



UNIVERSITI PUTRA MALAYSIA

**PRODUCTION, PROPERTIES AND APPLICATION OF BLENDS OF
PALM STEARIN WITH PALM KERNEL OLEIN, SUNFLOWER
OIL OR ANHYDROUS MILKFAT TRANSESTERIFIED
BY LIPASES**

LAI OI MING

FSMB 1998 6

**PRODUCTION, PROPERTIES AND APPLICATION OF BLENDS OF PALM
STEARIN WITH PALM KERNEL OLEIN, SUNFLOWER OIL OR
ANHYDROUS MILKFAT TRANSESTERIFIED BY LIPASES**

By

LAI OI MING

**Dissertation submitted in fulfilment of the requirements for the
Degree of Doctor of Philosophy in the Faculty of
Food Science and Biotechnology,
Universiti Putra Malaysia**

November 1998



ACKNOWLEDGEMENTS

I wish to express my deepest appreciation and gratitude to my supervisor, Assoc. Prof. Dr. Hasanah Mohd. Ghazali of the Department of Biotechnology, Faculty of Food Science and Biotechnology for her invaluable guidance, constructive suggestions and constant encouragement throughout the course of my study. My grateful thanks also to Dr. Chong Chiew Let of PORIM, a member of my supervisory committee, for giving me an opportunity to be exposed to the many aspects of physical and technology of fats and oils. The suggestions and insightful comments on the contents of my thesis given by another member of my supervisory committee, Assoc. Prof. Dr. France Cho, is gratefully acknowledged. My heartfelt appreciation also goes to En. Dzul kifly Mat Hashim for his generous advice on the rheological studies.

Many thanks are also due to the following people: Dr. Chow Mei Chin of PORIM for her technical assistance in the rheology work; Dr. Nor Aini Idris and her panel of sensory staffs for their assistance during the planning and execution of the sensory evaluation tests. The assistance and support rendered by the staffs of the Physics, Processing and Effluent Labs in PORIM are duly acknowledged and appreciated.

Acknowledgement is also due to the Government of Malaysia and Universiti Putra Malaysia for giving me the opportunity to carry out my PhD programme. I am



also grateful to the Head of the Department of Biotechnology, Prof. Mohamed Ismail Karim for granting me leave to carry out my work.

Heartfelt appreciation also go to all faculty members, staffs, technicians, fellow graduate and undergraduate students (they know who they are) for their kind cooperation throughout my study and for taking the time to share their expertise, knowledge and wisdom with me.

Last but not least, I would like to thank my family for their encouragement, understanding and patience in sharing my excitements and frustrations of research.



TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	ii
LIST OF TABLES	vii
LIST OF FIGURES	xi
LIST OF PLATES	xx
LIST OF ABBREVIATIONS	xxi
ABSTRACT	xxv
ABSTRAK	xxix
CHAPTER	
1 INTRODUCTION	1
2 LITERATURE REVIEW	7
Fats and Oils.....	7
Lipases.....	10
Definition of Lipases.....	10
Properties of Lipases.....	11
Specificity of Lipases.....	14
Food Application of Lipases.....	17
Interesterification of Fats.....	21
Chemical Transesterification.....	22
Enzymatic Interesterification.....	24
Factors Affecting Equilibrium and Rate of Chemical and Enzymatic Transesterification.....	28
The Effect of Transesterification on the Physico-Chemical Properties of Fats and Oils.....	35
Crystallisation of Fats.....	36
Polymorphism of Fats.....	38
Rheology of Fats.....	45
3 TRANSESTERIFICATION OF PALM STEARIN USING 1,3-SPECIFIC AND NON-SPECIFIC LIPASES	
Introduction.....	54
Materials and Methods.....	56
Materials.....	56
Methods.....	57
Results and Discussion.....	61
Effect of Lyophilisation on Transesterification of Palm Stearin.....	61

