study is to test samples of a high protein ice cream being formulated as part of a Master of Engineering thesis. Results from this study will be published in the thesis and may be published in an academic journal.

We are asking participants in the study to be involved in the taste testing of ice cream. The test will involve:

1. Completing a short questionnaire.
2. Tasting and ranking of 3 samples
3. With permission, participants will be asked to test three further samples, ranking specific attributes of each.

The total time expected to carry out all of the tests is 20 minutes. All information will be treated in the strictest confidence, and no personal data will be collected or retained. Data provided by participants will remain the property of the participants and can be returned at any time by contacting the researcher. Disputes can be brought to the attention of the researcher, in the first instance, or the supervisor should they not be resolved. If you have any questions feel free to ask us. You can withdraw from the study at any time.

If you have milk/dairy, gluten or nut allergies you should decline to participate as the samples may contain ingredients that could put you at risk. The samples do not have Kosher or Halal approval. The food product will be produced and served in accordance with NZFSA regulations to ensure its safety.

Participants will not be compensated for their participation. A summary of the findings of this research can be provided to the participants by email.

The study has received ethics approval from the FSEN Human Research Ethics sub-committee. If you have any concerns or complaints, please contact the researchers:

Researcher: Sean Nixon, sn68@waikato.ac.nz
Or Supervisor: Dr James Carson, jkcarson@waikato.ac.nz

We would like to invite you to complete an informed consent form.

Thank you in advance for your participation.

Participants consent form:

University of Waikato
Faculty of Science and Engineering
Human Ethics

CONSENT FORM

Research Project: **Development of a High Protein Ice Cream**

Name of Researcher: **Sean Nixon, sn68@waikato.ac.nz**

Name of Supervisor (if applicable): **Dr James Carson, jkcarson@waikato.ac.nz**

I have received an information sheet about this research project or the researcher has explained the study to me. I have had the chance to ask any questions and discuss my participation with other people. Any questions have been answered to my satisfaction.

I agree to participate in this research project and I understand that I may withdraw at any time. If I have any concerns about this project, I may contact the Chairperson of the Faculty of Science & Engineering Human Ethics Committee (Dr Howell Round, phone: 838 4173, e-mail: h.round@waikato.ac.nz)

Participant's Name: ______________________ Date:

Signature:

8.9 Appendix 9: Data Collected During Consumer Panel Testing and Results From Statistical Analysis

Table A20 : Raw data collected during hedonic testing off the Optimum High Protein Prototype frozen dessert and Tip Top™ Vanilla Ice Cream.

Category/ Assessor	Product/Score			
	OHPP		Tip Top™ Vanilla Ice Cream	
	Hedonic Score	Corresponding LAM Value	Hedonic Score	Corresponding LAM Value
Sweetness	6	55.62	9	87.11
	6	55.62	9	87.11
	7	68.12	9	87.11
	8	78.06	7	68.12
	8	78.06	9	87.11
	6	55.62	9	87.11
	6	55.62	9	87.11
	7	68.12	9	87.11
	8	78.06	6	55.62
	8	78.06	9	87.11
	7	68.12	9	87.11
	8	78.06	7	68.12
	8	78.06	9	87.11
	8	78.06	9	87.11
	6	55.62	9	87.11
	7	68.12	9	87.11
	4	44.69	8	78.06
	7	68.12	9	87.11
	8	78.06	8	78.06
	6	55.62	8	78.06
	6	55.62	7	68.12
	5	50	9	87.11
	7	68.12	9	87.11
	7	68.12	9	87.11
	8	78.06	8	78.06
	8	78.06	8	78.06
	6	55.62	8	78.06
	7	68.12	8	78.06
	9	87.11	7	68.12
	4	44.69	6	55.62
	8	78.06	7	68.12

