



**UNIVERSITI PUTRA MALAYSIA**

**CRYSTALLIZATION BEHAVIOR OF PALM OIL BLENDS AND PALM  
OIL-BASED FLUID SHORTENINGS**

**MISKANDAR MAT SAHRI**

**FSTM 2006 22**

**CRYSTALLIZATION BEHAVIOR OF PALM OIL BLENDS AND PALM  
OIL-BASED FLUID SHORTENINGS**

**By**

**MISKANDAR MAT SAHRI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia  
In Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**December 2006**



## **DEDICATION**

Especially dedicated to my beloved wife Hajjah Hanirah Hassan  
and children  
Hajar Marhamah, Muhammad Hanif, Hayati Munirah, Hanis Muslimah,  
Muhammad Halim and Muhammad Azim .....



Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in  
fulfilment of the requirements for the Degree of Doctor of Philosophy

**CRYSTALLIZATION BEHAVIOR OF PALM OIL BLENDS AND PALM  
OIL-BASED FLUID SHORTENINGS**

By

**MISKANDAR MAT SAHRI**

**December 2006**

**Chairman: Professor Yaakob Bin Che Man, PhD**

**Faculty: Food Science and Technology**

This thesis covers the establishment of palm oil-based fluid shortening production by investigating the static and dynamic crystallization behaviors of palm oil blends with and without emulsifier at various temperature treatments. Solid fat content (SFC), crystal size and distribution, fatty acid content (FAC) and triacylglycerol (TAG) composition of the palm oil blends were determined and analyzed using ANOVA at 95% confidence level. Palm oil-based fluid shortening formulation, emulsifier and stirring speed were optimized using response surface methodology (RSM) based on the storage study that included SFC, viscosity, pourability and crystal size and distribution.



Crystal development of the blends as a function of time had developed crystallization curves that demonstrated distinct steps corresponding to crystallization stages due to the occurrence of mixed crystallization. Slow crystallization without emulsifier was influenced by the total saturated FAC, with significant ( $P < 0.05$ ) changes in SFC, crystal distribution and viscosity. Lecithin at 0.03% was generally a crystal promoter; however, at 0.06 and 0.09% it acted as a crystal inhibitor. STS was generally a crystal inhibitor at 0.03, 0.06 and 0.09%. Temperature cycling processes at Cycle 3 had caused the blends with slip melting points (SMP) of 26.5 - 33.5°C to crystallize forming uniform crystal aggregates. Crystal size of blends with emulsifier was significantly increased as the temperature cycling was reduced and the emulsifier content was increased. However, blends with 0.03 and 0.06% lecithin and 0.09% STS had low viscosities. Blends of SMP 21.6 - 26.5°C with 0.09% STS and 0.03% lecithin formed crystal aggregates ranging from 10 – 40  $\mu\text{m}$  and produced low SFCs. The model developed by RSM comprising of 20 - 23% palm oil, 77 - 80% palm olein, 0.02-0.06% lecithin and crystallized at stirring speed of 150 – 300 RPM had established palm oil-based fluid shortenings stable at storage of 25 – 30°C for three weeks. It is concluded that the size of the crystal aggregates and their distribution in the bulk, were important factors contributing to palm oil-based fluid shortening to flow.



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

**SIFAT PENGHABLURAN ADUNAN MINYAK SAWIT DAN LELEMAK  
CECAIR BERASASKAN MINYAK SAWIT**

Oleh

**MISKANDAR MAT SAHRI**

**Disember 2006**

**Pengerusi: Profesor Yaakob Bin Che Man, PhD**

**Fakulti: Sains dan Teknologi Makanan**

Tesis ini melaporkan kajian yang dijalankan untuk menghasilkan lelemak cecair berasaskan sawit yang merangkumi hasil kajian penghabluran dinamik dan statik adunan minyak sawit dengan bahan tambah pengemulsi atau tanpa pengemulsi dengan perlakuan pada pelbagai suhu. Kandungan lemak pepejal (SFC), saiz dan penyerakan hablur, kandungan asid lemak (FAC) dan komposisi triasilgliserol (TAG) adunan minyak sawit telah dianalisis menggunakan ANOVA pada tahap keyakinan 95%. Formulasi lelemak cecair berasaskan minyak sawit, bahan pengemulsi dan kelajuan adukan telah dioptimakan menggunakan 'response surface methodology (RSM)' berasaskan kajian penstoran yang melibatkan SFC, kelikatan, kebolehtuangan dan saiz dan penyerakan hablur.