	Effect of Reaction Time on Transesterification of Palm Stearin.....	70
	Effect of Reaction Time on Slip Melting Point (SMP) of Transesterified Products.....	76
	Effect of Temperature on Transesterification.....	80
	Catalytic Stability of Repeated Use of Immobilised Lipases.....	80
	Summary.....	85
4	PHYSICAL AND CHEMICAL PROPERTIES OF LIPASE-CATALYSED TRANSESTERIFIED BLENDS OF PALM STEARIN WITH PALM KERNEL OLEIN, SUNFLOWER OIL AND ANHYDROUS MILKFAT	
	Introduction.....	86
	Materials and Methods.....	88
	Materials.....	88
	Methods.....	88
	Results and Discussion.....	91
	Effect of Different Lipases on Transesterification.....	91
	Effect of Different Lipases on Slip Melting Point (SMP) and Solid Fat Content (SFC).....	96
	Thermal Analysis of Palm Stearin, Palm Kernel Olein, Sunflower Oil and Anhydrous Milkfat.....	113
	Comparisons of Last Melting Peak (LMP) Temperature from DSC Thermograms With Slip Melting Point (SMP).....	124
	Thermal Analysis of Transesterified Mixtures of PS:PKO, PS:SO and PS:AMF.....	126
	Summary.....	134
5	PHYSICAL AND CHEMICAL PROPERTIES OF <i>R. MIEHEI</i> AND <i>PSEUDOMONAS</i> LIPASE-CATALYSED TRANSESTERIFIED BLENDS OF PALM STEARIN WITH PALM KERNEL OLEIN, SUNFLOWER OIL AND ANHYDROUS MILKFAT	
	Introduction.....	135
	Materials and Methods.....	137
	Materials.....	137
	Methods.....	138
	Results and Discussion.....	139
	Changes in Slip Melting Point (SMP).....	139
	Changes in Solid Fat Content (SFC).....	142
	Changes in Thermal Analysis.....	147
	Changes in Polymorphic Form(s).....	156
	Summary.....	164

6	PHYSICAL, CHEMICAL, RHEOLOGICAL AND SENSORY PROPERTIES OF TABLE MARGARINE PREPARED FROM BLENDS OF LIPASE CATALYSED TRANSESTERIFIED PALM STEARIN : PALM KERNEL OLEIN	
	Introduction.....	165
	Materials and Methods.....	168
	Materials.....	168
	Methods.....	168
	Results and Discussion.....	178
	Changes in Slip Melting Point (SMP).....	178
	Changes in Peroxide Value (PV).....	180
	Changes in Free Fatty Acids (FFA) Content	183
	Changes in Penetrometric Value.....	186
	Changes in Solid Fat Content (SFC).....	191
	Changes in X-Ray Diffraction (XRD) Analysis and Polarised Light Microscopy.....	196
	Changes in Differential Scanning Calorimetry (DSC).....	199
	Changes in Viscoelasticity.....	211
	Changes in Viscosity.....	232
	Sensory Evaluation.....	246
	Changes in Fatty Acid Composition and <i>Trans</i> Content...	256
	Summary.....	259
7	SUMMARY, CONCLUSION AND RECOMMENDATIONS	
	Summary.....	261
	Conclusion and Recommendations.....	265
	BIBLIOGRAPHY.....	267
	APPENDICES.....	300
	BIOGRAPHICAL SKETCH.....	308
	PAPERS PUBLISHED FROM THESIS.....	309