	8	78.06	7	68.12
	7	68.12	8	78.06
	7	68.12	7	68.12
	8	78.06	9	87.11
	6	55.62	6	55.62
	7	68.12	6	55.62
	7	68.12	8	78.06
	8	78.06	9	87.11
	8	78.06	9	87.11
Flavour	5	50	9	87.11
	6	55.62	9	87.11
	8	78.06	9	87.11
	6	55.62	8	78.06
	8	78.06	9	87.11
	5	50	9	87.11
	6	55.62	9	87.11
	8	78.06	9	87.11
	6	55.62	8	78.06
	8	78.06	9	87.11
	8	78.06	9	87.11
	6	55.62	8	78.06
	8	78.06	9	87.11
	5	50	9	87.11
	6	55.62	9	87.11
	7	68.12	9	87.11
	4	44.69	8	78.06
	7	68.12	9	87.11
	8	78.06	8	78.06
	6	55.62	8	78.06
	6	55.62	7	68.12
	5	50	9	87.11
	7	68.12	9	87.11
	7	68.12	9	87.11
	8	78.06	9	87.11
	8	78.06	8	78.06
	6	55.62	8	78.06
	7	68.12	8	78.06
	5	50	7	68.12
	4	44.69	9	87.11
	8	78.06	7	68.12
	7	68.12	7	68.12
	7	68.12	8	78.06
	7	68.12	9	87.11
	6	55.62	9	87.11

	6	55.62	6	55.62
	7	68.12	6	55.62
	7	68.12	8	78.06
	6	55.62	8	78.06
	8	78.06	9	87.11
Texture	7	68.12	9	87.11
	7	68.12	9	87.11
	8	78.06	9	87.11
	7	68.12	7	68.12
	9	87.11	9	87.11
	7	68.12	9	87.11
	7	68.12	9	87.11
	8	78.06	9	87.11
	7	68.12	7	68.12
	9	87.11	9	87.11
	8	78.06	9	87.11
	7	68.12	7	68.12
	9	87.11	9	87.11
	7	68.12	9	87.11
	7	68.12	9	87.11
	4	44.69	8	78.06
	7	68.12	9	87.11
	8	78.06	8	78.06
	9	87.11	8	78.06
	6	55.62	7	68.12
	5	50	9	87.11
	7	68.12	9	87.11
	9	87.11	9	87.11
	8	78.06	8	78.06
	8	78.06	8	78.06
	8	78.06	8	78.06
	7	68.12	8	78.06
	4	44.69	7	68.12
	5	50	9	87.11
	9	87.11	7	68.12
	6	55.62	8	78.06
	7	68.12	8	78.06
	8	78.06	9	87.11
	6	55.62	9	87.11
	7	68.12	7	68.12
	8	78.06	6	55.62
	8	78.06	7	68.12
	9	87.11	9	87.11
	7	68.12	7	68.12

	9	87.11	9	87.11
Hardness	7	68.12	9	87.11
	7	68.12	9	87.11
	4	44.69	9	87.11
	6	55.62	8	78.06
	8	78.06	9	87.11
	7	68.12	9	87.11
	7	68.12	9	87.11
	4	44.69	9	87.11
	6	55.62	8	78.06
	8	78.06	9	87.11
	4	44.69	9	87.11
	6	55.62	8	78.06
	8	78.06	9	87.11
	7	68.12	9	87.11
	7	68.12	9	87.11
	7	68.12	9	87.11
	8	78.06	8	78.06
	6	55.62	8	78.06
	6	55.62	7	68.12
	5	50	9	87.11
	7	68.12	9	87.11
	9	87.11	9	87.11
	9	87.11	8	78.06
	7	68.12	8	78.06
	8	78.06	8	78.06
	6	55.62	8	78.06
	4	44.69	7	68.12
	6	55.62	7	68.12
	6	55.62	7	68.12
	8	78.06	7	68.12
	7	68.12	8	78.06
	9	87.11	9	87.11
	6	55.62	9	87.11
	7	68.12	9	87.11
	8	78.06	8	78.06
	8	78.06	8	78.06
	9	87.11	8	78.06
	4	44.69	9	87.11
	6	55.62	8	78.06
	8	78.06	9	87.11
Overall Appeal	6	55.62	9	87.11
	8	78.06	9	87.11

