



**UNIVERSITI PUTRA MALAYSIA**

**EFFECTS OF BAKING TEMPERATURE, TIME AND HUMIDITY  
ON BREAD CRUST AND CRUMB PROPERTIES**

**YANTI MASLINA MOHD. JUSOH**

**FK 2008 57**



**EFFECTS OF BAKING TEMPERATURE, TIME AND HUMIDITY ON BREAD  
CRUST AND CRUMB PROPERTIES**

**By**

**YANTI MASLINA MOHD. JUSOH**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in  
Fulfilment of the Requirements for the Degree of Master of Science**

**June 2008**



Abstract of thesis presented to Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master in Science

**EFFECTS OF BAKING TEMPERATURE, TIME AND HUMIDITY ON BREAD CRUST AND CRUMB PROPERTIES**

By

**YANTI MASLINA MOHD JUSOH**

**June 2008**

**Chairman : Chin Nyuk Ling, PhD**

**Faculty : Engineering**

The main objectives of this study are to investigate the effects of baking temperature, time and humidity on bread qualities and subsequently find the relationship between bread crust and crumb properties.

The bread samples were prepared following the straight-dough method. In determining crust and crumb, the difference in colour between these two regions was used. The colour of crust and crumb were measured using a chromameter. The colour range obtained for crust based on top crust colour of commercial bread samples is  $L < 66.0$ ,  $a > 2.4$  and  $b > 22.3$  while crumb has a range of  $L > 66.0$ ,  $a < 2.4$  and  $b < 22.3$ . This colour range is used as a guideline in determining crust thickness of baked loaf samples. Bread slices were scanned to obtain its  $L a b$  values and the crust thickness was determined from the crumb region when the  $L a b$  values are met. The evaluation of crumb moisture content and firmness were conducted following the standard method of



American Association of Cereal Chemist (AACC) 14-5A and American Institute of Baking (AIB), respectively. Experimental results were statistically analyzed using Analysis of Variance (ANOVA).

Various combination of baking temperature, time and humidity affected the organoleptic properties of bread. Baking temperature and time significantly affect bread crust colour ( $P < 0.001$ ), thickness ( $P < 0.001$ ), initial moisture content ( $P < 0.05$ ) and firmness ( $P < 0.001$ ). Baking temperature has larger effect on crust colour and thickness compared to baking time. Higher baking temperature produced darker and thicker crust. Rate of thickness increment was also higher at high baking temperature (0.0465 mm/min) compared to low baking temperature (0.0085 mm/min). Increasing baking temperature produces crumb of high initial moisture content with high firmness value. The effect of baking time ( $P < 0.01$ ) is less significant than temperature however increasing baking time would also darken the crust colour and increases the thickness, increases crumb firmness and reduces crumb moisture content.

The application of humidified baking has no significant impact on crust coloration ( $P > 0.05$ ) however it causes a decrease in crust thickness ( $P < 0.05$ ), retain moisture ( $P < 0.01$ ) and reduce firmness ( $P < 0.05$ ). Humidified baking also reduces moisture migration ( $P < 0.01$ ) and firming rate ( $P < 0.01$ ) of breads during storage. Besides humidified baking, the usage of baking lid also have potential in increasing  $L$  and  $b$  values ( $P < 0.001$ ) and reducing  $a$  value and crust thickness ( $P < 0.001$ ). However, the

application of lid prevents bread expansion and causes high firmness value in bread. Sandwich bread has lower moisture content compared to open bread.