LIST OF TABLES

Table		Page
1	Effect of Different Reaction Times on the Slip Melting Points (SMP) of Palm Stearin Using Different Lipases.....	77
2	Triglyceride Composition and Concentration of Palm Stearin Before (Control) and After 24h Transesterification With Lipases.....	78
3	Lipase Activity (% Triglyceride Hydrolysed) and Rates of Transesterification of Lipases From Different Microbial Sources.....	92
4	Degree of Hydrolysis (% FFA) and Degree of Transesterification of Mixtures of Palm Stearin (PS) With Palm Kernel Olein (PKO), Anhydrous Milkfat (AMF) and Sunflower Oil (SO) at 40:60 Ratio.....	93
5a	Slip Melting Point (SMP) and Solid Fat Content (SFC) of Transesterified Palm Stearin:Palm Kernel Olein (PS:PKO) Mixtures at 40:60 Ratio Using Different Lipases.....	97
5b	Slip Melting Point (SMP) and Solid Fat Content (SFC) of Transesterified Palm Stearin: Sunflower Oil (PS:SO) Mixtures at 40:60 Ratio Using Different Lipases.....	98
5c	Slip Melting Point (SMP) and Solid Fat Content (SFC) of Transesterified Palm Stearin: Anhydrous Milkfat (PS:AMF) Mixtures at 40:60 Ratio Using Different Lipases.....	99
6	Triglyceride Composition (Area % by HPLC) of Palm Stearin.....	119



7	Last Melting Peak (LMP) and Slip Melting Point (SMP) Temperatures of Palm Stearin, Palm Kernel Olein, Anhydrous Milkfat and Sunflower Oil.....	125
8	Last Melting Peak (LMP) and Slip Melting Point (SMP) Temperatures of Mixtures of Palm Stearin (PS) With Palm Kernel Olein (PKO), Anhydrous Milkfat (AMF) and Sunflower Oil (SO) Before and After Transesterification With Lipases.....	125
9	Slip Melting Point (SMP) of Mixtures of Palm Stearin (PS) with (a) Palm Kernel Olein (PKO) (b) Sunflower Oil (SO) and (c) Anhydrous Milkfat (AMF) Before (Control) and After Transesterification with <i>Pseudomonas</i> and <i>R. miehei</i> Lipases.....	140
10	Polymorphic Forms of Mixtures of Palm Stearin (PS) with (a) Palm Kernel Olein (PKO) (b) Sunflower Oil (SO) and (c) Anhydrous Milkfat (AMF) Before (Control) and After Transesterification with <i>Pseudomonas</i> and <i>R. miehei</i> Lipases.....	161
11	Recipe for the Preparation of Experimental Table Margarine Prepared From <i>R. miehei</i> -Transesterified Palm Stearin (PS): Palm Kernel Olein (PKO) Feedstock.....	169
12	Slip Melting Point (SMP) of Experimental and Commercial Table Margarines During Storage.....	179
13	Peroxide Value (PV) of Experimental and Commercial Table Margarines During Storage.....	181
14	% Free Fatty Acids (% FFA) of Experimental and Commercial Table Margarines During Storage.....	184
15	Yield Value (g/cm ²) of Experimental and Commercial Table Margarines During Storage.....	187



16	Relationship Between Yield Value of Margarines and Shortenings as Measured by the Cone Penetrometer and Subjective Test (Thumb Tests) According to Haighton (1959).....	188
17	% Solid Fat Content (% SFC) of Experimental and Commercial Table Margarines During Storage.....	190
18	Polymorphic Form(s) of Experimental and Commercial Table Margarines During Storage.....	197
19	Crystallisation Temperature of Experimental and Commercial Table Margarines During Storage.....	206
20	Region of Stress Guaranteeing Linear Viscoelasticity.....	214
21	New Duncan Multiple Range Test for Comparison of Means of G', G'', η^* and $\tan \delta$ for Commercial and Experimental Table Margarines During Storage.....	229
22	η^* /η Ratio at Shear Rate of 1/s and Frequency of 1 rad/s...	233
23	Mean k (Consistency Coefficient) Obtained From the Power Law Model.....	242
24	Mean n (Shear Rate Index) Obtained From the Power Law Model.....	243
25	Regression Equations Relating Mean Viscosity and Mean k (Consistency Coefficient) With Significant Correlations ($p < 0.01$).....	247
26	Mean Scores for the Sensory Attribute of "Appearance" for the Commercial and Experimental Table Margarines During Storage.....	249

