UNIVERSITI PUTRA MALAYSIA

EFFECTS OF MONOGLYCERIDES ON AERATION ENHANCEMENT DURING INDUSTRIAL PRODUCTION OF CAKES AND ICE CREAMS

LEE LAI YEE

EFFECTS OF MONOGLYCERIDES ON AERATION ENHANCEMENT DURING INDUSTRIAL PRODUCTION OF CAKES AND ICE CREAMS

By

LEE LAI YEE

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Engineering

May 2017

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Engineering

EFFECTS OF MONOGLYCERIDES ON AERATION ENHANCEMENT DURING INDUSTRIAL PRODUCTION OF CAKES AND ICE CREAMS

By

LEE LAI YEE

May 2017

Chair: Prof. Ir. Chin Nyuk Ling, PhD
Faculty: Engineering

Monoglycerides are the most commonly used food emulsifiers, as crumb softener, emulsion stabiliser and aeration enhancer. Putting aside the product composition, the main variations in monoglycerides are the fatty acid composition and degree of unsaturation. This study aimed to evaluate the aeration enhancement effects of monoglycerides in bakery and dairy applications in view of the bakery manufacturers perception that monostearin (C18) performs better than monopalmitin (C16), and the fact that the blend of saturated monoglycerides and polysorbate 80 have been used historically in ice creams formulations instead of unsaturated monoglycerides. Four types of monoglycerides from different raw materials (different C16 to C18 ratio) were used to make cake gel, assessed and applied into sponge cakes and found to perform equally well in terms of batter aeration and final cake volume and softness. Two saturated and three unsaturated monoglycerides were applied in ice creams. The mix and ice creams were evaluated for aeration performances through quantification of fat globules size distribution, meltdown resistance and heat shock stability. A slightly higher degree of unsaturation (17 – 25 g I_2/100g compared to 10 – 17 I_2/100g) gave better meltdown and heat shock resistances. Both unsaturated monoglycerides performed better than saturated monoglycerides and when it was dosed in combination with polysorbate 80. The meltdown rate between the saturated and unsaturated monoglycerides was 0.17 – 0.26% per min and 0.12 – 0.19% per min respectively. It was also concluded that ice creams with meltdown rate below 0.2% per min could be defined to have good meltdown resistance performance. Monoglycerides are added into ice cream through texturising system in the ice cream industry. Although unsaturated monoglycerides gives better aeration performances in general, its use is carefully evaluated as it could lead to change of textural and organoleptic properties of the ice cream of which some manufacturers find it undesirable. The other quality concerns and challenges faced by the ice cream manufacturers in Asia Pacific region include excessive mix viscosity, poor heat shock resistances, product shrinkage and ice crystals development over time.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Kejuruteraan

KESAN MONOGLYCERIDES ATAS PENGUDARAAN SEMASA PENGHASILAN INDUSTRI KEK DAN AIS KRIM

Oleh

LEE LAI YEE

Mei 2017

Pengerusi: Prof. Ir. Chin Nyuk Ling, PhD
Fakulti: Kejuruteraan

Monoglycerides adalah pengemulsi yang paling kerap digunakan dalam makanan, sebagai pelembut roti, penstabil emulsi dan agen pengudaraan. Monoglycerides berbeza dari segi lemak komposisi asid dan tahap ketidaktepuan. Kajian ini bertujuan untuk menilai kesan penambahbaikan monoglycerides dari segi pengudaraan dalam aplikasi bakeri dan tenusu memandangkan tanggapan pengilang bakeri bahawa monostearin (C18) memberi prestasi yang lebih baik daripada monopalmitin (C16); manakala dari segi tenusu, monoglycerides tepu bersama polysorbate 80 selalu digunakan untuk membuat ais krim tetapi bukan untuk monoglycerides tidak tepu. Empat monoglycerides yang mengandungi nisbah lemak asid C16 dan C18 yang berlainan digunakan untuk membuat gel kek yang digunakan untuk membuat kek span dan semua sampel didapati seimbang dari segi pengudaraan adunan dan isipadu serta kelembutan kek. Dua jenis monoglycerides tepu dan tiga jenis tidak tepu telah dinilai dalam ais krim. Prestasi pengudaraan dari segi taburan saiz lemak, rintangan kelembapan dan kestabilan terhadap perubahan suhu telah dinilai. Monoglycerides tidak tepu menunjukkan prestasi lebih unggul berbanding monoglycerides tepu, apabila diguna sendiri atau ditambah dengan polysorbate 80. Kadar kelembapan antara monoglycerides tepu dan tidak tepu dicatatkan di 0.17 – 0.26% per min and 0.12 - 0.19% per min masing-masing. Ia juga telah disimpulkan bahawa kadar kelembapan sebanyak 0.2% per min adalah kadar maksima untuk ais krim yang tahan lembap. Monoglycerides ditambahkan menerusi system tekstur semasa penghasilan ais krim. Walaupun monoglycerides tak tepu memberi prestasi pengudaraan yang lebih unggul, ia mungkin membawa perubahan dari segi tekstur dan sensori yang tidak diingini oleh para pengilang. Masalah dan cabaran lain yang dihadapi oleh para pengilang ais krim di rantau Asia Pasific ini termasuk kelikatan campura ais krim yang melampau tinggi, rintangan kestabilan terhadap perubahan suhu yang lemak, pengecutan produk, dan penghasilan kristal ais dari masa ke masa.

ACKNOWLEDGEMENTS

My deepest gratitude to my main supervisor Prof. Ir. Dr. Chin Nyuk Ling for her courage, inspiration and support in my journey of pursuing this doctorate programme, I would not be this far without her guidance. Thank you to my co-supervisors Assoc. Prof. Dr. Yuz Aniza and Assoc. Prof. Dr. Rosnita, as well as my industrial supervisor, Mr. Lim Choh Hock for the support. Thank you to the Ministry of Education Malaysia for the financial support, under the MyPhD Industry programme. Thank you to the management of the company I work with, Ecolex Sdn Bhd, and my team members for the support and assistance provided in completion of my study. My gratitude goes to Mr. Ejvind S. Christensen for his expert guidance in ice creams and frozen desserts. And finally, special thanks to my family members and friends whom have been very supportive in times, up and down. It has been a long yet fruitful journey.