Keluk pembinaan hablur adunan minyak sawit melawan fungsi masa jelas menghasilkan keluk bertangga yang berkaitan dengan tahap-tahap penghabluran yang terhasil daripada penghabluran berbaur. Penghabluran secara perlahan-lahan tanpa bahan pengemulsi dipengaruhi oleh jumlah asid lemak tepu dengan perubahan ketara ( $P < 0.05\%$ ) dalam SFC, penyerakan hablur dan kelikatannya. Lesitin pada 0.03% telah merangsang pembinaan hablur, walau bagaimanapun pada 0.06 dan 0.09% ia menghalang penghabluran. STS pula pada umumnya adalah penghalang penghabluran pada 0.03, 0.06 dan 0.09%. Proses kitaran suhu pada Kitaran 3 telah menyebabkan adunan yang mempunyai julat takat lebur 26.5 - 33.5°C menghablur dan membentuk agregat-agregat hablur yang seragam. Peningkatan saiz hablur pada adunan-adunan yang ditambah bahan pengemulsi adalah ketara apabila suhu kitaran direndahkan manakala kandungan bahan pengemulsi ditingkatkan. Walaupun demikian, adunan-adunan yang mengandungi 0.03 dan 0.06% lesitin dan 0.09% STS mempunyai kelikatan yang rendah. Adunan dengan SMP 21.6 - 26.5°C ditambah 0.09% STS atau 0.03% lesitin membentuk agregat-agregat hablur bersaiz dalam julat 10 – 40  $\mu\text{m}$  dan menghasilkan SFC yang rendah. Model yang terhasil melalui RSM yang mengandungi 20 – 23% minyak sawit, 80 – 77% minyak olein sawit, 0.02 – 0.06% lesitin dan kelajuan putaran adukan dalam julat 150 - 300  $\text{pus}/\text{min}$  telah menghasilkan lelemak cecair berasaskan minyak sawit yang stabil pada julat suhu penyimpanan 25 – 30°C selama tiga minggu. Sebagai kesimpulan, saiz agregat hablur dan penyerakannya di dalam pukalan, merupakan faktor terpenting yang mempengaruhi kebolehtuangan lelemak cecair.



## ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Professor Dr. Yaakob Bin Che Man, the chairman of my Supervisory Committee for his kind assistance, advice and encouragement during the preparation of this thesis. I am so grateful to the other members of the Supervisory Committee, Professor Dr. Russly Bin Abd. Rahman, Dr Nor Aini Idris of the Malaysian Palm Oil Board (MPOB) and Dr. Mohd Suria Affandi Bin Yusoff of Golden Hope Research Centre, Banting, Selangor, for their guidance, support and comments.

I would like to acknowledge the Ministry of Science Technology and Innovation for financing this research program, MPOB for granting my study leave and for the support on research materials and equipments. I would like to acknowledge the staff in the Oil and Fat Technology Centre, MPOB namely En Radzuan Hussein, En Suid Aziz, En Ahmad Hisham for their assistance during my work in the margarine laboratory, Cik Ramlah Ahmad who had assisted me during my work on Nuclear Magnetic Resonance, Che Maimun for Differential Scanning Calorimetry and Che Zulkarinah Kamaruddin for assisting me during my work on x-ray diffractometer.

Last but not least, I would like to express my heartiest appreciation to my beloved wife Hanirah Hassan and children for their moral support, encouragement, patience and understanding throughout my studies.