Three important correlations were obtained from the study that are between top crust colour difference ( $\Delta E$ ) and thickness,  $\Delta E$  and firmness and finally crust thickness and firmness. The correlation between  $\Delta E$  and thickness for non-humidified (NH) baking is represented by  $y_{NH} = 0.1724x$  and  $y_H = 0.1712x$  for humidified (H) baking. The coefficient of correlation,  $R^2$ , for correlation between  $\Delta E$  and thickness for non-humidified baking and humidified baking are given by 0.9467 and 0.9341, respectively. A simple model of  $T = k\Delta E$  derived from the correlation between  $\Delta E$  and thickness indicates that the crust thickness (T) can be predicted by the changes in crust colour ( $\Delta E$ ). The heating constant,  $k$ , is dependant of baking temperature. The correlation,  $\Delta E$  and firmness has the  $R^2$  of 0.8306 for non-humidified baking and 0.8025 for humidified baking. The correlation between  $\Delta E$  and firmness for non-humidified baking is represented by  $y_{NH} = 0.8375x + 20.824$  and  $y_H = 0.8127x + 25.035$  for humidified baking. The other correlation, thickness and firmness has the  $R^2$  of 0.7436 and 0.6915, for non-humidified and humidified baking, respectively. The correlation of thickness and firmness for non-humidified baking is represented by  $y_{NH} = 4.0385x + 26.952$  and  $y_H = 3.921x + 30.852$  for humidified baking. The high value of  $R^2$  shows that there is a strong relationship between colour, thickness and firmness. Crust colour can be used in predicting crust thickness and crumb firmness.

In conclusion, the results show that the bread crust and crumb properties are highly dependent of baking temperature and time. The moisture content and firmness in crumb are also affected by crust formation. This research also produces several significant contributions for bakery study; new method of measuring crust thickness using colour, humidified baking application for improving the storage quality of bread and finally establishment of correlations and linear model that can be used to estimate crust thickness and probably anticipate crumb behavior during storage.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**KESAN SUHU, MASA DAN LEMBAPAN BAGI PEMBAKARAN KE ATAS  
SIFAT-SIFAT KERAK DAN ISI ROTI**

Oleh

**YANTI MASLINA MOHD. JUSOH**

**Jun 2008**

**Pengerusi : Chin Nyuk Ling, PhD**

**Fakulti : Kejuruteraan**

Tujuan penyelidikan ini adalah untuk mengkaji kesan suhu, masa dan kelembapan ketika pembakaran ke atas kualiti roti dan seterusnya mendapatkan hubungan di antara kerak dan isi roti.

Sampel roti telah disediakan mengikut kaedah *straight-dough*. Perbezaan warna di antara kerak dan isi roti telah digunakan untuk membezakan kedua-dua bahagian ini. Ukuran ke atas warna kerak dan isi roti telah dilakukan menggunakan alat *chromameter*. Dengan menggunakan sample roti komersial, julat warna bagi kerak dan isi roti telah ditetapkan yang mana bahagian kerak mempunyai julat warna  $L < 66.0$ ,  $a > 2.4$  dan  $b > 22.3$  dan bahagian isi roti mempunyai julat warna  $L > 66.0$ ,  $a < 2.4$  dan  $b < 22.3$ . Julat warna yang diperolehi ini digunakan untuk mengukur ketebalan kerak roti. Kepingan

roti diimbas bagi mendapatkan nilai-nilai *L a b* dan seterusnya ketebalan kerak ditentukan apabila nilai-nilai *L a b* mencapai nilai julat warna bagi bahagian kerak roti. Kandungan lembapan dan kepadatan isi roti diukur berdasarkan kaedah piawai *American Association of Cereal Chemist (AACC) 14-5A* dan *American Institute of Baking (AIB)*. Keputusan eksperimen telah dianalisa menggunakan *Analysis of Variance (ANOVA)*.

Gabungan pelbagai suhu, masa dan kelembapan ketika pembakaran telah memberi kesan ke atas sifat-sifat roti. Masa and suhu memberikan kesan yang signifikan ke atas warna ( $P < 0.001$ ) dan ketebalan ( $P < 0.001$ ) kerak roti, lembapan awal ( $P < 0.05$ ) dan kepadatan isi roti ( $P < 0.001$ ). Suhu pembakaran mempunyai kesan yang lebih ketara ke atas warna dan ketebalan kerak roti berbanding masa pembakaran. Suhu pembakaran yang tinggi menyebabkan pembentukan kerak yang lebih gelap dan tebal. Kadar peningkatan ketebalan kerak berlaku dengan lebih pantas ketika suhu pembakaran tinggi (0.0465 mm/min) berbanding suhu yang rendah (0.0085 mm/min). Peningkatan suhu pembakaran menghasilkan isi roti berkelembapan awal yang tinggi dan meningkatkan kepadatannya. Kesan masa pembakaran ( $P < 0.01$ ) kurang signifikan berbanding suhu pembakaran, namun peningkatan masa pembakaran turut menghasilkan kerak yang lebih gelap dan tebal, meningkatkan kepadatan isi roti tetapi menurunkan kandungan lembapannya.