I certify that a Thesis Examination Committee has met on 5 May 2017 to conduct the final examination of Lee Lai Yee on her thesis entitled "Effects of Monoglycerides on Aeration Enhancement during Industrial Production of Cakes and Ice Creams" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Engineering.

Members of the Thesis Examination Committee were as follows:

Mohd Noriznan bin Mokhtar, PhD
Associate Professor –Ing.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Shamsul bin Anuar, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Rosnah binti Shamsudin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Nantawan Therdthai, PhD
Associate Professor
Kasetsart University
Thailand
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 8 August 2017

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Engineering. The members of the Supervisory Committee were as follows:

Chin Nyuk Ling, PhD
Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairperson)

Yus Aniza binti Yusof, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Rosnita binti A.Talib, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Lim Choh Hock
Operations Director
Ecolex Sdn Bhd
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: Lee Lai Yee (GS35738)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____	Signature: _____
Name of Chairman of Supervisory Committee: _____	Name of Member of Supervisory Committee: _____
Signature: _____	Signature: _____
Name of Member of Supervisory Committee: _____	Name of Member of Supervisory Committee: _____

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AACC	American Association for Clinical Chemistry
AMF	Anhydrous milk fat
ANOVA	Analysis of variance
AP	Asia Pacific
BMP	Butter milk powder
CAGR	Compound annual growth rate
CITREM	Citric acid esters of mono and diglycerides
DATEM	Diacetyl tartaric acid ester of mono- and diglycerides
DMG	Distilled monoglycerides
EFEMA	European Food Emulsifiers Manufacturers Association
EPE	Expanded polyethylene
EPS	Expanded polystyrene
FAC	Fatty acid composition
FDA	Food and Drug Administration
FPDF	Freezing point depression factor
HFCS	High fructose corn syrup
HLB	Hydrophile-Lipophile Balance
HPKO	Hydrogenated palm kernel oil
HPO	Hydrogenated palm oil
HPST	Hydrogenated palm stearin
HPST+FA	Hydrogenated palm stearin + fatty acid
HSBO	Hydrogenated soya bean oil
IBC	Intermediate bulk container

LACTEM	Lactic acid esters of mono and diglycerides
MDG	Mono- and diglycerides
MNC	Multinational companies
MSNF	Milk solids non-fat
ND	Not detected
NDC	Non-dairy creamer
PGE	Polyglycerol esters
PGME	Propylene glycol mono esters
PGMS	Propylene glycol mono stearates
Rel. S	Relative sweetness
SE MDG	Self emulsifying mono- and diglycerides
SEF	Solvent extractable fat
SMP	Skim milk powder
SMS	Sorbitan monostearate
SSL	Sodium stearoyl lactylates
STS	Sorbitan tristearate
SWP	Sweet whey powder

CHAPTER 1

INTRODUCTION

1.1 Research background

The global food emulsifier market is expected to grow at a growth rate estimated at 4 – 5% compound annual growth rate (CAGR) from 2014 to 2020, equivalent to USD 3.2 – 4.3 billion. The Asia Pacific (AP) food emulsifier market is anticipated to grow at a higher rate of 7 – 8% CAGR from 2014 to 2020. In 2014, the AP owned the largest food emulsifier market share at 34.4%, followed by Europe at 28.6% (Transparency Market Research, 2015). Among the food emulsifiers investigated, monoglycerides owns the biggest market volume and is the most commonly applied food emulsifier.

The increase in the consumption of food emulsifiers has been largely due to the increasing demand for packaged and convenience foods contributing to the expansion of the food manufacturing industry. There has also been increasing health awareness in consumers, creating market for reduced or low fat food which requires the use of food emulsifiers to aid in stabilising the food properties giving it the required shelf life. In addition, increasing numbers of consumers now seek for sensory sensation, pleasure and satiety when comes to food choices, for example when ice cream is being consumed (Transparency Market Research, 2015). All these factors have led to the need to increase food quality and preserve its properties throughout its shelf life. This could be achieved with the use of food emulsifiers.

Food system is typically a sophisticated matrix. This is the result of processing a combination of ingredients with different properties. For aerated foods, the matrix gets more complicated with increased numbers of ingredient types and processes. Ingredient types include the different surface active materials while processes are like aeration, heat or cool treatment. Several examples of the very common aerated food products consumed on a daily basis are cakes, breads and breakfast cereals, while examples of those consumed for sensory sensation include ice creams and carbonated soft drinks. These food products are so common that many consumers are not aware that they are aerated. Air in food is present in the form of air bubbles. The use of food emulsifiers in aerated foods help to ensure that these air bubbles are uniformly and finely distributed within the food matrix and stabilised throughout the products shelf life.

Emulsifiers are comprised of hydrophilic and lipophilic parts. One of the ways to classify food emulsifiers is by the charges of the hydrophilic part, which are non-ionic, anionic, cationic and amphoteric (Krog & Sparsø, 2004). Each of these has individually unique surface active properties. These emulsifiers could be present in solid format such as powder, beads, flakes or pellets, semi-solid format such as paste,

or in the liquid format, depending on its raw materials characteristics. Among all types, the non-ionic emulsifiers are the principal emulsifiers used in food products, particularly monoglycerides in powder format (Moonen & Bas, 2004).