27	Mean Scores for the Sensory Attribute of "Texture" for the Commercial and Experimental Table Margarines During Storage.....	250
28	Mean Scores for the Sensory Attribute of "Taste" for the Commercial and Experimental Table Margarines During Storage.....	251
29	Mean Scores for the Sensory Attribute of "Ease of Spreadability" for the Commercial and Experimental Table Margarines During Storage.....	252
30	Correlation Analysis Between Mean Sensory Scores and Physical and Chemical Tests.....	255
31	Fatty Acid Composition and <i>trans</i> Content of Commercial and Experimental Table Margarine.....	257



LIST OF FIGURES

Figure		Page
1	Catalysis of Triglyceride by Lipases.....	11
2a	Effect of Lyophilisation of Immobilised (i) <i>A. niger</i> and (ii) <i>M. javanicus</i> Lipases on the Degree of Hydrolysis (% FFA) and % Triglyceride (TG) Remaining.....	63
2b	Effect of Lyophilisation of Immobilised (i) <i>R. javanicus</i> and (ii) <i>R. niveus</i> Lipases on the Degree of Hydrolysis (% FFA) and % Triglyceride (TG) Remaining.....	64
2c	Effect of Lyophilisation of Immobilised <i>Alcaligenes</i> Lipase on the Degree of Hydrolysis (% FFA) and % Triglyceride (TG) Remaining.....	65
2d	Effect of Lyophilisation of Immobilised (i) <i>Pseudomonas</i> and (ii) <i>C. rugosa</i> Lipases on the Degree of Hydrolysis (% FFA) and % Triglyceride (TG) Remaining.....	66
3	Effect of Lyophilisation of Immobilised <i>Mucor javanicus</i> Lipase on the Triglyceride Profile of Palm Stearin (a) Control (Zero-time Mixtures) and After Lyophilisation for (b) 0 h (c) 2 h (d) 4 h (e) 6 h and (f) 8 h.....	67
4	Effect of Lyophilisation of Immobilised <i>Pseudomonas</i> Lipase on the Triglyceride Profile of Palm Stearin (a) Control (Zero-time Mixtures) and After Lyophilisation for (b) 0 h (c) 2 h (d) 4 h (e) 6 h and (f) 8 h.....	68
5a	Effect of Reaction Time of Immobilised (i) <i>A. niger</i> and (ii) <i>M. javanicus</i> Lipases on the Degree of Hydrolysis (% FFA) and % Triglyceride (TG) Remaining.....	71



5b	Effect of Reaction Time of Immobilised (i) <i>R. miehei</i> and (ii) <i>R. javanicus</i> Lipases on the Degree of Hydrolysis (% FFA) and % Triglyceride (TG) Remaining.....	72
5c	Effect of Reaction Time of Immobilised (i) <i>R. niveus</i> and (ii) <i>Alcaligenes</i> Lipases on the Degree of Hydrolysis (% FFA) and % Triglyceride (TG) Remaining.....	73
5d	Effect of Reaction Time of Immobilised (i) <i>Pseudomonas sp.</i> and (ii) <i>C. rugosa</i> Lipases on the Degree of Hydrolysis (% FFA) and % Triglyceride (TG) Remaining.....	74
6a	Catalytic Stability of Immobilised <i>R. miehei</i> Lipase in Repeated Batch Transesterification of Palm Stearin (i) Before Transesterification and After (ii) Five and (iii) Ten Runs of Repeated Usage.....	82
6b	Catalytic Stability of Immobilised <i>Pseudomonas</i> Lipase in Repeated Batch Transesterification of Palm Stearin (i) Before Transesterification and After (ii) Five and (iii) Ten Runs of Repeated Usage.....	83
7	Percent Free fatty Acid (% FFA) and % Triglyceride (TG) Remaining in Palm Stearin Obtained From Using Immobilised (a) <i>R. miehei</i> and (b) <i>Pseudomonas sp.</i> Lipases After Ten Runs	84
8a	Triglyceride Profile of Palm Stearin:Palm Kernel Olein (40:60) Mixtures (i) Before and After Transesterification with Non-Specific (ii) <i>Pseudomonas sp.</i> and (iii) <i>C. rugosa</i> Lipases.....	100
8b	Triglyceride Profile of Palm Stearin:Palm Kernel Olein (40:60) Mixtures After Transesterification with 1,3-Specific (i) <i>A. niger</i> (ii) <i>M. javanicus</i> and (iii) <i>R. miehei</i> Lipases.....	101
8c	Triglyceride Profile of Palm Stearin:Palm Kernel Olein (40:60) Mixtures After Transesterification with 1,3-Specific (i) <i>R. javanicus</i> (ii) <i>R. niveus</i> and (iii) <i>Alcaligenes</i> Lipases.....	102