Aplikasi kelembapan ketika pembakaran tidak memberi kesan kepada warna kerak ( $P > 0.05$ ) namun ia menyebabkan pengurangan ketebalan kerak ( $P > 0.01$ ), mengekalkan



kelembapan ( $P < 0.01$ ) dan mengurangkan kepadatan ( $P < 0.05$ ) pada isi kerak. Kaedah ini juga mengurangkan kadar perpindahan lembapan ( $P < 0.01$ ) and kepadatan ( $P < 0.01$ ) pada isi roti ketika roti dalam penyimpanan. Selain daripada kaedah ini, penggunaan penutup acuan pembakaran juga berpotensi dalam meningkatkan nilai  $L$  dan  $b$  ( $P < 0.001$ ) dan mengurangkan nilai  $a$  dan ketebalan kerak roti ( $P < 0.001$ ). Namun, aplikasi penutup acuan pembakaran merencat pengembangan roti dan mengakibatkan nilai kepadatan yang tinggi pada roti. Roti *sandwich* mempunyai kandungan lembapan rendah berbanding roti *open*.

Tiga korelasi penting telah didapati dari kajian ini iaitu korelasi di antara perbezaan warna ( $\Delta E$ ) kerak dan ketebalan kerak,  $\Delta E$  kerak dan kepadatan isi roti dan akhir sekali hubungan di antara ketebalan roti dan kepadatan isi roti. Korelasi di antara  $\Delta E$  dan ketebalan kerak untuk pembakaran tanpa kelembapan (NH) diwakili oleh  $y_{NH} = 0.1724x$  and  $y_H = 0.1712x$  bagi pembakaran berkelembapan (H). Pekali korelasi,  $R^2$ , bagi korelasi antara  $\Delta E$  kerak dan ketebalan kerak untuk pembakaran tanpa kelembapan dan berkelembapan adalah 0.9467 dan 0.9341. Satu terbitan mudah  $T = k\Delta E$  yang diperolehi daripada korelasi di antara  $\Delta E$  kerak dan ketebalan kerak menunjukkan bahawa ketebalan kerak (T) boleh diunjurkan melalui perubahan warna pada bahagian kerak ( $\Delta E$ ). Pemalar pemanasan,  $k$ , bergantung kepada suhu pembakaran. Korelasi antara  $\Delta E$  kerak dan kepadatan isi roti mempunyai  $R^2$  0.8306 bagi pembakaran tanpa lembapan dan 0.8025 bagi pembakaran berkelembapan. Korelasi ini diwakili oleh  $y_{NH} = 0.8375x + 20.824$  bagi pembakaran tanpa lembapan (NH) dan  $y_H = 0.8127x + 25.035$  bagi pembakaran berkelembapan (H). Korelasi penting yang lain ialah antara ketebalan

kerak dan kepadatan isi roti dengan nilai  $R^2$  0.7436 dan 0.6915, bagi pembakaran tanpa kelembapan dan berkelembapan, masing-masing. Korelasi ini diwakili  $y_{NH} = 4.0385x + 26.952$  bagi bagi pembakaran tanpa lembapan dan  $y_H = 3.921x + 30.852$  bagi pembakaran berkelembapan. Nilai  $R^2$  yang tinggi menunjukkan bahawa terdapat hubungan yang kuat antara warna, ketebalan kerak dan kepadatan isi roti. Warna kerak roti boleh digunakan untuk menganggar ketebalan kerak dan ketegangan isi roti.

Kesimpulannya, keputusan ujikaji menunjukkan bahawa sifat-sifat kerak dan isi roti adalah bergantung kepada suhu dan masa pembakaran. Kandungan kelembapan dan kepadatan isi roti dipengaruhi oleh proses pembentukan kerak roti. Pelbagai penemuan penting dalam bidang pembuatan bakeri telah dicapai melalui penyelidikan ini iaitu kaedah baru untuk mengukur ketebalan kerak roti menggunakan warna, penggunaan kelembapan dalam pembakaran bertujuan untuk memperbaiki kualiti penyimpanan roti dan penemuan terhadap beberapa korelasi dan model linear yang boleh digunakan untuk menganggarkan ketebalan dan perubahan sifat isi roti ketika dalam penyimpanan.