I certify that an Examination Committee met on 18<sup>th</sup> December 2006 to conduct the final examination of Miskandar Mat Sahri on his Doctor of Philosophy thesis entitled “Crystallization Behavior of Palm Oil Blends and Palm Oil-Based Fluid Shortenings” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

**Hasanah Mohd Ghazali, PhD**

Professor  
School of Graduate Studies  
Universiti Putra Malaysia  
(Chairman)

**Tan Chin Ping, PhD**

Lecturer  
Faculty of Food Science and Technology  
Universiti Putra Malaysia  
(Internal Examiner)

**Azis Ariffin, PhD**

Associate Professor  
Faculty of Food Science and Technology  
Universiti Putra Malaysia  
(Internal Examiner)

**Fereidoon Shahidi, PhD**

Professor  
Faculty of Science  
Memorial University of Newfoundland, Canada  
(External Examiner)

---

**HASANAH MOHD GHAZALI, PhD**

Professor /Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 20<sup>th</sup> February 2007



This thesis submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

**Yaakob Che Man, PhD**

Professor  
Faculty of Food Science and Technology  
Universiti Putra Malaysia  
(Chairman)

**Russly Abd Rahman, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Nor Aini Idris, PhD**

Principal Research Officer  
Malaysian Palm Oil Board (MPOB)  
(Member)

**Mohd. Suria Affandi Yusoff, PhD**

Chief Research Officer  
Golden Hope, Malaysia  
(Member)

---

**AINI IDERIS, PhD**

Professor / Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:



## DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or currently submitted for any other degree at UPM or other institutions.

---

**MISKANDAR MAT SAHRI**

Date:



## TABLE OF CONTENTS

	<b>Page</b>
<b>DEDICATION</b>	ii
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	v
<b>ACKNOWLEDGEMENTS</b>	vii
<b>APPROVAL</b>	x
<b>DECLARATION</b>	xiv
<b>LIST OF TABLES</b>	xvi
<b>LIST OF FIGURES</b>	xx
<b>LIST OF ABBREVIATIONS</b>	xxvi

<b>CHAPTER</b>		<b>Page</b>
1	<b>GENERAL INTRODUCTION</b>	1
2	<b>LITERATURE REVIEW</b>	6
	2.1 History of Shortening	7
	2.2 Types of Shortenings	8
	2.2.1 Plasticized Semi-solid Shortening	9
	2.2.2 Fluid and Liquid Shortenings	9
	2.2.3 Powdered, Flakes, or Beads Shortening	11
	2.3 Oils and Fats	12
	2.3.1 Physical and Chemical Characteristics of Oils and Fats	12
	2.3.2 Formulation of Oils and Fats	21
	2.4 Physical Characteristics of Solid and Fluid Shortenings	29
	2.4.1 Consistency and Theology	30
	2.4.2 Fluidity / Pour ability	31
	2.4.3 Liquid Oil Separation	34
	2.4.4 Dynamic Viscosity	34
	2.5 Crystallization Theory	35
	2.5.1 Crystallization of Oils and Fats	36
	2.5.2 Solidification	37
	2.5.3 Isothermal Crystallization	39
	2.5.4 Dynamic Crystallization	40
	2.5.5 Polymorphism	41
	2.5.6 Polymorphic Form and Crystal Size	43
	2.6 Emulsifiers	48
	2.6.1 Characteristics of Emulsifiers	49
	2.6.2 Lecithin	52
	2.6.3 Sorbitan Tristearate	55