Monoglycerides are the most versatile emulsifiers with its applications across a wide range of food products. This includes the bakery, dairy and non-dairy, edible oils and fats, confectionery, flour, savoury, and snacks. Similarly to triglycerides, monoglycerides are comprised of a glycerol backbone. One of the glycerol's hydroxyl groups is replaced with fatty acid compared to three in triglycerides. The fatty acid chain that is attached to the glycerol backbone is the key in determining the properties of the monoglycerides. The variations are mainly the carbon chain length and the degree of unsaturation. Monoglycerides are classified following its compositions into two categories, which are the mono- and diglycerides (MDG) and distilled monoglycerides (DMG) (Moonen & Bas, 2004). A MDG has lower monoglycerides content with high diglycerides compositions, while the main composition in DMG is monoglycerides and a minimal amount of diglycerides and impurities (Flack, 1976).

In the bakery industry, monoglycerides are added to impart softness and enhance volume of baked goods, for example in cakes. Optimum air incorporation into cake batter is critical in securing a good volume and texture during the final stage of baking (Conforti, 2006). Cake batter is conventionally prepared in two stages to incorporate maximum amount of air. This could now be done in single stage all-in method through the addition of cake emulsifiers in gel or powder format to obtain similar or more air incorporation. Both gel and powder format cake emulsifiers contain emulsifiers readily activated that are functional upon application. The gel format, commonly known as cake gel in the industry, is widely available and more economical compared to the powder system. The main emulsifier in cake gel is the monoglycerides (Moonen & Bas, 2004).

In the dairy and non-dairy industry, monoglycerides are used for its emulsion stabilisation effect but not in the case of ice cream. They are used in ice creams for emulsion destabilisation to achieve structure stabilisation. Monoglycerides destabilised ice cream mix emulsion by weakening fat globules surface membranes through displacing part of the adsorbed proteins. During shearing at freezing of ice cream mix, the weakened surface of fat globules collided and agglomerated forming fat aggregates. These fat aggregates layered on the air bubbles incorporated and stabilised the matrix of the ice cream structure. Monoglycerides are typically added along with stabilisers to make ice creams with desirable textural and organoleptic properties (Clarke, 2005).

Both cakes and ice creams are similarly an emulsion and foam at the intermediate stage prior transformed into the final texture. Cake batters are baked, where starch is gelatinised and protein denatured to form the final firm texture. Ice cream mix are frozen, where the water are converted into ice crystals. One main difference between both is the final structures and storage conditions. Aerated cake structure is

firmed and irreversible. Cakes are easily handled, stored and distributed at ambient. Whereas for ice creams, once the structure is developed, they require freezing to maintain the foamy matrix. This structure is vulnerably dependent on the handling in subsequent distribution channels and storage conditions. The structure of ice cream is generally irreversible, but there is a huge possibility that it would collapse if the cold chain is broken.

1.2 Problem statement

Putting aside the product composition, the variations of monoglycerides are the carbon chain length and degree of unsaturation. In the cake gel industry, the carbon chain length has been a focus to certain manufacturers. While in the ice cream industry, the degree of unsaturation has gained some highlight in recent years. An important point to note is that not all food manufacturers using monoglycerides are aware of these possible variations.

The major composition in cake gel is monoglycerides. The raw materials used to make monoglycerides decide its ultimate fatty acid composition. There have been perceptions by certain manufacturers that monoglycerides with high monostearin (C18) performs better than those of high monopalmitin (C16). This contradicts to literature reviews where Lagendijk and Pennings (1970) found that monopalmitin performed better than monostearin. Nonetheless, Lagendijk and Pennings (1970) concluded that both monopalmitin and monostearin were the two most active monoglycerides compared to any other carbon chain length. Commercial monoglycerides are typically a combination of monopalmitin and monostearin. The ratio of monopalmitin and monostearin is determined by the raw materials source. Palm source raw materials tend to give higher monopalmitin over monostearin compared to non-palm source.

Emulsifiers related ice cream researches have been comparing performances of different emulsifiers, such as monoglycerides against polysorbate 80. Little has been published about variations of monoglycerides, for instance monoglycerides of different degree of unsaturation. The most common emulsifier studied in ice creams is the saturated monoglycerides, some included polysorbate 80 as it is believed to enhance performances (Méndez-Velasco & Goff, 2012b; Granger et al., 2005b; Zhang & Goff, 2005; Relkin et al., 2003; Bolliger et al., 2000a; Goff, 1997; Gelin et al., 1994; Barfod et al., 1991). Over the years, the ice cream industry has settled with a blend of saturated monoglycerides and polysorbate 80 at a ratio of 4:1. While saturated monoglycerides are in solid form, polysorbate 80 is in liquid form. Blending the two at the ratio helps keep the emulsifier blend in solid format for convenient handling. The use of polysorbate 80 is strictly regulated in ice cream. A maximum dosage of only 0.10% in total formulation is allowed in the European Union countries. As Polysorbate 80 is present in liquid format, it fails to contribute to the desirable fat crystallisation during aging of ice cream mix (Goff & Hartel, 2013). As the combination of saturated monoglycerides and polysorbate 80 gave

some degree of unsaturation in the blend, it is worthwhile to investigate its performances against unsaturated monoglycerides.

The challenges faced by the ice cream industry are divided into two. The first within the manufacturers capacity, while the other within the distribution channels and retail landscape which are beyond the control of the ice cream manufacturers. Most consumers seek for sensation of coldness when consuming ice cream. Little pay attention to the structure and complexity of the ice cream matrix. Generally, it is fair to state that consumers' lack of knowledge in science of ice creams to appreciate its uniqueness. Not many are aware that a single digit change in temperature for a short time frame is sufficiently impactful to melt the ice crystals hence affects the quality of ice cream significantly. As such, analyses of the information collected during field work in the ice cream industry across the Asia Pacific (AP) region are structured. The data includes the ice cream composition and ingredients, typical quality concerns and challenges of the industry. These are based on experiences handling and troubleshooting production issues along with product development exercise with ice cream manufacturers across AP region. Nonetheless, the toughest challenge faced by the ice cream industry is at the distribution channel and retail landscape level.