9a	Triglyceride Profile of Palm Stearin:Sunflower Oil (40:60) Mixtures (i) Before and After Transesterification with Non-Specific (ii) <i>Pseudomonas sp.</i> And (iii) <i>C. rugosa</i> Lipases.....	105
9b	Triglyceride Profile of Palm Stearin:Sunflower Oil (40:60) Mixtures After Transesterification with 1,3-Specific (i) <i>A. niger</i> (ii) <i>M. javanicus</i> and (iii) <i>R. miehei</i> Lipases.....	106
9c	Triglyceride Profile of Palm Stearin:Sunflower Oil (40:60) Mixtures After Transesterification with 1,3-Specific (i) <i>R. javanicus</i> (ii) <i>R. niveus</i> and (iii) <i>Alcaligenes</i> Lipases.....	107
10a	Triglyceride Profile of Palm Stearin:Anhydrous Milkfat (40:60) Mixtures (i) Before and After Transesterification with Non-Specific (ii) <i>Pseudomonas sp.</i> And (iii) <i>C. rugosa</i> Lipases	109
10b	Triglyceride Profile of Palm Stearin:Anhydrous Milkfat (40:60) Mixtures After Transesterification with 1,3-Specific (I) <i>A. niger</i> (ii) <i>M. javanicus</i> and (iii) <i>R. miehei</i> Lipases.....	110
10c	Triglyceride Profile of Palm Stearin:Anhydrous Milkfat (40:60) Mixtures After Transesterification with 1,3-Specific (i) <i>R. javanicus</i> (ii) <i>R. niveus</i> and (iii) <i>Alcaligenes</i> Lipases.....	111
11a	Melting Profile of Palm Stearin at Heating Rates (i) 80 (ii) 40 (iii) 20 and (iv) 10°C/min.....	114
11b	Melting Profile of Palm Kernel Olein at Heating Rates (i) 80 (ii) 40 (iii) 20 and (iv) 10°C/min.....	115
11c	Melting Profile of Anhydrous Milkfat at Heating Rates (i) 80 (ii) 40 (iii) 20 and (iv) 10°C/min.....	116
11d	Melting Profile of Sunflower Oil at Heating Rates (i) 80 (ii) 40 (iii) 20 and (iv) 10°C/min.....	117