	2.6.4	Functions of Emulsifiers	56
	2.6.5	Mechanism of Crystal Inhibition	58
2.7		Application of Fluid Shortening	60
	2.7.1	Frying	60
	2.7.2	Bread and Cake	61
	2.7.3	Non-dairy	62
2.8		Various Methods in Fluid Shortening	
		Production	62
	2.8.1	Batch Process in Crystallization Vessel	63
	2.8.3	Product Monitoring	65
2.9		Relevant Patents on Shortening	67
<b>3</b>		<b>ISOTHERMAL CRYSTALLIZATION OF PALM OIL BLENDS: EFFECTS OF TEMPERATURE, COOLING TIME AND OIL CONTENT</b>	<b>69</b>
	3.1	Introduction	69
	3.2	Materials and Methods	71
	3.2.1	Materials	71
	3.2.2	Physical and chemical analyses	71
	3.2.3	Statistical Analysis	73
	3.3	Results and Discussion	74
	3.3.1	SFC Profile of Palm Oil Blends	74
	3.3.2	SFC of Palm Oil Blends at Isothermal Temperatures	77
	3.3.3	Distribution of Crystals at Isothermal Temperatures	85
	3.4	Conclusions	89
<b>4</b>		<b>EFFECTS OF EMULSIFIERS ON CRYSTAL BEHAVIOR OF PALM OIL BLENDS ON SLOW CRYSTALLIZATION</b>	<b>91</b>
	4.1	Introduction	91
	4.2	Materials and Methods	93
	4.2.1	Materials	93
	4.2.2	Physical Analyses	93
	4.2.3	Statistical Analysis	95
	4.3	Results and Discussions	95
	4.3.1	Slow Crystallization of Palm Oil Blends without Emulsifiers	95
	4.3.2	Crystal Distribution at Slow Crystallization without Emulsifiers	97
	4.3.3	SFC, Viscosity and Crystal Behavior without Emulsifiers	100
	4.3.4	SFC of Palm Oil Blends with Emulsifiers	103
	4.3.5	Crystal Behavior of Palm Oil Blends with Lecithin	105



4.3.6	Relationship of Viscosity and SFC in Palm Oil Blends with Lecithin	107
4.3.7	Crystal Behavior of Palm Oil Blends with STS	108
4.3.8	Relationship of Viscosity and SFC in Palm Oil Blends with STS	109
4.4	Conclusions	114
5	<b>EFFECTS OF EMULSIFIERS ON CRYSTALLIZATION PROPERTIES OF LOW MELTING PALM OIL BLENDS</b>	116
5.1	Introduction	116
5.2	Materials and Methods	118
5.2.1	Materials	118
5.2.2	Physical Analyses	118
5.2.3	Statistical Analysis	119
5.3	Results and Discussions	120
5.3.1	SFC and Crystallization without an Emulsifier	120
5.3.2	Relationship between SFC and Viscosity	125
5.3.3	Effect of Lecithin on SFC	126
5.3.4	Effect of Lecithin on Viscosity	127
5.3.5	Effect of Lecithin on Crystal Distribution	129
5.3.6	Effect of STS on SFC	132
5.3.7	Effect of STS on Viscosity	133
5.3.8	Effect of STS on Crystal Distribution	134
5.4	Conclusions	135
6	<b>EFFECTS OF CYCLIC TEMPERATURE ON STATIC CRYSTALLIZATION OF FLUIDIZED PALM OIL BLENDS</b>	136
6.1	Introduction	136
6.2	Materials and Methods	138
6.2.1	Materials	138
6.2.2	Methods	138
6.2.3	Statistical Analysis	140
6.3	Results and Discussions	140
6.3.1	Chemical Composition	140
6.3.2	Effects of Cyclic Crystallization on Crystal Size and Distribution	141
6.3.3	Effects of Cyclic Crystallizations on SFC	148
6.3.4	Effects of Cyclic Crystallization on Viscosity	151
6.4	Conclusions	154