1.3 Objectives

The aim of the study was to evaluate the performances of monoglycerides as an aerating agent in bakery and dairy applications. For bakery applications, monoglycerides were dosed into cake gel and applied to make sponge cake for performance evaluations. Cake gel is a common process ingredient in the cake industry. For dairy applications, ice cream was selected as the media to evaluate the performances of monoglycerides. The specific objectives of this study were:

i) To evaluate monoglycerides of different monopalmitin (C16:0) to monostearin (C18:0) ratios in cake gel and measure the effects of the cake gel at 2.5%, 5%, 7.5% egg weight on sponge cakes by measuring aeration performances in batter and cakes

ii) To evaluate monoglycerides of different degree of unsaturation in ice creams at 0.2%, 0.3% and 0.4% total weight and investigate the effects on aeration enhancement in ice creams

iii) To investigate effect of unsaturated monoglycerides against combination of saturated monoglycerides and polysorbate 80 at 80:20 on aeration enhancement in ice creams

iv) To evaluate and review ice cream markets, formulations, ingredients choices, typical quality concerns and challenges faced by the ice cream industry in the AP region

1.4 Scope of study

The current research focused on the use of monoglycerides as aerating agent and aimed to investigate if the types of monoglycerides affect the aeration rate or product performances. The types of monoglycerides were applications specific. The two applications selected were cakes and ice creams. Monoglycerides with the highest monoglycerides composition in powder format is used in bakery products. Therefore distilled monoglycerides (DMG) was used for cakes in the present study. Lower monoglycerides composition is required for ice creams, hence the mono- and diglycerides (MDG) was used. Nonetheless, they are all addressed as monoglycerides in the following discussions.

Monoglycerides require heat to activate its functionality, for example upon baking or pasteurisation. In cakes, its functionality is needed at batter preparation stage where no heat is involved. Therefore, cake gels were prepared at laboratory scale to transform monoglycerides into readily functional format, and applied into sponge cakes for aeration evaluation at cake batter and final product stage. In cakes, aeration capabilities of monoglycerides were measured directly. In ice creams, aeration is more complicated and measured indirectly through emulsion destabilisation or fat agglomeration rate. This was done through quantification of amount and size of fat aggregates formed as well as meltdown and heat shock resistance performance. All ice creams were made with 100% overrun as the amount of air incorporated has an impact on the meltdown resistance. The ice cream samples in the present study was prepared following the standard formulation applicable in the AP region although it did not meet the minimum 10% milk or vegetable fat level as stated in the Malaysian Food Regulations 1985.

The review chapters consist of analysis of the ice cream industry, comparison of ice creams formulations and ingredients, and data collected and summarised during market survey, troubleshooting production issues and product development exercises with ice cream manufacturers in the Asia Pacific countries such as Malaysia, Thailand, Indonesia, Philippines, and Australia. This was focused on the ice cream industry as ice creams are very vulnerable in contrast to cakes. The structure of cakes is irreversible, but the structure of ice creams would change following the cold chain conditions.

1.5 Significance of study

Triglycerides are source of making monoglycerides that determines the content of monopalmitin and monostearin. A monoglycerides with higher monopalmitin content could be obtained easily from palm raw materials, whereas monoglycerides with higher monostearin level most often needs triglycerides of non-palm source. The bakery application part of the study is important to support if palm based monoglycerides performed as good as non-palm based monoglycerides.

The dairy application part of the study focused on degree of unsaturation of the monoglycerides. In the recent years, unsaturated monoglycerides has surfaced for use in ice cream manufacturing for better performance over saturated monoglycerides. There is potential for unsaturated monoglycerides to impart benefits similar to when polysorbate 80 is used, which is worth an investigation. The analysis and review of ice cream industry was written following information collected during field experiences with great insights. In addition, it was hoped that the publication of these research chapters will help raise consumer awareness in appreciations to ice creams.

1.6 Scope of thesis

This thesis is written in a research chapter basis to adapt to the scope of research. Chapter 1 gives an overview of aerated food and emulsifiers in food applications as well as introduction to the research and thesis scope. Chapter 2 is literature review that gives a summary of aerated food and food emulsifiers, in particular monoglycerides. This chapter focused on cakes and ice creams, including the development of their structure, processing, compositions and properties.

Chapter 3 is divided into two parts. The first part covers study on applications of monoglycerides with different monopalmitin to monostearin ratio in cake gels applied into sponge cakes to investigate aeration performance. The second part covers the research on effects of saturated and unsaturated monoglycerides in ice creams, including the blend of saturated monoglycerides and polysorbate 80.

Chapter 4 reviews the ice cream industry in the AP region by analysing the ice creams markets, formulations and compositions variations by countries. This chapter includes a summary of typical quality concerns and technical challenges experienced by the ice cream manufacturers and industry. This chapter was written based on information and data collected from the field during product development and production or quality troubleshooting exercise with the ice creams manufacturers. They portray usage and knowledge application of monoglycerides for improving ice cream products and overcoming challenges of the ice cream industry.

The last chapter, Chapter 5, summarises all findings in the present study scope, and recommendations for future research work.

REFERENCES

Aleong, J. M., Frochot, S., & Goff, H. D. (2008). Ice recrystallisation inhibition in ice cream by propylene glycol monostearate. *Journal of Food Science, 73*(9), E463 - E468.

Amendola, J., & Rees, N. (2003). Chapter 14: Cake baking. In *Understanding Baking, 3rd edition: The art and science of baking* (pp. 187 - 205). New Jersey: John Wiley & Sons, Inc.

Anderson, D. (2005). A primer on oils processing technology. In F. Shahidi (Ed.), *Bailey's Industrial Oil and Fat Products, 6th edition. Volume 5: Edible Oil and Fat Products: Processing Technologies* (p. 33). New Jersey: John Wiley and Sons, In.

Arboleya, J.-C., García-Quiroga, M., Lasa, D., Oliva, O., & Luis-Aduriz, A. (2014). Effect of highly aerated food on expected satiety. *International Journal of Gastronomy and Food Science, 2*(1), 14 - 21.