## ACKNOWLEDGEMENTS

First of all, I would like to express my deepest gratitude to my supervisor, Dr. Chin Nyuk Ling, who has been a wonderful tutor and friend during my period of study. There is not enough word to describe my appreciation for her never ending guidance, patience, support, comments, motivation and knowledge to improve myself. My special thanks also go to Professor Russly Abdul Rahman and Dr. Yus Aniza Yusof for giving me ideas and thoughts for this thesis.

Secondly, my deepest gratitude to Dr. Nasir Azuddin, Mr. Norizat Rashid, Ms Suwaibah Ghaffar, Ms Voon Yit Yang and other staffs from Interflour Sdn. Bhd. This thesis would not have completed without their consent and helpful assistance in utilizing the Interflour Baking Laboratory.

At the same time, I would also like to thanks Mr. Haji Kamrul Zaman Dahlin, Md. Noh, Meor Nazri and Badrul Shah from KPM for their technological supports and advice.

To my dearest colleague, Dayang Norulfairuz, thank you for your help and encouraging spirit. Last but not least, my deepest affection and gratitude to my wonderful mother, husband, son and family for all support, patience and sacrifice throughout this period.

I would like to end this segment with an encouraging thought by Arland Gilbert:

*"When we accept tough jobs as a challenge to our ability and made into them with joy and enthusiasm, miracles can happen."*



I certified that an examination committee has met on 30<sup>th</sup> June 2008 to conduct the final examination of Yanti Maslina bt. Mohd. Jusoh on her Master of Science thesis entitled “Effects of Baking Temperature, Time and Humidity on Bread Crust and Crumb Properties” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1990 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommended that the candidate be awarded relevant degree.

Members of the Examination Committee were as follows:

**Mohd. Nordin Ibrahim, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Siti Mazlina Mustapa Kamal, PhD**

Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Ling Tau Chuan, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Ida Idayu Muhammad, PhD**

Senior Lecturer  
Faculty of Chemical and Natural Resources Engineering  
Universiti Teknologi Malaysia  
(External Examiner)

---

**HASANAH MOHD. GHAZALI, PhD**

Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:



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

**Chin Nyuk Ling, PhD**  
Senior Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Russly Abdul Rahman, PhD**  
Professor  
Faculty of Food Science and Technology  
Universiti Putra Malaysia  
(Member)

**Yus Aniza Yusof, PhD**  
Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**AINI IDERIS, PhD**  
Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 11 September 2008



## **DECLARATION**

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

-----

**YANTI MASLINA MOHD. JUSOH**

Date : 20 August 2008



## TABLE OF CONTENTS

	<b>Page</b>
<b>ABSTRACT</b>	ii
<b>ABSTRAK</b>	vi
<b>ACKNOWLEDGEMENTS</b>	x
<b>APPROVAL</b>	xi
<b>DECLARATION</b>	xiii
<b>LIST OF TABLES</b>	xvii
<b>LIST OF FIGURES</b>	xviii
<b>LIST OF ABBREVIATIONS</b>	xxiii

### CHAPTER

<b>1 INTRODUCTION</b>	<b>1</b>
1.1 An Overview on Bread in Malaysia	1
1.2 Bread History	3
1.3 Breadmaking Process	4
1.4 Significance of the Study	5
1.5 Objectives	6
1.6 Scopes of Work and Thesis Outline	7
<b>2 LITERATURE REVIEW</b>	<b>10</b>
2.1 Introduction	10
2.2 Overview on Bread Studies	10
2.3 Crust and Crumb	12
2.4 Functions of Crust on Bread	12
2.5 Crust Colour and Browning Effect	14
2.6 Browning Kinetics and Crust Formation	16
2.7 Baking and its Significance on Crust	18
2.8 Bread Staling	22
2.8.1 Starch Retrogradation	23
2.8.2 Gluten – Starch Interaction	25
2.8.3 Moisture (Evaporation, Drying and Redistribution)	26
2.8.4 Crust Formation	28
2.9 Factors Affecting Moisture Content and Rheological Properties in Bread Crumb	29
2.9.1 Wheat Flour Compositions	29
2.9.2 Ingredients Factors	30
2.9.3 Processing Factors	32
2.9.4 Crust	37