7	68.12	9	87.11
7	68.12	8	78.06
8	78.06	9	87.11
6	55.62	9	87.11
8	78.06	9	87.11
7	68.12	9	87.11
7	68.12	8	78.06
8	78.06	9	87.11
7	68.12	9	87.11
7	68.12	8	78.06
8	78.06	9	87.11
6	55.62	9	87.11
8	78.06	9	87.11
7	68.12	9	87.11
8	78.06	8	78.06
6	55.62	8	78.06
6	55.62	7	68.12
8	78.06	9	87.11
7	68.12	9	87.11
9	87.11	9	87.11
8	78.06	8	78.06
8	78.06	8	78.06
9	87.11	8	78.06
6	55.62	8	78.06
4	44.69	7	68.12
5	50	7	68.12
6	55.62	7	68.12
8	78.06	8	78.06
7	68.12	8	78.06
7	68.12	8	78.06
6	55.62	9	87.11
7	68.12	6	55.62
8	78.06	8	78.06
8	78.06	8	78.06
9	87.11	9	87.11
7	68.12	9	87.11
7	68.12	8	78.06
8	78.06	9	87.11

Table A21: Full results from analysis of frozen dessert prototype scores for significance using the Mann-Whitney U-test.

Product Attribute: Sweetness	**Sample: OHPP**	**Tip Top™ Vanilla Ice Cream**	**Rank1**	**Rank2**	**T1**	**T2**	
	55.62	87.11	10.00	70.00	1190.5	2049.5	**Total Rank**
	55.62	87.11	10.00	70.00	68.12	82.59	**Median**
	68.12	87.11	26.00	70.00	40.00	40.00	**n1, n2**
	78.06	68.12	47.50	26.00		1229.5	**U1**
	78.06	87.11	47.50	70.00		370.5	**U2**
	55.62	87.11	10.00	70.00		370.5	**U**
	55.62	87.11	10.00	70.00		1620	**E(U1)**
	68.12	87.11	26.00	70.00		1620	**E(U2)**
	78.06	55.62	47.50	10.00		800	**E(U)**
	78.06	87.11	47.50	70.00		103.92305	**s**
	68.12	87.11	26.00	70.00		1416.3146	**Action(L)**
	78.06	68.12	47.50	26.00		1823.6854	**Action(U)**
	78.06	87.11	47.50	70.00		0.05	**a**
	78.06	87.11	47.50	70.00		4.1328657	**z**
	55.62	87.11	10.00	70.00		3.58E-05	*p*
	68.12	87.11	26.00	70.00		Reject Null Hypothesis at alpha=0.05	
	44.69	78.06	1.50	47.50			
	68.12	87.11	26.00	70.00			
	78.06	78.06	47.50	47.50			
	55.62	78.06	10.00	47.50			
	55.62	68.12	10.00	26.00			
	50	87.11	3.00	70.00			
	68.12	87.11	26.00	70.00			
	68.12	87.11	26.00	70.00			
	78.06	78.06	47.50	47.50			
	78.06	78.06	47.50	47.50			
	55.62	78.06	10.00	47.50			
	68.12	78.06	26.00	47.50			
	87.11	68.12	70.00	26.00			
	44.69	55.62	1.50	10.00			
	78.06	68.12	47.50	26.00			
	78.06	68.12	47.50	26.00			
	68.12	78.06	26.00	47.50			
	68.12	68.12	26.00	26.00			
	78.06	87.11	47.50	70.00			
	55.62	55.62	10.00	10.00			

68.12	55.62	26.00	10.00
68.12	78.06	26.00	47.50
78.06	87.11	47.50	70.00
78.06	87.11	47.50	70.00