Baik, O. D., Marcotte, M., & Castaigne, F. (2000). Cake baking in tunnel type multi-zone industrial ovens. Part I. Characterisation of baking conditions. *Food Research International, 33*, 587 - 598.

Barfod, N. M., & Sparsø, F. V. (2007). Structure and function of emulsifiers and their role in microstructure formation in complex foods. In D. J. McClements, *Understanding and Controlling the Microstructure of Complex Foods* (pp. 113 - 152). Cambridge: Woodhead Publishing Limited.

Barfod, N. M., Da Lio, M., & Christensen, F. H. (2005). *Patent No. WO 2005/060763 A1.* International Patent.

Barfod, N. M., Krog, N., Larsen, G., & Bucheim, W. (1991). Effects of emulsifiers on protein-fat interaction in ice cream mix during ageing I: Quantitative analyses. *European Journal of Lipid Science and Technology, 93*(1), 24 – 29.

Bennion, E. B., & Bamford, G. T. (1997). *The Technology of Cake Making, 6th Edition.* Dordrecht: Springer Science+Business Media.

Berger, K. G. (1997). Ice cream. In S. E. Friberg, & K. Larsson (Eds.), *Food Emulsions, 3rd edition* (pp. 413 - 490). New York: Marcel Dekker.

Bolliger, S., Goff, H. D., & Tharp, B. W. (2000a). Correlation between colloidal properties of ice cream mix and ice cream. *International Dairy Journal, 10*, 303 - 309.

Bolliger, S., Kornbrust, B., Goff, H. D., Tharp, B. W., & Windhab, E. J. (2000b). Influence of emulsifiers on ice cream produced by conventional freezing and low-temperature extrusion processing. *International Dairy Journal, 10*, 497 - 504.

Bruce, B. (2010). *Fraser & Neave takes Lion Nathan's King's Creameries*. Retrieved June 2, 2016, from http://www.foodbev.com/news/fraser-neave-takes-lion-nathans-kings-creameries/

Campbell, G. M., & Mougeot, E. (1999). Creation and characterisation of aerated food products. *Trends in Food Science and Technology, 10*, 283 - 296.

Carey, K. (2013). *Sara Lee acquisition the 'cherry on top' for McCain Foods*. Retrieved June 2, 2016, from http://ausfoodnews.com.au/2013/02/07/sara-lee-acquisition-the-cherry-on-top%E2%80%99-for-mccain-foods.html

Chang, Y., & Hartel, R. W. (2002). Development of air cells in a batch ice cream freezer. *Journal of Food Engineering, 55*, 71 - 78.

Chesterton, A. S., Pereira de Abreu, D. A., Moggridge, G. D., Sadd, P. A., & Wilson, D. I. (2013). Evolution of cake batter bubble structure and rheology during planetary mixing. *Food and Bioproducts Processing, 91*, 192 - 206.

Clarke, C. (2005). *The Science of Ice Cream.* Cambridge: The Royal Society of Chemistry.

Codex Alimentarius. (2015). *CODEX STAN 210-1999: Codex Standard for Named Vegetable Oils.* Retrieved July 5, 2016, from http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCODEX%2BSTAN%2B210-1999%252FCXS_210e_2015.pdf

Conforti, F. D. (2006). Cake Manufacture. In Y. H. Hui (Ed.), *Bakery Science: Science and Technology* (pp. 393 - 410). Iowa: Blackwell Publishing.

Cook, K. K., & Hartel, R. W. (2010). Mechanisms of ice crystallisation in ice cream production. *Comprehensive Review in Food Science and Food Safety, 9*, 213 - 222.

Cottrell, T., & Peij, J. (2004). Sorbitan esters and polysorbates. In R. J. Whitehurst (Ed.), *Emulsifiers in Food Technology* (pp. 162 - 185). Oxford: Blackwell Publishing.

Cropper, S. L., Kocaoglu-Vurma, N. A., Tharp, B. W., & Harper, W. J. (2013). Effects of locust bean gum and mono- and diglycerides concentrations on particle size and melting rates of ice cream. *Journal of Food Science, 78*(6), C811 - C816.

Davies, E., Dickinson, E., & Bee, R. D. (2001). Orthokinetic destabilisation of emulsions by saturated and unsaturated monoglycerides. *International Dairy Journal, 11*, 827 - 836.

Daw, E., & Hartel, R. W. (2015). Fat destabilisation and melt-down of ice creams with increased protein content. *International Dairy Journal, 43*, 33 - 41.

Edoura-Gaena, R. B., Allais, I., Trystram, G., & Gros, J. B. (2007). Influence of aeration conditions on physical and sensory properties of aerated cake batter and biscuits. *Journal of Food Engineering, 79*(3), 1020–1032.

Edwards, W. P. (2007). *The Science of Bakery Products.* Cambridge: RSC Publishing.

El-Rahman, A. A., Madkor, S. A., Ibrahim, F. S., & Kilara, A. (1997). Physical characteristics of frozen desserts made with cream, anhydrous milk fat, or milk fat fractions. *Journal of Dairy Science, 80*, 1926 – 1935.

European Food Emulsifier Manufacturing Associations (EFEMA). (2013). *EFEMA index of food emulsifiers.* Brussels: EFEMA.

Faergemand, M., & Krog, N. (2003). Using emulsifiers to improve food texture. In B. M. McKenna (Ed.), *Texture in Food* (Vols. Semi-solid foods, pp. 216 - 250). Cambridge: Woodhead Publishing Ltd.

Faergemand, M., & Krog, N. (2006). Interactions of emulsifiers with other components in foods. In A. G. Gaokar, & A. McPherson (Eds.), *Ingredient Interactions: Effects on Food Quality* (pp. 389 - 421). Florida: Taylor & Francis Group.