2.10	Summary	37
<b>3</b>	<b>EXPERIMENTAL DESIGN AND METHODOLOGY</b>	<b>39</b>
3.1	Introduction	39
3.2	Materials	39
3.3	Methods	41
3.3.1	Dough Preparation and Baking Tests	42
3.3.2	Crust Colour Measurement	46
3.3.3	Crust Thickness Measurement	48
3.3.4	Moisture Content Measurement	51
3.3.5	Crumb Firmness Measurement	52
3.4	Experimental Design	54
3.4.1	Determining Crust and Crumb Region Based on Colour	54
3.4.2	Studying the Characteristics of Sandwich and Open Bread	55
3.4.3	Investigating the Effects of Baking Temperature and Time on Open Bread Properties	55
3.4.4	Investigating the Effects of Baking Temperature, Time and Humidity on Open Bread Properties	56
3.4.5	Statistical Analysis	56
<b>4</b>	<b>RESULTS AND DISCUSSIONS</b>	<b>57</b>
4.1	Introduction	57
4.2	Preliminary Studies	57
4.2.1	Crust and Crumb Colour Range	58
4.2.2	Method of Measuring Crust Thickness	60
4.2.3	Effect of Baking Temperature and Time on Top Crust Colour Thickness of Open Breads	61
4.2.4	Simple Correlations Between Crust Colour and Thickness	64
4.2.5	Effects of Baking Temperature and Time on Moisture Content and Firmness of Open Breads	65
4.2.6	Comparison Between Sandwich and Open Bread in Terms of Crust Colour, Thickness, Moisture Content and Firmness	67
4.2.7	Summary of Preliminary Tests	73
4.3	Baking Temperature, Time and Humidity Effects on Open Bread Properties	74
4.3.1	Crust Colour	74
4.3.2	Crust Thickness	75
4.3.3	Crumb Moisture Content	76
4.3.4	Crumb Firmness	80
4.4	Comparison Between Humidified and Non-humidified Baking	84
4.5	Correlations Between Crust Colour, Thickness and Firmness	91
4.6	Relationship Between Crust and Crumb Properties	97
4.7	Summary	100
<b>5.0</b>	<b>CONCLUSIONS AND RECOMMENDATION</b>	<b>104</b>
5.1	Introduction	104





5.2	Summary of the Work	104
5.3	Recommendations for Future Work	108
<b>REFERENCES</b>		110
<b>APPENDICES</b>		117
1	Data for Section 4.2.1	117
	Data for Section 4.2.2 and 4.2.3	120
	Data for Section 4.2.4	122
	Data for Section 4.2.5	124
	Data for Section 4.3 and 4.4	127
2	ANOVA Results	134
3	Flour Analysis Report	143
<b>BIODATA OF STUDENT</b>		145



## LIST OF TABLES

Table		Page
3-1	Flour compositions (based on Flour Analysis Report)	40
3-2	Details of other ingredients used	40
3-3	Bread formulation (supplied by Interflour)-based on 3000 gram flour loading	40
4-1	A summary of the bread properties as effect of baking temperature, time and humidity	84
4-2	Comparison between actual and predicted crust thickness (T) using actual and modelled heating constant, $k$	94
4-3	Relationship between crust and crumb properties for non-humidified baking	100
4-4	Relationship between crust and crumb properties for humidified baking	100



## LIST OF FIGURES

<b>Figure</b>		<b>Page</b>
2-1	Mechanism of bread staling (adapted from Pateras, 1999)	25
2-2	The mechanism of crumb firming due to starch-gluten interaction (adapted from Martin, Zeleznak and Hoseney, 1991)	26
3-1	Vertical mixer	41
3-2	Baking oven	41
3-3	Retarded proofer	41
3-4	Automatic moulder	41
3-5	Flowchart of the experimental works	42
3-6	Mixing	43
3-7	Resting	43
3-8	Moulding	43
3-9	Dividing	43
3-10	Second Rounding	43
3-11	Second Resting	43
3-12	Moulding	44
3-13	Place in baking tins	44
3-14	Proofing	44
3-15	Humidity baking diagram	45
3-16	Example of (a) sandwich, (b) open and (c) standing bread	46