7	<b>EFFECTS OF CYCLIC TEMPERATURE ON STATIC CRYSTALLIZATION OF PALM OIL BLENDS WITH ADDITION OF EMULSIFIERS</b>	155
7.1	Introduction	155
7.2	Materials and Methods	157
7.2.1	Materials	157
7.2.2	Physical Analyses	158
7.2.3	Statistical Analysis	159
7.3	Results and Discussion	159
7.3.1	Effects of Crystallization Cycles on SFC	159
7.3.2	Effects of Lecithin and STS on SFC	164
7.3.3	Effect of Emulsifier on Viscosity	168
7.3.4	Crystal Distribution	172
7.4	Conclusions	180
8	<b>DYNAMIC CRYSTALLIZATION OF PALM OIL BLEND FOR FLUID SHORTENING FORMULATION</b>	182
8.1	Introduction	182
8.2	Materials and Methods	184
8.2.1	Materials	184
8.2.2	Production of Fluid Shortening	184
8.2.3	Sampling and Analyses	186
8.2.4	Statistical Analysis	187
8.3	Results and Discussions	188
8.3.1	Physical Properties of Product during Production	188
8.3.2	Effect of Stirring on Crystal Distribution	189
8.3.3	Effect of Lecithin on Crystal Distribution	194
8.3.4	Factors Affecting the Physical Properties	195
8.3.5	Interaction Effects of Processing Factors on Physical Properties	200
8.4	Formulation and Production Constraints	201
8.5	Conclusions	203
9	<b>MONITORING CRYSTAL DEVELOPMENT IN PALM -BASED FLUID SHORTENING PRODUCTS BY FT-IR SPECTROSCOPY</b>	204
9.1	Introduction	204
9.2	Materials and Methods	206
9.2.1	Materials	206
9.2.2	Production of Fluid Shortening	206
9.2.3	Sampling and Analyses	206
9.2.4	Calibration / validation of FT-IR Spectra	207



9.3	Results and Discussions	210
	9.3.1 Spectra	210
	9.3.2 Calibration and Validation	213
9.4	Conclusions	221
10	<b>OPTIMIZATION OF PALM-BASED FLUID SHORTENING FORMULATION AND STIRRING SPEED BY RESPONSE SURFACE METHODOLOGY</b>	223
10.1	Introduction	223
10.2	Materials and Methods	225
	10.2.1 Materials	225
	10.2.2 Experimental Design and Statistical Analysis	225
	10.2.3 Preparation of Fluid Shortening	226
	10.2.4 Physical and Chemical Analyses	227
10.3	Results and Discussion	228
	10.3.1 Physical Properties of Fluid Shortening at 25°C	228
	10.3.2 Effects of Lecithin on Storage at 25°C	232
	10.3.3 Effect of Palm Oil on Storage at 25°C	234
	10.3.4 Effects of Stirring on Fluid Shortening at 25°C	235
	10.3.5 Response Contour for Storage at 25°C	237
	10.3.6 Physical Properties of Fluid Shortening at 30°C	240
	10.3.7 Effect of Lecithin during Storage at 30°C	242
	10.3.8 Effect of Palm Oil during Storage at 30°C	245
	10.3.9 Effect of Stirring on Storage at 30°C	247
	10.3.10 Response Contour for Storage at 30°C	248
	10.3.11 Crystal Polymorphs on Storage	252
10.4	Conclusions	255
11	<b>GENERAL CONCLUSIONS AND RECOMMENDATIONS</b>	258
	<b>REFERENCES</b>	261
	<b>APPENDICES</b>	278
	<b>BIODATA OF THE AUTHOR</b>	309





## LIST OF TABLES

<b>Table</b>		<b>Page</b>
2.1	Common name for fatty acids available in vegetable oils and their SMPs	16
2.2	Physical appearance of selected oils and fats at room temperature	25
2.3	Polymorphic forms of selected hydrogenated oils	43
2.4	Polymorphic forms of oils and fats contributed by the TAG numbers	46
2.5	Crystal polymorphic forms as contributed by the TAG types	47
3.1	Blend ratios of palm oil and palm olein and fatty acid composition of the blends	75
3.2	Distribution of trisaturated, disaturated-monounsaturated, monounsaturated-diunsaturated and triunsaturated TAG in the Blends	86
4.1	The effects of emulsifiers on the SFC of palm oil and olein blends at Cycle 1	98
4.2	The effects of lecithin on the viscosity (cP) of palm oil and olein blends at Cycle1	103
4.3	The effects of STS on the viscosity (cP) of palm oil and olein blends at Cycle 1	113
5.1	Distribution of trisaturated, disaturated – monounsaturated, mono unsaturated – diunsaturated and triunsaturated TAGS of selected blends	120
5.2	The effects of emulsifiers on the SFC of palm oil and olein blends	122
5.3	The effects of lecithin on the viscosity (cP) of palm oil and olein blends	128
5.4	The effects of STS on the viscosity (cP) of palm oil and olein blends	133