Product Attribute: Texture	**Sample OHPP**	**Tip Top™ Vanilla Ice Cream**	**Rank1**	**Rank2**	**T1**	**T2**	
	68.12	87.11	20.50	66.00	1285	1955	**Total Rank**
	68.12	87.11	20.50	66.00	68.12	87.11	**Median**
	78.06	87.11	42.00	66.00	40.00	40.00	**n1, n2**
	68.12	68.12	20.50	20.50		1135.0	**U1**
	87.11	87.11	66.00	66.00		465.0	**U2**
	68.12	87.11	20.50	66.00		465.0	**U**
	68.12	87.11	20.50	66.00		1620	**E(U1)**
	78.06	87.11	42.00	66.00		1620	**E(U2)**
	68.12	68.12	20.50	20.50		800	**E(U)**
	87.11	87.11	66.00	66.00		103.92305	**s**
	78.06	87.11	42.00	66.00		1416.3146	**Action(L)**
	68.12	68.12	20.50	20.50		1823.6854	**Action(U)**
	87.11	87.11	66.00	66.00		0.05	**a**
	68.12	87.11	20.50	66.00		3.223539	**z**
	68.12	87.11	20.50	66.00		1.27E-03	*p*
	44.69	78.06	1.50	42.00		Reject Null Hypothesis at alpha=0.05	
	68.12	87.11	20.50	66.00			
	78.06	78.06	42.00	42.00			
	87.11	78.06	66.00	42.00			
	55.62	68.12	6.50	20.50			
	50	87.11	3.50	66.00			
	68.12	87.11	20.50	66.00			
	87.11	87.11	66.00	66.00			
	78.06	78.06	42.00	42.00			
	78.06	78.06	42.00	42.00			
	78.06	78.06	42.00	42.00			
	68.12	78.06	20.50	42.00			
	44.69	68.12	1.50	20.50			
	50	87.11	3.50	66.00			
	87.11	68.12	66.00	20.50			
	55.62	78.06	6.50	42.00			
	68.12	78.06	20.50	42.00			
	78.06	87.11	42.00	66.00			
	55.62	87.11	6.50	66.00			
	68.12	68.12	20.50	20.50			
	78.06	55.62	42.00	6.50			

	78.06	68.12	42.00	20.50
	87.11	87.11	66.00	66.00
	68.12	68.12	20.50	20.50
	87.11	87.11	66.00	66.00

Product Attribute: **Hardness**	**Sample** **OHPP**	**Tip Top™ Vanilla Ice Cream**	**Rank1**	**Rank2**	**T1**	**T2**	
	68.12	87.11	24.50	68.00	1073.5	2166.5	**Total Rank**
	68.12	87.11	24.50	68.00	68.12	87.11	**Median**
	44.69	87.11	3.00	68.00	40.00	40.00	**n1, n2**
	55.62	78.06	11.50	44.00		1346.5	**U1**
	78.06	87.11	44.00	68.00		253.5	**U2**
	68.12	87.11	24.50	68.00		253.5	**U**
	68.12	87.11	24.50	68.00		1620	**E(U1)**
	44.69	87.11	3.00	68.00		1620	**E(U2)**
	55.62	78.06	11.50	44.00		800	**E(U)**
	78.06	87.11	44.00	68.00		103.92305	**s**
	44.69	87.11	3.00	68.00		1416.3146	**Action(L)**
	55.62	78.06	11.50	44.00		1823.6854	**Action(U)**
	78.06	87.11	44.00	68.00		0.05	**a**
	68.12	87.11	24.50	68.00		5.2586987	**z**
	68.12	87.11	24.50	68.00		1.45E-07	*p*
	68.12	87.11	24.50	68.00		Reject Null Hypothesis at alpha=0.05	
	78.06	78.06	44.00	44.00			
	55.62	78.06	11.50	44.00			
	55.62	68.12	11.50	24.50			
	50	87.11	6.00	68.00			
	68.12	87.11	24.50	68.00			
	87.11	87.11	68.00	68.00			
	87.11	78.06	68.00	44.00			
	68.12	78.06	24.50	44.00			
	78.06	78.06	44.00	44.00			
	55.62	78.06	11.50	44.00			
	44.69	68.12	3.00	24.50			
	55.62	68.12	11.50	24.50			
	55.62	68.12	11.50	24.50			
	78.06	68.12	44.00	24.50			
	68.12	78.06	24.50	44.00			
	87.11	87.11	68.00	68.00			
	55.62	87.11	11.50	68.00			
	68.12	87.11	24.50	68.00			
	78.06	78.06	44.00	44.00			
	78.06	78.06	44.00	44.00			