Federal Register of Legislation Australia. (2015). *Australia New Zealand Food Standards Code – Standard 2.5.6 – Ice cream*. Retrieved August 4, 2016, from https://www.legislation.gov.au/Details/F2015L00424

Flack, E. A. (1976). Monoglycerides and their derivatives - Production and utilisation. *International Flavours and Food Additives, 7*(3), 104, 106 - 108, 110.

Flores, A. A., & Goff, H. D. (1999a). Ice crystal size distributions in dynamically frozen model solutions and ice cream as affected by stabilisers. *Journal of Dairy Science, 82*, 1399 - 1407.

Flores, A. A., & Goff, H. D. (1999b). Recrystallisation in ice cream after constant and cycling temperature storage conditions as affected by stabilisers. *Journal of Dairy Science, 82*, 1408 - 1415.

Fonterra Co-operative Group. (n.d.). Product Bulletin: Anhydrous Milkfat (AMF) GDT Regular Grade [Version 7.08.12]. Fonterra NZ and Australia.

Gelin, J. L., Poyen, L., Courthaudon, J. L., Le Meste, M., & Lorient, D. (1994). Structural changes in oil-in-water emulsions during the manufacture of ice cream. *Food Hydrocolloids, 8*(3 - 4), 299 – 308.

Gisslen, W. (2005). *Professional Baking* (Fourth ed.). New Jersey: John Wiley & Sons.

Goff, H. D. (1997). Instability and partial coalescence in whippable dairy emulsions. *Journal of Dairy Science, 80*, 2620 - 2630.

Goff, H. D. (2006). Ice Cream. In P. F. Fox, & P. H. McSweeney (Eds.), *Advanced Dairy Chemistry, Volume 2: Lipids, 3rd edition* (pp. 441 - 450). New York: Springer.

Goff, H. D., & Hartel, R. W. (2013). *Ice Cream* (Seventh ed.). New York: Springer Science + Business Media.

Goff, H. D., Liboff, M., Jordan, W. K., & Kinsella, J. E. (1987). The effects of polysorbate 80 on the fat emulsion in ice cream mix: Evidence from transmission electron microscopy studies. *Food Microstructure, 6*, 193 - 198.

Goff, H. D., Verespej, E., & Smith, A. K. (1999). A study of fat and air structures in ice cream. *International Dairy Journal, 9*(11), 817 - 829.

Golding, M. (2012). Interfacial phenomena in structured foods. In B. Bhandari, & Y. H. Roos (Eds.), *Food Materials Science and Engineering* (pp. 94 - 135). West Sussex: Blackwell Publishing Ltd.

Gómez, M., Ronda, F., Caballero, P. A., Blanco, C. A., & Rosell, C. M. (2007). Functionality of Different Hydrocolloids on the Quality and Shelf-Life of Yellow Layer Cakes. *Food Hydrocolloids, 21*, 167 - 173.

Granger, C., Leger, A., Barey, P., Langendorff, V., & Cansell, M. (2005a). Influence of formulation on the structural networks in ice cream. *International Dairy Journal, 15*, 255 - 262.

Granger, C., Schöppe, A., Leger, A., Barey, P., & Cansell, M. (2005b). Influene of formulation on the thermal behaviour of ice cream mix and ice cream. *Journal of the American Oil Chemists' Society, 82*(6), 427 - 431.

Hartel, R. W. (1996). Ice crystallisation during the manufacture of ice cream. *Trends in Food Science & Technology, 7*, 315 - 321.

Hasenhuettl, G. L. (2008). Synthesis and commercial preparation of food emulsifiers. In G. L. Hasenhuettl, & R. W. Hartel (Eds.), *Food Emulsifiers and Their Applications* (pp. 11 - 38). New York: Springer Science+Business Media.

Heertje, I., Roijers, E. C., & Hendrickx, H. (1998). Liquid Crystalline Phases in the Structuring of Food Products. *LWT - Food Science and Technology, 31*(4), 387 – 396.

Hyvönen, L., Linna, M., Tuorila, H., & Dijksterhuis, G. (2003). Perception of melting and fllavor release of ice cream containing different types and contents of fat. *Journal of Dairy Science, 86*, 1130 - 1138.

ICI Americas, Inc. (1980). *The HLB System: A time-saving guide to emulsifier selection.* Wilmington: ICI Americas, Inc.

Innocente, N., Biasutti, M., Venir, E., Spaziani, M., & Marchesini, G. (2009). Effect of high pressure homogenisation on droplet size distribution and rheological properties of ice cream mixes. *Journal of Dairy Science, 92*, 1864 - 1975.

International Law Book Series. (2006). *Food Act 1983 (Act 281) & Regulations (As at 1st March 2006).* Kuala Lumpur: Percetakan Maziza Sdn Bhd.

Koxholt, M. R., Eisenmann, B., & Hinrichs, J. (2001). Effect of the fat globule sizes on the meltdown of ice cream. *Journal of Dairy Science, 84*, 31 - 37.

Krog, N. (1977). Functions of emulsifiers in food systems. *Journal of the American oil Chemists' Society, 54*, 124 - 131.

Krog, N., & Larsson, K. (1968). Phase behavior and rheological properties of aqueous systems of industrial distilled monoglycerides. *Chemistry and Physics of Lipids, 2*, 129 - 143.

Krog, N., & Sparsø, F. V. (2004). Food Emulsifiers: Their Chemical and Physical Properties. In S. E. Friberg, K. Larsson, & J. Sjöblom (Eds.), *Food Emulsions, 4th edition.* New York: Marcel Dekker Inc.

Lagendijk, J., & Pennings, H. J. (1970). Interaction of monoglycerides in different physical states with amylose and their anti-firming effects in bread. *Cereal Science Today, 15*, 354.