6.1	Fatty acid composition and SMP of blends of palm and palm olein	142
6.2	Distribution of trisaturated, disaturated-monounsaturated, monounsaturated-diunsaturated and triunsaturated TAG in the Blends	143
6.3	Polymorphic form of the product after one day storage at 20 and 30°C	148
8.1	Experimental design and product evaluation within 30 min after production.	185
8.2	Crystal size of fluidized palm oil during processing	192
8.3	Coefficient estimate and $R^2$ for physical properties of fluidized palm oil	198
9.1	Actual SFC value by NMR at 20 and 30°C measured every 6 min	209
9.2	Statistical comparison of SFC of palm oil-based fluid shortening obtained by NMR and FT-IR method during crystallization for calibration at 20°C	214
9.3	Statistical comparison of SFC of palm oil-based fluid shortening obtained by NMR and FT-IR method during crystallization for validation at 20°C	214
9.4	Statistical comparison of SFC of palm oil-based fluid shortening obtained by NMR and FT-IR method during crystallization for calibration at 30°C	215
9.5	Statistical comparison of SFC of palm oil-based fluid shortening obtained by NMR and FT-IR method during crystallization for validation at 30°C	215
10.1	Experimental design of effects of lecithin, palm oil content and stirring speed	226
10.2	Physical properties and crystal size of fluid shortening during storage at 25°C for week one and three.	230



10.3	Optimum points of response factors during storage at 25°C for week one and three.	231
10.4	Coefficient estimate and R <sup>2</sup> values of product trend at 25°C for week one and three	233
10.5	Physical properties and microstructure of fluid shortening during storage at 30°C for week one and three	241
10.6	The optimum points of response factors during storage at 30°C for week one and three.	243
10.7	Coefficient estimate and R <sup>2</sup> values of product trend at 30°C for week one and three	244
10.8	Crystal distribution (%) of samples P1 - P15 at storage temperature 25°C for one week	252
10.9	Crystal distribution (%) of samples P1 - P15 at storage temperature 30°C for one week	253
10.10	Crystal distribution (%) of samples P1 - P15 at storage temperature 25°C for three weeks	254
10.11	Crystal distribution (%) of samples P1 - P15 at storage temperature 30°C for three weeks	255
A-1	Triacylglycerol composition of palm oil and palm kernel oil fractions	278
A-2	SFC of palm oil and palm kernel oil fractions	279
A-3	Regulatory status of emulsifiers	279
A-4	Solid fat content profile of experimental fluid shortening	280
A-5	Size of crystal (µm) during processing	281



## LIST OF FIGURES

Figure		page
2.1	Typical SFI profiles of different shortenings	19
2.2	Unsaturated fatty acid chains	38
2.3	Chemical structure of lecithin.	53
2.4	Phosphatidylcholine (lecithin) showing the active ends.	53
2.5	Emulsion of water-in-oil (Source: Stauffer, 1996b)	54
2.6	Sorbitan tristearate	55
2.7	Model of inhibition and promoting activities of emulsifier	60
2.8	Perspective view of a crystallizer vessel.	64
3.1	The SFC profile of Blends P90, P50 and P20 as a function of temperature.	76
3.2	Isothermal SFC of Blends 0P90, 0P50 and 0P20 as a function of time at 0°C.	78
3.3	Isothermal SFC of Blends 5P90, 5P50 and 5P20 as a function of time at 5°C.	79
3.4	Isothermal SFC of Blends 10P90, 10P50, 10P20 and 10P0 as a function of time at 10°C.	81
3.5	The isothermal SFC of Blends 15P90, 15P50, 15P20, and 15P0 as a function of time at 15°C.	83
3.6	Isothermal SFC of Blends 20P90, 20P50, 20P20 and 20P0 as a function of time at 20°C.	83
3.7	Photomicrographs Showing the Crystal Distribution of Various Blends at Magnification of 10X10.	88
4.1	Photomicrograph of effect of lecithin on crystal dispersion of palm oil and olein blend on slow crystallization (10x10 magnifications).	99