3-17	Minolta Chroma Meter (CR-410, Minolta, Japan)	47
3-18	Measuring bread crust colour	47
3-19	Locations for measuring outer crust and crumb colour	48
3-20	Location of crust and crumb based on colour separation	49
3-21	Measuring crust thickness using grid and L a b reading from Photoshop application (inset: L a b value of bread surface)	50
3-22	Flowchart of crust thickness measurement method	51
3-23	Blender (IT013, Itronic, Malaysia)	52
3-24	Oven (HA1350, Hanabishi, Malaysia)	52
3-25	The texture analyzer system	53
3-26	Measuring crumb firmness	53
4-1	<i>L</i> value for crust and crumb of commercial sandwich (SW), open (OP) and standing bread (ST)	59
4-2	<i>a</i> value for crust and crumb of commercial sandwich (SW), open (OP) and standing breads (ST)	59
4-3	<i>b</i> value for crust and crumb commercial sandwich (SW), open (OP) and standing breads (ST)	60
4-4	Image of bread for measuring crust thickness	60
4-5	Effect of baking temperature and time on <i>L</i> value of open bread top crust	61
4-6	Effect of baking temperature and time on <i>a</i> value of open bread top crust	62
4-7	Effect of baking temperature and time on <i>b</i> value of open bread top crust	62
4-8	Effect of baking time on top crust thickness for baking temperature at 175 ° C (◆), 185 ° C (■) and 200° C (▲)	63
4-9	Correlation between crust thickness with (a) <i>L</i> , (b) <i>a</i> and (c) <i>b</i> value	64



4-10	Effect of baking temperature and time on open bread (a) moisture content and (b) crumb firmness baked at 180°C and 200°C at 25 and 35 minutes	67
4-11	Effect of baking temperature on (a) $L$ , (b) $a$ and (c) $b$ value of crust for sandwich (□) and open (□) breads	68
4-12	Effect of baking temperature on crust thickness of sandwich (SW) and open (OP) bread	69
4-13	Moisture content comparison between open bread (OP) and sandwich (SW) bread baked at (a) 180°C and (b) 200°C	71
4-14	Moisture content comparison at different baking temperature for (a) sandwich (SW) and (b) open bread (OP)	71
4-15	Effect of crumb firmness on sandwich (SW) and open (OP) breads baked at (a) 180°C and (b) 200°C	73
4-16	Effect of baking temperature and time on (a) $L$ , (b) $a$ and (c) $b$ values of crust (non-humidified baking)	75
4-17	Effect of baking temperature and time on (a) $L$ , (b) $a$ and (c) $b$ values of crust (humidified baking)	75
4-18	Effect of baking temperature and time on top crust thickness for (a) non- humidified and (b) humidified baking	76
4-19	Effect of baking (a) temperature and (b) time on initial bread moisture content (non-humidified baking)	77
4-20	Effect of baking (a) temperature and (b) time on initial bread moisture content (humidified baking)	78
4-21	Effect of baking temperature and time moisture retention in bread (non-humidified); (a) 185°C, (b) 195°C and (c) 205°C	79
4-22	Effect of baking temperature and time on moisture retention in bread (humidified); (a) 185°C, (b) 195°C and (c) 205°C	80
4-23	Effect of baking temperature on initial crumb firmness at (a) non-humidified (NH) and (b) humidified baking (H)	81