Lallemand Inc. (1996). *Lallemand Baking Update: Chemical Leaveners.* Retrieved July 26, 2016, from http://www.lallemand.com/BakerYeastNA/eng/PDFs/LBU%20PDF%20FILES/1_12CHEM.PDF

Lallemand Inc. (2000). *Lallemand Baking Update: Cakes and Muffins.* Retrieved July 20, 2016, from http://www.lallemand.com/BakerYeastNA/eng/PDFs/LBU%20PDF%20FILES/2_17CAKE.PDF

Langley, S. (2014). *Peters Ice Cream sold to UK-based R&R Ice Cream*. Retrieved May 28, 2016, from http://ausfoodnews.com.au/2014/05/28/peters-ice-cream-sold-to-uk-based-rr-ice-cream.html

Larsson, K., Fontell, K., & Krog, N. (1980). Structural relationships between lamellar, cubic and hexagonal phases in monoglyceride-water systems. possibility of cubic structures in biological systems. *Chemistry and Physics of Lipids, 27*, 321 - 328.

LeBail, A., & Goff, H. D. (2008). Freezing of Bakery and Dessert Products. In J. A. Evans (Ed.), *Frozen Food Science and Technology* (pp. 184 - 204). Oxford: Blackwell Publishing.

Leducq, D., NDoye, F. T., & Alvarex, G. (2015). Phase change material for the thermal protection of ice cream during storage and transporation. *International Journal of Refrigeration, 52*, 133 - 139.

Méndez-Velasco, C., & Goff, H. D. (2012a). Fat structure in ice cream: A study on the types of fat interactions. *Food Hydrocolloids, 29*, 152 - 159.

Méndez-Velasco, C., & Goff, H. D. (2012b). Fat structures as affects by unsaturated or saturated monoglyceride and their effect on ice cream structure, texture and stability. *International Dairy Journal, 24*, 33 - 39.

Minister of Agriculture and Agri-Food Canada. (2012). *Consumer Trends - Ice Cream in the United Arab Emirates*. Retrieved August 4, 2016, from http://www.agr.gc.ca/eng/industry-markets-and-trade/statistics-and-market-information/agriculture-and-food-market-information-by-region/middle-east-and-africa/consumer-trends-ice-cream-in-the-united-arab-emirates/?id=1410083148795

Mintel. (2015). *Ice Cream - Malaysia.* Mintel Group Ltd.

Moonen, H., & Bas, H. (2004). Mono- and Diglycerides. In R. J. Whitehurst (Ed.), *Emulsifiers in Food Technology* (pp. 40 - 58). Oxford: Blackwell Publishing.

Munk, M. B., Marangoni, A. G., Ludvigsen, H. K., Norn, V., Knudsen, J. C., Risbo, J., Andersen, M. L. (2013). Stability of whippable oil-in-water emulsions: Effect of monoglycerides on crystallisation of palm kernel oil. *Food Research International, 54*, 1738 - 1745.

Muse, M. R., & Hartel, R. W. (2004). Ice cream structural elements that affect melting rate and hardness. *Journal of Dairy Science, 87*, 1 - 10.

Nesvadba, P. (2008). Thermal properties and ice crystal development in frozen foods. In J. A. Evans (Ed.), *Frozen Food Science and Technology* (pp. 1 - 25). Oxford: Blackwell Publishing.

Norn, V. C., & Ludvigsen, H. K. (2010). *Patent No. US 2010/0092644 A1*. USA.

Orthoefer, F. (2008). Applications of Emulsifiers in Baked Foods. In G. L. Hassenhuettl, & R. W. Hartel (Eds.), *Food Emulsifiers and Their Applications* (pp. 279 - 281). New York: Springer Science + Business Media.

Pelan, B. C., Watts, K. M., Campbell, I. J., & Lips, A. (1997). The stability of aerated milk protein emulsions in the presence of small molecule surfactants. *Journal of Dairy Science, 80*(10), 2631 - 2638.

Peters Ice Cream. (2014). *Sustainability*. Retrieved June 2, 2016, from http://www.peters.com.au/peters-corporate/sustainability/

Regand, A., & Goff, H. D. (2006). Ice recrystallization inhibition in ice cream as affected by ice structuring proteins from winter wheat grass. *Journal of Dairy Science, 89*(1), 49 - 57.

Relkin, P., Sourdet, S., & Fosseux, P. Y. (2003). Fat crystallisation in complex food emulsions – Effects of adsorbed milk proteins and of a whipping process. *Journal of Thermal Analysis and Calorimetry , 71*, 187 - 195.

Research and Markets. (2014). *Ice Cream in Asia-Pacific*. Retrieved August 2, 2016, from

http://www.researchandmarkets.com/reports/2505306/ice_cream_in_asiapacific.pdf

Richardson, G., Langton, M., Fäldt, P., & Hermansson, A. M. (2002). Microstructure of α-Crystalline Emulsifiers and Their Influence on Air Incorporation in Cake Batter. *Cereal Chemistry, 79*(4), 546 - 552.

Ruger, P. R., Baer, R. J., & Kasperson, K. M. (2002). Effect of double homogenisation and whey protein concentrate on the texture of ice cream. *Journal of Dairy Science, 85*, 1684 - 1692.

Sahi, S. S., & Alava, J. M. (2003). Functionality of emulsifiers in sponge cake Production. *Journal of the Science of Food and Agriculture, 83*, 1419 - 1429.

Schlegel, M., & Vieira, J. B. (2009). *Patent No. EP1584241 B1*. Europe.

Schmidt, K. A. (2004). Dairy: Ice Cream. In J. S. Smith, & Y. H. Hui (Eds.), *Food Processing Principles and Applications* (pp. 287 - 296). Iowa: Blackwell Publishing.

Scholten, E. (2014). Ice Cream. In H. G. Merkus, & G. H. Meesters (Eds.), *Particulate Products: Tailoring Properties for Optimal Performance* (pp. 273 - 294). Springer International Publishing Switzerland.

Segall, K. I., & Goff, H. D. (2002). A modified ice cream processing routine that promotes fat destabilisation in the absence of added emulsifier. *International Dairy Journal, 12*, 1013 - 1018.