4.2	The effect of lecithin (%) on the viscosity (cP) and SFC (%) of palm oil blend by slow crystallization	102
4.3	The effect of sorbitan tristearate (%) on the viscosity (cP) and SFC (%) of palm oil blends by slow crystallization	110
4.4	Photomicrograph of effect of STS on crystal dispersion of palm oil and olein blend on slow crystallization (10x10 magnification).	112
5.1	The SFC Profile of Blends P40 (---●---), P30(----○---), P20(—◆—), P10(--◇--)) as a function of temperature.	123
5.2	Microstructure of crystal development of sample P40 with Lecithin and STS.	124
5.3	Microstructure of crystal development of sample P30 with lecithin and STS.	130
5.4	Crystal development of sample P10 with Lecithin and STS	131
6.1	Crystal microstructure of Blend P90 and P60 at different cyclic crystallization by magnification of 10x10.	145
6.2	SFC (%) as a function of cyclic crystallization with no emulsifier.	149
6.3	Viscosity (cP) as a function of cyclic crystallization with no emulsifier.	152
7.1	SFC as a function of temperature cycling with 0.03% lecithin (A) and STS (B).	160
7.2	SFC as a function of temperature cycling with 0.06% lecithin (A) and STS (B).	162
7.3	SFC as a function of temperature cycling with 0.09% lecithin (A) and STS (B).	163
7.4	SFC as a function of palm oil blends with 0.03% lecithin and STS	165



7.5	SFC as a function of palm oil blends with 0.06% lecithin and STS.	166
7.6	SFC as a function of palm oil blends with 0.09% lecithin and STS	167
7.7	Viscosity as a function of temperature cycling with 0.03% lecithin (A) and STS (B).	169
7.8	Viscosity as a function of temperature cycling with 0.06% lecithin (A) and STS (B).	170
7.9	Viscosity as a function of temperature cycling with 0.09% lecithin (A) and STS (B).	171
7.10	Crystal Microstructure of Blend P90 at different crystallization cycles by magnification 10x10	174
7.11	Crystal Microstructure of Blend P60 with lecithin at different crystallization cycles by magnification 10x10.	177
7.12	Crystal Microstructure of Blend P60 with STS at different crystallization cycles by magnification 10x10.	180
8.1	Blends of PO 23% and lecithin 0.06% processed by stirring speeds of 450 and 150RPM by temperature cycles. Magnification of 10x10.	190
8.2	Blends of PO 23%. Processed by stirring speeds of 300 rpm by temperature cycles. Magnification of 10x10.	191
8.3	SFC trend of fluid palm oil with 0.02% lecithin processed by different stirring speed (rpm) as a function of palm oil content (%)	195
8.4	Viscosity (cPs) trend of fluid palm oil with 0.02% lecithin processed by different stirring speed (rpm) as a function of palm oil content (%)	196
8.5	Crystal diameter ( $\mu\text{m}$ ) trend of fluid palm oil with 0.02% lecithin processed by different stirring speed (rpm) as a function of palm oil content (%)	199