12a	Melting Profiles of Palm Stearin:Palm Kernel Olein (40:60) Mixtures (i) Before and After Transesterification with (ii) <i>A. niger</i> (iii) <i>M. javanicus</i> (iv) <i>R. miehei</i> (v) <i>R. javanicus</i> (vi) <i>R. niveus</i> (vii) <i>Alcaligenes</i> (viii) <i>Pseudomonas sp.</i> and (ix) <i>C. rugosa</i> at Heating Rates of 10°C/min.....	127
12b	Melting Profiles of Palm Stearin:Sunflower Oil (40:60) Mixtures (i) Before and After Transesterification with (ii) <i>A. niger</i> (iii) <i>M. javanicus</i> (iv) <i>R. miehei</i> (v) <i>R. javanicus</i> (vi) <i>R. niveus</i> (vii) <i>Alcaligenes</i> (viii) <i>Pseudomonas sp.</i> and (ix) <i>C. rugosa</i> at Heating Rates of 10°C/min.....	131
12c	Melting Profiles of Palm Stearin:Anhydrous Milkfat (40:60) Mixtures (i) Before and After Transesterification with (ii) <i>A. niger</i> (iii) <i>M. javanicus</i> (iv) <i>R. miehei</i> (v) <i>R. javanicus</i> (vi) <i>R. niveus</i> (vii) <i>Alcaligenes</i> (viii) <i>Pseudomonas sp.</i> and (ix) <i>C. rugosa</i> at Heating Rates of 10°C/min.....	133
13	Solid fat Content (SFC) of Palm Stearin:Palm Kernel Olein (PS:PKO) Blends (a) Before and After Transesterification with (b) <i>Pseudomonas</i> and (c) <i>R. miehei</i> Lipases.....	143
14	Solid fat Content (SFC) of Palm Stearin:Sunflower Oil (PS:SO) Blends (a) Before and After Transesterification with (b) <i>Pseudomonas</i> and (c) <i>R. miehei</i> Lipases.....	144
15	Solid fat Content (SFC) of Palm Stearin:Anhydrous Milkfat (PS:AMF) Blends (a) Before and After Transesterification with (b) <i>Pseudomonas</i> and (c) <i>R. miehei</i>	145
16a	Melting Thermograms of Palm Stearin:Palm Kernel Olein (PS:PKO) Blends Before Transesterification (Control) at Heating Rates of 5°C/min.....	148
16b	Melting Thermograms of Palm Stearin:Palm Kernel Olein (PS:PKO) Blends After Transesterification With <i>Pseudomonas</i> Lipase at Heating Rates of 5°C/min.	149



16c	Melting Thermograms of Palm Stearin:Palm Kernel Olein (PS:PKO) Blends After Transesterification With <i>R. miehei</i> Lipase at Heating Rates of 5°C/min.....	150
17a	Melting Thermograms of Palm Stearin:Sunflower Oil (PS:SO) Blends Before Transesterification (Control) at Heating Rates of 5°C/min.....	152
17b	Melting Thermograms of Palm Stearin:Sunflower Oil (PS:SO) Blends After Transesterification With <i>Pseudomonas</i> Lipase at Heating Rates of 5°C/min.....	153
17c	Melting Thermograms of Palm Stearin:Sunflower Oil (PS:SO) Blends After Transesterification With <i>R. miehei</i> Lipase at Heating Rates of 5°C/min.....	154
18a	Melting Thermograms of Palm Stearin:Anhydrous Milkfat (PS:AMF) Blends Before Transesterification (Control) at Heating Rates of 5°C/min.....	157
18b	Melting Thermograms of Palm Stearin:Anhydrous Milkfat (PS:AMF) Blends After Transesterification With <i>Pseudomonas</i> Lipase at Heating Rates of 5°C/min.....	158
18c	Melting Thermograms of Palm Stearin:Anhydrous Milkfat (PS:AMF) Blends After Transesterification With <i>R. miehei</i> Lipase at Heating Rates of 5°C/min.....	159
19	Schematic Diagram for the Processing of Experimental Table Margarine.....	170
20	Regression Correlation of Yield Value (g/cm ²) and % Solid Fat Content (% SFC) of Table Margarine During Storage.....	194
21a	Differential Scanning Calorimetry (DSC) Melting Profile of Commercial Table Margarine Kept at 20°C During Storage.....	200