4-24	Effect of baking time on initial crumb firmness at (a) non-humidified (NH) and (b) humidified baking (H)	82
4-25	Crumb firmness value for baking temperature at (a) 185°C, (b) 195°C and (c) 205°C (non-humidified baking)	83
4-26	Crumb firmness value for baking temperature at (a) 185°C, (b) 195°C and (c) 205°C (humidified baking)	83
4-27	Comparison between humidified (H) and non-humidified (NH) baking on the <i>L</i> value of crust at (a) 185°C, (b) 195°C and (c) 205°C	85
4-28	Comparison between humidified (H) and non-humidified (NH) baking on the <i>a</i> value of crust at (a)185°C, (b)195°C and (c) 205°C	85
4-29	Comparison between humidified (H) and non-humidified (NH) baking on the <i>b</i> value of crust at (a) 185°C, (b) 195°C and (c)205°C	86
4-30	Comparison between humidified (H) and non-humidified baking (NH) on crust thickness at (a) 185°C, (b) 195°C and (c) 205°C	87
4-31	Initial moisture content comparison between humidified (H) and non-humidified baking (NH) at (a) 185°C, (b) 195°C and (c) 205°C	88
4-32	Moisture content comparison between humidified (H) and non-humidified baking (NH) at (a) 185°C, (b) 195°C and (c) 205°C for 25 minutes baking	88
4-33	Moisture content comparison between humidified (H) and non-humidified (NH) baking at (a) 185°C, (b) 195°C and (c) 205°C for 30 minutes baking	89
4-34	Moisture content comparison between humidified (H) and non-humidified baking (NH) at (a) 185°C, (b) 195°C and (c) 205°C for 35 minutes baking	89
4-35	Firmness comparison between humidified (H) and non-humidified (NH) baking at (a) 185°C, (b) 195°C and (c) 205°C for 25 minutes baking	90
4-36	Firmness comparison between humidified (H) and non-humidified (NH) baking at (a) 185°C, (b) 195°C and (c) 205°C for 30 minutes	90
4-37	Firmness comparison between humidified (H) and non-humidified (NH) baking at (a) 185°C, (b) 195°C and (c) 205°C for 35 minutes	90
4-38	Correlation between colour difference ( $\Delta E$ ) and thickness for non-humidified (NH) and humidified baking (H)	91

4-39	Relationship between $\Delta E$ and thickness for (a) non-humidified and (b) humidified baking	92
4-40	Correlation between temperature and heating constant, ( $k$ ) for non-humidified (NH) and humidified (H) baking	93
4-41	$T = k\Delta E$ model verification plot for non-humidified (NH) and humidified (H) baking	93
4-42	Correlation between $\Delta E$ with crumb firmness for non-humidified (NH) and humidified (H) baking	95
4-43	Correlation between crust thickness and crumb firmness for non-humidified (NH) and humidified (H) baking	96
4-44	Relationship between crust thickness and rate of moisture loss for (a) non-humidified and (b) humidified baking breads	98
4-45	Relationship between crust thickness and rate of firming for (a) non-humidified and (b) humidified baking breads	99



## LIST OF ABBREVIATIONS

ANOVA	analysis of variance
AVE	average
CLSM	confocal laser scanning microscope
DSC	differential scanning calorimetry
SEM	scanning electron microscope
STD DEV	standard deviation
STD ERR	standard error





# CHAPTER 1

## 1 INTRODUCTION

### 1.1 An Overview on Bread in Malaysia

Bread is the second most popular staple food in Malaysia (Anon., 2007a). Bread industry in Malaysia has risen significantly throughout these years in parallel to the growing number of Malaysian population. The increasing bread sales trend of 4 % from year 2005 to year 2006 is a strong indicator that bread is a significant food in Malaysia's modern society. According to the Euromonitor 2007 market research report, the value of sales for bread in Malaysia is up to Ringgit Malaysia 636 millions in 2007 (Anon, 2007a). The changes in Malaysian society life-styles and an increase in population influence the Malaysians eating habit (Anon., 2006). Health awareness and busy lifestyles with the increasing cost of living contribute to the buoyant demand for bread in this country.

Bread is accepted as an important substitute for Malaysian staple food, rice, as it generally contains similar nutritional diet as rice in terms of its carbohydrate, protein and starch contents. It is also as filling as rice. Apart from its nutritional value and being a stomach filler, bread is also famous because it is easy to consume, and no additional dishes requires to compliment it. Besides that, bread can be fortified with functional ingredients that could benefit people health. Functional breads, where ordinary bread is combined with functional ingredients such as calcium, collagen, vitamins, fiber,