Sein, A., Verheij, J. A., & Agterof, W. M. (2002). Rheological characterization, crystallization, and gelation behavior of monoglyceride gels. *Journal of Colloid and Interface Science, 249*, 412 - 422.

Silva Junior, E., & Lannes, S. S. (2011). Effect of different sweetener blends and fat types on ice cream properties. *Ciência e Tecnologia de Alimentos, 31*(1), 217 - 220.

Sofjan, R. P., & Hartel, R. W. (2004). Effects of overrun on structural and physical characteristics of ice cream. *International Dairy Journal, 14*, 255 - 262.

Spagnuolo, P., Dalgleish, D. G., Goff, H. D., & Morris, E. R. (2005). Kappa-carrageenan interactions in systems containing casein micelles and polysaccharide stabilizers. *Food Hydrocolloids, 19*, 371 - 377.

Stauffer, C. E. (2005). Emulsifiers for the food industry. In F. Shahidi (Ed.), *Bailey's Industrial Oil and Fat Products, 6th Edition* (pp. 229 - 267). New Jersey: Wiley-Interscience.

Sung, K. K., & Goff, H. D. (2010). Effect of solid fat content on structure in ice creams containing palm kernel oil and high oleic sunflower oil. *Journal of Food Science, 75*(3), C274 – C279.

Suriya, P., Gan, C., Hu, B., & Cohen, D. A. (2013, August). *The impacts of the Thailand-Australia Free Trade Agreement and Thailand-New Zealand Closer Economic Partnership on Thailand dairy import prices. Faculty of Commerce Working Paper No. 3.* Retrieved May 20, 2016, from https://researcharchive.lincoln.ac.nz/bitstream/handle/10182/5610/FoC_wp_03.pdf?sequence=1

Tan, M. C., Chin, N. L., Yusof, Y. A., & Abdullah, J. (2016). Novel 2D and 3D imaging of internal aerated structure of ultrasonically treated foams and cakes using X-ray tomography and X-ray microtomography. *Journal of Food Engineering, 183*, 9 -15.

Tetra Pak. (1996). Whey Processing. In *Dairy Processing Handbook* (pp. 331 - 352). Sweden: Tetra Pak Processing Systems AB.

Tetra Pak International S.A. (n.d.). *Tetra Pak® Continuous Freezer LT – low temperature second stage ice cream freezers*. Retrieved Dec 19, 2016, from http://www.tetrapak.com/processing/freezing/tetra-pak-continuous-freezer-lt

Tharp, B. W., & Young, L. S. (2013). *Tharp & Young on Ice Cream: An Encyclopedic Guide to Ice Cream Science and Technology.* Lancaster: Destech Publications, Inc.

Tosaki, M., Kitamura, Y., Satake, T., & Tsurutani, T. (2009). Effects of homogenisation conditions on the physical properties of high-fat ice cream. *International Journal of Dairy Technology, 62*(4), 577 - 583.

Transparency Market Research. (2015). *Food Emulsifier Market By Product Types - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2015 - 2021*. Retrieved July 14, 2016, from http://www.transparencymarketresearch.com/food-emulsifier-market.html

Underdown, J., Quail, P. J., & Smith, K. W. (2011). Saturated fat reduction in ice cream. In G. Talbot (Ed.), *Reducing saturated fats in foods* (pp. 350 – 369). Cambridge: Woodhead Publishing Limited.

Unilever. (2016). *The Philippines' number one ice cream brand*. Retrieved June 2, 2016, from https://www.unilever.com.ph/brands/our-brands/selecta.html

University of Guelph. (n.d.). *The Ice Cream eBook - Colloidal aspects of ice cream*. Retrieved October 8, 2016, from https://www.uoguelph.ca/foodscience/book-page/colloidal-aspects-ice-cream-structure

US FDA. (1992). *§184.1505 Mono- and diglycerides.* Retrieved July 14, 2016, from http://www.ecfr.gov/cgi-bin/text-idx?SID=daa6f8e463d74d81571ceec94befc336&mc=true&node=se21.3.184_11505&rgn=div8

Van de Walle, D., Goossens, P., & Dewettinck, K. (2008a). Influence of sodium soap and ionic strength on the mesomorphic behavior and the α-gel stability of a commercial distilled monoglyceride. *Food Research International, 41*, 247 - 254.

Van de Walle, D., Goossens, P., & Dewettinck, K. (2008b). Influence of the polarity of the water phase on the mesomorphic behavior and the α-gel stability of a commercial distilled monoglyceride. *Food Research International, 41*, 1020 – 1025.

Varela, P., Pintor, A., & Fiszman, S. (2014). How hydrocolloids affect the temporal oral perception of ice cream. *Food Hydrocolloids, 36*, 220 - 228.

Vega, C., Dalgleish, D. G., & Goff, H. D. (2005). Effect of k-carrageenan addition to dairy emulsions containing sodium caseinate and locust bean gum. *Food Hydrocolloids, 19*, 187 - 195.

Vereecken, J., Meeussen, W., Foubert, I., Lesaffer, A., Wouters, J., & Dewettinck, K. (2009). Comparing the crystallization and polymorphic behavior of saturated and unsaturated monoglycerides. *Food Research International, 42*, 1415 - 1425.

Weyland, M., & Hartel, R. (2008). Emulsifiers in Confectionery. In G. L. Hasenhuettl, & R. W. Hartel (Eds.), *Food Emulsifiers and Their Applications* (pp. 285 - 305). New York: Springer Science+Business Media, LLC.

Zhang, Z., & Goff, H. D. (2004). Protein distribution in air interfaces in dairy foams and ice cream as affected by casein dissociation and emulsifiers. *International Dairy Journal, 14*, 647 - 657.

Zhang, Z., & Goff, H. D. (2005). On fat destabilisation and composition of the air interface in ice cream containing saturated and unsaturated monoglycerides. *International Dairy Journal, 15*, 495 - 500.