21b	Differential Scanning Calorimetry (DSC) Melting Profile of Commercial Table Margarine Kept at 30°C During Storage.....	201
21c	Differential Scanning Calorimetry (DSC) Melting Profile of Experimental Table Margarine Kept at 20°C During Storage....	202
21d	Differential Scanning Calorimetry (DSC) Melting Profile of Experimental Table Margarine Kept at 20°C During Storage...	203
22a	Differential Scanning Calorimetry (DSC) Cooling Profile of Commercial Table Margarine Kept at 20°C During Storage.....	207
22b	Differential Scanning Calorimetry (DSC) Cooling Profile of Commercial Table Margarine Kept at 30°C During Storage.....	208
22c	Differential Scanning Calorimetry (DSC) Cooling Profile of Experimental Table Margarine Kept at 20°C During Storage...	209
22d	Differential Scanning Calorimetry (DSC) Cooling Profile of Experimental Table Margarine Kept at 20°C During Storage...	210
23a	Linear Viscoelastic (LVE) Region of Commercial Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	212
23b	Linear Viscoelastic (LVE) Region of Experimental Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	213
24a	Storage Modulus (G') versus Frequency of Commercial Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	216
24b	Storage Modulus (G') versus Frequency of Experimental Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	217

25a	Loss Modulus (G'') versus Frequency of Commercial Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	218
25b	Loss Modulus (G'') versus Frequency of Experimental Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	219
26a	Complex Viscosity (η^*) versus Frequency of Commercial Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	220
26b	Complex Viscosity (η^*) versus Frequency of Experimental Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	221
27a	Tan delta (δ) versus Frequency of Commercial Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	222
27b	Tan delta (δ) versus Frequency of Experimental Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	223
28	Storage Modulus (G') at 1 Hz of Experimental and Commercial Table Margarine During Storage.....	226
29	Loss Modulus (G'') at 1 Hz of Experimental and Commercial Table Margarine During Storage.....	226
30	Complex Viscosity (η^*) at 1 Hz of Experimental and Commercial Table Margarine During Storage.....	227
31	Tan delta (δ) at 1 Hz of Experimental and Commercial Table Margarine During Storage.....	227
32a	Log Viscosity versus Log Shear Rate of Commercial Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	230



32b	Log Viscosity versus Log Shear Rate of Experimental Table Margarine Kept at (i) 20°C and (ii) 30°C During Storage.....	231
33a	Log Stress versus Log Shear Rate of Commercial Table Margarine Stored at (i) 20°C and (ii) 30°C	235
33b	Log Stress versus Log Shear Rate of Commercial Table Margarine Stored at (i) 20°C and (ii) 30°C	236
34	Mean Yield Stress versus Storage Weeks for the Experimental and Commercial Table Margarine.....	238
35	Log Mean Viscosity at Shear Rate $1s^{-1}$ for Commercial and Experimental Table Margarine During Storage.....	240
36	Log Mean K (Consistency Coefficient) Value versus Storage Weeks for Commercial and Experimental Table Margarine.....	244
37	Log Mean n (Shear Rate Index) Value versus Storage Weeks for Commercial and Experimental Table Margarine.....	245
38	Mean Scores for the Sensory Attribute of "Appearance" for the Commercial and Experimental Table Margarine During Storage.....	249
39	Mean Scores for the Sensory Attribute of "Texture" for the Commercial and Experimental Table Margarine During Storage.....	250
40	Mean Scores for the Sensory Attribute of "Taste" for the Commercial and Experimental Table Margarine During Storage.....	251



41	Mean Scores for the Sensory Attribute of "Ease of Spreadability" for the Commercial and Experimental Table Margarine During Storage.....	252
42	Triglyceride (TG) Profile of (a) Palm Stearin and (b) Palm Kernel Olein.....	301
43	Triglyceride (TG) Profile of (a) Anhydrous Milkfat and (b) Sunflower Oil.....	302