8.6	Pourability (s/100 ml) trend of fluid palm oil with 0.02% lecithin processed by different stirring speed (rpm) as a function of palm oil content (%)	200
9.1	Overlaid spectra of palm oil-based fluid shortening with SFC values of 8.92 and 4.21 by NMR at wave number region 3068 to 2496 $\text{cm}^{-1}$ , 1831 to 1032 $\text{cm}^{-1}$ and 777 to 650 $\text{cm}^{-1}$ .	211
9.2	The difference spectrum of palm oil-based fluid shortening with SFC values of 8.92 and 4.21 by NMR at wave number region 3068 to 2496 $\text{cm}^{-1}$ , 1831 to 1032 $\text{cm}^{-1}$ and 777 to 650 $\text{cm}^{-1}$ .	211
9.3	Calibration plot of SFC by NMR vs. FT-IR predicted SFC of wave number region 3068 to 2496 $\text{cm}^{-1}$ , 1831 to 1032 $\text{cm}^{-1}$ and 777 to 650 $\text{cm}^{-1}$ obtained for palm oil-based fluid shortening at 20°C.	218
9.4	Validation plot of SFC by NMR vs. FT-IR predicted SFC of wave number region 3068 to 2496 $\text{cm}^{-1}$ , 1831 to 1032 $\text{cm}^{-1}$ and 777 to 650 $\text{cm}^{-1}$ obtained for palm oil-based fluid shortening at 20°C	219
9.5	Calibration plot of SFC by NMR vs. FT-IR predicted SFC of wave number region 3068 to 2496 $\text{cm}^{-1}$ , 1831 to 1032 $\text{cm}^{-1}$ and 777 to 650 $\text{cm}^{-1}$ obtained for palm oil-based fluid shortening at 30°C.	220
9.6	Validation plot (B) of SFC by NMR vs. FT-IR predicted SFC of wave number region 3068 to 2496 $\text{cm}^{-1}$ , 1831 to 1032 $\text{cm}^{-1}$ and 777 to 650 $\text{cm}^{-1}$ obtained for palm oil-based fluid shortening at 30°C.	221
10.1A	Stirring speed (RPM) as a function of palm oil content (%) with 0.02% lecithin on SFC (%) at storage of 25°C for three weeks.	237
10.1B	Stirring speed (RPM) as a function of palm oil content (%) with 0.02% lecithin on viscosity (cP) at storage of 25°C for three weeks.	238
10.1C	Stirring speed (RPM) as a function of palm oil content (%) with 0.02% lecithin on crystal size diameter ( $\mu\text{m}$ ) at Storage of 25°C for three weeks.	239



10.1D	Stirring speed (RPM) as a function of palm oil content (%) with 0.02% lecithin on pourability (s/100ml) at storage of 25°C for three Weeks	240
10.2A	Stirring speed (RPM) as a function of palm oil content (%) with 0.06% lecithin on SFC (%) at storage of 30°C for three weeks	249
10.2B	Stirring speed (RPM) as a function of palm oil content (%) with 0.06% lecithin on viscosity (cP) at storage of 30°C for three weeks.	249
10.2C	Stirring speed (RPM) as a function of palm oil content (%) with 0.06% lecithin on diameter ( $\mu\text{m}$ ) at storage of 30°C for three weeks.	250
10.2D	Stirring speed (RPM) as a function of palm oil content (%) with 0.06% lecithin on pourability (s/100 ml) at storage of 30°C for three weeks.	250
B-1	Flow Chart of Palm Oil-Based Fluid Shortening Processing	282
B-2	Samples of RBD Palm oil, Palm olein and Palm stearin	283
B-3	Jacketed Glass Crystallizer Vessel	284
B-4	Set Up of Crystallization Equipment (Jacketed Crystallizer Glass Vessel, Circulating Baths)	285
B-5	Collection of Sample for Analysis	286
B-6	Palm oil-based Fluid Shortening	287
B-7	Brookfield Digital Viscometer	288
B-8	Capillary Slip Melting Point	289
B-9	Fourier Transform Infra Red Spectrometer	290
B-10	Polarized Light Microscope Attached to A Leica Qwin (crystal analyzer)	291





C-1	Microstructure of Fluid Palm Oil of Different Formulations during Processing	292
C- 2	Microstructure of Fluid Palm Oil of Different Formulations on Storage at 25 and 30C for 1 and 3 weeks	299
D-1	Letter from the permission controller of Blackwell Publishing	307
D-2	Permission request form	308