87.11	78.06	68.00	44.00
44.69	87.11	3.00	68.00
55.62	78.06	11.50	44.00
78.06	87.11	44.00	68.00

Product Attribute:	**Sample**						
Overall Appeal	**OHPP**	**Tip Top™ Vanilla Ice Cream**	**Rank1**	**Rank2**	**T1**	**T2**	
	55.62	87.11	7.00	69.00	1128	2112	**Total Rank**
	78.06	87.11	43.00	69.00	68.12	82.59	**Median**
	68.12	87.11	20.00	69.00	40.00	40.00	**n1, n2**
	68.12	78.06	20.00	43.00		1292.0	**U1**
	78.06	87.11	43.00	69.00		308.0	**U2**
	55.62	87.11	7.00	69.00		308.0	**U**
	78.06	87.11	43.00	69.00		1620	**E(U1)**
	68.12	87.11	20.00	69.00		1620	**E(U2)**
	68.12	78.06	20.00	43.00		800	**E(U)**
	78.06	87.11	43.00	69.00		103.92305	**s**
	68.12	87.11	20.00	69.00		1416.3146	**Action(L)**
	68.12	78.06	20.00	43.00		1823.6854	**Action(U)**
	78.06	87.11	43.00	69.00		0.05	**a**
	55.62	87.11	7.00	69.00		4.7342722	**z**
	78.06	87.11	43.00	69.00		2.20E-06	*p*
	68.12	87.11	20.00	69.00		Reject Null Hypothesis	
	78.06	78.06	43.00	43.00		at alpha=0.05	
	55.62	78.06	7.00	43.00			
	55.62	68.12	7.00	20.00			
	78.06	87.11	43.00	69.00			
	68.12	87.11	20.00	69.00			
	87.11	87.11	69.00	69.00			
	78.06	78.06	43.00	43.00			
	78.06	78.06	43.00	43.00			
	87.11	78.06	69.00	43.00			
	55.62	78.06	7.00	43.00			
	44.69	68.12	1.00	20.00			
	50	68.12	2.00	20.00			
	55.62	68.12	7.00	20.00			
	78.06	78.06	43.00	43.00			
	68.12	78.06	20.00	43.00			
	68.12	78.06	20.00	43.00			
	55.62	87.11	7.00	69.00			
	68.12	55.62	20.00	7.00			
	78.06	78.06	43.00	43.00			
	78.06	78.06	43.00	43.00			

	87.11	87.11	69.00	69.00
	68.12	87.11	20.00	69.00
	68.12	78.06	20.00	43.00
	78.06	87.11	43.00	69.00

Table continued on Page 136.

Product Attribute:	**Sample**						
	OHPP	**Tip Top™ Vanilla Ice Cream**	**Rank1**	**Rank2**	**T1**	**T2**	
Overall LAM average for all attributes	67.89	78.60	3.00	6.00	15	40	**Total Rank**
	63.67	80.92	1.00	8.00	67.89	80.92	**Median**
	71.39	80.01	5.00	7.00	5.00	5.00	**n1, n2**
	65.75	81.57	2.00	10.00		25.0	**U1**
	69.48	81.03	4.00	9.00		0.0	**U2**
						0.0	**U**
						27.5	**E(U1)**
						27.5	**E(U2)**
						12.5	**E(U)**
						4.7871355	**s**
						18.117387	**Action(L)**
						36.882613	**Action(U)**
						0.05	**a**
						2.6111648	**z**
						9.02E-03	*p*
						Reject Null Hypothesis at alpha=0.05	