LIST OF PLATES

Plates		Page
1	Light Photomicrographs of Experimental Table Margarine Stored At (a) 20°C (b) 30°C and Commercial Table Margarine Stored at (c) 20°C and (d) 30°C During Week 0	303
2	Light Photomicrographs of Experimental Table Margarine Stored At (a) 20°C (b) 30°C and Commercial Table Margarine Stored at (c) 20°C and (d) 30°C During Week 3	304
3	Light Photomicrographs of Experimental Table Margarine Stored At (a) 20°C (b) 30°C and Commercial Table Margarine Stored at (c) 20°C and (d) 30°C During Week 6.....	305
4	Light Photomicrographs of Experimental Table Margarine Stored At (a) 20°C (b) 30°C and Commercial Table Margarine Stored at (c) 20°C and (d) 30°C During Week 9	306
5	Light Photomicrographs of Experimental Table Margarine Stored At (a) 20°C (b) 30°C and Commercial Table Margarine Stored at (c) 20°C and (d) 30°C During Week 12	307

LIST OF ABBREVIATIONS

TG	triglycerides
FFA	free fatty acids
SMP	slip melting point
SFC	solid fat content
PS	palm stearin
PKO	palm kernel olein
SO	sunflower oil
AMF	anhydrous milkfat
XRD	x-ray diffraction
GRAS	Generally Recognised As Safe
E	experimental
C	commercial
PV	peroxide value
CP	cone penetrometry
EM20	experimental table margarine stored at 20°C
EM30	experimental table margarine stored at 30°C
CM20	commercial table margarine stored at 20°C
CM30	commercial table margarine stored at 30°C
VE	viscoelastic
LVE	linear viscoelastic region
FA	fatty acids
MG	monoglycerides
DG	diglycerides
TLC	Thin Layer Chromatography
GC	Gas Chromatography
HPLC	High Performance Liquid Chromatography
AOCS	American Oil Chemist Society
C12:0	lauric acid



C14:0	myristic acid
C16:0	palmitic acid
C16:1	palmitoleic acid
C18:0	stearic acid
C18:1	oleic acid
C18:2	linoleic acid
C18:3	linolenic acid
C22:1	erucic acid
sp.	species
PUFA	polyunsaturated fatty acids
EFA	essential fatty acids
HMG	high melting glycerides
POL	1-palmitoyl-2-oleoyl-linoleoyl glycerol
POP	1,3-dipalmitoyl-2-oleoyl glycerol
SOS	1,3-distearoyl-2-oleoyl glycerol
PLP	1,3-dipalmitoyl-2-linoleoyl glycerol
SOO	1-stearoyl-dioleoyl glycerol
POS	1-palmitoyl-2-oleoyl-stearoyl glycerol
PLL	1-palmitoyl-dilinoleoyl glycerol
SOS	1,3-distearoyl-2-oleoyl glycerol
OOL	1,2-dioleoyl-linoleoyl glycerol
LOO	1-linoleoyl-dioleoyl glycerol
LOP	1-linoleoyl-2-oleoyl-palmitoyl glycerol
PPS	1,2-dipalmitoyl-stearoyl glycerol
PPP	tripalmitin
OOO	triolein
S	saturated
U	unsaturated
DTA	differential thermal analysis
DSC	differential scanning calorimetry

G'	storage modulus
G''	loss modulus
G^*	complex shear modulus
$\tan \delta$	tan delta
η	shear viscosity
η'	dynamic viscosity
% TGR	percent triglyceride remaining
SFI	solid fat index
NMR	nuclear magnetic resonance
HTST	high temperature short time
UHT	ultra high temperature
CBS	cocoa-butter substitute
$[TGI_t]$	concentration of triglycerides that increase in value at reaction time, t
$[TGI_0]$	concentration of triglycerides that increase in value at the start of reaction
X	rate of transesterification
v/v	volume/volume
w/w	weight/weight
IV	iodine value
MP	melting point
LMF	low melting fraction
MMF	middle melting fraction
HMF	high melting fraction
LMP	last melting peak
PORIM	Palm Oil Research Institute of Malaysia
FAME	fatty acid methyl esters
FID	flame ionisation detector
GLM	general linear model
τ_y	yield stress

k consistency coefficient
n shear rate index

